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Phone: 703-642-9090
Fax: 703-642-9094

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Technical Papers Program: Schedule and Contents*

KEYNOTE AND INVITED TALKS FOR ALL TRACKS ALL DAYS

Liberty Ballroom B

MONDAY, SEPTEMBER 8

Opening Ceremony and Keynote

Session Chair: Masahiko Fujii, Fuji Xerox Co., Ltd.

9:00 – 10:15 AM

9:00 **Super-Fine Ink-Jet Printing as a Novel Direct Patterning Process,** *Kazuhiro Murata, SIJTechnology, Inc. (Japan)* 1

The ink-jet method is the effective technology as a process to functionalize the by setting a functional material required for a required place. But conventional inkjet technology has a limitation in resolution of a few tens of micro-meters. We have developed a super-fine ink-jet technology (Super Ink Jet - SIJ) that enables the formation of fine features less than a micro-meter in diameter. Furthermore, the printing method is not limited by the tight viscosity requirements of normal inkjet inks and allows the use of a wide variety of inks: e.g. nano-metals, semiconductors, insulators, light emitting polymers, bio-materials etc. Using this method, the direct fabrication of circuits and three-dimensional structures with feature sizes of just a few microns has been achieved. The potential of the SIJ technology and its application to cutting-edge areas, such as flexible and printed electronics, fine-pitch direct interconnects and others will be shown.

State-of-the-Art Invited Talk: Textile Printing

Session Chair: Branka Lozo, University of Zagreb

3:15 – 3:45 PM

3:15 **State of the Art of Digital Textile Printing Status 2014,** *Hitoshi Ujiie, Philadelphia University (USA)* 2

Digital textile printing technology has become one of the production textile printing processes since introductions of production digital printing systems in early 2000's. However, over a decade since the introductions of the technologies, current utilization of digital printing technologies in the industrial textile printing sector is still small in contrast with the popularity of conventional textile printing systems. This paper focus on the current state of digital textile printing in terms of engineering, business and design based on empirical research, including international case studies and field trips over the past 10 years. The supply chains from engineering to user standpoints (mills, printing service operations) will be investigated. At the same time, the emerging new field of Surface Imaging, will be ascertained.

TUESDAY, SEPTEMBER 9

Tuesday Keynote

Session Chair: Christopher Tuck, University of Nottingham

9:00 – 10:00 AM

9:00 **High Viscosity Printing,** *David Rosen, Georgia Institute of Technology (USA)* 3

Typical commercial ink-jet print heads can eject fluids with viscosities up to 30-40 cP. However, most polymers of interest for mechanical parts have viscosities that are orders of magnitude higher than this; hence there is a need for print heads that can eject high viscosity fluids. After a brief survey, this talk will introduce a high viscosity print head based on an ultrasonic atomizer technology that was developed at Georgia Tech. The bulk of the talk focuses on the development of two types of models: ultrasonic atomizer modeling and droplet impingement modeling. In the first area, both high fidelity and simplified electro-mechanical models will be

SPECIAL EVENT

WELCOME RECEPTION

Sunday, September 7th
5:45 – 6:45 PM
Liberty Ballroom Foyer

Kick off the conference by joining colleagues on Sunday before heading to dinner

* Please note: Page numbers listed after paper titles refer to the page on which a paper is found in the full proceedings book found digitally on the USB stick that accompanies this book.

presented, with the objective of understanding and improving the pressure gradients in the atomizer nozzle. In the second area, a new Lattice-Boltzmann-based fluids model was developed to simulate droplet impact and droplet interactions in order to determine process conditions that enable the formation of planar films without splash. Implications of the research on printing process and ink developments will be provided. Also, some limits on how high is "high viscosity" will be offered.

WEDNESDAY, SEPTEMBER 10

Wednesday Keynote and IS&T Awards

Session Chair: Branka Lozo, University of Zagreb

9:00 – 10:10 AM

9:00 **Nanophotonics over Macroscopic Scales and its Associated Fabrication Challenges,** *Marin Soljacic, MIT (USA)* 4

In nanophotonics, we create material-systems which are structured at length-scales smaller than the wavelength of light. When light propagates inside such effective materials, numerous novel and exciting phenomena can emerge, enabling a variety of novel applications. However, in order to make use of these opportunities for many real-world applications of interest, one has to have the ability to implement nanophotonic structures over large scales. Printing techniques are often useful for implementation of such structures, especially when the wavelength of interest is sufficiently long. In this talk, I will present some of our recent theoretical and experimental progress in exploring these opportunities, as well as novel physics phenomena that emerges in this process.

THURSDAY, SEPTEMBER 11

Thursday Keynote and Conference Closing

Session Chair: Masahiko Fujii, Fuji Xerox Co., Ltd.

8:30 – 9:30 AM

9:00 **Recent Technology and Business Developments in Printed Electronics and Implications for Inkjet,** *Stan Farnsworth, NovaCentrix (USA)**

** Paper/abstract not available at time of publication.*

MONDAY SEPTEMBER 8, 2014

PRINTING TECHNOLOGY I

9:00 – 10:15 AM Opening Ceremony and Keynote, Liberty Ballroom B, see details page vii.

10:15 – 10:45 AM Coffee Break — Liberty Ballroom Foyer

Liberty Ballroom A

Ink Jet: The Head

Session Chairs: Abu Islam, Xerox Corporation; Werner Zapka, XaarJet AB; and Mineo Kaneko, Canon, Inc.

10:45 AM – 12:45 PM

10:45 **High Quality, High Speed, Next-Generation Inkjet Technology with Scalability from Serial Printheads to Lineheads (Focal),** *Shunsuke Watanabe, Satoshi Oguchi, Shunya Fukuda, Yuma Fukuzawa, and Satoru Hosono, Seiko Epson Corporation (Japan)* 5

Digital printing technologies are demonstrating strong growth due to their on-demand capability, which enables short run, varied-lot printing with rapid turnaround. Key growth segments in which piezo inkjet technology is recently increasing its presence are commercial, industrial and business printing, which demand professional quality and high productivity. Piezo inkjet technology uses mechanical energy rather than heat for ejection, enabling various types of ink to be used—from non-aqueous UV inks to water-based pigment inks. Thus far, we have developed MACH printheads with 120-180 npi/row nozzle resolution by enhancing the process of precision machining bulk piezo and ink channel components. Using a different approach, we dramatically raised the nozzle resolution with TFP (Thin Film Piezo) technology in 2007. TFP's high displacement piezo, with a thickness of around 1 μm, made it possible to increase the nozzle resolution up to 360 npi/row. We have since utilized TFP as our flagship technology in large format printers. Now, with a next-generation actuator chip, we have succeeded in broadening the application of TFP technology into a wider range of printing segments, from desktop serial printers to industrial linehead presses. In this paper, we explain this next-generation inkjet technology, which achieves high output quality, high speed printing and improved scalability through the miniaturization of the core chip.

11:15 **Development of New Inkjet Head Applying MEMS Technology and Thin Film Actuator,** *Kenji Mawatari, Koich Sameshima, Mitsuyoshi Miyai, and Shinya Matsuda, Konica Minolta, Inc. (Japan)* 11

We developed a new ink jet head by applying MEMS technology and thin film piezo actuator. Jetting properties of ink jet heads were calculated by the simulation method of the equivalent circuit model generated from actuator properties and ink flow channels of the ink jet head. We manufactured a test piece to investigate the jetting properties and oscillation forms of the actuator. As a result, our test piece was driven at maximum 70 kHz and ejected 3 pl droplet with an ink which viscosity was 10 mPa·s. We found that the experimented jetejecting properties and vibration forms agreed very well with the simulation.

11:35 **New Print Head Technology for High Productivity and Stability,** *Yoshinori Domae, Yuki Yamamura, Satoshi Horiguchi, and Masao Tachibana, SII Printek Inc. (Japan)* 15

SII Printek produces printheads characterized by their high productivity. Our ink-jet printheads realized such high productivity with edge shooter structure operating in shear mode until now. Most especially, 508GS model has been popular covering a wide range of ink chemistry and capable of jetting at a high frequency thanks to its isolated channel structure. However, even higher stability at high production rate is demanded in any industrial market, particularly those prints in single pass. Hence we developed a new product which adopted the following techniques to cope with such demands. Firstly, we adopted side shooter structure where a nozzle is located in the center of pressure chamber with openings at both ends to enable ink circulation across. Thereby we can save a large quantity of ink consumption wasted for filling of ink and cleaning of nozzle. Continual ink flow beside the nozzle realizes self- recovery of meniscus as well. Secondly, we adopted our isolated channel structure where discharging and non-discharging channels are alternately grooved and only the latter are actively driven.In this way, electrodes of discharging channels immersed in ink are free from any cor-

rosion and active channels can operate at a high frequency since they are isolated from each other and hence free from crosstalk. Thirdly, we adopted a cantilever structure where the channel walls of the actuator are held rigidly by stiff material at one end and flexibly at the other, from which electrodes extend covering about half height of the wall. This allows us to effectively drive the discharging channel without too much modifying the simple conventional process. Incorporating these three structures together allows us to jet a large volume of drop at a high frequency, but such a large ink flow digitally driven causes big pressure shock occurring at onset and end of a print streak, starving and over-pressuring the printhead in turn. We introduced a dumping structure to supress such a big shock affecting the actuator operation. Thus we could achieve good printing sustainability that can endure any pressure fluctuation, not only due to sudden change in pinting streak but also from outside disturbance. In conclusion, our new inkjet printhead RC512 realized very high productivity and sustainability for industrial printing. Its productivity exceeds our existing product lineup by far, and we are amazed to see a stable discharge is possible with such productivity. We are further developing a new model evolved in the line of this structure aiming at even higher performance.

11:55 **Drop Volume Modulation via Applied Backpressure in Inkjet Systems,** *Aaron Fulton, J. William Boley, Nikhil Bajaj, and George T.-C. Chiu, Purdue University (USA)* 20

To date, there are limited options in the ability to create droplets of smaller radii than that of the nozzle from which they are produced. Existing methods pertain largely to piezoelectric inkjet printing and time scale manipulation rendering them inapplicable to thermal inkjet technologies. In this work, a simple method for drop volume control in inkjet systems is proposed in which stable drop volume can be reduced by an order of magnitude with a constant nozzle radius by adjusting the back pressure in the reservoir that supplies the print head. The back pressure is regulated, droplet sizes, stability, and velocities are recorded. These results are then corroborated by rigorous modeling.

12:15 **A New "Edge-Mounted" Actuator: A New Compact Design (Focal),** *Angus Condie, James Arnold, Phil Mead, and Ian Starling, Xaar plc (UK)* 26

Xaar has deployed its Hybrid Side Shooter™ actuator technology successfully in its Xaar 1001/2 printhead. The ejection of ink from the 'side' of the ink channel and not the conventional 'end' of the ink channel has enabled it to use its patented Through-Flow technology (TF Technology™): This has transformed printing reliability and has led to the adoption of digital ink jet into single pass industrial printing; most noticeably for printing decoration of ceramic tiles. Xaar has now developed a new edge-mounted actuator architecture, which builds on the advantages of the side-shooter actuator and enables the capability to produce compact multiple row printheads and also improves manufacturing efficiency by using a 'wafer-scale' approach. This paper details some of the advantages of this new edge-mounted actuator architecture.

12:45 – 2:00 PM Lunch Break

Session sponsored by

XAAR®

Ink Jet: Process and Simulation I

Session Chairs: Jim Mrvos, Lexmark International, Inc.; Frits Dijksman, University of Twente; and Kye-Si Kwon, Soonchunhyang University

2:00 – 3:10 PM

2:00 **Jetting Complex Fluids Containing Pigments and Resins (Focal),** *Stephen D. Hoath,[1] Tri R. Tuladhar,[2] Damien C. Vadillo,[3] Simon A. Butler,[1] Malcolm R. Mackley,[1] Claire McIlroy,[4] Oliver G. Harlen,[4] Wen-Kai Hsiao,[1] and Ian M. Hutchings[1]; [1]University of Cambridge, [2]Trijet Ltd., [3]AkzoNobel Ltd., and [4]University of Leeds (UK)* 30

We have previously studied DoD jetting of complex model fluids based on dilute polymer solutions, resulting in the identification of a new regime of polymer jetting and some basic rules for predicting the limiting polymeric concentrations under real conditions such as print head nozzle diameter, jetting speed, solvent quality and polymer molecular weights. There has been no systematic experimental study of the effect of particles on DoD scale jetting, despite the ground-breaking work by Furbank and Morris as reported in NIP17 for the effects of particles on dripping, although theoretical modelling for liquid bridges/filaments containing particles has been recently published and could be relevant to local thinning of DoD ligaments. A series of pigmented inks in the solvent dipropylene glycol methyl ether (DPM) has been used to help study effects of pigment particle size (d_{90} = 3.6, 2.6, 1.6, 1.0, 0.8 μm) on DoD jetting. These inks contained 35 wt% of the inorganic black pigment copper chromite and had a low shear-rate viscosity of ~15 mPa s. Ink characterisation used a high frequency rheometer and a novel fast (5 m/s) filament stretching device, while the DoD jetting used MicroFab 80 μm diameter nozzles. Jetting experiments were performed at 100 Hz to avoid nozzle clogging. We report

the first systematic experimental studies for DoD scale jets of characterized inks comprising (a) particles in DPM; (b) resin DPM; and (c) combinations of particles and resins in DPM. These results will provide new insights into the jetting of pigmented inks and be important for new applications.

2:30 **Relationship between Jetting Performance and Surface Tension in Micro Second Order on Water based Inkjet Ink,** *Kaname Mitsuyoshi, Isao Tsuru, and Daisuke Hamada, Kao Corporation (Japan)* 34

Recently, inkjet systems have been used in the field of commercial printing thanks to print-on-demand. To disseminate the IJ widely in the commercial printing field, high speed printing for high productivity would be required. In high speed printing, high jetting performance is needed. Good jetting performance means that a jetted droplet forms a spherical droplet before it reaches the paper surface. From the hypothesis that jetting performance depends on dynamic surface tension in a time scale of micro second order, the relationship between jetting performance and dynamic surface tension was investigated using the ink including pigment, humectant and surfactant. To check the jetting performance, the ink jetting behavior was investigated using a commercial line type print head at high jetting frequency. Dynamic surface tension in micro second order was measured by the Continuous Ink Jet system. The higher dynamic surface tension in the short time range was found to show better jetting performance with its single droplet formation. It was concluded that good jetting performance could be achieved by adjusting the ink composition to control dynamic surface tension.

2:50 **Evaluation and Reduction of Elevated Height Printing Defects,** *Dan Barnett and Marlene McDonald, FUJIFILM Dimatix (USA)* 38

Ink jet printing at elevated heights is known to initiate unsteady laminar flows which lead to imaging defects often referred to as wood-grain or fogging. An investigation of the unsteady flow development was conducted using both experimental and numerical simulation techniques. High speed imaging revealed that the interaction between the air flow induced from droplet drag and the couette flow entrained from the substrate motion develops large eddies which roll along the droplet stream and lead to unsteady flows causing wood-grain defects. ANSYS CFX computational fluid dynamics (CFD) simulations are presented to support the experimental results and to provide a higher degree of understanding of the flow dynamics. Several techniques are revealed which illustrate how wood-grain defects can be improved. These techniques strive to enable ink jet technologies to be used in a wider range of applications with large height variations or which require jetting at elevated heights to prevent contact with print heads. In addition to unsteady flow defects, two other phenomenons related to elevated height printing were included in this study: (1) excessive nozzle plate wetting and (2) excessive drag on droplets ejected into a still flow field.

3:15 – 3:45 PM State-of-the-Art Invited Talk, Liberty Ballroom B, see details page vii.

3:45 – 4:15 Coffee Break — Liberty Ballroom Foyer

4:15 – 5:45 PM Colleague Connections: Monday Roundtable Discussions

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Recyclability and Deinking of Digital Prints–Ecolabels and Testing, *Philadelphia Ballroom North*

UV-Curable Printing for High-End Reflective and Backlit Photography, Fine Art, and "Viewed Up Close" Retail Markets, *Philadelphia Ballroom South*

Industry/Academia Partnerships to Solve Print Industry Challenges, *Salon 5/6*

PRINTING TECHNOLOGY II

9:00 – 10:15 AM Opening Ceremony and Keynote, Liberty Ballroom B, see details page vii.

10:15 – 10:45 AM Coffee Break — Liberty Ballroom Foyer

Liberty Ballroom C

Session sponsored by

RICOH

Electrophotography: Process and Devices

Session Chairs: Ligia Bejat, Lexmark International, Inc.; Lode Deprez, Xeikon Manufacturing NV; Nobuyuki Nakyama, Fuji Xerox Co., Ltd.; and Yoshihiro Hattori, Konica Minolta Business Technologies, Inc.

10:45 AM – 2:30 PM

10:45 **Xeikon Trillium: The Next Generation of High Quality, High Speed, and Low Cost Sustainable Digital Printing (Focal),** *Lode Deprez, Werner Op de Beeck, Wim Libaers, Mathias Van Remortel, and Dirk Gijsbrechts, Xeikon Manufacturing N.V. (Belgium)* 44

Trillium has been shown as a technology demonstration at Drupa 2012. This paper wants to explain in detail how the new printing system from Xeikon works and what specific challenges had to be overcome in order to make the technology mature. Xeikon wants go for new challenging markets where printing at high speed, at high quality, at high page coverage and with a cost lower than inkjet opens new market and business opportunities, especially on commercially available coated offset papers. Moreover there is also the sustainability aspect that no VOCs are used and that the printed materials are perfectly deinkable.

11:15 **Measurement Techniques of Micro Region Discharge Current for Analysis Discharge Mode of Contact Charging Roller,** *Minoru Ohshima, Masao Ohmori, Satoru Tsuto, and Nobuhide Inaba, Fuji Xerox Company, Ltd. (Japan)* 48

One of the major problems of electrophotography in a contact charging roller system is density nonuniformity of a printed image due to anomalous discharges. To find proper countermeasures to such a problem, characterization of the discharge phenomenon is crucial. We developed a measurement technique for micro region discharge currents using a minute electrode embedded in the surface layer of a photoreceptor drum that is capable of quantifying the time variation of the local discharge current. Using a measurement system that utilizes this technique, dependency of the discharge current mode on charging parameters was clarified. Based on changing the charging parameters, discontinuous changes in the discharge modes that affect the nonuniformity of the image density are observed. In this report, in addition to the measurement technique and results, the relationship between the discharge conditions and the density nonuniformity of the image is discussed.

11:35 **Development of Low-Heat-Capacity Pressure Roller,** *Akira Kato, Yuuki Nishizawa, Yasuo Yoda, Jun Hara, Hisashi Nakahara, Takao Kikutani, and Masayuki Suekuni, Canon, Inc. (Japan); and Toshihiko Ochiai, formerly of Canon Inc. (Japan)* 53

In the quest to produce energy-saving laser beam printers, the most promising solution is a fuser unit with low heat capacity. However, the rise in temperature at the non-paper feeding region causes problems. Canon has developed a low-heat-capacity pressure roller that reduces the required warm-up power. The pressure roller has an elastic layer and an outer layer of PFA (polytetrafluoroethylene). The elastic layer is made of sponge silicone rubber containing thermally conductive filler. In this study, we conducted heat transfer simulations to examine the influence of the physical properties of heat in terms of saving energy and suppressing the temperature rise of the non-paper region. A low heat permeability coefficient reduced the required warm-up power, and high heat conduction effectively suppressed the temperature rise of the non-paper region.

11:55 **Surface Heating Fuser with Roller Structure,** *Oh Hyun Baek, Keon Kuk, and Hee Moon Jeong, Samsung Electronics Co., Ltd. (Korea)* 57

The surface heating fuser structure has low energy consumption and high heating speed due to its low heat capacity and simple structure. The authors have introduced a surface heating fuser system in NIP 29. The heating material is composed of carbon nano tube and silicon rubber composite, and fabricated with thin film layer structure in order to minimize the heat capacity. A nip supporting member is applied to the heating tube inside slide along the surface of heating tube. But the high friction between the nip support member and the heating tube caused to the limitation of fusing speed and failure of electrical supply unit due to leaked lubri-

cant. In this study, the roller type surface heating fuser structure is proposed. The fusing performance has been predicted by numerical simulation and verified by fabricated proto sample. The high fusing speed and durability of structure is confirmed through the evaluation of fusing system.

12:15 – 2:00 PM Lunch Break

2:00 **Hot Offset Simulation in Fuser Process (Focal),** *Kyohei Kato, Takuma Onishi, Masaki Kouno, Hiroki Eguchi, Yasunari Kobaru, and Yasuo Yoda, Canon, Inc. (Japan)* 61

The toner deformation simulation based on the finite element method and Arbitrary Lagrangian-Eulerian (ALE) method has been used to calculate the hot offset in the fuser process. The viscoelasticity of toner, the adhesion force between toner and the material contacting the toner, and the fuser condition are taken into account. The method is able to calculate the toner deformation in the process of pressurization and strain in fusers, and the simulation results have reproduced the hot offset in fusers. When the method is used to estimate the hot offset level, the dependency of image density on the hot offset level matches experimental results.

Thermal Printing

Session Chair: Hirotoshi Terao, Alps Electric Co., Ltd.

2:30 – 3:10 PM

2:30 **Improvement on Heating Head Performance,** *Hideo Taniguchi, Mark Tatsuya, and Shigemasa Sunada, HIT Devices Ltd. (Japan); and Jiro Oi, HIT Devices Ltd. (USA)* 65

We have been improving the heating head structure for thermal printing processes. The major structural change is that the heating element is on the back side of ceramic substrate in a conventional sense. There are several advantages in this configuration such as the increased thermal capacity of the heating head, much higher mechanical anti-abrasion and scratch resistance ability, simplified substrate manufacturing process. We will discuss how the new heating head functionality can be improved from an application point of view. There are two areas we are addressing in this report: Heating head driving method and heating surface coating. The first area is maintaining the heating temperature constant. The heating head has the temperature sensing element

COLLEAGUE CONNECTIONS: MONDAY ROUNDTABLE DISCUSSIONS

Recyclability and Deinking of Digital Prints–Ecolabels and Testing
Moderator: Axel Fischer, INGEDE e.V.

Deinkability is becoming not only more accepted, but a required sustainability feature for printed products. Technical questions on how to evaluate recyclability/deinkability and how test results relate to "real life" in a mill remain—and perceptions are different in the US and Europe/Japan. After the establishment of the European Ecolabel for Printed Products, rules for acquiring German Blue Angels labels for printed paper have been updated to require proof of deinkablity starting in 2015. People are beginning to ask for deinkability and printers see it as an issue relevant to long-term investment. Participants are invited to discuss the role/relevance of recyclability and customer demand for it in their respective countries.

UV-Curable Printing for High-End Reflective and Backlit Photography, Fine Art, and "Viewed Up Close" Retail Markets
Moderator: Henry Wilhelm, Wilhelm Imaging Research, Inc.

Major advances in the image quality provided by large-format flatbed and roll-fed inkjet printers using high-stability UV-curable pigment inks have opened up whole new markets in the high-end photography and fine art world. Very-large-format prints are selling for more than $100,000 each. LED illuminated frames provide a new, lightweight, low-cost way to display brilliant backlit acrylic images. This focus on high image quality has created new opportunities in the retail and commercial sectors as well, with images backprinted on the glass tops of cosmetic counters, on a variety of materials for POP displays, and for other applications where prints are frequently viewed at a very close distance. In these markets, print speed plays a secondary role to superb photographic quality. Printer and ink manufacturers, print providers, and those in the art world discuss the newest technologies and emerging opportunities.

Colleague Connections: Industry/Academia Partnerships to Solve Print Industry Challenges
Moderator: Jim Mrvos, Lexmark International, Inc.

Join colleagues to discuss the biggest technical issues facing the printing industry in a forum designd to explore collaboration and cooperation opportunities for companies and academia that might help solve issues of common interest. Solutions to obstacles that inhibit collaboration, such as intellectual property and nondisclosure agreements, will be explored.

alongside of the heating element which is made of resistive material having a large positive temperature coefficient of resistance. The temperature change is reflected in the resistance change of sensing element which is fed into the heating element control circuit. The heating element energy can be controlled by varying the driving voltage with continuous on-time or varying the on time with constant supply voltage. We employed the later control method for this paper with the pulse width modulation circuit for a simplified way of maintaining the desired process heating head temperature. The second area is the ability to overcoat the heating surface with a material suitable for the heating process. Unlike the existing heating heads where the heating surfaces are overcoated by an insulative material such as glass which gives a limited freedom for the coating process on top, the new heating surface is ceramic and various coating materials which can be conductive and/or lower coefficient of friction can be used for overcoating. This capability enhances the width of heating process application range as the wider variety of media can be heated as well as the applications beyond printing field.

2:50 **Analytical Investigation of Effects of Thermophysical Properties on Transient Temperature Response of Papers in Thermal Printer,** *Takashi Fukue,[1] Hirotoshi Terao,[2] Koichi Hirose,[1] Tomoko Wauke,[2] and Hisashi Hoshino[2]; [1]Iwate University and [2]ALPS Electronic Company, Ltd. (Japan)* 69

This paper describes the effects of thermophysical properties of printing papers on transient temperature response in the Direct Thermal Printers (DTP). DTP produces printed images by selectively heating thermal papers when a thermal head, which includes dot heaters, contacts thermal papers directly. The printing quality of DTPs is strongly dependent on thermophysical properties of thermal papers. Our study aims to optimize the printing process of DTPs in order to reduce power consumption of DTPs while maintaining printing quality. In this paper, a relationship between thermophysical properties, which are density, specific heat and thermal conductivity of the printing paper, and the transient temperature response of the paper was investigated quantitatively using 3-dimentional thermal conduction analysis. Through the analysis, we clarified the dominant factor in the temperature rise of the papers from the viewpoint of the thermophysical properties.

3:15 – 3:45 PM State-of-the-Art Invited Talk, Liberty Ballroom B, see details page vii.

3:45 – 4:15 Coffee Break — Liberty Ballroom Foyer

4:15 – 5:45 PM Colleague Connections: Monday Roundtable Discussions

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Industry/Academia Partnerships to Solve Print Industry Challenges, *Salon 5/6*

IMAGE SCIENCE AND TECHNIQUES

9:00 – 10:15 AM Opening Ceremony and Keynote, Liberty Ballroom B, see details page vii.

10:15 – 10:45 AM Coffee Break — Liberty Ballroom Foyer

Liberty Ballroom B

Image Permanence

Session Chair: Wolfgang Schmidt, Schoeller Technocell GmbH & Co. KG

10:45 – 11:35 AM

10:45 **ISO 18930—A New Standard Test Method for Accelerated Weathering (Focal),** *Bruce M. Klemann, Electronics for Imaging, Inc., and Paul Landrum, Hewlett-Packard Company (USA)* 73

ISO 18930 was confirmed in 2011 as a new International Standard test method for accelerated weathering. It is a four-segment test cycle that simulates day, night, rain, and condensation. The spectral power distribution of the light source was created based upon a tolerance band around the CIE 85 spectral power distribution of sunlight. A round-robin test has been conducted to validate the new method. This is the first data published to substantiate the use of ISO 18930. Acceleration factors and Pearson correlation coefficients are presented for nine worldwide outdoor locations, along with examinations of lab-to-lab and replicate reproducibility. The results validate that ISO 18930 is a valid and versatile accelerated weathering test method that is applicable to a large range of materials. Due to the dark cycle segment with water spray followed by a light cycle segment at elevated temperature, it is believed that this cycle may perform better than ASTM G155, Cycle 1 for some materials that are brittle, porous, or hygroscopic. ISO TC 42 WG-5 has also recommended that an ISO Technical Report with a detailed data analysis be written to document the results of this round robin test.

11:15 **The Determination of Humidity Limits to Prevent Colorant Bleed in Inkjet Prints,** *Eugene Salesin and Daniel Burge, Image Permanence Institute (USA)* 79

The purpose of the project was to determine the absolute ceiling limits for temperature, humidity, and time combinations to prevent noticeable colorant bleed in photographs and documents printed with inkjet digital technologies. The research focused on a variety of dye printers and papers because it was known from previous work that these printer/paper combinations produced prints sensitive to humidity. The results of this work are intended to help cultural heritage institutions that collect these materials develop policies for use and care to prevent damage to their collections. The results may also benefit commercial services that offer prints made with these processes, as well as artists and photographers and the general public. In this so called "humidity limits" study a series of nine different dye printer/paper sets were included along with one pigment printer/paper combination to serve as a control. Specimens were treated to twelve different time, temperature, and humidity regimes covering a span of time from one day to four weeks, temperatures from 15°C to 35°C and relative humidities (RH) from 60% to 90%. The tests included measuring Delta E with a spectrophotometer for a checkerboard target and line width changes with image analysis software for a CMYK line target. Analysis of the data from the humidity limits study indicated that the behavior of the inkjet dye printer/paper combinations to the various treatment conditions were quite variable. Because institutions collections could contain prints similar to a very sensitive print in this study, a very conservative approach should be taken for their care. However, the results of this study indicate that that inkjet dye prints, even the most sensitive ones, are relatively safe from significant humidity bleed if kept at 65% RH or less.

UV Curable Ink Jet

Session Chairs: Henry Wilhelm, Wilhelm Imaging Research; Jürgen Volkmann, Marabu GmbH & Co. KG; and Atsushi Tomotake, Konica Minolta Inc.

11:35 AM – 12:40 PM

11:35 **Test Methods for the Long-Term Permanence Behavior of Photographs and Fine Art Prints Made with Large-Format Flatbed Printers Using UV-Curable Pigment Inks,** *Henry Wilhelm, Barbara C. Stahl, Kabenla Armah, and Carol Brower Wilhelm, The Center for the Image.org with Wilhelm Imaging Research, Inc. (USA)* 84

Recent advances the last several years in the image quality of wide-format inkjet printers using high-stability

UV-curable pigment inks made possible by smaller drop sizes; higher addressable DPI, use of dilute cyan, magenta, and gray (light black) inks in addition to standard full concentration CMYK ink; and the availability of white inks together with glossy and matte surface "clear inks" (some UV-curable printers now have up to nine separate ink channels), have now made it practical to utilize these printers for visually high-quality photography and fine art applications where images are frequently viewed at very close range. Improvements in the printers have coincided with a trend toward ever-larger prints in the high-end of the photography art market during the past ten years, and UV-curable technology is now poised to play a major role in this expanding market segment. (See paper for extended abstract.)

11:55 **Development of Filterability Test Method for Gel Retention Performance for UV Curable Ink Jet Inks,** *Masato Sumiya and Katsuhisa Yamada, Nihon Pall Ltd. (Japan)* 86

The purpose of this study was to provide a test method for gel retention performance of nonwoven filters for UV curable ink jet inks. Gel marked with elemental silver was formed from simulated UV curable ink. The silver marked gel was dispersed in the simulated UV curable ink by ultrasonic vibration. Large size gels were removed by pre-filtration with a track-etched membrane filter which had uniform 10 μm round shaped pores. Then the ink was subjected to filterability test to determine gel retention. Mass of silver element accumulated on filter medium was measured by ICP-MS after filter medium was dissolved in hot acid. Gel retention performance of nonwoven filters was compared as demonstration of effectiveness of this method. Characteristics of the gel in dynamic viscoelasticity, size and silver element release were investigated as well.

12:15 **Analysis of UV-Cured and Thermally-Cured Inkjet Printed Poly (Lactic Acid) Fabrics,** *Mohammad Nazmul Karim, Muriel Rigout, and Stephen G. Yeates, University of Manchester; and Chris Carr, University of Leeds (UK)* 92

Inkjet printing of Poly (Lactic Acid) (PLA) fabrics using UV-curable inks is of interest due to the thermal sensitivity of PLA and the opportunity for "ambient" temperature curing of the surface ink. In this study, PLA fabrics were printed with Mimaki LH - 100, LF - 140 and LF - 200 UV-curable inks and Mexar thermal inks using a Mimaki UJF - 3042 LED UV inkjet printer and R-Jet 4 DTG printer, respectively. The prints of CMYK colours printed with UV-curable and thermal inks were cured at ambient temperature using a UV LED device and at 150°C for 5 minutes using heat press machine, respectively. The colour fastness properties, Kawabata Evaluation System (KES-F) mechanical properties and bursting strength of the printed samples were evaluated and surface topography using Scanning Electron Microscopy (SEM) analysed. UV-curable inkjet printed PLA fabrics provided better or similar colour fastness and better handle than that of thermally-cured inkjet printed PLA fabrics. The curing condition appeared not to have any effect on the bursting strength of UV curable inkjet printed fabrics; however bursting strength of thermally-cured prints reduced significantly after curing.

12:35 **Advancements in UV LED Curing Performance for Digital Printing (Interactive),** *Michael Beck, Phoseon Technology (USA)* 96

Ultraviolet (UV) curing lamps based on Light Emitting Diode (LED) technology have progressed to the point that they represent a mainstream curing technology in the UV digital inkjet printing market. The historical obstacles of lamp power, cost, and optimized ink chemistry have largely been resolved and the result is a quantum leap in performance resulting from the inherent characteristics of properly designed UV LED lamps; high power, extremely long lifetime, exceptional reliability, consistency and uniformity of UV output, far lower heat load on the curing surface, superior health, safety, and environmental protection, and dramatic reduction in energy.

12:40 – 2:00 PM Lunch Break

Image Processing and Color Management

Session Chairs: Yu-Ju Wu, Appalachian State University, and Shuichi Maeda, Tokai University

2:00 – 3:10 PM

2:00 **FM Screening Algorithm of Multiplicative Congruence Pseudo-Random based on Dot Gathering Model (Interactive),** *Xiao Zhou, Ruizhi Shi, and Da Li, Zhengzhou Institute of Surveying and Mapping (China)* 100

In FM screening techniques, using pseudo-random generator to ensure exposure dots is a method to generate screen dot. Dots generated by traditional algorithm scatter greatly which leads to dot gain and cannot accurately reproduce manuscript's color and tone. On the basis of traditional algorithm, this paper brings forward

a multiplicative congruence pseudo-random algorithm based on dot gathering model. It firstly puts forward the modeling thought and screening project, and then sets multiplicative congruence pseudo-random algorithm as basic model to ensure pseudo-random number generator. On the analysis of dot data, it sets up the dot gathering magnitude model according to pixel grey level. Then coordinate system on the halftone unit is set up to ensure dot coordinate. Finally, dots are generated. By designing screening experiment, it compares this algorithm with traditional ones and evaluates the quality of halftone images and printed images respectively. Experiment testifies that this algorithm has the advantages of FM screening, whose printing characteristics are better than traditional AM screening and dither screening.

2:05 **Printing Quality Enhancement by Detection of Printhead Defects in Single-Pass Inkjet Printing (Interactive),** *Yongtai Zhang, Shihong Deng, Zhihong Liu, and Minhui Wu, Peking University (China)* 104

Banding and doubling are two of the most common problems in inkjet printing, which are caused by printheads defects including blocked nozzle and poor registration. It is expensive and inefficient to solve the problems by enhancing device accuracy or replacing the defective printhead, since the device or printhead may degrade over time. In this paper, we propose an economical and efficient method for banding and doubling reduction by detection of printhead defects without requirement of hardware renewal. We design a test pattern composed of specially organized dots to diagnose status of each nozzle by image processing. Specifically, after analyzing the printed and scanned test pattern, halftone images are modified according to the detected information for banding and doubling reduction. We adjust the size and placement of dots based on human perception in order to improve the printing quality. The detection and reduction are carried out in CMYK printing colorant channels separately. Thus, it could overcome the interchannel interference which may affect the detection accuracy. Experimental results show that the proposed technique is flexible, highly precise and has extensive self-adaptability for various devices, halftone styles, substrates and inks.

2:10 **Reducing Inkjet Ink Consumption with RIP Software for POP Display Media,**
Yu-Ju Wu, Appalachian State University (USA) 108
Most media used for POP display are not paper-based substrates. Finding an appropriate digital print configuration becomes crucial for color reproduction of display media. In most situations, running a digital printer wide-open without ink restriction will not achieve the most accurate, repeatable color. A third-party raster imaging processor (RIP) software interprets raster and vector data files for a specific postscript printer in either RGB or CMYK mode. By controlling CMYK inks directly, RIP software can provide better control for accurate digital color reproduction while reducing ink consumption. The purpose of this project is to reduce ink usage while achieve accurate/repeatable digital color reproduction for display media by establishing a digital print configuration with RIP software for tested display media. Four commercially available display media (DuPont Tyvek, Polypropylene, Satin Cloth, and Vinyl) were used in this study. A third-party RIP software, CGS ORIS Color Tuner, was used to control an Epson Stylus Pro 4800 inkjet printer. The ink usage was determined in terms of amount of ink restriction. Color reproduction quality was evaluated in terms of color gamut volume and inkjet-hooking diagram.

2:30 **Comparative Study on the Resolution Effect Difference between Hardcopy (Printed Image) and Softcopy (Displayed Image),** *Yasushi Hoshino,[1,2] Aran Hansuebsai,[2] and Nobuji Tetsutani[1]; [1]Tokyo Denki University (Japan) and [2]Chulalongkorn University (Thailand)* 112
The advance in imaging system of digital camera and display are remarkable recently. One of important factors of the imaging system is pixel number of camera area sensor and display. The pixel number of digital camera such as 36MPixels (D800, Nikon Corp.) has been on the market, and in some cameras, low pass filter is removed for high resolution. Concerning display, 4 K display (3840x2160 pixels) is already on market, and 8K display (7680x4320 pixels) is planned to sell in near future. It is recognized that the image quality increases according to the increase of the pixel number of input and output devices. Image quality has controlled by various factors such as color, sharpness, gradation, depth feeling, texture feeling and so on. From the view point of resolution, the studies on the effect are not enough. In this report, to understand the effect of resolution to hardcopy and softcopy, concerning perspective image, image quality in general and depth feeling, and concerning the still life image, image quality in general and texture feeling are subjectively investigated respectively. Softcopy of 4 K display is used. Concerning the pixel number, image data of 3840 x 2160 pixel (which is named 4K), 1920 x 1080 pixel (2K), 960 x 480 pixel (1K) and 480 x 240 pixel (0.5K) are prepared and subjectively estimated. Hardcopy is also nearly same data are prepared. Image quality, depth feeling and texture feeling increases as pixel number increase on the whole.

2:50 **Color Change Mechanism of Metal Films– Silver and Niobium,** *Isao Komatsu, Hayata Aoki, Yohei Ito, and Shuichi Maeda, Tokai University (Japan)* 116
We have studied the color change of silver films using sulfide solutions. In this present work, using a goniophotometer, we confirm that the color change of the film comes from thin film interference between silver sulfide and silver layers. In addition, the same procedures were carried out with niobium oxide and niobium films as the standard for comparison which is known to exhibit various colors due to thin film interference.

3:15 – 3:45 PM State-of-the-Art Invited Talk, Liberty Ballroom B, see details page vii.

3:45 – 4:15 Coffee Break — Liberty Ballroom Foyer

4:15 – 5:45 PM Colleague Connections: Monday Roundtable Discussions
choose among the following, details on page xiii
Recyclability and Deinking of Digital Prints–Ecolabels and Testing, *Philadelphia Ballroom North*
UV-Curable Printing for High-End Reflective and Backlit Photography, Fine Art, and "Viewed Up Close" Retail Markets, *Philadelphia Ballroom South*
Industry/Academia Partnerships to Solve Print Industry Challenges, *Salon 5/6*

TUESDAY SEPTEMBER 9, 2014

SPECIAL TOPICS: 3D PRINTING

9:00 – 9:50 AM Tuesday Keynote, Liberty Ballroom B, see details page vii.

Liberty Ballroom B

3D Printing Processes and Materials I

Session Chairs: Steven Ready, Xerox Palo Alto Research Center, and Christopher Tuck, University of Nottingham

10:00 AM – 3:50 PM

10:00 **Multi-Functional 3D Printing (Focal),** *Christopher Tuck, University of Nottingham (UK)**

Exhibit Hall Opens at 10:20 AM

10:30 – 10:50 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Sponsored by Esprix Technologies

10:50 **Multi-Material 3D Printing (Focal),** *Steve Ready, Gregory Whiting, and Tse Nga Ng, Palo Alto Research Center (USA)* 120

Digital manufacturing has garnered significant exposure recently with many announcements of new 3D printers, improved capabilities to print different materials, and the White House's announcement of the creation of a Digital Manufacturing Institute. These recent developments in digital manufacturing are primarily focused on techniques that create individual parts for subsequent assembly, with the most sophisticated printers allowing combinations of several similar structural materials. While it is amazing that the 3D printers today can create complex structures, in the end the current use of 3D printing is limited to proof-of-concept designs, and the final objects are commonly manufactured by conventional means. In order to make 3D printing more versatile, we envision a printing fixture that could produce an assembled object, with parts consisting of different materials (plastics of different characteristics, as well as metals), along with embedded electronic circuits consisting of both printed and conventional components. The printed object could enable embedded mechanical, optical, and electrical functionalities, such as sensors in complex structures that are difficult to produce with existing manufacturing methods. Coupled with the printer is user-friendly design software that analyzes the design in order to determine structural weaknesses, model electrical and mechanical operation, determine materials compatibility and diagnose other aspects of the design which may cause fabrication problems. At the point of this writing, we have demonstrated a wireless sensor circuit for sensing pressure and temperature embedded into a shoe insert and various inductor and antenna structures. In our presentation we will show a collection of our latest demonstrators of integrated multi-material printed objects and outline future directions.

11:20 **Further Developments in the 3D Printing of Self-Glazing Single Fire Ceramic Materials (Focal),** *David Huson and Katie Vaughan, University of the West of England (UK)* 124

David Huson and Katie Vaughan at the Centre for Fine Print Research at the University of the West of England are continuing their research into the 3D printing of ceramic bodies by investigating the possibilities of using techniques developed by the ancient Egyptians to produce a 3D printed ceramic body that will glaze itself during a single firing process. The Centre for Fine Print Research at the University of the West of England has funding from the Arts and Humanities Research Council for a three year research project entitled "Can Egyptian Paste Techniques (Faience) be used for 3D printed, Solid Free-form Fabrication of Ceramics?" Now in the second year of the project this research aims to create a set of functional ceramic materials through a process based upon historic Egyptian Faience techniques, which will allow ceramic artists, designers and craftspeople to 3D print actual objects in a familiar material that can be glazed and vitrified in one firing; a breakthrough for ceramic design and manufacture. The two methods used in ancient Egypt to enable self-glazing in one firing are efflorescence glazing and cementation glazing: In efflorescence glazing soluble salts are introduced in to the body mix, after forming and during the drying stage these salts migrate to the surface of the formed article and during firing fuse and react with the body materials to form a glaze on the surface, by introducing colouring oxides such as cobalt, iron, manganese or copper into the mix a range of coloured glazes can be produced. In cementation glazing the article that has been formed is surrounded in a saggar (a refractory box used to support and protect a ceramic object during firing) by a powder consisting of

** Paper/abstract not available at time of publication.*

SPECIAL EVENT

2014 EXHIBIT

Tuesday
10:20 AM – 6:00 PM
Wednesday
10:00 AM – 3:45 PM

Liberty Ballroom Foyer

Visit this year's exhibitors.
See list on page ii.

a glaze precursor, during the firing process a reaction takes place between the ceramic article and the glaze precursor powder and a glaze is formed on to the surface of the ceramic article, the firing temperature is below the melting temperature of the glazing powder so that the glazed ceramic article can be removed from the powder bed in which it was fired. This is a new area of research to create a functional 3D printed real ceramic material through a process based upon historic Egyptian Faience techniques, which will allow ceramic artists, designers and craftspeople to 3D print objects in a familiar material that can be glazed and vitrified in one low temperature energy efficient firing process, a breakthrough for ceramic design and manufacture which will be applicable to the arts and wider industries.

11:50 **Hybrid Manufacturing Technologies for Electromagnetic Structures,** *Nicholas A. Charipar, Kristin M. Charipar, Matthew A. Kirleis, Heungsoo Kim, Raymond C.Y. Auyeung, Scott A. Mathews, and Alberto Piqué, Naval Research Laboratory (USA)* 129

Advanced fabrication technologies are poised to revolutionize the manufacturing environment. While the development of additive manufacturing technologies for mechanical components has been rapidly evolving, the application of these methods to the fabrication of RF and microwave components has been limited. Hybrid manufacturing processes, which combine distinct techniques such as fused deposition modeling (FDM), and laser micromachining, enable the creation of complex three-dimensional (3D) electromagnetic components. At NRL, we have investigated the combination of 3D printing techniques with direct-write processes that allow for the metallization, laser patterning and room temperature processing of electromagnetic patterns on 3D printed surfaces. The resolution and print volume achieved with these methods are well suited for the rapid prototyping of electromagnetic structures. Several example structures fabricated using these techniques will be presented.

12:10 – 2:00 PM Lunch Break

2:00 **A Hybrid Approach Combining 3D and Conductive Inkjet Printing for the Generation of Linear Ion Traps for Mass Spectrometry Applications (Focal),** *Ingo Reinhold,[1,2] Mirko Wittkötter,[1] Maik Müller,[1] Fritz Koch,[1] Fabrizio Siviero,[3] Robert Murcott,[4] Boris Brkic,[5] Wolfgang Voit,[1] and Werner Zapka[1]; [1]XaarJet, AB (Sweden), [2]KTH Royal Institute of Technology (Sweden), [3]SAES Getters S.p.A. (Italy), [4]TWI Ltd. (UK), and [5]University of Liverpool (UK)* 133

Printed conductors have attracted strong interest in academia as well as the industry. While first applications using printed conductors on flat as well as curved surfaces are establishing in the market, extensive research still is conducted on the post-processing technologies needed for high-volume fabrication of solution processed conductors. With regards to the potential low-cost, high-throughput manufacturing of conductors on inexpensive polymeric foils, new applications start to evolve that call for an even more elaborate investigation of the printing and post-processing steps included. This paper assesses the potential of inkjet-printed conductors for the use in low-pressure environments, such as linear ion-traps for mass spectrometry. In these environments remainders of trapped air or organic solvents affect the performance and lifetime of the getter pump systems used. Additionally, high frequency characteristics of the processed conductors are investigated as these are essential for the sensitivity of an ion trap. In this contribution we establish the framework for the application of conductive inkjet printing on curved surfaces for sensing application in low-pressure environments. Inkjet-deposited nanoparticle inks were investigated with respect to their characteristics under vacuum conditions. The deposits on polymeric foils as well as on DLP processed three-dimensional semi-finished parts were subjected to thermal post-processing and measured with respect to their electrical characteristics as well as their outgassing behavior.

2:30 **The Optimization of Conductive Inks for 3D Inkjet Printing,** *Ehab Saleh, Bochuan Liu, Javier Ledesma Fernandez, Christopher Tuck, Ricky Wildman, Ian Ashcroft, Richard Hague, and Phill Dickens, University of Nottingham (UK)* 137

Commercially available nanoparticle precursor conductive inks are designed to prevent the blockage of the print-head nozzles by using low evaporation rate binder solvents. This low evaporation rate has the consequence of long drying times for those conductive inks which makes 3D printing of conductive routes a lengthy process. In this paper we identify a number of solvents that have suitable properties to prevent nozzle blockage and allow for enhanced drying rates so that multiple conductive layers can be printed within a short time to form 3D conductive elements. To achieve this propylene glycol monomethyl ether acetate (PGMEA) was used as a solvent to form a 30 wt% silver conductive ink which, after sintering, reached a resistivity of 1.66 μΩ.m.

2:50 **The Rheology of Dense Colloidal Pastes Used in 3D-Printing (Focal),** *Michael P. Avery,[1] Susanne Klein,[2] Robert Richardson,[1] Paul Bartlett,[1] Guy Adams,[2] Fraser Dickin,[2] and Steve Simske[3]; [1]University of Bristol (UK), [2]Hewlett-Packard Labs Bristol (UK), and [3]Hewlett-Packard Labs (USA)* 140

The rheology of dense, aqueous pastes of soda-lime glass frit and a polysaccharide binder, designed for use in a recently developed glass 3D-printing process, is reported. Pastes containing either xanthan gum or 2-hydroxyethyl cellulose binder and glass frit with average particle sizes of either 38 – 63 μm or 150 – 250 μm were investigated using a controlled stress rheometer over an applied stress range of (10.66 – 942.2 Pa). The pastes exhibited yield behaviour followed by shear-thinning as the applied stress was increased, in a similar manner to highly concentrated polysaccharide solutions. The yield stress was found to be reduced for pastes containing xanthan gum binder and larger glass particles. The physical properties (Young's modulus, opacity and density) of glass produced by kiln-firing pastes used for glass 3D-printing are also reported. Paste composition was varied to investigate the effect of micro scale changes on the macro scale glass properties. The average glass particle diameter in the frit was varied in the range 38 – 250 μm and glass produced from 'pastes' containing frit-only, frit with binder, and frit with binder and water were compared.

3:20 **3D Printing and Additive Manufacturing: 3D Systems Technology Overview and New Applications in Manufacturing, Engineering, Science, and Education,** *Trevor Snyder, 3D Systems Corp.; Mark Weislogel, Peter Moeck, Jennifer Stone-Sundberg, Derek Birkes, Madeline Paige Hoffert, Adam Lindeman, Jeff Morrill, Ondrej Fercak, Sasha Friedman, Jeff Gunderson, Anh Ha, Jack McCollister, Yongkang Chen, John Geile, Andrew Wollman, Babak Attari, Nathan Botnen, and Vasant Vuppuluri, Portland State University; Jennifer Shim, Princeton University; Werner Kaminsky, University of Washington; Dustin Adams, Xerox Corporation; and John Graft, NASA Johnson Space Center (USA)* 146

Since the inception of 3D printing, an evolutionary process has taken place where specific user and customer needs have crossed paths with the capabilities of a growing number of machines to create value added businesses. Even today, over 30 years later, the growth of 3D printing and its utilization for the good of society is often limited by the various users' understanding of the technology for their specific needs. This paper presents an overview of current 3D printing technologies and shows numerous examples from a multitude of fields from manufacturing to education.

4:00 – 6:00 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour
Liberty Ballroom Foyer

SPECIAL EVENT

INTERACTIVE PAPER, DEMONSTRATION SESSION, PRINT GALLERY AND EXHIBIT HALL HAPPY HOUR

Tuesday, 4:00 – 6:00 pm
Liberty Ballroom Foyer

Meet with interactive authors, exhibitors, and other colleagues over a beer.

PRINTING TECHNOLOGY I

9:00 – 9:50 AM Tuesday Keynote, Liberty Ballroom B, see details page vii.

Liberty Ballroom A

Ink Jet: Process and Simulation II

Session Chairs: Frits Dijksman, University of Twente, and Kye-Si Kwon, Soonchunhyang University
10:00 AM – 3:05 PM

Session sponsored by

10:00 **DoD Inkjet Printing of Weakly Elastic Polymer Solutions,** *Stephen D. Hoath,[1] Damien C. Vadillo,[2] Oliver G. Harlen,[3] Claire McIlroy,[3] Neil F. Morrison,[3] Wen-Kai Hsiao,[1] Tri R. Tuladhar,[4] Sungjune Jung,[5] Graham D. Martin,[1] and Ian M. Hutchings[1]; [1]University of Cambridge (UK), [2]AkzoNobel Ltd. (UK), [3]University of Leeds (UK), [4]Trijet Ltd. (UK), and [5]Pohang University of Science and Technology (Korea)* 152

Fluid assessment devices, such as high frequency rheometers and torsion resonators, filament stretching and thinning systems, and oscillating DoD drops, requiring small volumes and avoiding the need for jetting, are particularly useful in the design of functional fluids for inkjet printing applications. With the increasing use of complex (rather than Newtonian) fluids for manufacturing, single frequency fluid characterisation cannot reliably predict good

jetting behaviour, owing to the range of shearing and extensional flow rates involved. However, the scope of inkjet fluid assessments (beyond achievement of a nominal viscosity within the print head design specification) is usually focused on the final application rather than the jetting processes. The experimental demonstration of the clear insufficiency of such approaches shows that fluid jetting can readily discriminate between fluids assessed as having similar LVE characterisation (within a factor of 2) for typical commercial rheometry measurements at shearing rates reaching 10_4 rad s_{-1}. Jetting behaviour of weakly elastic dilute linear polystyrene solutions, for molecular weights of 110-488 kDa, recorded using high speed video was compared with recent results from numerical modelling and capillary thinning studies of the same solutions. The jetting images show behaviour ranging from near-Newtonian to "beads-on-a-string". The inkjet printing behaviour does not correlate simply with the measured extensional relaxation times or Zimm times, but may be consistent with non-linear extensibility L and the production of fully extended polymer molecules in the thinning jet ligament. Fluid test methods allowing a more complete characterisation of NLVE parameters are needed to assess inkjet printing feasibility prior to directly jetting complex fluids. At the present time, directly jetting such fluids may prove to be the only alternative

Exhibit Hall Opens at 10:20 AM

10:30 – 10:50 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Sponsored by Esprix Technologies

10:50 **Colloidal Suspension Rheology and Inkjet Printing,** *Stephen D. Hoath,[1] Wen-Kai Hsiao,[1] Huai Nyin Yow,[2] Simon R. Biggs,[2] Simon A. Butler,[1] Malcolm R. Mackley,[1] Graham D. Martin,[1] and Ian M. Hutchings[1]; [1]University of Cambridge and [2]University of Leeds (UK)* 157

This work reports the first systematic survey of colloidal suspension jetting, as opposed to dripping liquids containing particles, and it complements a previous survey of the jetting of complex fluids. Colloidal suspensions of stabilised polystyrene particles in water/ethylene glycol were formulated for maximum stable loadings (vol%) and low poly-dispersity index (PDI), for a range of spherical particle sizes (80 nm to 850 nm). Each preparation batch was characterised using squeeze mode rheometry and filament stretching devices while being independently assessed using drop-on-demand (DoD) inkjet printing from MicroFab nozzles with either 30 μm or 80 μm diameter. Nozzle blocking was reduced for the jetting tests by maintaining a 100 Hz printing frequency throughout waiting periods. Additional experiments used a transparent containment chamber around the 30 μm nozzle exit to examine jetting behaviours that might be caused by the humidity level. Jetting for each batch (characterised by colloidal particle size, vol%, nozzle size, etc.) was considered successful if high speed videos used for measurements of drop speed and determination of the jet break-off time from nozzle meniscus were reliably and consistently achieved at several drive voltages. Jetted drop speeds for all the colloid suspensions tested showed a linear dependence on drive voltage above a threshold voltage as previously reported for Newtonian and weakly elastic drop speeds. Mapping of successful DoD jetting as a function of colloidal particle size (nm) and vol% for 80 μm (30 μm) nozzle diameter reached 37 vol% (30 vol%) without any evidence for any spherical 80-850 nm (300-850 nm) particle size effect on jetting. The rheology of these colloidal suspensions, obtained independently from jetting, exhibits rather Newtonian behaviour with a range of viscosities within a factor of 2. Likewise, the filament stretching experiments that are sensitive to non-linear effects such as relaxation time could not discriminate between solvent and suspensions. Beyond issues with blocking (and stability), colloidal suspensions were jetted easily, in line with expectations based on the measured rheology and low non-linear effects.

11:10 **Towards Satellite Free Drop-on-Demand Printing of Complex Fluids (Focal),** *Neil F. Morrison and Oliver G. Harlen, University of Leeds; and Stephen D. Hoath, University of Cambridge (UK)* 162

We investigate the influence of fluid properties on jet breakup in the context of drop-on-demand inkjet printing. In drop-ondemand printing, each drop remains temporarily connected to the printhead by a ligament which thins while the drop is in flight. Upon pinch-off the severed ligament may recoil into the leading drop, or it may fragment into 'satellite drops' which reduce printing resolution. A key goal of inkjet research is to prevent or impede the creation of satellite drops while maintaining a high drop speed. Complex fluids often exhibit enhanced resistance to fragmentation in jetting flows compared to Newtonian fluids of similar viscosity. Indeed, some complex fluids have been found in experiments to produce satellite-free jets even at high drop speeds. In this work we exploit rheological considerations with the aim of eliminating satellite drops when printing at prescribed dropspeeds, without any alterations to the driving waveform other than a simple amplification. In explicit terms, we attempt to design the rheology of the fluid in such a way as to calibrate its effective viscosity during the key stages of a drop-on-demand flow cycle. Using a purely shear-thinning fluid model, we outline the key fluid parameters and dimensionless groups and we use a Lagrangian finite-element numerical method to simulate a dropon- demand printing flow under realistic industrial inkjet conditions, exploring the parameter space of

critical fluid poperties for a variety of drop speeds. We show that a shear-thinning fluid model with calibrated viscosity plateaus is able to eliminate satellites without compromising on drop speed and without adjusting the driving waveform. The present study complements previous work in which we have presented results of drop-on-demand simulations for a viscoelasticfluid model with constant shear-viscosity, a generalized Newtonian fluid model (shear-thinning), and the Giesekus fluid model which is both viscoelastic and shear-thinning. In each case we demonstrated the capacity of non-Newtonian fluid properties to reduce the number and net volume of satellite drops. In these works, the elimination or reduction of satellites was considered only as a desirable potential outcome; by contrast, in the current work the elimination of satellites is imposed as a requirement.

11:30 **Evaluating Novel Digital Methods for Jetting Large Particle High Viscosity Materials,**
Vince Cahill, Dene Taylor, and Patrice Giraud, The Solutions Group (USA) 166
Refinements in established digital methods and the arrival of novel deposition and printing technologies are expanding the range of materials that can be effectively jetted, even without the imposition of heat. Also some novel methods have obviated the dimensional restrictions of nozzles for the passage of large particles and complex polymers. These advances enable the deposition of temperature sensitive and large cell biologic and highly viscous polymeric materials.

11:50 **Tracking based Inkjet Measurement for Evaluating High Frequency Ink Jetting,**
Kye-Si Kwon, Min-Hyuck Jang, and Hyun-Seok Ko, Soonchunhyang University (Korea) 171
Inkjet technology has been used as a manufacturing tool for printed electronics. To increase productivity, the jetting frequency needs to be increased. When using high frequency jetting, the printed pattern quality can be non-uniform since jetting performance, including jetting speed and droplet volume, can vary significantly according to the jet frequency increase. Therefore, high frequency jetting behavior must be evaluated properly for performance improvement. However, it is difficult to measure high frequency jetting behavior using the previous vision analysis methods because subsequent droplets are very close and can even merge. In this paper, we present vision measurement techniques to evaluate the drop formation of high frequency jetting. The proposed method is based on the tracking of target droplets, and other subsequent droplets can therefore be excluded in the image analysis by focusing on the target droplet.

12:10 – 2:00 PM Lunch Break

2:00 **Ink-Particle Flight Simulation for Continuous Inkjet Type Printer,** *Masato Ikegawa and Eiji Ishii, Hitachi Ltd.; and Nobuhiro Harada and Tsuneaki Takagishi, Hitachi Industrial Equipment Systems Company, Ltd. (Japan)* 176
Industrial continuous inkjet printers typically are used for printing directly on various types of products such as cans, bottles, and food packaging in production lines. Their application to 3D printing (additive manufacturing) also has recently become a promising area of research. To enable their application to higher speed production lines, their print quality needs to be improved. This means that ink-particle flight simulation technology is needed to clarify the factors that affect print quality. Print distortion results from aerodynamic and electric interference among the ink-particles during their flight from the nozzle onto the print target. A simulation technique has been developed that enables the trajectories of the ink particles and the airflow around them to be calculated simultaneously. The functions needed to accomplish this, such as calculation of the electrostatic force, the Coulomb force, and the aerodynamic drag force for many flying ink particles were added to a Lagrangian method used for fluid dynamic analysis. The simulated velocities and positions of the flying ink particles agreed well with the experimental ones and helped clarify the factors affecting print quality. Simulated printing of multiple-dot lines revealed that the lines on the print target were distorted. This was because the trajectories of the charged particles in the lines were distorted by electric and aerodynamic interference during flight. Simulation showed that the appropriate insertion of dummy particles reduces the print distortion in computers.

2:20 **Numerical Analysis of Drop Dynamics of Acrylate Resin in Piezoelectric Inkjet Three Dimensional Printers,** *Kun Joong Park, Ohyun Baek, Yongtaek Hong, Changbae Park, and Keon Kuk, Samsung Electronics (Korea)* 181
The photopolymerized acrylate products, fabricated using piezoelectric inkjet three dimensional printers, can be deformed under some printing process conditions. To understand and solve this deformation problem, we focus on the drop dynamics of the acrylate resin ink before being cured by the ultraviolet light. We numerically solve the full Navier-Stokes equation with the Volume-of-fluid (VOF) method to investigate the impact, spreading, and recoiling behavior of the resin ink droplet to show how the resin ink flow characteristics result in the shape change of the products. We have successfully developed the numerical models for the analysis of the drop dynamics of the resin ink in piezoelectric inkjet three dimensional printers.

2:40 **Simulation Experiments to Model the Inkjet Printing Behavior of Functional Inks,** *Adarsh Anand, Paul D. Fleming III, and Margaret K. Joyce, Western Michigan University (USA)* 185

Flow simulations of jetting of ink jet drops are presented. The Z number of Fromm is used to characterize jettability. Simulation results are comparable to jetting behavior observed by the drop watcher on a Dimatix 2800 Materials Printer.

3:00 **Innovations in Inkjet Analysis (Interactive),** *Paul Best, ImageXpert, Inc. (USA)* 188

It is a general principle that measurement is key to consistently successful innovation, and this principle certainly holds when it comes to inkjet R&D. Deconvolving causes of poor performance, like misting, wetting, satellites, and poor sustainability, while in production, quickly becomes very difficult and expensive. New analysis tools have become available over the last years, however, by which these problems can now be identified and addressed independently. Drops in flight are not only visualized but repeatably measured, using high speed strobe and cameras, capable of capturing individual drops as small as 10 μm in diameter, or traveling at speeds over 50 m/s, using a single strobe. Significant automation is also possible, including analysis of all jets in a row, or analysis of inkjet performance at a range of frequencies.Over the last year, even newer tools for inkjet R&D have become available, notably now including a fully integrated testing and printing platform, which includes drop watching and analysis, belt printing with print controller, and adjustable ink supply, in a single system. These new ink development platforms may also include a drop weigh station, X--Y print table including densitometer, laser, and even automated print quality analysis of the final product. Direct imaging of drop-substrate interaction is becoming available, as well, by using a triggered strobe and motion stage to capture the impact of drops on custom surfaces, or on transparent material. With these new tools, we can expect inkjet innovation and performance improvement to continue apace, with applications in printed electronics,ceramics, textiles, 3D, medicine, science, and much more. Our goal in this presentation will be to give an overview of these new innovative techniques, tools, and products for inkjet R&D.

Ink Jet: Ink and Media I

Session Chairs: Alex Shaknovich, Cabot Corporation, and Stephen Hoath, University of Cambridge

3:05 – 4:00 PM

3:05 **Ink-Jet Printed Copper Complex MOD Ink for Plastic Electronics,** *Yousef Farraj,[1] Michael Grouchko,[1] Shlomo Magdassi,[1] Fritz Koch,[2] Mirko Wittkötter,[2] Maik Müller,[2] Ingo Reinhold,[2, 3] and Werner Zapka[2]; [1]The Hebrew University of Jerusalem (Israel), [2]XaarJet AB (Sweden), and [3]KTH Royal Institute of Technology (Sweden)* 191

The development of highly conductive copper patterns on low-cost flexible substrates (PET, PEN, etc.) by inkjet printing is reported. Copper films were obtained from a metallo-organic decomposition (MOD) ink composed of a copper complex and suitable low-viscosity solvents. Upon heating the ink decomposed and was converted into metallic copper under nitrogen as inert atmosphere. Additionally samples were prepared using inkjet technology on various substrates. The required layer thickness for current conduction was assessed by printing on PET and sintering at 150°C in a vacuum oven.

3:25 **Self-Dispersed Carbon Black for Inkjet Printing Application (Interactive),** *Chien-Wen Lee and Hsiao-San Chen, Everlight Chemical Industrial Corporation (ECIC) (Taiwan)* 194

Self-dispersed (SDP) carbon black inks have been successfully increased optical density by adding different multivalent metal ions. These selected metal ions cause SDP carbon black particles flocculating on paper surface after printing, but not affected the stability and jetability of inks.

3:30 **Fire Safety and Inkjet Printed Wallcovering Materials (Interactive),** *Bruno Fouquet, Sihl AG (France), and Patrick Le Galudec, Sihl AG (Switzerland)* 198

As wallcovering shifts to digital on-demand manufacturing, questions on safety and fire regulations have to be reconsidered. In a world of changing rules, where multiple actors intervene, it becomes important to conduct and extend research to predict fire resistance and behavior of materials once printed and finished. Sihl research aims to provide first insights and draw attention to the next manufacturing advances to be documented in the future.

3:35 **Modeling Ink Diffusion within Paper to Achieve a Raggedness Ruler for Print Quality Control (Interactive),** *Ali Azin,[1] Saeideh Gorji Kandi,[2] and Atasheh Soleimani Gorgani[1]; [1]Institute for Color Science and Technology and [2]Amirkabir University of Technology (Iran)* 201

Raggedness is one of the most important print quality factors. It is defined as the appearance of geometric distortion of an edge from its ideal position that should be absolutely straight along the length of the line.

Raggedness is caused by several phenomena. The non-uniformity absorption of ink, which may be because of the paper roughness or ink quality, may cause various degree of raggedness. Print quality assessments are usually based on comparing a test sample with a reference as a ruler of different quality samples. Therefore, it is important to prepare appropriate rulers for different quality metrics. The present study introduces a new method for modeling of raggedness by simulating ink diffusion within paper. It is assumed that different parts of a paper have different diffusion coefficients, so the ink can randomly diffuse through different paths. These paths can be changed via paper properties and drying time. Using this method and controlling the effective variables it is expected to generate different levels of raggedness. The experimental results show that with the proposed method it is possible to achieve different levels of raggedness, which can be used to generate test targets and raggedness rulers. Also, it can standardize objective and subjective test methods for measuring raggedness.

3:40 **Effect of Particle Size on Properties and Droplet Formation of Disperse Dye Multiphase Fluid (Interactive),** *Shaohai Fu, Ping Wang, Liping Zhang, Anli Tian, Guifang Zhang, and Chaoxia Wang, Jiangnan University (China)* 204

This research focus on investigating the effect of particle size on properties and droplet formation of disperse dye multiphase fluid. The results show that the stability, spreading area on the transfer paper and transfer rate increase with decreasing the particle size of disperse dye in multiphase fluid. The droplet formation process of multiphase fluid from a fine pinhole is composed of ejection, stretching, necking, pinch-off, recoil and recombination of primary drop and satellite. The larger particle size of the disperse dye, the shorter droplet pinch-off time is. And the larger disperse dye content leading to the smaller pinch-off time. A small droplet following the primary particles is formed when disperse dye content is high.

3:45 **Properties and Application of Carbon Black/Latex Composite via Miniemulsion Polymerization (Interactive),** *Yu Guan, Chunxia Wang, Liping Zhang, Anli Tian, Shaohai Fu, and Chaoxia Wang, Jiangnan University (China)* 208

The core-shell structure composite which used carbon black as core and latex as shell was prepared via miniemulsion polymerization. The morphology of the CB/latex composite have been investigated by transmission electron microscopy (TEM), Fourier transform infrared (FTIR) and thermogravimetic analysis (TGA). It showed that the prepared dispersion had small particle size and better dispersibility. Furthermore, CB/latex composite showed much better stability and printing performance.

3:50 **Preparation of TiO_2/Latex Composite for Inkjet White Ink (Interactive),** *Liping Zhang,[1] Fushun Bai,[1] Changsen Du,[2] Anli Tian,[1] Guocheng Mei,[2] and Shaohai Fu[1]; [1]Jiangnan University and [2]Shi Ming Science and Technology Corporation (China)* 212

A TiO_2/latex composite was prepared from KH570-modified TiO_2 and methylmethacrylate (MMA) via miniemulsion polymerization, and further was used to formulate a white inkjet ink. Fourier transform infrared spectrum (FTIR), Transmission electron microscopy (TEM) and thermogravimetric analysis (TGA) indicated that the copolymer of DNS-86 and MMA was successfully coated onto TiO_2 surface and amount of copolymer was about 40%. A white inkjet ink prepared from the TiO_2/latex composite had a small particle size, a narrow particle size distribution and enhanced stabilities to temperature and centrifugal forces. This research may provide a method to prepare a white inkjet ink for textile inkjet printing.

3:55 **Preparation of Nanoscale TiO_2-Encapsulated C.I. Pigment Blue 15:3 via Sol-Gel Method (Interactive),** *Shaohai Fu,[1] Changsen Du,[2] Chuanxia Wang,[1] Anli Tian,[1] and Chaoxia Wang[1]; [1]Jiangnan University and [2]Kunshan Sunmun Science and Technology Development Co. Ltd. (China)* 216

A nanoscale TiO_2-encapsulated C.I. pigment blue 15:3 was prepared through sol-gel method. The effects of encapsulation conditions on particle size were investigated in detail. Transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FTIR), contact angle analysis (CAA) and zeta potentials of TiO_2-encapsulated C.I. pigment blue 15:3 at different pH value proved that encapsulation layer of TiO_2 was formed on C.I. pigment blue 15:3 surface. The dispersion with small particle size was obtained when the mass ratio of octadecyl amine polyoxyethylene ether amine 2-quaternary ammonium salt (OPA) to pigment was 25%, the mass ratio of butyl titanate (BT) to pigment was lower than 11%, the dropping rate of BT was 3 mL/min and the pH value was 5.8. The encapsulated phthalocyanine blue pigment had enhanced stabilities to centrifugal force and freeze-thaw treatment.

4:00 – 6:00 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour

Liberty Ballroom Foyer

PRINTING TECHNOLOGY II

9:00 – 9:50 AM Tuesday Keynote, Liberty Ballroom B, see details page vii.

Liberty Ballroom D

Electrophotography: Materials

Session Chairs: Heather J. Gulley-Stahl, Lexmark International; Rüdiger Baur, Clariant; and Norio Nagayama, Ricoh Co., Ltd.

10:00 – 11:50 AM

10:00 **Detecting and Evaluating Toner Property Changes after Exposure to Coating Materials,** *Heather Gulley-Stahl, Whitney Burress, Jeremy Daum, Jim Doeltz, Connie Haberman, David MacMillan, Dale Massie, James Semler, and Robert Glenn Smith, Lexmark International (USA)* 220

This presentation highlights a specific case of toner plasticization that occurred during a storage situation. Three aspects of the investigation are discussed: determination of the root cause, analytical results with a correlation to functional testing, and the development of an offline materials compatibility screening test. Once the contaminant causing a change in toner properties was identified, functional testing and materials analysis confirmed a strong correlation. After the realization that coating materials from any location within the EP system could potentially interact with toner in an undesirable way, an offline materials compatibility test was developed. It is anticipated that this test method could provide a screening tool for low risk materials for use in EP subsystems.

Exhibit Hall Opens at 10:20 AM

10:30 – 10:50 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Sponsored by Esprix Technologies

10:50 **The Charge Properties and Durability of New Submicron Silica,** *Yusuke Tosaki, Yuki Amano, and Yukiya Yamashita, Nippon Aerosil Company Ltd. (Japan); Robert E. Johnson, Evonik Corporation (USA); and Paul Brandl, Evonik Specialty Chemicals Company Ltd. (China)* . . . 224

Submicron silicas produced by hybrid process and their corresponding surface-modified counterparts are compared with respect to their applicability as external additives for electro-photographic toners. The principal metric for comparison is tribo-electrostatic charge (T-ESC) stability under extended activation periods. Experimental samples are surface-modified submicron silicas produced by a hybrid process. The hybrid materials have sufficient hydrophobicity and can work as spacer particles to prevent the embedding of small particle size external additives. Further characteristics and advantages for this new external additive type will be presented. The surface modification improves charge stability and the spacer effect, especially under extreme environmental conditions, that can impact toner performance.

11:10 **The Improvement of Core-Shell Toner by Controlling the Interfacial Thickness between Core and Shell Polyesters,** *Tomohide Yoshida, Norihiro Fukuri, Eiji Shirai, and Katsutoshi Aoki, Kao Corporation (Japan)* 229

The fabrication of polyester core-shell toner by emulsion aggregation method was investigated to realize better balance of low-energy fusing and good storage stability. In core-shell toners which use high Tg shell resin and low Tg core resin, the storage stability can be significantly worse than expected from shell Tg. It was thought that the core moiety diffused into the shell by interfacial polymer diffusion in the heating coalescing process. From this viewpoint, the control of the interfacial diffusion (interfacial thickness: λ) between the core and shell was examined based on the χ parameter of the polyester resin combinations which was calculated by monomer composition. After examinations of several polyester combinations based on calculated χ parameters, it was found that 1,2-propanediol (1,2PD)/isophthalic acid (IPA) polyester and 1,2PD/alkenyl succinic anhydride (AS) polyester showed a strong phase separation. The ellipsometry measurement revealed that the interfacial thickness of this combination was only 10nm, which was too small for sufficient adhesion between the core and shell. Therefore larger interfacial thicknesses were tested by incrementally decreasing the χ parameter by changing monomer composition. A strong relationship between actual λ and the χ parameter was found. The λ could be controlled at 80nm by using a resin combination based on 1,2PD/IPA and 1,2PD/IPA/AS, and a core-shell toner was produced using this combination of polyester resins. The adhesion

between core and shell was found to be sufficiently strong, and the relationship between low temperature fusing and storage stability became significantly better compared with the toner having miscible core and shell.

11:30 **Study of the Effect of External Additives on Toner Admix Performance,** *James Boswell, Hajime Kambara, Vivian Zhang, Geoffrey Moeser, and Dmitry Fomitchev, Cabot Corporation (USA)* 233

The charge-admix-exchange process happening in the xerographic developer between aged and fresh toner, as well as carrier particles carrying different electrostatic charges, is a complex and not well-understood process from a theoretical point of view. Fast electrostatic charging of fresh toner particles to a desired steady state in a developer is very important to achieve high quality prints, especially in the case of high speed printing devices. One common way that formulators try to improve toner admix is by adjusting the external additive package. The goal of this study was to gain a better understanding of how different additive morphology and surface treatment influence admix. More specifically, we investigated what happens with the electrostatic charge of toner when aged and fresh developers are mixed in equal proportions and the mixture exercised over a short time period. Results of the study of a simple model developer containing a positively charging toner, a single fumed silica surface treated with a silane containing an amino group, and a silicone coated ferrite carrier, will be presented. The collected data indicate that the carrier's ability to gain electrostatic charge quickly decreases as a result of the transfer of silica particles or molecules of the silica treating agent to the carrier's surface. This leads to an unfavorable performance in the admix test. In the second part of the work, the effect of different types of spacer additives on carrier poisoning and admix was studied. The obtained results show that the formulations containing spacer particles have more stable charge vs. exercise time and better admix characteristics than the formulation containing only one silica additive.

11:50 AM – 2:00 PM Lunch Break

Security and Functional Printing/Printing Systems Interactive Previews

Session Chairs: Robert Ulichney, Hewlett-Packard Co.; Alan Hodgson, 3M UK PLC; and Shigeru Kitakubo, Nippon Institute of Technology

2:00 – 3:35 PM

2:00 **Fast Mobile Stegatone Detection Using the Frequency Domain (Focal),** *Robert Ulichney,[1] Stephen Pollard,[2] and Matthew Gaubatz[1]; [1]Hewlett-Packard Company (USA) and [2]Hewlett-Packard Company (UK)* 237

Data-bearing halftone images are an attractive high-capacity alternative to barcodes. We show that smartphone close-focus video capture can recover the associated data, and a frequencydomain- based algorithm enables a robust means of detecting the presence as well as determining the location, scale, and orientation of data-bearing designs. Android and iOS mobile implementations achieve this at near video rates. Using these affine transform parameters as a starting point, a method for full perspective correction for precise alignment is also developed. This functionality is fast, accurate, and achieved without the benefit of fiducial marks.

2:30 **Digital Watermark for Printing Image -Application to Thermal Transfer Printing Method,** *Nobuki Nemoto, Takeo Miki, and Takashi Yamaguchi, Toshiba Corporation (Japan)* 243

We have introduced an information embedding method on a digital watermark for a printing image and applied to thermal transfer printing. In this method, printed dots are arranged in staggered array to obtain area coverage modulation in each dot in thermal transfer printing. It is possible to correctly embed sub image information in this typical dot array and to electronically restore the sub image information. We confirmed that both invisibility characteristics and restoration characteristics are quite good and the digital watermarks can be normally embedded and restored as the result from the evaluations of 100 images printed at the resolution of 400 dpi after textual sub image information was embedded.

2:50 **Toner Printing for Secure Documents,** *Alan Hodgson and Lesley A Williams, 3M UK PLC(UK)* 249

This paper presents some specific challenges and opportunities in the security printing sector. As a demonstration of this it uses the example of high security national identity documents. It examines some of the technical problems that are specific to this market sector and the opportunities that arise from these, particularly in the area of the physics and chemistry of the materials in the digital printing process. The work concentrates on electrophotographic (toner) printing. It is noted that mainstream applications are evolving in a direction that appears to be divergent to security print. Finally, the challenge electrophotography faces in this market sector from inkjet is covered, particularly from pagewide printing.

3:10 **Printed Paper based Glucose Sensor Manufactured in Pilot Scale,** *Liisa Hakola and Kaisa Lehtinen, VTT Technical Research Centre of Finland (Finland)* 254

VTT has long experience in development of inkjet printable functional inks including printable enzymes. Also a method for controlling liquid flow on paper has been developed by VTT. This method is based on printed channel boundaries that guide flow of liquids such as water, blood, urine or other suitable liquid analyte. This technology can be used to manufacture inexpensive and simple-to-use diagnostic devices and tests that can provide results by visual colour change. This provides possibility for point-of-care or home testing. Use of paper based diagnostics has been proven to work for e.g. glucose indication in laboratory scale. Furthermore, VTT has studied and developed enzymes suitable for use in diagnostic devices. Many of the enzymes can be applied by using different printing technologies. The objective of this study was to demonstrate the feasibility of paper based diagnostics in pilot scale by utilizing roll-to-roll flexography printing and industrial scale inkjet printheads. A successful glucose sensor demonstrator was realized.

3:30 **Measuring Manufacturing Productivity (Interactive),** *David R. Spencer, Catherine Fiasconaro, and Vishal Sahay, Spencer & Associates Publishing, Ltd. (USA)* 258

Whether manufacturing 2D or 3D printed products, the press itself is one of your largest investments; improving your Return-on-Investment is one of your key goals. For many presses, the ROI is predicated on producing hundreds of thousands or even millions of dollars worth of output. An increase of just a few percent would have a very significant impact on ROI. The industry has heretofore been satisfied with merely tracking job flow. Historically, identifying the obstacles to improving press productivity, utilization, and ROI has relied on anecdotal information; real information—quantitative press productivity data—has not been available. Recognizing the problem, we focused upon the lack of data identifying the bottlenecks. One fundamental breakthrough was realizing that only press operators on the shop floor know much of the needed information. The information must be acquired in a minimally invasive manner, categorized, aggregated, analyzed, and presented as metrics that support and facilitate identification of the real obstacles and bottlenecks. We will describe and demonstrate a new, patent-pending methodology and system that actually measures productivity of any press or other output-producing machine over time. This is not another printing MIS system; rather, it highlights bottlenecks and opportunities for productivity improvement. Implemented with today's state-of-the-art technologies, the system incorporates touchscreen, tablet-based data collection GUI, cloud-based data storage and analysis, and browser-based anytime, anywhere graphical dashboard and reporting.

4:00 – 6:00 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour
Liberty Ballroom Foyer

IMAGE SCIENCE AND TECHNIQUES

9:00 – 9:50 AM Tuesday Keynote, Liberty Ballroom B, see details page vii.

Liberty Ballroom C

Image Measurement: Methods and Equipment

Session Chairs: Paul Best, ImageXpert, Inc.; Wolfgang Schmidt, Schoeller Technocell GmbH & Co. KG; and Takuroh Sone, Ricoh Co., Ltd.
10:00 AM – 12:15 PM

10:00 **Latent Image Measurement for Dot Pattern Formed by Scanning Laser Beam (Focal),** *Hiroyuki Suhara, Masato Iio, and Hiroto Tachibana, Ricoh Company, Ltd. (Japan)* 264

A method that enables the measurement of an electrostatic latent image equipped with a laser scanning unit is proposed. One of the features of this method is that the laser scanning unit is arranged outside the vacuum chamber. The vibration and the electromagnetic field interference of a polygon motor do not affect the orbit of the electron beam because the polygon motor is kept away from the electron optics system. A pair of laser diodes (LDs) is used as the light source of the laser scanning unit. The measurement results obtained

by the proposed method provide valuable new information on latent image characteristics for exposure conditions.

Exhibit Hall Opens at 10:20 AM
10:30 – 10:50 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer
Sponsored by Esprix Technologies

10:50 **Friction Properties of Inkjet and Laser Prints,** *Simona Grigaliunienė, Jonas Sidaravicius, and Vytautas Turla, Vilnius Gediminas Technical University (Lithuania)* 268
Friction between different papers, inkjet and laser prints were investigated experimentally. Static (SCOF) and kinetic (KCOF) friction coefficients between paper and paper, paper and prints, prints and prints were determined. The highest friction is between prints and prints and lowest is between paper and paper. The dependence of the SCOF and KCOF on pressure (both decrease) together with the roughness measurements enables to conclude that friction of prints is governed mainly by the adhesion forces.

11:10 **An Evaluation Method for Microgloss Uniformity,** *Takuroh Sone and Makoto Hino, Ricoh Company, Ltd. (Japan)* 272
Microgloss uniformity affects the final image quality of electrophotographic printers. The microgloss is the noise of the micro-gloss differential, and occurs because of either insufficient pressure or toner blistering. Microgloss uniformity evaluation methods have been proposed previously. However, these methods have not been used to establish a standard method. The purpose of this paper is to establish a simple quantitative microgloss evaluation method. The measurement device is composed of a charge-coupled device (CCD) camera and vertically-incident lighting equipment. Because the measurement geometry is 0°/0°, the measuring device is small in size and the camera angle adjustment process is simple. In addition, polarizing filters are inserted into the optical path to suppress any internal diffuse reflected light. The RGB (red-green-blue) image measured by the CCD camera is converted into an L*a*b* image. The L* image is then Fourier transformed to obtain the Wiener spectrum. An evaluation model using Hunter whiteness, a visual characteristic, and the Wiener spectrum was proposed. As a result, the contribution of the evaluation model and the subjective score was 0.94. Because this method is simple, it is expected to find widespread application in the printing industry.

11:30 **New Craze Testing Method,** *Dirk Fiedler, Petra Behnsen, and Yvonne Gierth, PTS (Germany); and Wolfgang Schmidt, Schoeller Technocell (Germany)* 277
Coated paper printed with black indigo shows marked crazing or fold cracking as it is known in offset printing. Photographic paper (silver salt) exhibit a magenta line in the fold after being turned umpteen times. E-PHOTO paper (Felix Schoeller Digital Media) printed with indigo exhibits neither crazing nor magenta crazing according to the findings gathered by Felix Schoeller Digital Media. PTS has been commissioned to develop a standardised method (PTS Craze Test) and to conduct it on three paper samples in order to determine the differences in the crazing behaviour of paper used in the photo album sector. This method must be conducted under pre-defined conditions and serve as certification of the above-mentioned problem area by virtue of its reproducibility.

11:50 **Analysing Banding Features for Classifying Print Processes Using Artificial Neural Networks,** *Shankhya Debnath and Jitamitra Bagchi, Jadavpur University (India)* 281
The need for verifying and authenticating printed documents for the purpose of determining its validity finds applications in various fields, including digital forensic analysis and forgery detection. Print security becomes a primary concern for end use consumers and application providers at all levels of usage. Identifying the authenticity of a print can be a challenging task, since print quality and features varies on varying the methods of printing. In order to determine the source or process of printing, various methods has been specified in literature. This paper provides an in depth analysis on one such measure. Each printer has some features which are inherently part of the process due to the mechanical parameters used while modelling the device. Such features may be called intrinsic features of a printer. One of these primary features is banding that occurs primarily in electrophotographic(EP) printing processes, which has been widely reported in standard literature. However, such existence in offset or gravure printing is yet to be verified. This paper deals with examining the presence of such banding frequencies in offset or gravure printing processes. Numbers of printing processes were examined and thereby the banding was analysed using their corresponding frequency spectrum. The data obtained from the method were used as features for classifying the printing method using a supervised multilevel perceptron.

12:10 **Introducing a New Method for Generating Test Targets to Evaluate Printing Mottle (Interactive),** *Ali Azin,[1] Saeideh Gorji Kandi,[2] and Atasheh Soleimani Gorgani[1]; [1]Institute for Color Science and Technology and [2]Amirkabir University of Technology (Iran)* 289

Printing mottle is one of the most important print quality factors. It is defined as measure of the appearance of unintended, periodic macroscopic fluctuations of lightness (macroscopic means: between 'spots' at distances > 1 mm). Mottle is caused by several phenomena. The non-uniformity absorption of ink, which may be because of the paper roughness or ink quality, may cause various degree of printing mottle. Print quality assessments are usually based on comparing test samples and references as a ruler of different quality samples. Therefore, it is important to prepare appropriate rulers for different quality metrics. There are methods like adding moisture to paper before printing to simulate printing mottle. The present study introduces a new method for generating test targets to evaluate printing mottle. In this method, a set of noise patterns like Hermit and Value noises were used. By changing parameters like frequency and amplitude, we achieved different levels of printing mottle. The experimental results show that with the proposed method, it is possible to generate different levels of mottle, which can be used to generate test targets and mottle rulers.

12:15 – 2:00 PM Lunch Break

E-Paper and Display

Session Chair: Makoto Omodani, Tokai University

2:00 – 2:40 PM

2:00 **Development of Rewritable Laser System (Focal),** *Yoshihiko Hotta, Takahiro Furukawa, Kazutaka Yamamoto, Tomomi Ishimi, and Shinya Kawahara, Ricoh Company, Ltd. (Japan)* . . 292

Various systems for rewritable recording technology have been proposed from the viewpoint of convenience and reducing environmental impact. However, such systems have limitations. A thermal rewritable recording medium that uses high-contrast leuco dye is not suitable for outdoor use because of rapid photofading. In vector scanning, which is an efficient method for drawing characters with a high power laser, repetition durability tends to be degraded by overheating at the crossing and turning points of character strokes. We solved these two problems to permit outdoor application under severe conditions by using novel technologies. The system is a rewritable recording technology suitable for use in physical distribution systems.

2:30 **Improvement of Particle Velocity of an Electrophoretic Display by Introducing Guide Blocks in a Display Cell (Interactive),** *Kotaro Sato and Makoto Omodani, Tokai University (Japan)* . . 296

Electrophoretic display has been utilized for reflective display panel fit for e-book readers. However, its slow response speed is one of major weak points. We have focused on the liquid flow generated by particle movement when driving voltage is applied in a display cell. We suppose that the liquid flow affects to the particle movement and its possible turbulence probably prevents smooth particle movement expected under the applied electric field. We have tried to control the liquid flow in a display cell by introducing guide block structure in a display cell. We expected the guide blocks decrease the turbulence of the liquid flow and can improve moving speed of particles. We have prepared two types of display cell, with and without the guide blocks, and measured speed of particle movement in the display cells. As a result, we have found two times faster particle velocity when using the display cell with the guide blocks than when using the display cell without block. These results suggest that appropriate arrangements of display cell structure can effectively improve the response time of electrophoretic displays.

PRINTED ELECTRONICS

Material / Processes and Systems Interactive Preview

Session Chairs: Stan Farnsworth, NovaCentrix; Jens Hammerschmidt, Chemnitz University of Technology; and Masaaki Oda, JAPERA

2:40 – 3:55 PM

2:40 **Properties of PEDOT: PSS from Oscillating Drop Studies (Focal),** *Stephen D. Hoath,[1] Wen-Kai Hsiao,[1] Sungjune Jung,[2] Lisong S. Yang,[3] Colin D. Bain,[3] Sid C. Wright,[4] Neil F. Morrison,[5] Oliver G. Harlen,[5] Graham D. Martin,[1] and Ian M. Hutchings[1]; [1]University of Cambridge (UK),*

[2]Pohang University of Science and Technology (Korea), [3]Durham University (UK), [4]University of Cambridge Queens' College (UK), and [5]University of Leeds (UK) 299

PEDOT:PSS is commonly inkjet printed in aqueous solutions with surfactant additives for improved electrical properties in organic electronics applications. These shear thinning complex fluids have been found to DoD jet surprisingly well over a wide range of drive voltages and drop speeds, behaving rather like Newtonian fluids with far (ten times) lower viscosities than measured at low shear-rate. As ~ 1 wt% PEDOT:PSS solutions showed little evidence for satellite production even at high jet speeds this would suggest that the fluid has regained high viscosity levels, in order to slow the necking rate, on timescales << 100 μs and much faster than accessible to conventional mechanical testing means. Experimental work on the break-up of Newtonian ligaments was recently extended to DoD-scale ligaments, and supports the interpretation that the PEDOT:PSS ligaments attain higher viscosity during flight than during the jet emergence from the print head nozzle, although such rapid recovery timescales for PEDOT:PSS were not predicted from its measured rheology. Our recent work has focused on oscillating drop (OD) techniques for determination of properties of DoD (50 μm) scale aqueous PEDOT:PSS solutions (with and without surfactants) and on a larger (3mm) dispensing scale for more general shear thinning fluids. Imaging studies by one of us (SW) evaluated diffraction effects on OD analyses. The small effects of weak elasticity on the drop oscillations, as assessed theoretically by Khismatullin and Nadim (2001), have been exploited to provide new limits to the recovery time for aqueous PEDOT:PSS based on the fluid viscosity deduced from measured rheology and OD decay rate. These limits are consistent with recent numerical simulations of shear thinning fluid jetting.

3:10 **Noncrystallizable Molecular Glasses for Stable and Long-Lived OLED and Organic Electronics,** *Michel F. Molaire, Molecular Glasses (USA)* 304

Organic Light Emitting Diode Technology (OLED) is poised to challenge Light Emitting Diode (LED) and Liquid Crystal Display (LCD) in flat panel displays, flexible displays, and lighting applications. OLED display has an advantage over LCD with its high response speed, wide viewing angle, and high contrast in dark settings. There are, however, two major challenges slowing down OLED: production costs must decrease and device longevity needs to improve. This presentation will introduce a new class of noncrystallizable charge transporting and/or electroluminescent materials designed to improve device stability and efficiency. We will report on the design, synthesis, and characterization of noncrystallizable electron-transporting, hole-transporting, bipolar charge-transporting, and luminescent small molecule materials. The concept behind this class of compounds and the reasons for their efficacy will be discussed. Traditional thermal OLED production is too expensive. Solution processes for spin, roll-to-roll, slot die, or inkjet coating are required. The traditional small molecules used for thermal deposition tend to crystallize in solvents. OLED systems using polymeric materials (PLED) are being developed. Polymeric charge transport materials tend to have relatively low transport properties. Recently, there have been a lot of activities surrounding "molecular glasses" for solution smOLED processes (small molecules OLED).4 These molecular glasses are defined as "amorphous materials in the state of thermodynamic non-equilibrium, and hence, they tend to undergo structural relaxation, exhibiting well-defined glass temperature T_g's. However they also tend to crystallize on heating above their T_g's, frequently exhibiting polymorphism". With time, equilibrium will lead to crystallization of these materials. When that happens, the performance of the device is degraded, limiting longevity. An additional problem with current small molecule OLED materials is their solubility. Either solubility is limited or requires non-green solvents. Molecular Glasses, a division of Molaire Consulting LLC, is developing a new class of truly noncrystallizable amorphous small molecule organic electronics materials with high solubility in various green solvents. This new class of amorphous small molecule OLED materials is defined as mixtures of compatible molecules with an infinitely low crystallization rate under the most favorable conditions. They are essentially noncrystallizable with a large entropy of mixing values amenable to compatibility with a wide range of materials at a very high concentration

3:30 **Inkjet Printing Graphene Films for Transparent Conductors,** *Pei He and Brian Derby, University of Manchester (UK)**

3:50 **Direct Write (Maskless) Patterning of Flexible Backplanes Using MicroLEDs (Interactive),** *Trevor P. Elworthy, LumeJet Limited (UK)**

4:00 – 6:00 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour

Liberty Ballroom Foyer

** Paper/abstract not available at time of publication.*

WEDNESDAY SEPTEMBER 10, 2014

SPECIAL TOPICS: 3D PRINTING

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Liberty Ballroom B, see details page viii.

Exhibit Hall Opens at 10:00 AM
10:10 – 10:40 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Liberty Ballroom B

3D Printing Processes and Materials II

Session Chairs: Steven Ready, Xerox Palo Alto Research Center, and Christopher Tuck, University of Nottingham
10:40 AM – 12:10 PM

10:40 **Bionic Nano-Printing (Focal),** *Michael C. McAlpine, Princeton University (USA)* 306
The development of a method for interweaving high performance devices with biology could yield breakthroughs in regenerative medicine, smart prosthetics, and human-machine interfaces. Yet, most high quality inorganic materials are two dimensional, hard and brittle, and their crystallization generally requires high temperatures for maximally efficient performance. These properties render the corresponding devices incompatible with biology, which is three-dimensional, soft, flexible, stretchable, and temperature-sensitive. Nanotechnology provides a route for overcoming these dichotomies, by altering the mechanics of materials and devices in order to promote biological compatibility. Further, 3D printing offers the ability to seamlessly merge nanomaterials and devices with biology in three dimensions. Our group has developed methods for 3D printing electronic materials—including insulators, metals, and semiconductors—along with biological materials, to enable a future vision of 'bionic nanodevices,' in which the electronics and biology are seamlessly interwoven in 3D. The unique properties of nanomaterials, co-printed with "living" platforms, may enable exciting avenues in fundamental studies and bioMEMS applications, including creating augmented bionic nano-organs.

11:10 **Characterization of Fully Inkjet-Printed Microsieves and of Patterns for the Mechanical Reinforcement of Fragile Membranes,** *Jens Hammerschmidt,[1] Peter Ueberfuhr,[1] Eva-Maria Eck,[1] Christian Zeiner,[1] Robert Thalheim,[1] and Reinhard R. Baumann[1,2]; [1]Technische Universität Chemnitz and [2]Fraunhofer ENAS (Germany)* 307
Microsieves are "permeable membranes densely interspersed with uniform pores with a thickness smaller than the pore diameter". They exhibit excellent properties for filtration applications such as high size selectivity and a high flow rate. We report on the further development of already published, inkjet-based approaches to (1) manufacture microsieves and (2) to reinforce microsieves mechanically: (1) With the inkjet technology microsieves with pores in the micrometer range can be manufactured. However, the distribution of the pore diameters is high which is disadvantageous for a precise size selection in filtration applications. In this report the printing processes are improved to obtain microsieves with uniform pores. In addition, the samples are characterized in terms of porosity and achievable flow rates. (2) Microsieves with pore diameters in the nanometer range can be obtained by float-casting. These are extremely thin and fragile. We developed a process to apply patterns for the mechanical reinforcement by inkjet printing. The patterns which were reported are composed of inhomogeneous lines with high deviations in width and thickness. This probably leads to weak spots which diminish the reinforcing effect locally. Therefore the printing process is improved to obtain patterns with homogeneous lines by a liquid-on-pinned printing strategy. Furthermore a tensile test is applied on a non-porous membrane with a pattern for the reinforcement on top.

11:30 **Self-Assembly Printer,** *Masayoshi Mitsui, Atsushi Masumori, and Hiroya Tanaka, Keio University (Japan)* 311
In this paper, We demonstrate the application of selfassembly system for human manufacturing processes at mesoand macro-scale in order to pursue and expand the engineering applicability of self-assembly. First, we implemented a prototype referred to as "self-assembly printer" which can generate a dynamic, transformable, two-dimensional moulding and reuse the units that compose the printed objects. Secondly, noteworthy technological components to explain our prototype system is introduced in this paper. Lastly, some potential appli-

cation based on the system such as "Self-Assembly Electronic Circuit (SAEC)" is implemented and proposed. As a result of these researches, our system attains scalability and alleviates the need for complex and accurate movements of assembler in traditional manufacturing system.

11:50 **RFID 3D Printing Objects that Connote Information,** *Ken Fujiyoshi, Chihiro Fukai, Hiroya Tanaka, Jin Mitsugi, and Jun Murai, Keio University (Japan)* 316

During the past century, a whole new world has been created: the digital world. Along with the development of computers, internet, mobile devices, and etc, the digital world has created a whole new reality for human beings. Combined with new sensors, nowadays, everything that can be observed digitally is stored online and is being used for marketing and other uses. In this research, we aim to combine the world of digital and physical by using RFID (radio frequency identifier) and 3D printing technology. In detail, we embedded RFID modules inside 3D printed object, and wrote its information after the object was fully printed. With this, we aim to enhance the interaction between the real world and the virtual world, bringing more rich data transition and data manipulation.

12:10 – 2:00 PM Lunch Break

3D Workflow and Applications I

Session Chairs: Vince Cahill, VCE Solutions; Adam Ellis, University of Sheffield; and Oh Hyun Baek, Samsung Electronics

2:00 – 3:10 PM

2:00 **Direct Three-Dimensional Visualization and Characterization of Microstructures Formed by Printing Particles (Focal),** *Shu Chang, Vineeth R. Patil, Di Bai, and Marcos Esterman, Rochester Institute of Technology (USA)* 320

Additive manufacturing performed with solid particles can form microscopic structures based on the properties of the particles used. These microstructures will likely impact the performance of the product produced. Characterizing these microstructures is difficult since the interior of powders is a challenge to image. Most imaging techniques are limited to surface visualizations. We have established a methodology to directly visualize the resulting particle structure by mapping powder particle positions in the interior three-dimensionally. We use Confocal Laser Scanning Microscopy (CLSM) to capture stacks of cross-sectional images of micron-sized poly-dispersed electro-photographic printing particles. Assisted with image analysis tools, we have obtained the co-ordinates and deduced the radius for each particle in selected sampling volumes.With this information, we are able to recreate the particulate structure in three-dimensional space and to determine the microstructural parameters, such the packing fraction for this powder system.

2:30 **Optimally Orient and Position Multiple Solid Objects for Batch Production in 3D Printing,** *Jun Zeng, Ana Patricia Del Angel, and Gary Dispoto, Hewlett-Packard Company (USA)* . . . 326

3D printing or layered manufacturing is a computer-aided manufacturing process that fabricates parts through layer-wise deposition of material(s). Even though its material deposition techniques exploit wide spectrum of process physics including fused model deposition, stereolithography, selective laser sintering, laminated object manufacturing and inkjet print, its process planning are largely universal: similar workflow steps (e.g., build tray stacking, slicing, tool-path/dot-map generation) and similar objectives (e.g., fast build time, high accuracy, reduced material consumption). The configurations of the print step encapsulate the heterogeneity of the process physics and the associative assistive procedures (e.g., compensation, support). This paper describes our ongoing research into developing an optimization solution to assist process planning to meet the multiple, oftentimes competing objectives. In particular, this paper focuses on batching multiple objects for simultaneous production within the same build tray. Even though throughout this paper we use Fused Deposition Modeling (FDM) as example to illustrate 3D printing production, our solution is printing technology agnostic and generally applicable to other printing technologies.

2:50 **Voxel based Material Distribution with Probability for 3D Printing,** *Yusuke Tominaka and Hiroya Tanaka, Keio University (Japan)* 331

This study searches for a compositional design method for digital fabrication in modeling environments. In this paper, we propose a method of voxel based compositional design for modeling with 3D printers. This method designs composites by allocating voxel patterns with different fill levels in relation to polygon model input. Compared to surface modeling, this method allows for the simple design of modeled composites. Furthermore, as it supports the input and output of STL data, there is no need for particular hardware that is

SPECIAL EVENT

CONFERENCE RECEPTION

Wednesday, 7:00 – 9:00 pm

Horizons Rooftop Ballroom

Join colleagues for an enjoyable evening of networking and great views of Philadelphia.

compatible with this method, and it can use modeling environments with typical 3D printers. It is expected that through the application of this method, that this can be applied to designs with material characteristics, such as softness and a center of gravity, by controlling localized composites within the model.

3:00 – 3:45 PM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer
Exhibit Closes at 3:45 PM

3:45 – 5:15 PM Colleague Connections: Wednesday Roundtable Discussions
choose among the following, details on page xxxvi
3D Printing: The Hype and the Future, *Liberty Ballroom B*
Digital Printing on Textiles, *Liberty Ballroom A*
What does it mean for Packaging to Go Digital?, *Liberty Ballroom C*

7:00 – 9:00 PM Conference Reception
Horizons Rooftop Ballroom

PRINTING TECHNOLOGY I

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Liberty Ballroom B, see details page viii.

Exhibit Hall Opens at 10:00 AM
10:10 – 10:40 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Liberty Ballroom A

Ink Jet: Ink and Media II

Session Chairs: Alex Shaknovich, Cabot Corporation, and Stephen Hoath, University of Cambridge
10:40 AM – 2:20 PM

10:40 **Molecular Weight Degradation of Synthetic and Natural Polymers during Inkjet Print (Focal),** *Joseph Wheeler,[1] Khalid A-Alamry,[1] Stuart W. Reynolds,[2] Steven Lancaster,[2] Nágila M.P.S. Ricardo,[3] and Stephen G. Yeates[1]; [1]University of Manchester (UK), [2]Domino UK Ltd. (UK), and [3]Federal University of Ceará (Brazil)* 335

We compare the different modes of molecular weight degradation in DOD and CIJ of synthetic vinyl polymers in good solvent and report for the first time extension to polysaccharides. This work has significance both in printer design but also in formulation of high molar mass functional and biological materials.

11:10 **Color InkJet Dispersions Utilizing Synergists as Dispersants,** *Alex Shakhnovich, Cabot Corporation (USA)* 339

Polymer-free colorant dispersions, based on yellow and red azo pigments as well as copper phthalocyanine, cocrystallized or mixed with ionic synergists, enable high pigment loadings and formulation flexibility in inkjet inks. Careful selection of synergist structure allows to significantly improve dispersion stability towards various ink cosolvents and surfactants. Structural factors, responsible for synergist performance depend on the substitution pattern in both azo pigment and synergist. It was shown that for optimal affinity to the pigment surface and for the stability of the final dispersion the synergist structure does not have to exactly match the structure of parent pigment. The yellow dispersions are obtained from two most common organic pigments, based on Acetoacetanilide chemistry—Pigment Yellow 1 and Pigment Yellow 74. For both of these colorants the dispersions with up to 30% solid contents and very low viscosity were prepared. Crystal structure differences between PY1 and PY74 dictates the synergist choice and explains variations in stability. Magenta (Red) dispersions were obtained from Pigment Red 8, Pigment Red 23, Pigment Red 269 and a few others, all based on Naphtol AS chemistry. These pigments provide an alternative for quinacridones, traditionally used as M component of digital CMY triade. Although their color is generally less bluish, than that of quinacridone, Naphthol AS pigments are a lot stronger and certainly less expensive, than quinacridones. It was also possible to generate cyan dispersions, based on PB15, using modified copper phthalocyanines as synergists.The technology of dispersion with synergists can be designed as a simple mixing process, without using additional chemicals. The process generates minimal amount of effluents, most of which can be recycled. All dispersions demonstrate good stability of particle size in presence of surfactants and cosolvents/humectants even at high loadings.

11:30 **Electrical Measurement of Ink Sedimentation,** *Andreas Rathjen, Nicki Grauert, and Klaus Krüger, Helmut Schmidt University/University of the Federal Armed Forces Hamburg; and Morten Mikolajek, Andreas Friederich, and Joachim R. Binder, Karlsruhe Institute of Technology (Germany)* 342

Characterization of inks, particularly sedimentation in particle inks, is an important challenge in inkjet printing. This paper proposes the approach of ink characterization by electrical measurements. A conductivity cell is used for the application of alternating current. This provides well-defined ink characteristics without changing ink properties. Thus, the method can be used not only in ink formulation but also for on-line monitoring during the printing process. Two different ink compositions are investigated regarding impedance and phase angle. Silver inks, common as the conductive component in printed circuits and barium titanate inks. The latter inks comprise of an insulating (dielectric) material. The method is proved to be applicable here. Both compositions show low-pass filter characteristics. Accordingly, similar analysis methods are used. The low-pass frequency response allows for the implementation of the random walk method to obtain equivalent capacity and resistance. From the measured values, accurate discrimination of the actual solid substance content is possible for both inks.

11:50 **Particle based Inks for Inkjet Printing of Thin Catalytic Layers,** *Danny Lehmann,[1] Klaus Krüger,[1] Iris Herrmann-Geppert,[1,2] Mauricio Schieda,[2] and Thomas Klassen,[1,2]; [1]Helmut Schmidt University/ University of the Federal Armed Forces and [2]Helmholtz Centre Geesthacht (Germany)* 347

We demonstrate that functional inks can be successfully and systematically formulated to obtain the required properties for printing Fe^2O^3-based photoelectrodes. The formulation of the ink as well as the parameters for the printing process can be varied within certain limits to adjust the properties of the electrodes. Characteristics of the formulation process and the printing process are comprehensively studied to estimate the potential of printing different dimensions and structures. For the examination of the photoelectrochemical properties, an optimized photoelectrode is fabricated applying inkjet printing.

12:10 - 2:00 PM Lunch Break

2:00 **Advanced Water-based Latex-Inks for Film Media,** *Naohiro Toda, Tomohiro Nakagawa, Nagashima Hidefumi, Juichi Furukawa, Hikaru Kobayashi, and Kiyofumi Nagai, Ricoh Company, Ltd. (Japan)* 353

A novel water-based latex ink has been developed, which is capable of forming images with ink-jet printers on non-osmotic media such as plastic media. This water-based latex ink provides image quality and discharge reliability comparable with those of solvent inks applicable to non-osmotic media that have been widely used in the field of sign graphics. This water-based latex ink also provides images with safety and high quality on osmotic media that are used for wallpaper, etc. We have discovered that, for improving image quality with water-based latex inks, it is important to suppress aggregation of particles when the ink undergoes a drying process, which has a great relation to the SP value (i.e., Solubility Parameter) of solvents. We have also discovered that water-based latex inks form skin layer as water evaporates at the meniscus part of ink-discharge nozzle, decreasing discharge reliability.

COLLEAGUE CONNECTIONS: WEDNESDAY ROUNDTABLE DISCUSSIONS

3D Printing: The Hype and the Future
Moderator: Christopher Tuck, University of Nottingham

The roundtable discusses where 3D printing has come from, what the current capability of the technology is, how this is being discussed in the general media, and the mismatch between them. It also outlines potential future avenues for research and applications, as well as how 3D printing may change the future of manufacturing.

Digital Printing on Textiles
Moderator: Hitoshi Ujiie, Philadelphia University

Digital Textile Printing can be defined as "surface imaging" on textiles. Surface imaging refers to actualization of imagery for various physical forms using a variety of printing technologies, including direct surface imaging on diverse porous and non-porous substrates, as well as fabrication printing (material deposition and subtraction printing technologies—laser and enhanced 3D). A transdisciplinary approach for broader concepts of digital printing on textile substrates is the focus of this roundtable. Discussions are expected to move beyond the boundaries of existing traditional disciplines to bring new innovations and creativities in product developments to the table.

What does it mean for Packaging to Go Digital?
Moderator: George Gibson, Xerox Corporation

Digital print is only just beginning to infiltrate the packaging market and demonstrate its true potential for seamless and personalized advertising, both on and offline. Digital print in packaging opens the door for the package to become more than the passive carrier of a valuable thing to an active component of value creation. One need only think of Coca-Cola's recent global "Share a Coke" campaign, which serves as the perfect success story to demonstrate the potential of digital printing for businesses. Originating in Australia and hitting Britain this summer, the campaign involves 375ml and 500ml PET bottles of Coke that feature 250 of the most common first names from around the world in multiple languages, allowing customers to "share a Coke" with friends, families, and loved ones. The campaign has been a huge success, seeing both sales and social media engagement with the brand increase. This roundtable explores the current state-of-the-art and imagines the future. Let's take the wraps off the future of digital print for packaging!

Ink Jet: Ink-Substrate Interaction I

Session Chairs: Hou T. Ng, Hewlett-Packard Co.; Emma Talbot, University of Durham; and Takumi Suzuki, Canon, Inc.

2:20 – 3:00 PM

Session sponsored by

tonejet

2:20 **Tuning Liquid Absorption and Ink Spreading by Polyelectrolyte Multilayering on Substrates with Different Levels of Internal Sizing,** *Katriina Mielonen, Sami-Seppo Ovaska, and Kaj Backfolk, Lappeenranta University of Technology (Finland)* 357

The effect of base paper hydrophobicity and polyelectrolyte multilayer surface treatment on the subsequent liquid absorption and ink–substrate interaction was studied. It was found that the internal sizing degree affects the inkjet print quality, but that it is dependent on deposited polyelectrolyte layer chemistry and composition. A rather different ink absorption and spreading behavior was seen with dyes than with pigment-based inks.

2:40 **A Novel Method to Study the Effect of Corona Treatment on Ink Wetting and Sorption Behavior,** *Sami-Seppo Ovaska,[1] Katriina Mielonen,[1] Esa Saukkonen,[1] Tadeusz Lozovksi,[2] Ringaudas Rinkunas,[2] Jonas Sidaravicius,[2,3] and Kaj Backfolk[1]; [1]Lappeenranta University of Technology (Finland), [2]Vilnius University (Lithuania), and [3]Vilnius Gediminas Technical University (Lithuania)* 362

A novel absorption test method was developed based on a modification of the Bristow Absorption Apparatus. The proposed method combines corona treatment (CT) with short contact time absorption behavior to study particularly ink wetting and sorption on substrates in-line. The method makes it possible to study e.g. the coagulation of pigment inks induced by deposited charges i.e. electrocoagulation, the effect of short contact times on liquid/substrate interactions, and problems related to charge decay such as whiskering. In-line measurement with a short delay time minimizes the effect of ambient conditions (heat, moisture) on charge decay, and thus simulates the conditions in commercial digital printing processes. The functionality of the method was evaluated by testing paper samples with and without polymer coatings. Uncoated samples were used to study absorption properties. It was found that in some cases the CT changes both the wetting and absorption of ink and that in other cases the main changes are in the absorption behavior. Four CT levels (0, -100, -450, and -900 W*min/m2) were studied and it was found that the highest treatment level increased the absorption of the applied inkjet ink the most. As expected, the contact time between liquid and substrate was found to be an important variable affecting the absorption. Print density and mottle were determined on coated samples with the CT levels of 0, -160, and +160 W*min/m2. CT improved print density significantly, whether the treatment was positive or negative, and also reduced the mottling tendency.

3:00 – 3:45 PM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer
Exhibit Closes at 3:45 PM

3:45 – 5:15 PM Colleague Connections: Wednesday Roundtable Discussions
choose among the following, details on page xxxvi
3D Printing: The Hype and the Future, *Liberty Ballroom B*
Digital Printing on Textiles, *Liberty Ballroom A*
What does it mean for Packaging to Go Digital?, *Liberty Ballroom C*

7:00 – 9:00 PM Conference Reception
Horizons Rooftop Ballroom

PRINTING TECHNOLOGY II

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Liberty Ballroom B, see details page viii.

Exhibit Hall Opens at 10:00 AM
10:10 – 10:40 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Liberty Ballroom D

Printing Systems

Session Chairs: Olivier Morel, Xennia, and Teruaki Mitsuya, Ricoh Co., Ltd.
10:40 AM – 3:00 PM

10:40 **Embedded Scanning, Encryption and Certification Workflows on Multi-Function Printers (MFPs) (Focal),** *Helen Balinsky and Nassir Mohammad, Hewlett-Packard Labs (UK)* 366
A recently proposed document format: Publicly Posted Composite Documents (PPCDs) has been developed to tackle both the containment and security aspects of composite documents participating in inter-organizational workflows. Here, the access control and authentication material together with the actual contents form a tamper proof digital bundle that was designed to be securely transmitted over potentially low security channels. Though PPCDs can be created, shared cross-organizationally and edited using software on a computer, a key functionality to efficiently and securely incorporate scanned documents inside Multi-Function Printers (MFPs) was missing. We solve this problem by enabling users with assigned modification rights to specific content-parts of a PPCD, to update such parts through scanning physical documents at a standalone MFP. The scans are then securely and automatically encrypted, signed and inserted as new PPCD content. Thus, in this paper we provide a comprehensive solution for document workflow participants to securely update or insert new contents to the PPCD at a standalone MFP device through non-trivial extension of HP MFP firmware.

11:10 **Development of the 23"x29.5" Sheet-Fed Inkjet Press KM-1,** *Mitsuru Obata, Toyoaki Sugaya, Toshiyuki Mizutani, Hideo Watanabe, Toshiyuki Takabayashi, and Hirotaka Iijima, Konica Minolta, Inc. (Japan)* 372
To materialize the "digital print," we have been developing a new digital printing system with our inkjet technology. We adopted so called "single pass printing system" for the system. It has a page-wide print head array and can print ink droplets on a rapid-delivered paper. We developed a variety of technologies such as a new print head, a new ink, a new image compensation technique, and so on, for the system. We integrated 1,800 printing nozzles into 600 npi density that can eject small droplets in higher frequency. We developed a new ink formulation that can show performances necessary for the single pass printing. We also developed a new technique that can compensate streaky image defects. Combined these new technologies, we achieved to develop a new digital printing system that can print a high-resolution and high-quality image quickly.

11:30 **Failure Prediction Method for Long Life Photoconductor based on Statistical Machine Learning,** *Yasushi Nakazato and Mikiko Imazeki, Ricoh Company, Ltd, and Osamu Komori and Shinto Eguchi, Institute of Statistical Mathematics (Japan)* 375
In the production printing market, the electrophotography system is asked for high durability, and long-life photoconductors are usually implemented in it. Ordinary method of periodic maintenance uses print volume counter and preset limitation value to alert an operator. But damage processes depend on various phenomena and there are difficulties to predict the exact lifespan of each photoconductor. We examined the methodology for developing new risk decision rule by using the logged data of the field machines. In this method, we focused on photoconductor's three basic parameters and used one of the machine learning method "AdaBoost" to find failure signal pattern. These basic parameters were pre-calculated to the physical and statistical characteristic value to estimate abnormality of these value. We selected learning data from the typical fatigue log data and "AdaBoost" algorithm generated the risk decision rule that consist with the weak learners. The field tests showed enough result for practical use. Additionally it was confirmed that this risk decision rule was almost coincident with the photoconductor deterioration model knowledge by "Score plots". We obtained the calculation method to determine the risk of image defect from monitoring signal data log and it can be predicted whether photoconductor should be replaced or not. This failure prediction method can reduce urgent imaging trouble and the loss of photoconductor's lifespan that occurred in the ordinary method.

11:50 **Industrial Digital Manufacturing: Myth, Hype or Reality?,** *J. R. Barritt, W. A. Kaimouz, O. J. X. Morel, T. Philips, J. Tardrew, and R. A. Wilkinson, Xennia Technology Ltd. (UK)* . . 379

Implementing digital manufacturing technology into an industrial process has the potential to achieve better performance products at lower cost. Manufacturers are increasingly taking advantage of the benefits that this new technology brings and leaving traditional methods behind. This paper analyses how digital printing penetrated the ceramic tile market, how it is penetrating the textile one and how it will penetrate other markets such as décor, glass and electronics. Those markets are taken as examples and for each, the importance of application and process understanding is discussed, as well as the contribution of printhead technology, software and fluid chemistry in making the implementation successful.

12:10 - 2:00 PM Lunch Break

2:00 **Incorporation of Nano-Particle Carbon Black into Polyurethane Rollers and its Influence on Digital Electro-Photography Print Quality,** *Krishna Chaurasia, Fenner Precision (USA)**

2:20 **Mechanical Modeling of Indigo's Printing Machine Parts,** *Nurith Schupper, Peter Forgacs, and Wael Salalha, Hewlett-Packard Indigo (Israel)* 384

We develop methods to predict printing machines components behavior in order to reduce cost, shorten production time, and to improve lifespan and print quality. These methods of optimization are based on finite element calculations using Abaqus program. Specifically, we model HP-Indigo's machine units, such as the printing blanket, an ink dispersion unit seal and a substrate coating unit. For each component we first characterize the materials by off-line measurements and propose appropriate material descriptions. Then the system is analyzed and dependence of its behavior on relevant parameters is found. This allows for optimization and proposing future configurations, where expensive and time consuming prototypes can be built and tested only for most preferable candidates. These methods are very interesting for a wide range of applications.

2:40 **Digital Creation of Hand Engraved Copper Plates to Secure a Historic Process,** *Stephen Hoskins, University of the West of England (UK)* 390

Underglaze tissue ceramic transfer printing was first developed circa 1750 and involved the use of engraved or etched copper plates, from which a wet strength tissue paper was printed with an oxide (commonly cobalt for blue colour) the famous 'Willow Pattern' being the best known example. However skilled engravers are no longer trained or available. The project addresses that issue by introducing the potential of printing the traditional potter's tissue and applying it in the same way as the late 18th Century process, but creating the printing plate from a digital file. Thus creating a combination of the digital capabilities of flexographic printing technology and the earliest printing process developed for the ceramic industry. The results of the project reduced the time from one month needed to engrave a roller to less than a day to create a digital equivalent, whilst retaining the integrity of the final product. The authors are collaborating with Burleigh Pottery in Stoke-on-Trent, the last remaining company to produce ceramic tableware decorated using the traditional printed underglaze tissue method. The project title is Combining digital print technologies with 18th Century underglaze ceramic printing to retain an industrial heritage process. The pottery was recently saved from closure by the Princes' Regeneration Trust, who wish to maintain the traditional manufacturing skills for the next 25 years.

3:00 – 3:45 PM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer
Exhibit Closes at 3:45 PM

3:45 – 5:15 PM Colleague Connections: Wednesday Roundtable Discussions
choose among the following, details on page xxxvi
3D Printing: The Hype and the Future, *Liberty Ballroom B*
Digital Printing on Textiles, *Liberty Ballroom A*
What does it mean for Packaging to Go Digital?, *Liberty Ballroom C*

7:00 – 9:00 PM Conference Reception
Horizons Rooftop Ballroom

PRINTED ELECTRONICS

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Liberty Ballroom B, see details page viii.

Exhibit Hall Opens at 10:00 AM
10:10 – 10:40 AM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer

Liberty Ballroom C

Printed Electronics: Processes and Systems I

Session Chairs: Jim Stasiak, Hewlett-Packard Co.; Ingo Reinhold, XaarJet AB; Shinichi Nishi, Konica Minolta; and Koei Suzuki, Ricoh Co., Ltd.

10:40 AM – 3:00 PM

10:40 **Inkjet Printing as a Roll-to-Roll Compatible Technology for the Production of Large Area Electronic Devices on a Pre-Industrial Scale (Focal),** *Pit Teunissen,[1] Eric Rubingh,[1] Tim van Lammeren,[1] Robert Abbel,[1] and Pim Groen[1,2]; [1]Holst Centre and [2]Delft University of Technology (the Netherlands)* 395

Inkjet printing is a promising approach towards the solution processing of electronic devices on an industrial scale. Of particular interest is the production of high-end applications such as large area OLEDs on flexible substrates. Roll-to-roll (R2R) processing technologies involving inkjet printing have especially high potential, since they allow a continuous production of large volumes with high throughput. Here we report on our research activities to scale up printed OLED production on foils to an industrial scale. When building up the device, necessarily deposition will have to be done on very different types of surfaces, some of which are highly prone to damage upon mechanical load. Inkjet printing as a non-impact technology is therefore expected to have decisive advantages compared to e. g. screen printing. We have evaluated both methods for silver shunt line deposition on a barrier layer which protects the OLED against humidity. Screen printing on the barrier layer resulted in a significantly higher number of defects than did inkjet printing. For post-deposition treatment we have used photonic flash sintering as a highly efficient and R2R compatible method. We were thus able to demonstrate that a core step of OLED production can be carried out by R2R processing. Finally, our efforts resulted in the production of fully functional large area OLED devices, with inkjet printed silver shunt lines. Our future plans include moving towards fully integrated R2R production of OLEDs to demonstrate this concept's feasibility for industrial scale manufacturing.

11:10 **Roll-to-Roll Infrared Sintering of Gravure Printed Silver Patterns in Applications of Back-Injection-Molded Functional Lightweight Structures,** *M. Hartwig,[1] P. Ueberfuhr,[1] A. Mischke,[1] M. Gaitzsch,[1] M. Heinrich,[1] T. D. Großmann,[1] S. Kurth,[2] L. Kroll,[1] T. Gessner,[1] and R. R. Baumann,[1, 2]; [1]Technische Universität Chemnitz and [2] Fraunhofer Institute for Electronic Nano Systems (ENAS) (Germany)* 399

We report on the manufacturing of functional lightweight structures by the combination of roll-to-roll gravure printing technology and back injection molding technology. The objective is to manufacture conductive grid patterns consisting of thin lines in the lower micrometer range integrated in lightweight components. We already reported on the roll-to-roll manufacture of thin conductive lines by gravure printing of a nano-silver ink which is rapidly sintered by infrared radiation at web velocities up to 1 m/s. This approach is employed for the fast manufacturing of conductive grid patterns on a flexible substrate. Afterwards, the printed patterns are integrated in lightweight structures by back injection molding. The final composites shall be applied as smart components for example in cars and rotor blades of wind turbines for electrical applications like power supply, electrical circuits and data communication.

11:30 **High Speed Sintering: The Influence of Print Density on Feature Resolution and Accuracy,** *Lawrence Kantor-Dyson, Adam Ellis, and Neil Hopkinson, The University of Sheffield (UK)* . . 404

High Speed Sintering is a novel additive manufacturing technology which uses an InkJet printhead and infra-red radiation. The printhead deposits a radiation absorbing material directly onto a powder bed, the entire bed is then irradiated by an infra-red lamp. Areas printed with radiation absorbing material will absorb sufficient energy to sinter, whereas areas without will not. Another layer of powder is deposited and the process repeats until the part is complete. To date, a large proportion of research has used the maximum print density possible, very little research has focused on how altering print density influences the minimum feature size and dimensional accuracy. As such this research was designed to investigate how print density influences feature

resolution, accuracy and powder removability. Results showed improved powder removal and feature resolution can be achieved using a print that is not fully dense. However, beyond a certain point the print density becomes too low and the parts fail. Thus it is imperative that the correct balance is struck if parts are to be manufactured successfully and possess improved accuracy and feature resolution.

11:50 **High-Speed, Low-Volume Inkjet and its Role in Jet and Flash™ Imprint Lithography (Focal),** *Ingo Reinhold,[1] Matthew S. Shafran,[2] Whitney Longsine,[3] Matthew C. Traub,[3] Yeshwanth Srinivasan,[3] Van N. Truskett,[3] and Werner Zapka[1]; [1]XaarJet AB (Sweden), [2]Molecular Imprints, Inc. (USA), and [3]Canon Nanotechnologies, Inc. (USA)* 408

Imprint lithography is an effective technique for replication of nanoscale features. Jet and Flash™ Imprint Lithography (J-FIL™) uses field-by-field deposition and exposure of a low viscosity resist deposited by inkjet printing onto the substrate. The patterned mask is lowered into the fluid, where capillary action assists to flow the fluid into the relief patterns. Following the filling step, the resist is UV cured, the mask is removed, and a patterned resist is left on the substrate. J-FIL™ is a technique, where the imprint technology provides the nanoscale pattern resolution while the inkjet technology contributes the throughput that is required for industrial applications. The drop volume and drop placement accuracy of the inkjet-printed resist is critical, allowing the volume to be distributed appropriately across the substrate surface to achieve a uniform target thickness and preventing non-filling of the relief patterns. With J- FIL™ it is possible to resolve 28 nm structures with residual layer thickness of 13 and 20 nm on 300 mm and 450 mm Si-wafers. In this study, improvements during the filling step are explored for low droplet volumes at high ejection frequencies when using standard printheads with jetting performance of 12 kHz, <3 pL and modified printheads with jetting performance of 28 kHz, <2 pL.

12:10 - 2:00 PM Lunch Break

2:00 **Printed Monolithic Photovoltaic Interconnects (Focal),** *Maikel F.A.M. van Hest, Matthew S. Dabney, Vincent P. Bollinger, and Jeremy D. Fields, National Renewable Energy Laboratory (USA)* 413

Monolithic interconnects in photovoltaic modules connect adjacent cells in series, and are typically formed sequentially involving multiple deposition & scribing steps. Interconnect widths on order of about 500 µm every 10 mm result in about 5 % dead area, which does not contribute to power generation in an interconnected solar panel. This work introduces an alternative interconnection method capable of producing interconnect widths less than 100 ¼m, which can be accomplished in a single pass after deposition of active layers and electrodes. This alternative method can be used for all types of thin film photovoltaics. Voltage addition using printed interconnects and ongoing efforts to optimize performance of modules with printed interconnect are discussed.

2:30 **Automated Continuously-Manufacturing Line of All-Printed Organic TFT Array Flexible Film (Focal),** *Shinichi Nishi and Toshihide Kamata, JAPERA (Japan)* 414

In the printed electronics field, it has been needed to realize the manufacturing technologies for inventing mass production phase. We JAPERA, which was organized 2011 as a NEDO project to develop the manufacturing technologies of large area flexible printed electronics, established the automated and continuously operated manufacturing line for which produced the all-printed TFT array flexible film. We operated the offset printer, inkjet printer, screen printer, and slit-die coater. Specialized ink materials, for example Ag nano particle ink for gate electrode and source/drain electrode, highly purified polymer ink for gate insulator, and organic semiconductor ink for TFT active layer have been developed. We have been acquiring successful results of TFT array flexible film by high yield. The applications of our THT array flexible film for making a display device or a sensor device are presented.

3:00 – 3:45 PM Coffee Break — in the Exhibit Hall, Liberty Ballroom Foyer
Exhibit Closes at 3:45 PM

3:45 – 5:15 PM Colleague Connections: Wednesday Roundtable Discussions
choose among the following, details on page xxxvi
3D Printing: The Hype and the Future, *Liberty Ballroom B*
Digital Printing on Textiles, *Liberty Ballroom A*
What does it mean for Packaging to Go Digital?, *Liberty Ballroom C*

7:00 – 9:00 PM Conference Reception
Horizons Rooftop Ballroom

THURSDAY SEPTEMBER 11, 2014

SPECIAL TOPICS: 3D PRINTING

8:30 – 9:25 AM Keynote and Conference Closing, Liberty Ballroom B, see details page viii.

Liberty Ballroom B

3D Workflow and Applications II

Session Chairs: Vince Cahill, VCE Solutions; Adam Ellis, University of Sheffield; and Oh Hyun Baek, Samsung Electronics

9:30 – 10:30 AM

9:30 **From Scan to Print: 3D Printing as a Means for Replication,** *Susanne Klein,[1] Michael Avery,[2] Guy Adams,[1] Stephen Pollard,[1] and Steve Simske[3]; [1]Hewlett-Packard Labs (UK); [2] University of Bristol (UK); and [3]Hewlett-Packard Labs (USA)* 417

Replication, or making exact copies with consistent results, is at the heart of manufacturing. It is used in mass production of all kinds of items, from foodstuff to cars, from houses to books. But it is also used to reproduce already existing objects. In the 18th and 19th centuries plaster casting was used to bring the wonders of the world to private collections and museums. In the cast court of the Victoria and Albert Museum in London, a life sized replica of Trajan's column can be admired. The combination of a 3D scanner and printer offers the possibility of a new way to make a three dimensional copy of an existing object. Whereas in a plaster cast, where high fidelity is achieved by creating a physical mould from the original object, scanning does not require physical contact to the original. This can be an advantage when the object is fragile, but can lead to loss of fidelity during the reproduction process. We discuss the difficulties in achieving a truly high fidelity copy of even simple objects when a scanner and 3D printer are used for object replication.

9:50 **Material Matters: Lowering Barriers to Uptake, Diversifying Range of Application, Carrying Forward Legacy Processes,** *Philip Robbins, Keith Doyle, and Hélène Day Fraser, Emily Carr University of Art and Design (Canada)* 422

New production technologies and modes of enterprise based on proprietary and cost-effective, open-source production platforms are changing the nature of making. An exemplar of this change, 3D Printing has created a rapidly developing presence as an emergent production technology across many sectors. As this technology's development continues, artists and designers are no longer constrained by traditional models of form development and production: accessible 3D technology stands to markedly revise a broad range of legacy production practices. Material Matters—a research cluster within the Intersections Digital Studios of the Emily Carr University of Art and Design—is exploring these new digital technologies as a viable analogue to traditional methods and materials. As 3D printing becomes less expensive, more powerful and more pervasive it diffuses into a wider range of opportunities. As these new means of creative production emerge they intersect with established practice, Material Matters examines these points of contact with an emphasis on four interrelated components: material development and lateral application; and commercial application and partnership. This paper will highlight elements of these four streams.

10:10 **Issues of Tacit Knowledge, within 3D Printing for Artists, Designers, and Makers,** *Stephen Hoskins, University of the West of England (UK)* 426

The creative industries are directly interfacing with 3D printing technology and how it is changing the practices of many artists and designers across the globe. However for the creative community it is not possible to take on a new manufacturing technology without an inherent understanding of materials. All too often with the adoption of new technology, in whatever discipline, one can instantly tell a work that has been dictated and created by the simple constraints of a new process. It will not possess any of the inherent material or aesthetic qualities that are obvious in a piece that is made so skillfully that it transcends the process. Therefore the adoption of 3D printing technology is not simply a matter of detailing scientific or engineering advances to a new process. A selection of case studies of leading designer makers who demonstrate both skill and technical expertise will be presented to reveal the spread and problems of the technology over a number of diverse disciplines

10:30 - 11:00 AM Coffee Break — Liberty Ballroom Foyer

11:00 AM – 12:30 PM Late Breaking News / Success Stories
Liberty Ballroom B

PRINTING TECHNOLOGY I

8:30 – 9:25 AM Keynote and Conference Closing, Liberty Ballroom B, see details page viii.

Liberty Ballroom A

Ink Jet: Ink-Substrate Interactions II

Session Chairs: Hou T. Ng, Hewlett-Packard Co.; Emma Talbot, University of Durham; and Takumi Suzuki, Canon, Inc.

9:30 – 10:30 AM

Session sponsored by

tonejet

9:30 **Objective Measurement of the Ink Wicking, Surface Topography (Roughness), and "Show Through" Properties of Papers Produced for Ink Jet Print,** *Roy R. Rosenberger, Verity IA, LLC (USA)* 432

The image analysis technique (IA) described in this work uses an established statistical method (Standard Deviation) coupled with a standard IA visible object size measurement technique to capture the degree of ink movement along surface and sub-surface paper fibers. This wet ink movement occurs immediately after the wet low viscosity ink strikes the paper surface and before the ink vehicle solvents evaporate. Post deposit ink movement is the cause of visual image distortions often referred to as edge raggedness, feathering, and wicking.

9:50 **Ink–Media Interaction: Aggregation of Color Pigments by Salt with Different Valency and Impact on Print Quality,** *Jonas Örtegren and Anna Lundberg, Mid Sweden University (Sweden)* 437

We previously reported on the effect of surface properties on inkjet print quality and print functionality. Printing can furthermore be used to effectively functionalize paper surfaces or to modify surface properties of paper for subsequent inkjet printing. Migration of molecules and particles from the paper surface may cause destabilization of the pigment dispersion and result in aggregation of pigments, as shown previously for different concentrations of calcium chloride at the surface of uncoated paper. In this work, utilizing standardized methods such as inkjet printing, ink draw down and print density measurements, it is shown that surface functionalisation using di- and trivalent salts may effectively destabilize a pigment dispersion, causing aggregation of pigments which in turn has a major impact on the print quality.

10:10 **Control of the Particle Deposition in Inkjet-Printed Droplets,** *Emma L. Talbot, Lisong Yang, Arganthael Berson, and Colin D. Bain, Durham University (UK)* 440

Radial flow in drying droplets forms a ring stain deposit. By controlling the amount of radial flow using an evaporation-driven sol–gel transition in laponite suspensions, a uniform deposit can be achieved. Droplets gel from the contact line inwards, reducing particle flow to the droplet periphery. The method is demonstrated for picolitre droplets relevant to inkjet printing. Internal flows are visualized using high-speed imaging techniques. The final deposits are characterized by scanning electron microscopy and white light interferometry.

10:30 - 11:00 AM Coffee Break — Liberty Ballroom Foyer

11:00 AM – 12:30 PM Late Breaking News / Success Stories
Liberty Ballroom B

PRINTED ELECTRONICS

8:30 – 9:25 AM Keynote and Conference Closing, Liberty Ballroom B, see details page viii.

Liberty Ballroom C

Printed Electronics: Processes and Systems II

Session Chairs: Jim Stasiak, Hewlett-Packard Co.; Ingo Reinhold, XaarJet AB; and Shinichi Nishi, Konica Minolta

9:30 – 10:30 AM

9:30 **Production Technologies for Large Area Flexible Electronics,** *Thomas Kolbusch and Klaus-Peter Crone, Coatema Coating Machinery GmbH (Germany)* 444

There is a wide variety of printed large area flexible electronic devices and at the same time a number of different visions and estimates for this new emerging industry and market. But as every new industry or technology, printed electronics has to overcome technology red brick walls, survive the valley of death for the start-ups and spin offs and be competitive enough against existing technologies, like silicon technologies. The talk wants to give a broad picture on these new markets and describes the potential market outlook based on the Organic Electronic Association roadmap. Out of the five markets defined by the OE-A the author describes two markets in detail, the market for OPV and flexible display. Then the talk tries to give a definition of common characteristics for printed electronics and the potential of not only single printed devices, but for integrated products which can consist of only printed devices or a mix of printed and silicone devices, also described now in literature as hybrid devices.

9:50 **Breaking the Limits of Line Width and Aspect Ratio for Inkjet Printed Conductive Lines by Controlling Post-Deposition Ink Contraction,** *Pit Teunissen,[1] Robert Abbel,[1] Jasper Michels,[1] and Pim Groen[1,2]; [1]Holst Centre and [2]Delft University of Technology (the Netherlands)* 447

Electrically conductive structures comprising both narrow line widths and high aspect ratios are indispensable components of many electronic devices. Producing them reliably on an industrial scale by inkjet printing of metal-based inks is a serious challenge. Firstly, due to spreading of the ink on the substrate, widths of 30 microns are currently the limit of any standard industrial inkjet technology. Secondly, the solid loads of conductive inkjet fluids are usually confined to a low volume fraction. Consequently, fine and high conductive structures are difficult to reach with single pass printing approaches. Here we report on a method which circumvents these limits by employing specific changes in the ink-substrate interactions during solvent evaporation. Freshly printed lines have widths in the order of 100 microns. Upon drying, these structures reproducibly shrink to very narrow (< 25 micron), though still continuous and highly conductive lines with heights of several microns. This results in aspect ratios of up to 0.3, which are unprecedented for single pass inkjet printing. We propose a mechanism for this process which involves the sequential evaporation of the ink's solvents according to their vapour pressures. Since their volatilities correspond inversely with their respective polarities, the effective polarity of the material remaining on the substrate will continuously increase. A continuous movement out of the wetting envelope of the substrate is the logical consequence, resulting in ever poorer wetting, increasing contact angles and line shrinkage.

10:10 **Additive Manufacturing Utilizing Aerosol Jet® Printing Technology for LED Wire Bond Replacement,** *Andreas Rudorfer, Heinz Pichler, Christian Palfinger, Frank Reil, Franz Peter Wenzl, and Paul Hartmann, Joanneum Research (Austria)* 451

During the last years additive manufacturing has gained a lot of attention due to material cost saving- and rapid prototyping capabilities. In this paper additive manufacturing was successfully demonstrated using Aerosol Jet® Printing Technology for LED wire bond replacement in order to improve the mechanical stability of state of the art LED modules. LED working samples were fabricated by using polyimide as dielectric and silver as conductive interconnect material. Shape and thickness of the printed lines were characterized by profilometry. The conductivity of the printed silver connectors as well as the threshold voltage were measured and compared to the commercially used gold wire bonds. Results show a comparable behavior regarding electrical and optical properties.

10:30 - 11:00 AM Coffee Break — Liberty Ballroom Foyer

11:00 AM – 12:30 PM Late Breaking News / Success Stories
Liberty Ballroom B