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State-of-the-Art Invited Talk: 3D Printing

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

2:30 - 3:10 PM

2:30 **New File Format for 3D Printing, its Extensions and Applications (Focal),** *Hiroya Tanaka, Keio University (Japan)* 3

STL has been used as the 'de facto' standard for over 20 years. New file format called AMF was developed in order to overcome numbers of limitations of STL. The author reports his brief interpretations of AMF, applications using the current AMF, and ideas of extensions for next version AMF.

drupa® 2016 Preview

Session Chair: Werner Zapka, XaarJet AB

3:10 – 3:25 PM

3:10 **drupa® 2016: Touch the Future,** *Eva Rowe, Messe Düsseldorf North America**

WEDNESDAY, SEPTEMBER 30

Wednesday Keynote and IS&T Awards

Session Chair: Branka Lozo, University of Zagreb

9:00 - 10:10 AM

9:00 **3D Printed Bionic Nanomaterials,** *Michael McAlpine, University of Minnesota (USA)* 7

The ability to three-dimensionally interweave biology with nanomaterials could enable the creation of bionic devices possessing unique geometries, properties, and functionalities. The development of methods for interfacing high performance devices with biology could yield breakthroughs in regenerative medicine, smart prosthetics, and human-machine interfaces. Yet, most high quality inorganic materials: 1) are two dimensional, 2) are hard and brittle, and 3) require high crystallization temperatures for maximally efficient performance. These properties render the corresponding devices incompatible with biology, which is: 1) three-dimensional, 2) soft, flexible, and stretchable, and 3) temperature sensitive. These dichotomies are solved by: 1) using 3D scanning and printing for hierarchical, interwoven, multiscale material and device architectures, 2) using nanotechnology as an enabling route for overcoming mechanical discrepancies while revealing new effects due to size scaling, and 3) separating the materials synthesis and 3D printed assembly steps to enable conformal integration of high quality materials with biology. The coupling of 3D printing, novel nanomaterial properties, and 'living' platforms may enable next-generation nano-bio interfaces and 3D printed bionic nanodevices.

** Presentation only; no proceedings paper.*

MONDAY SEPTEMBER 28, 2015

DIGITAL PRINTING TECHNOLOGIES

9:00 – 10:00 AM Opening Ceremony and Keynote, Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon F

Inkjet-Based Processes

Session Chairs: Jim Przybyla, Hewlett-Packard Co.; Werner Zapka, XaarJet AB; Mineo Kaneko, Canon Inc., and Kye-Si Kwon, South Korea Soonchunhyang University

10:10 AM - 5:30 PM

Session sponsored by

10:10 **A Simple Model for DoD Inkjet Frequency Response,** *Stephen D. Hoath, University of Cambridge (UK)* 8

A simple linear model of piezo DoD inkjet print-head jetting output (drop speed, volume, momentum) provides an analytic prediction for the frequency response for steady state and initial printing streams from nozzles. The model has been applied to both existing commercial and development inkjet print-head devices.

10:30 **Ink-Particle Simulation for Continuous Inkjet Type Printer,** *Masato Ikegawa, Masanori Ishikawa, and Eiji Ishii, Hitachi Ltd., and Nobuhiro Harada and Tsuneaki Takagishi, Hitachi Industrial Equipment Systems Co., Ltd. (Japan)* 13

Industrial continuous inkjet printers are typically used for printing directly onto various types of products such as cans, bottles, and food packaging in production lines. To enable their application to higher speed production lines, their print quality needs to be improved. This means that ink-particle simulation technology is needed to clarify the factors that affect print quality. Print distortion is caused by certain droplet shapes in inkjet breakup and aerodynamic and electric interference among the ink particles flying from the nozzle to the print target. A simulation technique has been developed that enables the breakup into droplets and the trajectories of the ink particles flying from the nozzle to the print target to be calculated with initial data obtained by breakup simulation. Printing of a line of seven dots was simulated well with this simulation code without initial particle input data. Also print distortion was prevented by inserting dummy particles between charged ones in the simulation.

10:50 - 11:30 AM Coffee Break — Oregon Ballroom Lobby

11:30 **Jetting Frequency and Evaporation Effects on the Measurement Accuracy of Inkjet Droplet Amount (JIST-first Paper),** *Kye-Si Kwon, Dahai Zhang, and Hyun-Seok Go, Soonchunhyang University (Korea)* 19

Inkjet technology has been used as a tool to manufacture printed electronics, and the size of the droplet should be properly measured and controlled in order to improve the print quality. To this end, the volume of an inkjet droplet can be measured by assessing an image of the droplet through the use of a visualization system. However, a vision-based method may have accuracy issues, so, in this study, an alternative method is proposed by using a microbalance to measure the droplet mass. The mass and the volume of the droplet are simultaneously measured for verification and comparison. Since the results of the proposed mass measurement method are susceptible to the evaporation of liquid on the microbalance, the accuracy of the measurement is improved by employing an evaporation compensation method. Finally, the effects of the jetting frequency on the measurement uncertainty of the mass and the volume of the droplet are investigated by using several jetting materials with different boiling temperatures.

11:50 **Aerodynamic Effects in Industrial Inkjet Printing (JIST-first Paper),** *Cristina Rodriguez-Rivero, José Rafael Castrejón-Pita, and Ian Hutchings, University of Cambridge (UK)* 29

The quality achieved by inkjet printing is limited by various factors, including the nozzle–substrate throw distance, the substrate velocity, and the occurrence of satellite droplets. Under certain conditions, particularly for large throw distances, unacceptable inaccuracies and defects in drop placement occur. In this paper, a new technique based on high-speed imaging and laser optics is presented that allows the visualization of air currents and droplet movement patterns beneath and in the proximity of a printhead and a moving substrate. The images obtained with this technique provide better temporal and spatial resolution than those obtained in

previous studies. Tests with two different commercial printheads show that the entrained airflow depends on the interaction with the stream of printed droplets. The formation of unsteady eddies, particularly between nozzle rows, can result in serious errors in drop placement.

12:10 **3D Inkjet Printing of Optics (Focal),** *Ricardo Blomaard and Joris Biskop, LUXeXceL Group BV (the Netherlands)* 39
Established additive manufacturing technologies such as Fused Deposition Modeling (FDM), stereo lithography (SLA) and Polyjet are commonly used in the creation of functional 3D prototypes. The disadvantage of these technologies is the formation of visible layering, which only can be removed by labor intensive technique such as polishing. We have developed an inkjet based process that is able to 3D print fully transparent products with high smoothness. No post-processing is required, which makes the technology suitable for rapid manufacturing and small series production of optics. In this paper we provide an overview of the manufacturing process in general, as well as some technical details of the inkjet printer and optical material.

12:40 **InkJet Printing System for High Print Quality on Offset Coated Paper,** *Shinta Moriya, Yoshinari Suzuki, Shigeru Kinpara, and Yoshihisa Ohta, Ricoh Company, Ltd. (Japan)* 42
Recently, inkjet printing has been gradually replacing some of the offset pressing printing applications since it can easily handle small quantity and large variety printing production. We are offering RICOH Pro VC60000 to cover this customers' requirements on not only plain paper but also offset coated paper. To achieve high print quality especially on offset coated paper, we introduce the key technologies on this system such as SUS based 2-inch wide print head, Pigment based Quick-Drying Ink (QDI), Under Coat Liquid (UCL), Protector Coat Liquid (PCL), and Strong Dryer Unit.

1:00 **Functional Coating Developments for the Digital Manufacturing Age (Interactive),** *Patrick Le Galudec and Daniel Loosli, Sihl AG (Switzerland)**

1:05 – 2:30 PM Lunch Break

2:30 **Effects of Ink-Paper Interaction and System Parameters on Drying Quality in High-Speed Color Inkjet with Infrared Ray Heater,** *Satoshi Hasebe, Tomozumi Uesaka, Kumiko Tanaka, Masahiko Sekimoto, Motoharu Nakao, Toshinobu Hamazaki, and Eizo Kurihara, Fuji Xerox Co., Ltd. (Japan)* 46
Expanding high-speed full color inkjet system to production printing market requires applicability for various papers. However coated paper has difficulties such as interference among adjacent droplets, dryness and jetting stability, whereas normal paper has difficulties in achieving both fixing quality and image quality such as offset, optical density, color gamut and bleeding. Additionally, in normal paper, absorption speed depends on combination of inks and papers. Therefore, there are risks of insufficient fixing in slow absorption speed and bleeding or low optical density in fast absorption speed. In this study, focused on the combination of aqueous pigment ink and inkjet treated paper that shows relatively slow absorption speed, we studied on optimal condition which enhancing absorption and controlling fixed position of pigments in a paper. Setting up inkjet offline bench with infrared radiation heating system, relationship between fixing quality (smear) and optical density were investigate for following system parameters: drop volume, interval (time duration between inkjet head and the heater) and heating energy, which covered the conditions in actual high-speed inkjet printing system.

2:50 **Something for Nothing—Developing MEMS Silicon for a Vertically Integrated Market Leading Business-The Example of HP Thermal Inkjet,** *Jim Przybyla, Robel Vina, and Jeff Hintzman, Hewlett Packard Co. (USA)* 52
There are two essential steps in growing and sustaining vertically-integrated market leading technologies in a field as diverse as digital printing, and these steps can be summarized as creation and refreshment of technology platforms. Growth is enabled by the creation of new platforms that bring new capabilities to open new application opportunities. Because maturing markets present price and performance challenges to each new generation, sustaining market presence over time can be achieved by refreshing existing platforms—offering "Something for Nothing" by extending the current platforms. 'Improved performance at the same cost', or 'the same performance at reduced cost' can be strong value propositions to extend existing platforms. Traditionally in integrated circuit businesses, this is done by reducing electronics cost or increasing performance according to Moore's Law. MEMS (Micro Electro-Mechanical System) processes take considerably longer to develop than conventional IC processes resulting in a more difficult challenge to keep up with the fast pace of product introductions. This is partially-compensated by the much longer lifetime a successful MEMS process can enjoy,

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so it becomes essential to create improved MEMS designs and process variants that add features and/or reduce cost.

HP's Scalable Printing Technology (SPT) is used in HP's vertically-integrated inkjet printer and web press product lines that span a price range from $99 to $4.5M and are produced by many HP divisions. Innovations within SPT that enable new silicon value propositions will be used to demonstrate the strategic benefits of giving internal product developers and HP customers 'Something for Nothing'. Examples include silicon circuit and process simplifications to enable cost reductions, fluidic process and design optimizations to enhance performance, and radical design and process technology improvements within the existing footprint of silicon printhead chips (called "die") to add completely new capabilities.

3:10 **Study of Paper Deformation Mechanism in Color Inkjet Printing Process with Infrared Radiation Heater,** *Motoharu Nakao, Satoshi Hasebe, Ryosuke Takahashi, and Takashi Ogino, Fuji Xerox Co., Ltd. (Japan)* 57

In high speed inkjet printing system equipped with a drying system, IR type drying system is preferable considering recent needs for compact and light-weight design. However, the IR type drying system has a risk that a cockle height changes depending on colors of ink. Thus, the authors investigated the relationship between the cockle height and exposure energy of IR heater for different colors of ink (black and magenta) by setting up an off-line drying bench. As a result, the cockle height on the area printed with pigmented magenta ink became higher than that with pigmented black ink since the absorption ratio depends on colors. Furthermore, the number of peaks in cockle profile shifts from one peak to two peaks with increasing the exposure energy. Hence, we tried to clarify the mechanism about changing of cockle profile by simulation. Physical properties such as water swelling ratio and Young's modulus of ink soaked paper were measured using a newly developed instrument. Consequently, the changing of cockle profile was reproduced by considering shrink of the non-printed area.

3:30 **Intense Pulsed Light Sintering and Parameter Optimization for Various Inkjet Printed Silver Electrodes,** *Dana Weise[1], Christoph Sternkiker[1], and Reinhard R. Baumann[1,2]; [1]Technische Universität Chemnitz and [2]Fraunhofer Institute for Electronic Nano Systems ENAS (Germany)* 62

Flexible and even stretchable electronic devices are showing more and more growth in interest in the field of printed electronics. Various kinds of material classes, like conducting, semi-conducting and insulating materials are used to manufacture multilayer devices, such as transistors and capacitors. One of the key components is the conductive layer, in the easiest way a resistor or contacts for diverse connections. Within the last years these metallic layers, e.g. silver copper or gold, were optimized regarding their morphological and electrical performance. On main step next to the printing process is the post-treatment, which forms in printed electronics a solid conductive structure out of the liquid printed films. New methods of selective sintering, using for example infrared (IR) radiation, microwaves or intense pulsed light (IPL) open the opportunity to form conductive metallic layers on even temperature instable substrates like polymeric foils. However, these post-treatment methodologies require detailed studies to obtain optimal results regarding the performance without damaging the base-substrates. For this purpose this research includes a detailed study on the novel method of IPL sintering technology. Various nanoparticle silver inks are inkjet printed on thin Poly(ethylene terephthalate) [PET] foil and post-treated with intense pulsed light to form conductive metal layers. It is shown, how to adjust the IPL flashing parameters depending on the silver ink to achieve highest conductivities without defects in the printed silver layers and the PET substrates.

3:50 – 4:30 PM Coffee Break — Oregon Ballroom Lobby

4:30 **Recent Developments in Moving Nozzle Inkjet Printhead Technology,** *Peter J. Brown, The Technology Partnership (UK)* 66

The developments seen in inkjet printing over the past two decades have resulted in the adoption of the technology in significant, previously untapped, markets. Applications such as ceramic tile decoration, printed electronics and additive manufacturing have all been transformed by the increased reliability, speed and range of materials that can be deposited, delivering huge commercial upsides to the end users.

Nevertheless, there is still significant room for further technical developments to drive inkjet technology into new markets. Incremental changes to the performance of established technologies could deliver this vision given sufficient time and investment, but there is plenty of opportunity for a new, disruptive approach to drive the industry forwards. The Technology Partnership plc (TTP) has been developing a portfolio of droplet generating technologies for a number of applications, one embodiment of which is an industrial inkjet printhead. The ejection mechanism is based on a 'moving nozzle' approach, which is characterized by driving a nozzle plate at ultrasonic frequencies in order to generate the fluidic pressure required to generate the droplet.

This paper provides an update on the anticipated benefits of the technology, applications where we believe it could deliver significant commercial advantages and the current status of development.

4:50 **Polyaniline Nanofibers for Security Printing Applications,** *Jeevan M. Meruga[1], Connor Holland[2], Jacob Petersen[1], William Cross[1], Jon Kellar[1], and Grant Crawford[1]; [1]South Dakota School of Mines and Technology and [2]Southwestern Oklahoma State University (USA)* 69

In this research we utilize polyaniline nanofibers in security printing applications. Polyaniline nanofibers were synthesized to allow an aqueous-based ink to be created. Inks with different weight percentages of polyaniline nanofibers were formulated, printed into desired patterns on a variety of substrates using digital fabrication and characterized for their conductive properties. The conductivity differences between the flash welded regions and non-flash welded regions were determined to help determine applicability for security-end products.

5:10 **Development of Inkjet Supply for Offset Paper,** *Yuuki Yokohama, Hiroshi Gotoh, Mariko Kojima, Tsutomu Maekawa, and Michihiko Namba, Ricoh Company, Ltd. (Japan)* . . 72

Ink-jet printing is the fast-growing category for printing on various different materials. In production printing, the print speed is fast on coated paper. The use of ink-jet printing has been expected in this area, but now the use is limited to coated paper with ink absorbing capacity. Ink-jet supplies have been developed to print fine images on coated paper for offset printing where it is difficult for the paper to absorb ink-jet ink. Three types of supplies with different functions have been developed as follows.

concurrent event

3:30 – 5:50 PM Colleague Connections—
Surface Manufacturing Roundtables and White Paper Input

choose among four topic areas, see full details on page xvii, meet in Oregon Ballroom Salon G

MATERIALS, METHODS, AND PERFORMANCE

9:00 – 10:00 AM Opening Ceremony and Keynote, Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon A

Physics and Chemistry of Materials

Session Chairs: Greg Herman, Oregon State University; Frits Dijksman, University of Twente; and Norio Nagayama, Ricoh Co., Ltd.

10:10 – 11:50 AM

10:10 **Break-up Time in Inkjet Printing from Bulk Rheological Data,** *Maik Müller[1], Gustaf Mårtensson[2], Ingo Reinhold[1], Tim Wickens[3], and Werner Zapka[1]; [1]XaarJet AB (Sweden), [2]Mycronic AB (Sweden), and [3]Xaar plc (UK)* 76

A number of mathematical methods exist to characterize the underlying mechanism of the thinning and break-up of a liquid jet. These methods however, have not been applied to fluids used in inkjet printing. In this work, we used filament stretching experiments to demonstrate the applicability of similarity solutions found in literature to determine the dominating thinning mechanism for a variety of sample fluids. The thinning velocities and break-up times were computed and compered with the experimental results from the filament stretching. We observed that an additional correction factor was required to match the used similarity solutions with the experimental data. Furthermore, we could calculate the break-up time of the filament experiment from the bulk data of the sample fluids. The calculation was used to predict the overall break-up time of a liquid jet emerging from the nozzle of an inkjet printhead. The results were in good agreement with the general limits of drop formation. Differences between the required pre-factors and from literature were observed and need to be investigated further.

10:30 **Measurement Technique for Electrostatic Charge on Single Toner Particle with MEMS-based Actuated Tweezers,** *Daichi Yamaguchi, Shuusuke Someno, and Masaya Hamaguchi, Ricoh Company, Ltd. (Japan)* 81

A measurement technique for the charge on a single toner particle using nanotweezers (MEMS-based actuated tweezers) and an AFM cantilever has been developed. This unique system was designed to measure the image force on the cantilever induced by a charged toner particle gripped by nanotweezers. A method for calculating the toner charge from the image force has also been established by replacing the non-uniform charge distribution with an imaginary point charge. The proposed technique is validated with consistent results using the blow-off method and is promising for analyzing single isolated toner particles, e.g., fogging or transfer dust toner.

10:50 **Preparation of Copper Conductive Patterns Using Reactive Inkjet Printing followed by Two-step Electroless Plating (Interactive),** *Jin-Ju Chen, Ya-Dong Wan, Zhe-Sheng Feng, Da-Yong Wang, and Xin Zheng, University of Electronic Science and Technology of China (China)**

A simple and low-cost process for fabricating copper conductive patterns on flexible polyimide substrates is demonstrated. Catalyst pattern of copper nanoclusters was directly produced on substrate using reactive inkjet printing of Cu (II)-bearing ink and reducing ink. Copper conductive pattern was then generated after a two-step electroless plating procedure. Morphology, microstructure, and element ingredients of copper layer were characterized using optical microscope (OM), scanning electron microscope (SEM), X-ray diffractometer (XRD) and energy dispersive X-ray spectrometer (EDS). Copper nanoclusters in catalyst patterns were found distributed uniformly and homogeneously. A thin copper layer with small particle size was formed after the first electroless plating step, and a thick copper layer more than 10 microns with dense particle arrangement and fine crystallinity was then produced after the second electroless plating step. This resulting copper layer had an excellent solderability, a reliable adhesion strength and a low resistivity of 5.68×10-8Ω·m without sintering.

10:55 – 11:30 AM Coffee Break — Oregon Ballroom Lobby

11:30 **Complete Incorporation of Wax in Polyester CPT Using Polyester-Encapsulated Wax Emulsion,** *Machiko Ie, Tomohide Yoshida, Shoichi Murata, and Eiji Shirai, Kao Corporation (Japan)* . . 85

Polyester-encapsulated wax emulsions were investigated in the synthesis of polyester CPT to achieve a toner with complete incorporation of wax. The toner provided not only low-temperature fusing, but also improved durability, storage stability, and reduced contamination of print engine components. Polyester-encapsulated

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paraffin wax emulsions were prepared by phase-inversion emulsification with MEK as the solvent. To achieve good compatibility between the polyester resin and wax, the resin hydrophobicity was increased by grafting of hydrophobic moieties, including alkenyl succinic anhydride and styrene acrylate segments. With these resins, however, there was wax bleeding and separation of wax from the polyester emulsion. After evaluation of several resins, we found the following key conditions to achieve polyester emulsions with encapsulated wax. Firstly, the polyester was grafted with styrene acrylate segments containing long alkyl chain monomer such as stearyl methacrylate. Secondly, the wax was added internally to the hybrid polyester resin during resin synthesis. By using a resin produced under these conditions, the wax and polyester were emulsified with complete encapsulation of the wax, as confirmed by TEM. An EA toner was prepared from this emulsion and no wax was observed on toner surfaces by SEM. This means the wax stayed completely encapsulated even during coalescence, which was at a temperature above the wax melting point. In performance testing of the toner, the durability, storage stability and machine contamination levels were improved dramatically.

Metrology Tools for Digital Printing Processes

Session Chairs: Jeff Nielsen, Hewlett-Packard Co.; Steven Hoath, University of Cambridge; and Takuroh Sone, Ricoh Co., Ltd.

11:50 AM – 1:15 PM

11:50 **The Colour of Glass,** *Susanne Klein[1], Michael P. Avery[2,3,4], Robert M. Richardson[3], Paul Bartlett[4], and Steven Simske[5]; [1]Hewlett-Packard Labs (UK), [2]Bristol Centre for Functional Nanomaterials (UK), [3]School of Physics, University of Bristol (UK), [4]School of Chemistry, University of Bristol (UK), and [5]Hewlett-Packard Labs (USA)* 89

3D-printing, along with other additive manufacturing (AM) and rapid prototyping (RP) techniques, involves building up structures in a layer-by-layer fashion based upon a computer design file. Such techniques are well-suited to the production of one-off, complex structures that would often be difficult to produce using traditional manufacturing methods. There has been rapid growth and interest in this field during recent years, and a range of techniques are now available which make use of many common materials such as plastic, metal, wood and ceramic. However, relatively little has been done to develop AM using glass. Since glass was first made, thousands of years ago in Mesopotamia, it has been appreciated because of its vibrant colours. To allow a successful design and print of any glass object, these colours have to be captured and classified in such a way that they can be incorporated in the CAD design of the object and lead to the desired result in the print. The colours of architectural glass are often classified by RAL charts or by BS4800:2100 colour codes. Both colour classification systems have been developed for paints and coatings, but are a good first approximation. What they cannot capture is, for example, that some glasses display different colours in reflection and transmission and/or the colour change occurring in glass when it is reheated. In 3D printed glass, gas inclusions are another source of colour changes. Scattering at the air/glass interface leads to the addition of white to the underlying glass colour. Using CIE chromaticity coordinates, glass samples are characterized before and after processing. We used two different measurement methods to determine colour coordinates as a function of sample thickness and frit size, to check how robust the results were as a function of the measurement method.

12:10 **Measurement Method of Toner Mass Distribution by Reflectance Using Multiple Exposure (Focal),** *Takuroh Sone, Makoto Hino, Yumiko Kishi, and Naoki Sakai, Ricoh Company, Ltd. (Japan)* 94

It is important to measure the toner mass distribution on paper, on intermediate transfer belts and on OPCs (organic photo-conductors) to analyze the structure of the toner image in electrophotography. However, toner distributions are difficult to measure. When the amount of the black toner is high, the reflectance is very low. Therefore, a charge-coupled array (CCD) camera cannot detect minor differences in the reflectance. Additionally, when the exposure time is long, the signals from the paper are saturated. The purpose of this paper is to establish a toner mass distribution measurement method. To archive this, we propose a measurement method using a multiple exposure. First, the toner area and the paper are measured by the multiple exposure process. Next, based on the relationship between the exposure time and the brightness values of the CCD camera, two approximately linear equations are obtained by the least squares method and the two lines slopes are obtained from these equations. The toner reflectance is calculated using the line slopes. If we calculate the reflectance at each pixel of the camera, then the reflectance distribution can be obtained. This method can prevent detection shortages and saturation of the camera to enable toner and paper measurements while using entire the dynamic range. Furthermore, the method can reduce random noise to calculate the reflectance using multiple images of the same area. Finally, we propose an unfixed toner mass prediction model. This model can vary the reflectance relative to the toner mass, and the toner mass distribution can thus be obtained. This method can visualize the uniformity of the toner mass, and we expect this method to be used for image analysis.

COLLEAGUE CONNECTIONS—SURFACE MANUFACTURING ROUNDTABLES AND WHITE PAPER INPUT

Monday, 3:10 – 5:50 PM
Organizer: Steven Simske, Hewlett-Packard Laboratories

The printing world is undergoing an exciting transformation as 3D printing augments traditional 2D printing and print finishing approaches such as in lenticular and security printing (collectively "2.5D printing").

To help our community better understand this transformation, those interested in this topic will meet in four parallel roundtables to address different technological, systems, and even business aspects of this expansion in printing. Output from these discussions will be collected and used to help generate a white paper to be posted and acted upon by the World Economic Forum's Global Agenda Council on the Future of Electronics. The white paper will be produced in time for the Forum's mid-November 2015 meeting.

The four roundtable areas are:
(1) Materials: plastics/polymers, ceramics and metals
2) Scanning to 3D modeling/printing: imaging approaches, systems, and software
(3) Merging mass production with mass customization: methods, workflows, processes, accounting systems, track and trace, authentication
(4) Substitutability in manufacturing (how to re-define machining and manufacturing processes in light of 1, 2, and 3, above.

Roundtable participants should meet in Oregon Ballroom Salon G for an overview of the afternoon.

12:40 **Study on Atomistic Behavior of Macromolecules by Molecular Dynamics Simulation and its Enlargement in Scale,** *Tomohiro Seko, Yuki Sasaki, Kazuhiko Yanagida, Kazuki Inami, and Nobuyuki Nakayama, Fuji Xerox Co., Ltd. (Japan)* 98

Properties of materials are constituted by molecular structures. The molecular dynamics simulation technique has an advantage in clarifying the relationship between molecular structure and properties through analysis of atomistic structure and dynamics, which are difficult to measure by experiment. On the other hand, major problems with applying this technique to larger and more complicated molecules consist of controlling the calculation time, and the larger scale of molecules.

In this study, first, a relationship between melting properties and molecular structure is investigated by using the atomistic molecular dynamics simulation to verify effectiveness of this technique. The relationship between the reciprocal of self diffusion coefficients obtained from the simulation and 1/2 FT, which is an experimental indicator for melting properties, shows good agreement. This result indicates that atomistic molecular behavior affects melting properties, and implies that polymers with Bisphenol A structure have higher molecular dynamics.

Next, a reduction of calculation cost and an enlargement of molecular simulation are examined by following 2 approaches—the coarse-grained united-atom model and the supercomputer K computer. The coarse-grained united-atom model shows good parallel scalability. For polycarbonates, it has the equivalent accuracy of the full atomistic model, and is more than 15 times faster than the full atomistic model with the same number of molecules and cores. These techniques expanded the spatial scale of molecular dynamics simulation by one digit larger than ever before.

1:00 **Identification Technology of Paper—Authenticity Detection Using Multiple Feature Quantities (Interactive),** *Takahisa Nakano, Nobuki Nemoto, and Takeo Miki, Toshiba Corporation (Japan)* 104

Counterfeiting ID cards and negotiable securities such as bills and gift certificates are always repeated. To improve performance of detection for authenticity, development of new technology that combines sensor technology and encoding techniques for security information are required. There are many reports to confirm printing regions for security documents, however, methods to detect features of paper media are rarely studied We have developed a method for detecting the authenticity of paper by optically sensing the characteristics of uniformity, brightness, color values, gloss and near-infrared absorption properties. Using multiple features, the separation boundary in a multidimensional feature space is determined. We report results of separation abilities of twenty kinds of paper media based on a multidimensional analysis.

1:05 **Atomic Force Microscopy Characterization of Printing Dots (Interactive),** *Maria J. Cadena, Ronald Reifenberger, Jan P. Allebach, and Arvind Raman, Purdue University (USA)* 109

Functional atomic force microscopy (AFM) techniques are proposed as a high resolution tool to understand relevant physical properties of colorants and printing substrates at nanoscale. In this work, we present an exploratory AFM study of colorants used by three digital printing technologies: LaserJet, Indigo, inkjet and two printing substrates: white paper and transparent media. Surface morphology and phase-contrast imaging

are performed using amplitude-modulation (AM) AFM and measurements of surface potential and capacitance gradient are measured through 2nd harmonic Kelvin Probe Force microscopy (KPFM). Compositional mapping contrast is analyzed using both techniques. Non-homogeneous mechanical properties are clearly evident in the AM-AFM images while the variations of local electrical properties are apparent from the KPFM studies.

1:10 **Study on Correlation between Linear Perspective and Depth Feeling by Subjective Estimation (Interactive),** *Yasushi Hoshino, Kota Uehira, and Nobuji Tetsutani, Tokyo Denki University (Japan), and Aran Hansuebsai, Chulalongkorn University (Thailand)* 115

Image quality of image printing system has been improving rapidly. Depth feeling is important in image quality. Depth feeling is controlled by various factors such as linear perspective, size, overlapping, shade and density so on. Linear perspective is powerful technique for expressing depth on flat surface. Concerning the studies on depth feeling, its dependence on pixel number has been reported. But other factors influence depth feeling is not yet understood well. Landscape image include linear perspective components is generated by computer graphics method. Changing linear perspective intensity, depth feeling is subjectively estimated. It is confirmed that linear perspective is very important in depth feeling.

1:15 – 2:30 PM Lunch Break

Performance of Digital Print Products

Session Chairs: Jeff Hintzman, Hewlett-Packard Co.; Patrick le Galudec, Sihl; and Hirotoshi Terao, Alps Electric Co., Ltd.

2:30 — 5:50 PM

2:30 **Mitigation of Pollution-Induced Deterioration of Digital Prints through the Use of Enclosures,** *Daniel Burge and Andrew Lerwill; Image Permanence Institute, RIT (USA)* 119

The potential for common enclosures to reduce or prevent pollutant-induced deterioration of inkjet materials was investigated, with the specific research question being: Can any of the various commonly-used enclosure designs and materials (envelopes/boxes, paper/plastics) be used to effectively reduce or prevent the damage to digital prints caused by Ozone or Nitrogen Dioxide air pollution? The results indicate clear guidelines how to best proceed to mitigate pollutant gas damage. Polyester sleeves show by far the greatest potential for both pollutants over all tests conducted, which indicates this benefit may extend to the parts-per-billion range. Increasing ppm values and equally reducing exposure times to create the same ppm-days exposure did not always result in the same color change to the prints inside or outside enclosures. This importantly indicates extended time periods and lower concentrations could mean an enclosure's effectiveness in preventing damage from pollution could be in fact much lower than that observed in highly accelerated testing (as seen in this work and elsewhere). This raises questions regarding the suitability of such techniques to appraise the efficacy of enclosures employed to deter pollution damage caused over longer periods (decades) at real world environmental pollution levels.

2:50 **Investigating the Validity of Microfading Spectroscopy to Predict Photochemically Induced Color Change at Lower Light Levels,** *Andrew Lerwill, Image Permanence Institute, RIT, and Christel Pesme, Vincent Beltran, and James Druzik, Getty Conservation Institute (USA)* 123

Two investigations of the validity of microfading spectroscopy to predict the fading behavior of a diversity of colorants at lower light levels is discussed. The specific research question being: what is the probability that a particular sample being tested with micro-fading will alter significantly differently from the same lux-hours light exposure at ambient light intensities? In one experiment two ISO Blue Wool Standards and 15 dyed papers were tested. Accelerated light aging at four illuminance levels stepping from 250 lux to one tenth of the microfading irradiance of 12.5 Mlux was conducted over different time periods using either standard fadometer lightfastness testing apparatus or a microfadometer. Samples received similar lux-hours exposure. In a second experiment a 2.2 Mlux illuminance from a microfadometer was compared to that of a QUV Weatherometer light aging chamber (with UV filtration). Ten different dyes were each faded for 10 minutes using the microfadometer and then for 21 hours using a QUV Weatherometer (with UV filtration). Samples again received the same lux-hours exposure. Results from both experiments illustrate a positive correlation between the compared light sensitivity testing methods, leading to the conclusion that fugitive colorants can be reliably highlighted by the microfading technique. In both experiments a lower value of induced color difference was observed when using microfading compared to standard lightfastness testing apparatus (light box aging) indicating that the quantative prediction of color change from real illumination in lower illuminance conditions is not secure. A short discussion of the origins of error in the technique follows.

3:10 **Standardization of Inkjet Drop Speed Measurement Methods for Printed Electronics,** *Stephen D. Hoath, University of Cambridge (UK)* 129
Methods for measurement of inkjet-printed drop speed at various precision levels were proposed in a draft international standard by IEC TC119: Printed Electronics WG3—Equipment. These are reviewed and discussed for feedback by NIP31/DF2015.

3:30 **Evaluation of the Image Permanence of Digital Colour Photographic Prints based on Colour Difference,** *Yoshi Shibahara[1], Evert Groen[2], and Nobuhiko Uchino[1]; [1]Fujifilm Corporation (Japan) and [2]Fujifilm Manufacturing Europe B.V. (the Netherlands)* 135
The validity of a colour difference approach for evaluating the image permanence of photographic colour prints was determined by comparing its performance with that of optical density analysis, which has been conventionally used in this field. Criteria for determining the endpoints of photographic images are also proposed in this study.

Light-fading tests were conducted for 20 consumer photographic and production prints, which were produced using dye-based inkjet, pigment-based inkjet, silver halide, electrophotography and D2T2 systems. The lives of these prints were evaluated on the basis of both optical density and colour difference data. Furthermore, the faded images were visually assessed by professional observers.

It was confirmed that the colour difference approach produced results that correlated well with those of the visual assessment and that it was an effective measure for evaluating the image permanence of photographic prints. The results also indicated that the colour difference between faded and fresh images, 'ΔE76 = 10' or 'ΔE00 = 5', was appropriate criteria for determining the endpoints of photographic images.

3:50 **Fire Safety and Inkjet Printed Wallcovering Materials (Interactive),** *Bruno Fouquet, Diatechnologies SAS (France), and Patrick Le Galudec, Sihl (Switzerland)* 140
The session is a follow-up of 2014 presentation on development of fire-retardant wallcoverings. The initial research had indicated that printing with water-based and eco-solvent inks of different types had no measur-

able impact on the fire-retardancy properties of media. Risks identified were associated with new styles of wallpaper installations and a certain confusion resulting from the multiplicity of measuring methods and fire retardancy standards.

Mr. Fouquet and his team explored ways to deliver a compliant media meeting at the same time the visual and haptic expectations of designers and artists.

A multi-layer treatment (frontside) and the impregnation of paper backside are added to enhance the fire-retardancy performance. Another parameter to consider is a reduction of the paper weight. This may has some impact on the aesthetic and is thus to be handled with care. With wallcovering shifting to digital on-demand manufacturing, questions on installation safety and compliance with fire regulations have to be reconsidered.

Sihl advocate the impregnation of front-side and back-side of wallpapers in order to provide users with an increased safety level without compromise on the aesthetic value. It is a balancing act. We hope that industry will share our concerns and join us with safer and healthier products for the greater benefit of users.

3:55 – 4:30 PM Coffee Break — Oregon Ballroom Lobby

4:30 **Relationship between Chinese Text (Kanji) Quality and Card Printing Technology,** *Mark B. Mizen, HID Global, and Ming-Kai Tse, Quality Engineering Associates (QEA), Inc. (USA)* 143

Reproduction of Chinese text is inherently more difficult than the reproduction of Latin characters due to the complexity of Chinese characters. Contrast, resolution, and color registration are critical, and failure to maintain these factors rapidly leads to degradation of Chinese text quality.

Analysis of a representative Chinese character illustrates how these factors vary with imaging systems typically used to produce plastic cards. In fact, a direct correlation exists between resolution and the ability to accurately reproduce small font sizes, with 300 dpi sufficient for 8 pt text, 600 dpi required for 4 pt, and 1200 dpi for 3 pt. This correlation represents minimum required resolution. If other factors, such as low contrast or color registration, degrade the image, even higher resolution is required.

4:50 **Spot Color Matching for Digital Package Prototyping Using UV Ink-Jet Printer,** *Yu Ju Wu, Appalachian State University (USA), and Reem El Asaleh, Ryerson University (Canada)* 146

Digital printing technology is dramatically changing the packaging/prototyping market. Packaging work is among the most color critical in the industry. Matching corporate and brand colors is essential, as is the ability to accurately reproduce spot colors. The main purposes of this experimental study are to (1) examine the quality of spot color reproduction using UV wide-format inkjet printer for digital package prototyping, and (2) establish printing workflows for digital package production. In order to examine the spot color matching capability and establish a digital printing workflow for digital package prototyping, sets of test samples were prepared. Spot colors from the Pantone color guide were used to design the spot color test chart for this study. CIE L*a*b* values of Pantone color swatches were used as target values. Adobe Photoshop CC 2014 was employed to generate the spot color test chart in digital form. The designed test target was printed on different grade of paperboards and corrugated board on an EFI Vutek PV 200 UV inkjet printer. Color management with ICC profiles was used to investigate the reproduction of specific spot colors. These profiles were used to compare the device gamut and to investigate reproduction of specific spot colors. The quality of spot color matching was evaluated in terms of the ΔE2000 in CIE L*a*b* color space.

5:10 **Belt Fuser Torque: Modeling Mechanism Drag as Parametric Damping and Corroborating Measurement with EHL Theory,** *Benjamin Johnson and David Battat, Lexmark International, Inc. (USA)* 151

This study pertains to the intrinsic mechanism drag of a belt image fix system which arises mainly due to friction between the heating element and belt. This drag typically increases through module life and can be a main cause of fatigue failure for this type of system. An experimentally obtained parametric damping model is utilized to construct an equation of motion for the system. Properties of the empirical model are used to make inferences regarding the lubrication state in the nip. Mechanism failure due to lubricant starvation is discussed in the context of the model. Finally, reconciliation of the empirical model with elastohydrodynamic lubrication (EHL) theory will be discussed.

5:30 **Quantifying Print Quality for Practice,** *Elisa H. Barney Smith, Boise State University, and Eric Maggard, Scott Line, and Mark Shaw, Hewlett-Packard Co. (USA)* 157

To aid in the process of evaluating print quality, five print quality metrics and methods to measure them have been developed. The attributes of interest are: (1) Edge quality, Sharpness, Detail, Raggedness; (2) Scatter, Particles, Halo, Character ghosts; (3) Readability, broken characters (4) Readability, touching characters; (5)

Inverse text. The print quality is measured from a test chart containing typical text in a range of sizes and multiple fonts. The test chart is scanned on a commercial desk top scanner. Quantitative values are returned without human input or human surveys, but relate to human perception of these quantities.

concurrent event

3:30 – 5:50 PM Colleague Connections—
Surface Manufacturing Roundtables and White Paper Input

choose among four topic areas, see full details on page xvii, meet in Oregon Ballroom Salon G

DIGITAL FABRICATION AND 3D PRINTING

9:00 – 10:00 AM Opening Ceremony and Keynote,
Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon G

Digital Printing and Fabrication Principles and Processes

Session Chairs: Marie Vans, Hewlett-Packard Co., and Masaaki Oda, JAPERA

10:10 AM – 11:50 PM

10:10 **Paper Wrinkle in Printing Devices,** *David Battat, Lexmark International, Inc. (USA)* 163

Paper wrinkle is problematic because it is system-related, occurring at the end of the development cycle when hardware has already been committed. In belt fusing paper wrinkle is more involved than in roll fusing, due to the system being less robust and due to constraints by rapid warm-up requirements. The main objectives here are to elucidate the mechanics of paper wrinkling, and to generate a methodology to mitigate wrinkle formation. The analysis addresses the concept of 'creep', the small differences in velocities between belt, paper and backup roll (BUR), the mechanics of paper feed in long rolls, and their relevance to paper wrinkle in belt fusing.

Paper wrinkle arises due to non-uniformities along the roll which ultimately affect paper feed rates. Non-uniformities are inherent to the design of the fuser; however there are ways to control wrinkling tendencies, e.g. by optimizing system rigidity, profiling the BUR surface and core, and saddling the shape of the belt, to name but a few. One objective of the analysis is to understand the behavior of the system before hardware selection has been firmed up. To this end a master wrinkle curve is generated, which describes the propensity of the system to wrinkle and the directions to mitigate the effect.

10:30 **Electrophotographic Ghosting Detection and Evaluation,** *Xiaochen Jing[1], Steve Astling[2], Renee Jessome[2], Eric Maggard[2], Terry Nelson[2], Mark Shaw[2], and Jan P. Allebach[1]; [1]Purdue University and [2]Hewlett-Packard Co. (USA)* 169

Ghosting is a well-known Print Quality (PQ) defect which may appear as a single or repetitive artifact presenting vestigial objects at a certain interval. The overall print quality will be limited if ghosting is present. Therefore, an algorithm that can accurately provide the information of both the ghosting source and its severity is greatly needed.

In this paper, we propose an algorithm to detect and evaluate ghosting by first applying template matching in the CIE L*a*b* color space, and then calculating the color difference. The template matching step in the L* channel will indicate the position and the type (light or dark) of the ghosting. We then calculate the color difference among L*, a*, and b* channels to get the Delta E for the purpose of evaluation. Our algorithm can automatically detect, quantify, and label the severity of ghosting according to a final metric. Base on 82 samples in total, the accuracy of our algorithm is 92% compared with expert visual evaluation. Our algorithm is also suitable to be used as a quality control tool to set limits in production processing.

10:50 – 11:30 AM Coffee Break — Oregon Ballroom Lobby

11:30 **Modulated Extrusion for Textured 3D Printing,** *Paul O'Dowd, Stephen Hoskins, Peter Walters, and Adrian Geisow, University of the West of England (UK)* 173

This research utilises a Fused Deposition Modelling 3D Printer to investigate the aesthetics of 3D printing and its broader applications. The presented research re-evaluates the 3D printer as a tool to manipulate materials, as opposed to a machine that discretely reproduces digital models at a fine resolution. The research questions the utility of automation, and attempts to find a level that permits materially expressive modes of fabrication.

The exploration of aesthetics has uncovered a variety of unexpected textures and interesting material properties that may have wider use. For instance, rigid plastic has been extruded and manipulated finer than the extrusion nozzle diameter, which confers flexibility and fabric like qualities to the printed object. The discovered techniques for 3D printed aesthetics are reproducibly reliable and can be incorporated back into orthodox digital-model driven fabrication.

Digital Fabrication of Functional Products

Session Chair: James Stasiak, Hewlett-Packard Co.; Ingo Reinhold, XaarJet AB; Shinichi Nishi, Konica Minolta IJ Technologies; and Koei Suzuki, Ricoh Co., Ltd.

11:50 AM – 3:30 PM

11:50 **Manufacturing of Touch Sensors Integrated in Decorative Laminates for Furniture Surface,** *Wolfgang A. Schmidt, Rainer Gumbiowski, and Rijk Van der Zwan, Schoeller Technocell GmbH & Co. (Germany)* 179

This paper reports an application example of printed electronics function on paper. We laminated printed conductive areas into a standard low pressure laminate structure on chipboard, together with a digitally printed decorative surface layer. Thus a demonstrator of customized touch sensors in furniture was realized.

12:10 **Electrohydrodynamic Jet Printing for Columnar Discotic Liquid Crystal Alignment and Applications in Organic Electronics (Focal),** *Adam V. S. Parry[1], Daniel J. Tate[1], Richard J. Bushby[2], and Stephen G. Yeates[1]; [1]University of Manchester and [2]University of Leeds (UK)* 181

A review of the past and present work on discotic liquid crystals is presented paying particular attention to their use in organic electronics and uniaxial planar alignment. The use of electrohydrodynamic printing for micron and sub-micron resolution patterning is then investigated and the latest high resolution drop-on-demand techniques are reported. Finally, the use of the state of the art SIJ printer is demonstrated for its use in creating high resolution patterns of silver and SU8 photoresist for discotic liquid crystal alignment.

12:40 **Rectification Characteristics of Dual-Layered Organic Device Incorporating Ohmic Contact: Triphenylamine Derivative/C60-Doped Triphenylamine Derivative,** *Norio Nagayama[1,2], Mitsuhiko Katagiri[1], and Minoru Umeda[1]; [1]Nagaoka University of Technology and [2]Ricoh Company Ltd. (Japan)* 188

In this report, we describe rectification characteristics of a dual-layered organic device sandwitched with Au electrodes. Triphenylamine derivatives are commonly used in organic photoconductors as hole-transport materials for laser-beam printers. In the photoconductors, photogenerated holes are injected easily from a carrier generation layer to the hole-transport layer (HTL). However, in the case of metal/HTL/metal device, it is needed a high voltage for injecting a hole to the HTL even when Au electrode having a large work function is used. For realizing an ohmic contact, we employed a structure of Au/triphenylamine derivative (TPA; the

molecular structure is shown in Fig. 1) doped with C60. Then, a metal/TPA/C60-doped TPA/metal was prepared and its rectification property was measured.

1:00 – 2:30 PM Lunch Break

2:30 **Exfoliated Layered Materials for Digital Fabrication,** *Viviane Alecrim, Renyun Zhang, Magnus Hummelgård, Britta Andres, Christina Dahlström, Duc T. Duong, Magnus Norgren, Mattias Andersson, and Håkan Olin, Mid Sweden University (Sweden)* 192

We introduced an exfoliation method of MoS2 in a 3% solution of sodium dodecyl surfactant at high concentration (*i.e.* 2 g/L). The bulk MoS2 was thinned by mechanical exfoliation between sand papers and the resulting powder was used to prepare dispersions by liquid exfoliation through probe sonication. The resulting dispersion consisted of very thin MoS2 nanosheets in surfactant solution with average lateral size around 126 nm. This may be interesting for applications in inkjet printed electronics.

2:50 **Application of Inkjet Printing for 3D Integration (Focal),** *Kim Eiroma and Heikki Viljanen, VTT Technical Research Centre of Finland (Finland)* 195

Inkjet printing is an attractive deposition tool to complement the traditional processing methods used in microelectronics integration. Its maskless, digital and non-contact nature provides many generic benefits, such as savings in processing steps and material usage, production flexibility and scalability to large areas. In addition, inkjet printing can be utilized in the integration of e.g. silicon and polymer or paper based systems, such as for the new wave of hybrid large-area, flexible devices, which are out of the scope of traditional clean room processing.

In this paper, we study the process of metallization of a Through-Silicon Via hole (TSV) by inkjet deposition. We describe the process of sample preparation and characterization. We finally demonstrate the creation of a fully inkjet printed 3D electrical interconnection using a Kelvin TSV test structure.

3:20 **Fundamental Characteristics on Nano Porous Titania Layer of Dye-Sensitized Solar Cell (DSC) Utilizing Electrostatic 3D Printer (Interactive),** *Masafumi Ogawa, Yoshihito Kunugi, and Satoru Iwamori, Tokai University, and Shinjiro Umezu, Waseda University (Japan)* 201

We are now developing a new electrostatic 3D printer. We are now applying the 3D printer for fabricating the 3D cell structure in biotechnology and the dye-sensitized solar cell (DSC). The 3D printer is based on electrostatic inkjet printer. In this case, the nozzle was filled with the titania paste. The plate electrode was set under the nozzle. When the high voltage was applied between the nozzle and the plate electrode, small droplets were ejected from the nozzle because of balance among the high electrostatic force, gravity force, and the surface tension and the titania layer was formed. The thickness of the titania layer was controlled by the printing time, the applied voltage, and the air gap. The titania layer had many cavities. In this paper, we investigated fundamental characteristics of the nano porous titania layer. With the nano porous titania layer, the surface of the titania layer was increased, and the efficiency was higher than the solid titania layer that was fabricated utilizing doctor blade method. SEM and another experiment was applied to investigate the nano porous titania layer.

3:25 **Determination of Minimum Inhibitory Concentrations Using Thermal Ink-Jet Printing (Interactive),** *Cornelius C. Dodoo, Mustafa Alomari, Paul Stapleton, and Simon Gaisford, University College of London (UK)* 204

Ink-jet printing is a cost-effective technology that has had varied applications recently. The technology was applied here to an important microbiological procedure, minimum inhibitory concentration (MIC) determination.

MIC evaluations were conducted by printing varying concentrations of the antibiotics, ampicillin or tetracycline, onto agar-coated glass slides then printing an even film of known bacterial density of Lactobacillus acidophilus onto the antibiotic-imprinted slide. Results obtained were validated with a broth microdilution technique. The MICs for ampicillin and tetracycline obtained were two-fold higher than those determined by the conventional technique.

Colleague Connections— Surface Manufacturing Roundtables and White Paper Input

Session Chair: Steve Simske, Hewlett-Packard Laboratories

3:30 – 5:50 PM

choose among four topic areas, see full details on page xvii, meet in Oregon Ballroom Salon G

3:50 — 4:30 PM Coffee Break during session — Oregon Ballroom Lobby

TUESDAY SEPTEMBER 29, 2015

SPECIAL EVENT

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

Session Chair:
David Stüwe, Notion Systems GmbH
Tuesday, 4:20 – 6:15m
Oregon Ballroom Salon E

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

DIGITAL PRINTING TECHNOLOGIES

9:00 – 10:00 AM Tuesday Keynote, Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon G

Inkjet-Based Processes con't

Session Chairs: Jim Przybyla, Hewlett-Packard Co.; Werner Zapka, XaarJet AB; Mineo Kaneko, Canon Inc., and Kye-Si Kwon, South Korea Soonchunhyang University
10:10 – 11:50 AM

10:10 **Emerging Hybrid Ink Technology: Challenges in Jetting and Print Process,** *Mark Bale, Joanna Mantle, Scott Whittaker, Sam Moncur, Andrew Balch, Derek Illsley and Shaun Herlihy, Sun Chemical Ltd. (UK), and Yair Kipman, Paul Best, and Kyle Pucci, ImageXpert Inc. (USA)* . . 209

With a focus on aqueous ink technology we describe the jetting and print testing of different ink formulations across selected inkjet print head platforms applicable to high speed printing industrial print applications. Specific challenges relating to the necessary compromise between head performance and application/substrate performance are discussed with respect to the observations made on newly developed hybrid inks. The available methods for optimizing the ink performance are contrasted and compared and future routes for improvement discussed.

10:30 **Droplet-on-Demand Printing of Polymer Solutions,** *J. Frits Dijksman, University of Twente, and Paul C. Duineveld, Philips Consumer Lifestyle Technology Expert Group (the Netherlands)* . . 214

Droplet-on-demand inkjet printing of polymer solutions offers the possibility to deposit in a patterned way very small amounts of polymer functional materials. One of the characteristics of jetting on demand polymer solutions is the existence of a long stretching fluid filament between the main droplet and the fluid contained in the nozzle. The forces generated in the stretching fluid filament may be so large that initially the droplet leaves the nozzle but is retracted in course of its flight. The very existence of the fluid filament is a sign of the viscoelastic nature of the ink used. By investigating carefully the kinematics and dynamics involved in the stretching of the fluid filament, the rheology of the ink can be retrieved, especially its elongational properties. The kinematics involves the stretching of the fluid filament, the growth of the droplet during flight and tail hooking. The dynamics involve the deceleration of the main droplet, viscous forces and surface tension.

Exhibit Hall Opens at 10:30 AM
10:50 – 11:30 AM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:30 **Printed p-type CuI TFTs,** *Chang-Ho Choi, Zhen Fang, Jenna Gorecki, Marshall Allen, and Chih-hung Chang, Oregon State University (USA), and Liang-Yu Lin and Chun-Cheng Cheng, AU Optronics Corporation (Taiwan)* 219

Printing technique offers several advantages in manufacturing electronics such as a direct writing of materials, reduction of chemical waste, and reproducibility with high-resolution scale, which are not affordable from other solution-based approaches. Especially for the TFTs fabrication, printing can significantly simplify manufacturing processes by directly defining the channel area, the gate, and the source and drain contacts, allowing for much low costs and high throughput manufacture of TFTs. Most of the printed TFTs have been mainly associated with p-type organic semiconductors and n-type metal oxide semiconductors. In this paper, printed p-type CuI semiconductors are demonstrated for the application of TFTs.

Toner-Based Processes

Session Chairs: Jim Mrvos, Lexmark International Inc.; Herman Van de Straete, Xeikon Manufacturing n.v.; and Yoshihiro Hattori, Konica Minolta

11:50 AM – 4:20 PM

Session sponsored by

RICOH

11:50 **Technology for Electrostatic Separation of Charged Toner Particles with Different Sign by Utilizing Electrostatic Traveling Wave,** *Yasuhiro Maruyama, Brother Industries, Ltd. (Japan)* . . 221

The author has studied toner transport utilizing electrostatic traveling wave with high-speed photography, measurements of toner charge distributions, and numerical simulations. In this study, the author has concentrated on the toner cloud above the main transport stream. The mechanism of the toner cloud formation has been identified, and a method to separate the correct sign toner from the wrong sign toner particles utilizing the mechanism has been developed. For the fewer toner particles and a lower speed toner transport, we used high-speed photography to observe an arch-shaped toner cloud above the transport. Using a simplified model, we have found that such an arch-shaped toner cloud is formed by the effect of air-drag. On the other hand, in the development system conditions such as a higher toner concentration and a faster speed toner transport, the arch-like cloud becomes dense because of the effect of the electrostatic attraction force. The author has proposed that the cloud comprises the same number of toner particles of both signs, and has designed toner separation and re-charging system using vertical toner transporting.

12:10 **Development of Dual Heater Technology for On-Demand Fixing System,** *Hiroki Eguchi, Masatake Usui, Akira Kato, Atsushi Iwasaki, and Hiroaki Sakai, Canon Inc. (Japan)* 225

Canon has developed a dual heater technology for controlling the temperature rise at non-paper regions for the on-demand fixing (ODF) system and has applied the technology to numerous laser-beam printer models. For the fuser heater, this technology uses a dual heater with two types of heating elements that differ in their lengthwise heat distribution. Further, the power applied to each of the two types of heating elements is varied according to the width of the paper to be printed on in order to control the heater's lengthwise heat distribution and thereby suppress the temperature rise at non-paper regions. In this study, the effect of the dual heater technology in suppressing the temperature rise at non-paper regions was estimated through comparison with the conventional ODF heater by using three dimensional heat transfer simulation. The temperature rise at non-paper regions in a prototype dual heater was found to be a close match to the estimation obtained through simulation, showing that the prototype operated as expected.

12:30 **Functionality Evaluation of Airflow Systems for Scattered Toner Dust in a Copy Machine,** *Kazuya Tamura, Masafumi Kudo, Yasunori Momomura, Minoru Kasama, and Koji Udagawa, Fuji Xerox Co., Ltd. (Japan)* 229

Scattered toner dust is a well-known problem in copying and printing machines using the electro photographic development process. The collection of toner dust by forming airflow in order to capture the dust with filters placed at fans was investigated. Specifically, system selections of airflow, which can effectively collect toner dust, were analyzed. In recent research, a conflict was found where forming airflow for collecting toner dust would generate more scattered toner dust. In other words, to avoid problems of such dirt in copy machines caused by toner dust, it is necessary to solve this conflict simultaneously. Therefore, a method for evaluating functionality of an airflow system was proposed. This method can evaluate the collection and restraint of toner dust with one index. By using this method, two airflow systems that have completely different concepts for collecting and suppressing toner scatter were evaluated. As a result, it was found that an airflow system with the concept of forming airflow clearly around developing units is better for collecting toner dust. Furthermore, it was clarified that this result is based on a mechanism of sedimentation adhesion of scattered toner by an influence of gravity.

12:50 – 2:30 PM Lunch Break

2:30 – 3:30 PM State-of-the-Art Invited Talk: 3D Printing and drupa® 2016 Preview
Oregon Ballroom Salon F, see details page x.

3:40 **Gloss Prediction Model for Electro-Photographic Printing based on Image Structures Related to the Physical Phenomena in the Image Forming Processes,** *Kenichi Hamada, Minoru Ohshima, Toru Ogawa, Nobuyuki Nakayama, and Yoshihisa Kitano, Fuji Xerox Co., Ltd. (Japan)* . . . 233

In developing copiers and printers, it is necessary to design the image gloss according to customers' preferences. In electro-photographic printers, the image gloss depends on the system parameters, such as parameter sets for fusing (pressure, temperature, and dwell time), viscoelastic property of toners, and surface properties of paper. Therefore, it is necessary to develop system models that indicate relations between the image gloss and system parameters.

In this paper, we describe the development of an image gloss prediction model based on image structures that are related to the physical phenomena in the system. We have extracted two characteristic image structures from the analysis of image samples printed by various system parameters. A "micro hollow at the toner boundary" is a boundary dimple among a few toner particles, and a "macro hollow" is a pit composed of a group of toner particles. The "micro hollow at the toner boundary" is formed by a melting phenomenon of the toner particle in the fusing process, and the "macro hollow" is affected by the arrangement of the toner particles in the pre-fusing process. Furthermore, we succeeded in constructing a model that predicts the image gloss based on the sum of the area ratios (occupancy ratio in the surface area) of the two image structures.

4:00 **Fusing Study of Silica-Polymer Composite Particles for Toners,** *Li Cheng, Jie Wang, Hairuo Tu, Dmitry Fomitchev, and Hajime Kambara, Cabot Corporation (USA)* 238

Toner fusing is a critical step which determines both the quality of printed image and the amount of energy consumed by a laser printer. Therefore, manufacturers of laser printers and toners constantly work on improving fuser units and designing new toner formulations. It turns out that the external additives, which are primarily used to improve toner electrostatic charging, flowability, and durability, also affect toner fusing. For instance, when used at relatively high loading treated silica affects toner melt flow behavior by increasing viscosity of melted toner. If viscosity of melted toner is high this results in inefficient flow of toner and poor fusing. Some toner manufacturers have begun using new external additives which enable fusability at low fusing temperatures.

Silica composite particles—a new class of materials that was developed by Cabot Corp. for application in laser printer toners. At the NIP29, we discussed how this material is synthesized and how it improves toner durability. In this paper we demonstrate that the model toner formulations containing silica composite additives have better fusability than the formulations containing colloidal silica.

4:20 – 6:15 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour
Oregon Ballroom Salon E

MATERIALS, METHODS, AND PERFORMANCE

9:00 – 10:00 AM Tuesday Keynote, Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon A

Print Systems Optimization

Session Chairs: Jeff Hintzman, Hewlett-Packard Co., and Teruaki Mitsuya, Ricoh Co., Ltd.
10:10 AM – 12:50 PM

10:10 **HP Large Format PageWide Array Printer Servicing Hardware,** *Rafael Ulacia, Hewlett-Packard Co. (Spain)* 242

Unlike traditional Large Format Printers, with a scanning printing carriage that stops in a Service Station for Printhead Servicing, the new HP Large Format PageWide Array Printer has numerous Mechanisms that move to the Printheads to perform Maintenance tasks: These are the Fast Spittoon, Service Carriage, Blow Primer and Capping Station.

The Spittoon permits simultaneous spitting of all Nozzles inside a reservoir that has the capability to extract waste ink into an offline container. This reservoir, the spit during massive spit operations a lot of aerosol is generated inside the spittoon but it is also controlled and collected to prevent it from travelling into sensitive printer elements.

The printer has a Servicing Carriage that moves along the Printbar axis , where the Printheads are placed, that features a User Consumable Cloth Cleaning mechanism (aka Wiper) capable of performing 500 wipe full span operations before replacement.

It also houses a Drop Detector to measure nozzle health along the Printbar that closes the loop and permits a customized servicing strategy. Finally, it has an Optical Sensor focusing the Printzone with which Alignment and color consistency calibrations are performed. This sensor allows us to calibrate media advance parameters and others like side edges, top and bottom of form.

In the event of severe issues like air ingestion, pigment settling or clogging a Blow Primer that is built in the each of the Printheads latching mecahnism can flush large amounts of ink out the nozzles at a pressure as high as that provided by the Ink Delivery System. Each Printhead is primed individually.

Last of all, the printer has a Printhead storage device called Capping System that provides maintenance of the moisture levels in the nozzles to ensure readiness to print and long term Nozzle health and protection.

10:30 **Separation of Granularity into Uniformity Deterioration Factors for Electrophotographic Images,** *Yumiko Kishi and Makoto Hino, Ricoh Company, Ltd. (Japan)* 246

It is important to not only evaluate granularity but also clarify the factors affecting it in order to improve the graininess of an image. A method for separating graininess into elements on the basis of the fluctuation of the background, lightness, and toner adherent area is proposed. By using this method following estimations will be enabled; 1. By obtaining the relation between the ordinary graininess and elements, the effect of each elements to the image quality can be estimated. This makes it possible to categorize printer. 2. Measuring by means of a polarizing plate, an effect of gloss ununiformity to the image quality can be detected. 3. By defining the standard contrast for a monochrome image, even though the dot density differs, the area fluctuation factor of graininess can be compared.

Exhibit Hall Opens at 10:30 AM

10:50 – 11:20 AM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:20 **Newly Developed UV-Curable Inkjet Technology for Digital Inkjet Press KM-1 (Focal),** *Toshiyuki Takabayashi, Hirotaka Iijima, Katsunori Goi, Mitsuru Obata, Toshiyuki Mizutani, Hideo Watanabe, and Tadashi Hirano, Konica Minolta, Inc. (Japan)* 251

We have developed a new and unique UV-curable inkjet technology for a sheet-fed off-set like inkjet printer "KM-1", which will bring a new wave of digitalization into the commercial printing world. There were many technical challenges to realize both high-speed and high-quality recording process in a system. We studied the imaging process thoroughly and reached a new and unique UV-curable ink formulation and a process that can cure images at extremely high speed with extremely high definition. To support the ink and the process, we also developed a variety of technologies such as a new durable print head with high nozzle density, an image correction system, and so on. Combined these new technologies, as a synergy of inks, print heads, and system, we have succeeded to develop a new inkjet printing system for digital press market.

11:50 **Intelligent Image Rendition,** *Chunghui Kuo and Horia Neamtu, Eastman Kodak Company (USA)* 256

The traditional image rendition process assumes an ideal output imaging system where each image pixel will be perfectly reproduced regardless of different image formation processes. In reality, each individual imaging system can be approximated as a linear system with its own unique transfer function characteristics, which could exhibit spatial and/or temporal variations. Consequently, it will produce inconsistent tone scale reproduction curves during the print production run. The objective of this paper is to investigate the tone reproduction curve variations caused primarily by the interaction of neighboring imaging pixels. An intelligent image rendition algorithm is presented to compensate for this macroscopic imaging process deficiency. Experimental results will be demonstrated to show the effectiveness of the proposed algorithm, which has been deployed commercially on a digital printing press.

12:10 **Embedded Differential Access Control for Printing Variable Jobs,** *Helen Balinsky and Nassir Mohammad, Hewlett-Packard Labs (UK)* 260

Business case requirements have resulted in related documents that are native to their individual formats being combined into a collection called composite documents. These are used for a variety of activities such as presentations, premium/sensitive content distributions and business workflows, and may include standard types such as PDF, Word, Excel, PowerPoint Slides and other specially formatted files. Additionally, cross-organizational workflow demands have created new challenges for the management of such composite documents. These include access control to individual parts, security and privacy issues in the absence of shared trusted infrastructure, communication over popular and potentially insecure channels, auditing, print control and

disposal. These challenges led to the development of Publicly Posted Composite Documents (PPCDs) as a recently proposed document format that enables the secure containment and transfer of personalized document versions over insecure channels, with the access control and policies built into and carried within the document itself (as an integral part). PPCD technology is intended to act as the central pillar of document workflow scenarios, where a single document can be created, controlled, accessed, used and monitored throughout its life cycle as it participates in inter-organizational workflows. However, PPCD technology is currently missing an important property of electronic documents: the ability to be securely printed to a physical copy. The limited resources on multi-function printer (MFP) devices and the security focused structure of PPCDs makes this a challenging and non-trivial problem. Thus, in this paper we utilize the unique structure of PPCDs to describe novel mechanisms and firmware extensions on MFPs for enforcing differential access control and printing.

12:30 **Noise-Reduction Technology for Density Unevenness in Electrophotographic Process,** *Satoshi Kaneko, Shuji Hirai, Shinji Kato, Terumichi Ochi, Shinichi Akatsu, Takeshi Shintani, and Yasuhiro Maehata, Ricoh Company, Ltd. (Japan)* 268

This paper introduces a noise-reduction technology for density unevenness caused by resistance unevenness of the charge roller in the electrophotographic (EP) process.

Generally, active noise control (ANC) is known to reduce noise in real time. With this technology, the control signal is applied to the noise source in the same physical quantity and antiphase signal of the noise source. To reduce density unevenness by applying this technology for the EP process, it is necessary to move the rotators, such as photoconductors and development rollers, to cancel the fluctuation in the developing gap; however, the moments of inertia of the rotators are too large to respond sufficiently. Against such a situation, we previously developed a control method based on ANC to reduce noise (image density unevenness) in the EP process by applying the control input of different physical quantities from the noise source. With this method, the developing electric field is controlled using the modulation of the developing bias voltage and charging bias voltage instead of making an adjustment in the distance of the developing gap.

In this study, we applied our previous method to the periodic fluctuation in the charging process and developed a noise-reduction method that reduces the periodic image density unevenness caused by the resistance unevenness of the charge roller. With this proposed technology, the surface voltage on the photoconductor is measured by surface voltage sensor without forming toner patterns, the control table is calculated from the detected uneven surface voltage, and the periodic fluctuation is reduced by modulation of the charging bias voltage in real time based on the rotation of the charge roller. The experiments we conducted confirmed that our proposed method improves periodic density uniformity caused by the resistance unevenness of the charge roller effectively.

12:50 – 2:30 PM Lunch Break

2:30 – 3:30 PM State-of-the-Art Invited Talk: 3D Printing and drupa® 2016 Preview
Oregon Ballroom Salon F, see details page x.

Hybrid Technologies

Session Chairs: Greg Herman, Oregon State University, and Oh Hyun Baek, Samsung Electronics, Inc.

3:40 – 4:20 PM

3:40 **Relationship between Thermal Conduction Process and Transient Temperature Response of Printing Papers in DTP Process,** *Takashi Fukue[1], Hirotoshi Terao[2], Koichi Hirose[1], Tomoko Wauke[2], and Hisashi Hoshino[2]; [1]Iwate University and [2]ALPS Electric Co., Ltd. (Japan)* 273

This study describes effects of a thickness of printing papers and a thermal conduction from the printing paper to a platen roller on a temperature transient response of the printing papers through 3 dimensional thermal conduction analysis. Especially, a level of the effects of these factors on the transient temperature response was evaluated. A 3-dimentional analytical model which was composed of the paper and a dot heater was prepared and a transient thermal conduction analysis was performed while changing the condition of heat leak from the paper surface opposite to the thermal head to the platen roller. In order to evaluate the transient temperature response of the paper, temperature rise at the heating point of the test paper after 1 second from the start of the heating was calculated. It is found that that the thickness of the paper and the level of the conduction to the platen roller affect the temperature response of the paper separately. In addition, the change of the thickness and the condition of the conduction also affects the level of the effects of the thermal diffusivity on the temperature response.

4:00 **Soluble Graphene and Printing,** *Khe C. Nguyen, HK IPT Lab (Vietnam)* 277
We are developing graphene derivatives by physical functionalization. The products are believed to be composed of graphene core surrounded by functional groups which are helping out the solubility of material in certain kind of solvents. These functional groups are cleavage under high heat and or irradiation to render pure graphene. The differentiated physical properties of the graphene precursor under energy sources could be used for printing technologies.

4:20 – 6:15 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour
Oregon Ballroom Salon E

DIGITAL FABRICATION AND 3D PRINTING

9:00 – 10:00 AM Tuesday Keynote, Oregon Ballroom Salon F, see details page ix.

Oregon Ballroom Salon F

3D Printing and Additive Manufacturing

Session Chairs: Trevor Snyder, 3D Systems; Martin Baumers and Richard Hague, University of Nottingham; and Shinri Sakai, University of Tokyo
10:10 AM – 4:00 PM

10:10 **Through a Glass Clearly: The Challenge of Glass 3D-Printing,** *Michael P. Avery[1,2], Susanne Klein[3], Robert Richardson[2], Paul Bartlett[2], and Steven Simske[4]; [1]Bristol Centre for Functional Nanomaterials (UK), [2]University of Bristol (UK), [3]Hewlett-Packard Labs (UK), and [4]Hewlett-Packard Labs (USA)* 280
With the recent rapid development and interest in 3D-printing, the technology is greatly improving, however, challenges such as expanding the material palette available and producing prints with controllable and reproducible properties still remain. For glass 3D-printing, optical properties are key to a print's usefulness and success. Herein we provide a brief overview to direct and indirect methods for glass 3D-printing, describe how printing paste composition influences the opacity of the resulting print and report our efforts to use X-ray micro CT and thermogravimetric analysis to better understand how changes in paste composition lead to the changes in microstructure that are believed to control the bulk glass properties.

10:30 **Voxel-based 3D Processing for 3D Printing,** *Atsushi Masumori, Keio University SFC (Japan)* 285
In this paper we discuss about an efficiency of voxel model data in 3D printing system. Particularly, we propose a voxel-based data structure that is called "FAV" (Fabable Voxel) file format, where information about connection between each voxel can be stored, for designing, analyzing and fabricating 3D object seamlessly. This kind of data structure based on networked voxel model has significant advantages: storing network information for fabrication or simulation. We propose some methods for generating tool path from voxel model data directly and show that dynamic simulation with this networked voxel model has more accuracy than non-networked voxel model.

Exhibit Hall Opens at 10:30 AM
10:50 – 11:20 AM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:20 **Food Printing Technologies out of White Rice (Focal),** *Hiroya Tanaka, Yoshihito Asano, Moeka Watanabe, and Atsushi Masumori, Keio University Shonan Fujisawa Campus (Japan)* 289
One of killer applications for 3-D Printing 'at home' may be food printing. In Japan and Asian countries, white rice contains suitable properties to be used as the best deposited materials.

In this paper, we describe our trials to use white rice by combining with our original desktop 3D Printer and our original CAE software, and show context-based food applications.

11:50 **Single-Build Additive Manufacturing of Autonomous Machines,** *Trevor Snyder, 3D Systems; Johnathan Mick, Oregon State University; Mark Weislogel, Martin Beyl, Adam Buchholz, Emilio Molina, Daniel Norris, Kyle Viestenz, and Jon Vu, Portland State University (USA)* 293

There are numerous 3D printing methods—each with unique attributes and limitations. There are likewise numerous end-use applications for each method. One such application discussed herein is the ability to manufacture complete and functional additive manufacturing autonomous machines. These machines are made in a single-build with no post-build assembly or added mass. These devices can store and expend internal energy to perform useful functions. While presently only mechanical in design, future materials and machine capabilities will enable the creation of highly complex single-build electromechanical devices. This paper defines a specific type of single-build autonomous machine termed Addimata and describes key components of such devices. A selection of demonstrated designs are presented and described that utilize commonly available 3D printing processes and materials.

12:10 **Micro-3D Inkjet Printing,** *Jie Wang, Yong Zhou, Xiongwei Shi, Qibin Bao, Sen Yang, Yong Zhang, Xiaofei Luo, and Yingcai Xie, Advanced 3D Printing Technology (ZH) Co., Ltd. (China)* 299

Based on 2D digital fast and precision inkjet wide-format printing technology and page wide print head technology, we have developed a novel micro 3D stereo digital printing or 3D object accurate and fast production. By using UV curable inkjet technology or IR curable inkjet technology, we can easily and fast solidify the true colorful 3D objects and bring 2D digital technology up to 3D digital printing level. Two types of 3D printers will be addressed to show micro-3D inkjet technology including their various applications on textile, fashion, ceramics, leather, plastics, glass, packaging, personal decorations, detailed stereo sculpture, dental, spine, biotech application, etc.

12:30 **Speed and Accuracy of High Speed Sintering,** *Adam Ellis, Antonis Hadjiforados, and Neil Hopkinson, The University of Sheffield (UK), and Ingo Reinhold, XaarJet AB (Sweden)* . 303

High Speed Sintering is a novel powder based additive manufacturing process that retains the major benefits of Laser Sintering but eliminates some major drawbacks. The process uses inkjet print head and infrared lamps to fabricate parts layer by layer using polymer powder.

The purpose of this research was to evaluate the speed and accuracy of High Speed Sintering by closely following a method published in the research paper of Rapid Prototyping Journal, entitled 'Speed and Accuracy Evaluation of Additive Manufacturing Machines'. This methodology involves the manufacturing of test parts defined in the paper analysis using the method provided, speed and accuracy of High Speed Sintering is assessed and then benchmarked against four other Additive Manufacturing processes.

Based on a theoretical speed evaluation, results show that High Speed Sintering is able to achieved superior average manufacturing speed than the other specified Additive Manufacturing technologies.

12:50 **3D Printing Magnetic Material with Arbitrary Anisotropy (Interactive),** *Garrett Clay[1], Han Song[1], Jeffrey Nielsen[2], James Stasiak[2], Mehrgan Khavari[2], Albrecht Jander[1], and Pallavi Dhagat[1]; [1]Oregon State University and [2]Hewlett-Packard Co. (USA)* 307

A process for 3D printing of magnetic materials with programmatically controlled anisotropy is presented. Using an experimental thermal inkjet printer magnetic structures with and without anisotropy are printed and characterized to demonstrate the unique advantage afforded by inkjet printing—that of arbitrarily controlling the anisotropy orientation within the structure during printing. The technique will make possible 3D printed inductor and transformer cores with low losses, antenna loading materials and graded index lenses for processing microwave signals, and magnetic field sensors to name a few applications. In the inkjet printing technique presented here, a magnetic ink composed of magnetic nanoparticles in a UV curable resin is jetted on the substrate. The nanoparticles are then aligned in a magnetic field generated using a two-axis electromagnet and the ink cured to obtain a composite with the desired magnetic anisotropy. The process is repeated to fabricate a 3D structure of the desired shape and dimensions.

12:55 – 2:30 PM Lunch Break

2:30 – 3:30 PM State-of-the-Art Invited Talk: 3D Printing and drupa® 2016 Preview
Oregon Ballroom Salon F, see details page x.

This paper constructs a combined build time, process energy consumption and cost estimator for an Additive Manufacturing platform of the material jetting type (Stratasys Objet Connex 260). Unlike previous estimation approaches, this paper develops a model of build time that reflects the movement of a print head depositing material in the build process. In a series of validation experiments, this approach produced accurate build time estimates in the majority of cases. The observed absolute errors range from 4.00% to 39.18% for build time estimation and from 2.58% to 48.28% for process energy consumption, exhibiting an overall mean absolute error of 15.31%. The proposed build time estimator is compared to two more general specifications, one treating deposition time per layer as fixed and one relating total build time to deposition area per layer. It is shown that both alternative specifications produce greater estimation errors.

4:20 – 6:15 PM Interactive Papers, Demonstration Session, Print Gallery, and Exhibit Hall Happy Hour

Oregon Ballroom Salon E

WEDNESDAY SEPTEMBER 30, 2015

SPECIAL EVENT

CONFERENCE RECEPTION

Wednesday, 7:00 – 9:30 pm

Portland Art Museum –
Mark Building
1219 SW Park Ave

Join colleagues for an enjoyable evening at Portland's Art Museum.

DIGITAL PRINTING TECHNOLOGIES

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Oregon Ballroom Salon F, see details page x.

Oregon Ballroom Salon F

Pagewide Printing

Session Chairs: Jim Przybyla, Hewlett-Packard Co.; Mark Crankshaw, Xaar plc; and Nobuyuki Nakayama, Fuji Xerox Co., Ltd.

10:20 AM – 2:50 PM

10:20 **HP Pagewide System Printhead Architecture for a Compact Printer (Focal),** *Rafael Ulacia, Hewlett-Packard Co. (Spain)* 317

When designing a pagewide thermal ink jet printing system you can use one of three different engine architectures. The first is "design for width" where individual silicon die are assembled into a monolithic printbar which is wide enough to print on the media size you are targeting. HP's OfficeJet Pro x uses this approach, and it provides the smallest and least expensive path, but it gives you no direct flexibility in print width.

The second architecture stacks monolithic printbars into a wide array like you would stack bricks to make a wall. While this provides media width flexibility, it creates a much wider print zone where you must keep the media flat, and a bigger zone where you must maintain absolute position and velocity control. Even then there will be artifacts created between the staggered printbars caused by differential drying time. And of course the printer itself becomes larger. But this system can allow you to bring large products to market quickly, and HP has done this with its family of ink jet based web presses.

The third method involves designing a nestable module, several of which can then be assembled into printbars of various lengths, from an office printer size machine up to the 40 inch print swath recently introduced on the HP pagewide product. This approach combines the low cost of architecture 1 with the flexibility of architecture 2. And since each module is individually replaceable it is more convenient for the customer as well. This paper focusses on some of the benefits and challenges of the nestable design.

Exhibit Hall Opens at 10:30 AM

10:50 AM – 11:30 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:30 **High Definition Nozzle Architecture Inkjet Printhead for Commercial/Industrial Markets (Focal),** *Jim Przybyla, Chris Bakker, Eric Martin, and James Gardner, Hewlett-Packard Co. (USA)* 320

Over 100 million silicon die have been built into HP Thermal Inkjet printheads and shipped to customers in the HP Scalable Printing Technology (HP SPT) platform since 2005. All these HP SPT printheads have a common attribute: the nozzle density and underlying power transistors are at 1200 nozzles per slot inch (NPSI). By re-engineering firing FET topology, simplifying nozzle logic and other circuit improvements, a new silicon platform has been developed that doubles the density of the underlying power transistors, resulting in 2400 NPSI on HP SPT in the new High Definition Nozzle Architecture (HDNA) platform. To address the increased demand for print data, the data rate between the print system and printhead silicon has been improved by a factor of three. The new printhead, the HP A53 Printhead, is form-factor compatible with the existing HP A51 Printhead and existing HP Inkjet Web Presses can be field-upgraded to use it. Its versatile nozzle configuration allows it to be reconfigured to exactly suit each application.

12:00 **Printer Calibrations for HP Large Format Page Wide Technology,** *Martí Rius, Marc Casaldàliga, Xavier Fariña Vargas, Xavier Quintero, and Romà Segura, Hewlett-Packard Española (Spain)* . . 326

We present the main printer calibration procedures for HP Page Wide XL 4/8000 page wide array (PWA) printer. They ensure consistent, uniform printouts by calibrating print elements to each other, both for relative positioning and relative colorimetric densities. Requirements for (PWA printers are much stricter than for scanning printers, and for that, new solutions have been devised.

Furthermore, in large format PWA printers there are more restrictions for the carriage subsystem that

include the calibration sensors, so that the trajectory of sensors relative to the calibration patterns is less accurate than in scanning printers. We present the new print-head alignment strategy and detailed patterns innovations to overcome the challenges in scanning trajectory and at the same time meeting the precision requirements. Innovations comprise the use of new position based patterns, to obtain a fast and wide error range "coarse grained" measurement, in combination with high precision interferential patterns that refine the final measurements.

Colorimetric calibration includes novelties such as using floating references to make sure almost all available media can be calibrated, in opposition to past calibrations that used references defined in absolute domains. Furthermore, it incorporates means for reusing a calibration run on a given paper to the rest of paper types loaded in the printer. All of that ensures maximum color deltas between adjacent print elements in the order of 0.5dL*, with percentile 95 in the order of 0.2dL* (data obtained in selected paper types).

The solutions for the problems derived from the incompleteness of calibrations when the media used does not cover the full printing region are also presented. To enable a satisfactory user experience in a variety of media usage scenarios in a multi-roll printer a number of innovations have been introduced, ranging from the use of print-head module manufacturing data to the optimal selection of the media roll to calibrate when different media qualities and widths rolls are loaded in the printer.

The presentation covers the basic concepts of print-head positioning and colorimetric calibrations, and then reviews novel solutions adopted in HP page wide array technical printers.

12:20 **Designing a Long-Life, Page-Wide Print-Head,** *Stephen Conner, Lisa Underwood, Minal Shah, Thom Sabo, Clayton Holstun, Brian Canfield, and Curt Voss, Hewlett-Packard Co. (USA)* . . . 332

This paper discusses three key concepts we used to develop a pagewide printhead designed for a long service life. First we analyzed the product goals as well as past products' strengths and weaknesses. This resulted in a product reliability specifications and an initial identification of which areas needed reliability improvements.

Then we introduce the concept of Discovery Testing. This technique stresses the system, subsystems and components to higher levels of stress than what would be experienced in a typical customer environment. This allows for rapid discovery of design weakness with fewer parts and in less time.

Finally, following the Discovery Testing phase, a classic build-test-fix cycle was followed. Weaknesses identified in the Analyze and Discover phases are eliminated or improved through design or assembly changes.

To help make this process more tangible, the paper deals with four case studies of actual problems we discovered and took to resolution.

12:40 **HP Inkjet Large Format Page Wide Array: Solution for Drop Detection and Nozzle Replacement (Focal),** *Jose Luis Valero and Laura Portela, Hewlett-Packard Co. (Spain)* 336

The new HP Inkjet Page Wide Array technology delivers breakthrough speed via an array of inkjet nozzles covering the entire paper width. Printing is done in a single pass, which makes nozzle health critical to meet product image quality and reliability requirements. A nozzle or groups of nozzles failing to eject drops create visible straight white lines on the printouts. The nozzle array contains a total of more than 200,000 nozzles.

There is a challenge compared to current large format inkjet printing systems. First, single pass is much more sensitive to failing nozzles than multi-pass. Secondly, the number of nozzles and the productivity requirements are an order of magnitude higher. Existing solutions for nozzle health measure and compensation are no longer valid.

The paper describes a new solution (hardware and algorithms) developed to measure and compensate for those nozzles that may temporarily or permanently fail to eject drops. The solution developed highly reduces time to measure, it allows checking 200K nozzles in 90 sec. It is easily scalable to different types of print heads and array sizes, it can even also work in scanning systems. Nozzles are analyzed regularly and printer classifies them based on historic measures. Compensation algorithms include nozzle substitution using adjacent nozzles or nozzles of a different color that are in line in paper axis direction. Specific cleaning routines can be self-triggered to guarantee proper printout quality. Customer is informed about the status of the quality of print heads.

1:10 – 2:30 PM Lunch Break

2:30 **One-Pass Printing Challenges in Large Format Printers,** *Isabel Borrell Bayona and Xavier Fariña Vargas, Hewlett-Packard Co. (Spain)* 342

In the search of breakthrough productivity, HP has developed a new print technology capable of printing an image in a single continuous paper movement. This is possible thanks to an array of nozzles covering the full paper width. However, the big challenge of this technology is the print quality. Scanning Printer technology has been in use for long enough that most of its inherent problems have been understood and solved. PageWide technology is relatively new and there are a lot of printing challenges to solve. This paper will cover

the aspects affecting print quality in one pass printing such as the impact of distance between modules, printhead to paper spacing and media drive, with focus on the position of the drop on the media. These critical parameters have been modeled and used to predict the position error of any single drop on the paper.

Intellectual Property Presentation and Discussion

Session Chairs: Steve Simske, Hewlett-Packard Co, and Norio Nagayama, Ricoh Co., Ltd.

2:50 – 3:50 PM

2:50 **Patenting Inventions Related to Non-Impact Printing in Light of the Recent U.S. Supreme Court Case: ALICE CORP. v. CLS BANK,** *Scott M. Slomowitz, Gary A. Greene, and Nicholas M. Tinari, Jr., Caesar Rivise, PC (USA)* 347

Patent law is a vital aspect of research and development in all areas of technology. The field of non-impact printing is no exception. In 2014, the U.S. Supreme Court dramatically changed the landscape of what is considered patentable subject matter, with broad-ranging effect on technologies that rely on software and mathematical algorithms. The ruling, in a case titled Alice Corp.v. CLS Bank, prevents inventors from obtaining patents on what the court termed "abstract ideas" and went even further by stating that the use of a generic computer to implement an "abstract idea" is also not patentable . While practitioners in high tech fields may not consider algorithms they create to be "abstract," the Alice case and its interpretation by the U.S. Patent and Trademark Office ("PTO") place potential roadblocks to patentability that require careful navigation based on the most recent case law decided in relevant lower federal courts across the country. For example, one court in New Hampshire rejected a CAD/CAM patent for mapping a ventilation system into digital form and processing the imported data into 3D drawings using standard parts. The rationale was that this was an "abstract" process that could be performed manually and that the use of a computer did not make the process patentable. Across the country, a California court upheld a Caltech patent on an error correction code algorithm. That court took issue with Alice in that it provided no clear dividing line between the patentable and the unpatentable: "Although software is patentable generally, neither Alice nor any other Supreme Court precedent defines when software is patentable . . . This has proved detrimental to the patent system." Ultimately, the Cal Tech court found the error correction algorithm patentable because it "provided a specific computing solution for a computing problem." The uncertainty that the Alice ruling has created for high-tech fields can be unnerving for engineering professionals who are trained to rely on physical rules that are unwavering regardless of the geographic state where they are applied. This paper aims to unravel some of the uncertainty by surveying relevant post-Alice court decisions and identifying common themes to help guide inventors whose products involve software-implemented algorithms. The paper concludes with a set of basic guidelines for patent claims in high tech fields based on the most recent law and on cases involving products related to non-impact printing.

3:10 **Open Discussion on Alice Corp. V. Cls Bank, 134 S.Ct. 2347 (2014)**

3:50 – 4:30 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

Novel Print Technologies and Extensions

Session Chairs: James Stasiak, Hewlett-Packard Co.; Ingo Reinhold, XaarJet AB; and Makoto Omodani, Tokai University

4:30 – 5:50 PM

4:30 **Changing Demand—Evaluating Effects Using Simulation as a Service,** *Sunil Kothari, Thomas Peck, Jun Zeng, Francisco Oblea, and Gary Dispoto, Hewlett-Packard Labs (USA)* . . . 353

Many industrial and commercial print service providers (PSPs) are dealing with fragmentation of high copy count, low-mix demands to low copy count, high-mix demands due to mass customization and personalization of content. To understand the true dynamics of a changing demand, a stochastic discrete event simulator such as Ptolemy, from UC Berkeley, could be a very useful tool. However, simulation usage presents a high technology and knowledge barrier to solution architects. Additionally, IT requirements such as periodic upgrade and update of software and hardware infrastructure further imperils the use of simulation for solution architects. With the advent of cloud technology and service broker architecture, both problems can be solved effectively. Solution architects can now quantify effects of these changes using simulation-as-a-service (SimaaS) without worrying about simulation and the hardware and software updates.

COLLEAGUE CONNECTIONS—SECURITY PRINTING: IDENTIFYING THE OPPORTUNITIES

Wednesday, 4:30 – 5:50 PM
Moderator: Alan Hodgson, Alan Hodgson Consulting Ltd.

Identifying opportunities for the digital printing community in the area of security printing is the goal of this discussion. Using material presented in the Security Printing Session and short course as a springboard, participants will debate the implications for our industry. Without wishing to prejudge the discussion here are a number of topic areas that might be discussed.

- Printing engines: At present both toner and inkjet engines find application in security printing. Does solid toner have a future here? And where can inkjet add value?
- Substrates: Both paper and plastic substrates are widely used in this sector. What are the print and product opportunities here? There is market demand for secure colour print onto polycarbonate substrates. How can this be achieved?
- Printable Fluids: The physical and chemical characteristics of common inkjet inks and toners have significant weaknesses. How can we address these? Where are the opportunities? And, where are the digital fabrication opportunities in this space?

4:50 **Silver Electrodeposition based Multicolor Electrochromic Device Showing CMY Three Primary Color States (Focal),** *Norihisa Kobayashi, Kazuki Nakamura, Ryo Onodera, and Ayako Tsuboi, Chiba University (Japan)* 356

Novel multicolor electrochromic (EC) device with on electrochemical silver deposition mechanism was successfully demonstrated. The novel EC device enabled reversible color change between transparent, red and blue color in a single cell by using voltage step method which controlled the size of deposited Ag nanoparticles.

5:20 **Study of Improved Heating Head High Speed Heating and Efficient Usage (Focal),** *Hideo Taniguchi[1], Shigemasa Sunada[1], Jiro Oi[2], and Mark Tatsuya[1]; [1]HIT Devices Ltd. (Japan) and [2]HIT Devices Ltd. (USA)* 360

HIT Devices Ltd., developed the HDR-0670 heating head. The structural difference between this heating head and the existing products is basically the contact surface with the media is not the heat-generating side of the substrate. The media contacting surface is made of ceramic which has excellent anti-abrasion capability and it can be treated according to the application purposes for various media. Also, it utilizes the thermal energy efficiently by employing the structure which transfers the generated heat to the media effectively by observing the surface temperature drop at the time of media contact. It is possible to heat the necessary part of the media with the proper temperature for the determined amount of time easily by the combination between the heating head and temperature control circuit which monitors and measures the amount of heat transferred on real-time. The heat transfer between the heating head and media when the media moves at high rate was investigated. This report is the result of study of diverse and efficient usage methods including the improvement and kaizen of explicit or hidden problems by visualizing (mieruka) and analyzing the various thermal characteristics.

concurrent event
Security Printing: Identifying the Opportunities Roundtable Discussion
see full details above, Oregon Ballroom Salon A

7:00 – 9:30 PM Conference Reception
Portland Art Museum, Mark Building

MATERIALS, METHODS, AND PERFORMANCE

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Oregon Ballroom Salon F, see details page x.

Oregon Ballroom Salon A

Security Printing

Session Chairs: Jon Kellar, South Dakota School of Mines and Technology; Alan Hodgson, Alan Hodgson Consulting Ltd.; and Hiroshi Yamazaki, Imaging Society of Japan

10:20 AM – 3:50 PM

10:20 **Inkjet Printing for Secure Documents (Focal),** *Alan Hodgson, Alan Hodgson Consulting Ltd.; Matt Hensman, Sale; and David Westgate, National Document Fraud Unit (UK)* 365

This paper presents some of the specific challenges and opportunities for inkjet in the security printing sector. It follows on from a paper at this conference last year that examined the place of toner based printing. Both papers examine 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. In this paper particular emphasis will be given to the challenge inkjet faces in security paper printing as market requirements diverge from typical office based inkjet.

This work examines the wetting and penetration of inkjet ink on security printing substrates. Inkjet engines used in this market sector from a number of manufacturers and generations are discussed and results presented. The implications of practical variables such as print driver settings are also included.

Exhibit Hall Opens at 10:30 AM

10:50 AM – 11:30 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:30 **Countering Counterfeiting of Drugs: Unique Fluorescent Inks for Direct Printing onto Pharmaceuticals (Focal),** *Brian A. Logue[1], Jamie Kern[1], Shelby Altena[1], Jacob Petersen[2], Sierra Rassmusan[2], Robert P. Oda[1], and Jon J. Kellar[2]; [1]South Dakota State University and [2]South Dakota School of Mines and Technology (USA)* 371

Counterfeiting of pharmaceuticals is a growing and extremely concerning problem as supported by the increased prevalence, revenues (in the tens of billions), and sophistication of counterfeit medications. Current anti-counterfeit technologies for pharmaceuticals are generally easy for counterfeiters to imitate and typically rely on printing on packages, engraving or standard printing on pills, and pedigrees (only adopted by a few governmental organizations). Considering the dire impacts of counterfeit pharmaceuticals, including loss of life, an extra layer of difficult to replicate anti-counterfeit technology could alert medical personnel and consumers of potential counterfeit pharmaceuticals prior to consumption. In this contribution, two "non-toxic" fluorescent compounds (fluorescein and tryptophan) where formulated into inks for direct printing on medications. Fluorescein is a compound currently used in eye surgeries and tryptophan is a non-toxic amino acid. These inks were successfully printed on a number of medications and evaluated for authentication purposes. The success of these inks may ultimately lead to an easy way for medical personnel and consumers to identify counterfeit pharmaceuticals.

12:00 **Functional Summarization of Non-Text Data,** *Steven J. Simske, Marie Vans, and Margaret Sturgill, Hewlett-Packard Labs (USA)* 375

Summarization techniques can be applied to non-text data in order to perform classification and clustering of important imaging, video and other document-associated but non-text content. The advantage to this approach is that there is a multiplicity of inexpensive (even free) summarization engines, and so a robust solution can be crafted with relatively modest effort. In this paper, we present the applicability of this approach to video and imaging data, in addition to broader binary and genetic data.

12:20 **A Low-Cost Hyperspectral Scanner for Security Printing,** *Charles Santori[1], James Stasiak[2], Garry Hinch[2], and Raymond G. Beausoleil[1]; [1]Hewlett-Packard Labs and [2]Hewlett-Packard Co. (USA)* 380

We demonstrate a hand-held scanner that acquires two-dimensional images with up to 40 distinct wavelength channels. Light is collected through a combined slit and illumination assembly, dispersed by a diffraction grating film and analyzed using a webcam. Custom software is used to track the scanner motion and build the

hyperspectral image data in real time. We tested the performance on printed fluorescent ink patterns that are of interest for security printing applications, and obtained results that are consistent with spectra acquired using a laboratory-grade spectrofluorometer.

12:40 **Upconverting Nanoparticle Security Inks based on Hansen Solubility Parameters (Focal),** *Jacob Petersen[1], Jeevan Meruga[1], Aravind Baride[2], P. Stanley May[2], William Cross[1], and Jon Kellar[1]; [1]South Dakota School of Mines and Technology and [2]University of South Dakota (USA)* 383

Hansen solubility parameters (HSPs) provide quantitative insight into the surface chemistry of nanomaterials, enabling a unique approach to ink formulation. In this work, HSPs of upconverting NaYF4 nanoparticles were subjected to a broad spectrum solvent testing method, and a binary solvent gradient (BSG) method to elucidate their HSPs. The outcome of these experiments enables the selection of a number of potential solvents to meet printer and substrate requirements.

1:10 – 2:30 PM Lunch Break

2:30 **Additive Manufacturing of Optical Devices Using Inkjet Printing on Optical Nanostructures,** *Sheida Arabi, Hao Jiang, Haleh Shahbazbegian, Jasbir N. Patel, and Bozena Kaminska, Simon Fraser University (Canada)* 386

We present a novel additive strategy to manufacture nano-optical devices using inkjet printing on nanostructured surfaces. To print optically variable devices, silver ink is jetted on the surface of nanopillar arrays to selectively activate or deactivate the structural color pixels. We study the effects of surface chemical properties on inkjet printing and two different printing modes: bright silver mode on hydrophilic surface and dark silver mode on hydrophobic surface. The printed silver film activates the structural color pixels in bright silver mode while deactivates the pixels in dark silver mode. Color images are printed in 120 pixels per inch resolution using both modes. 27 different colors can be achieved from bright silver mode and more than 512 colors from dark silver mode. The color images printed with bright silver mode show high color contrast owing to the index matching process that deactivates unwanted pixels. Color images printed from dark silver mode exhibit brighter colors owing to the high grating efficiency but lower color saturation due to the difficulty in completely deactivating pixels.

2:50 **Porous-Wall Hollow Glass Microspheres for Security Printing Applications,** *Forest Thompson[1], George Wicks[2], and Grant Crawford[1]; [1]South Dakota School of Mines and Technology and [2]Applied Research Center (USA)* 391

Porous-wall hollow glass microspheres are a one-of-the-kind material with many potential uses in security technology. This work focuses on the development of security inks containing porous-wall hollow glass microspheres, whereby the microspheres serve as storage vessels for a variety of functional materials. This preliminary work comprises two feasibility studies. One study resulted in the successful aerosol jet deposition of hollow glass microspheres onto a substrate. The other study resulted in the loading of porous-wall hollow glass microspheres with gold nanoparticles. Both studies demonstrate the feasibility of developing and delivering a security ink utilizing porous-wall hollow glass microspheres that are loaded with functional materials. The results encourage the continuation of research to achieve this goal.

3:10 **Structural Color for Security Printing: Patterned Robust Colloidal Crystals,** *Takaharu Kobayashi, Research Institute of National Printing Bureau (Japan); and Mark Owens, William Cross, Jon Kellar, and Grant Crawford, South Dakota School of Mines and Technology (USA)* . . . 395

Structural color is a unique optical property of nano- or microstructured materials with periodic dimensions similar to the wavelength of visible light. Characteristic color is produced through reflectance, interference, scattering, diffraction or refraction of incident light of a specific wavelength in visible spectrum, thereby producing a specific color or so-called structural color. Structural color is seen throughout nature, notably Morpho butterflies and opals present a striking sheen and accompanying vivid hue. Prior analysis of minerals and organisms that produce these distinctive colors allows for continuing analysis of color developing mechanisms. Recently, with improvements in micro-fabrication, trial reproduction of these naturally occurring structural colors is proceeding across the field of Biomimetics.

Mono-dispersed micro-particles, structured in an ordered arrangement, are called colloidal crystals. Through Bragg reflection they exhibit structural color with a vivid hue. Colloidal crystals are relatively easy to produce by self-organization, and since dielectric periodic structures can be used as a photonic crystal for controlling electromagnetic waves, it has been extensively studied as a structural color element and photonic crystal. Some of the methods for manufacturing colloidal crystals include capillary method, electric electrophoresis, spin coating, spray coating, and substrate raising. The color developing mechanism for structural color

differs from pigment and does not absorb a specific wavelength, therefore in principle, fading from UV rays should be reduced. These materials can be used in applications that require pigments with excellent light-resistance and durability. In addition, since these colored micro-particle aggregates are non-toxic with a high level of safety, they show promise for wide use in printed materials.

3:30 **Recent Advances in Upconversion Nanoparticle Inks in Security Printing (Focal),** *Stanley May, University of South Dakota; and Jon Kellar, William Cross, Grant Crawford, and Jeevan Meruga, South Dakota School of Mines and Technology (USA)**

3:50 – 4:30 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

Colleague Connections—Security Printing: Identifying the Opportunities Roundtable Discussion

Moderator: Alan Hodgson, Alan Hodgson Consulting Ltd.; and Hiroshi Yamazaki, Imaging Society of Japan

4:30 – 5:50 PM

See details, page xxxv.

7:00 – 9:30 PM Conference Reception

Portland Art Museum, Mark Building

DIGITAL FABRICATION AND 3D PRINTING

9:00 – 10:10 AM Wednesday Keynote and IS&T Awards, Oregon Ballroom Salon F, see details page x.

Oregon Ballroom Salon G

Bio-Printing

Session Chairs: Jeff Nielsen, Hewlett-Packard Co.; Achim Weber, Fraunhofer IGB; and Koei Suzuki, Ricoh Co., Ltd.

10:20 – 11:10 AM

10:20 **Biopolymer-based Functional Inks for the Preparation of Artificial Cartilage via Bioprinting Technology,** *Eva Hoch[1], Achim Weber[1,2], and Kirsten Borchers[1,2]; [1]University of Stuttgart and [2]Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB (Germany)* 397

We present bioinks based on biopolymers from the native extracellular matrix, namely gelatin and chondroitin sulfate, which are suitable for bioprinting technology applying living mammalian cells. The bioinks can be crosslinked due to chemical modification of the biopolymers with methacrylic functions. Such insoluble hydrogels with tunable physico-chemical propertie are able to closely mimic the native extracellular matrix of biological tissues (ECM). Highly methacrylated gelatin (GM10) resulted in solutions with low viscosities (e.g. 15 wt%: 6.7 ± 1.0 mPa s at 37°C) within the inkjet-printable range and crosslinked hydrogels with high mechanical strength. Less methacrylated gelatin (GM2) was proper for preparation of soft hydrogels and highly viscous bioinks for pneumatic dispensing technology (e.g. 15 wt%: 39.3 ± 3.6 mPa s at 37°C). By additional acetylation of GM2 (GM2A8) the solution viscosity could be significantly lowered (e.g. 15 wt%: η = 5.2 ± 0.5 mPa s, 37°C) and, thus, inkjet-printable bioinks with low crosslinking capacity were also gained. Consequently, a versatile bioink system for bioprinting technology was created.by adjustable twofold modification of gelatin with photochemically reactive and inert groups.

Introduction of an additional methacrylated component of the ECM, methacrylated chondroitin sulfate (CSM), further tuned the chemical and physical properties of bioink and hydrogels. GM(A)-CSM hybrid hydrogels possessed for example significantly higher swellability than pure GM(A) hydrogels of the same mass fraction. CSM also influenced bioink viscosity: For unmodified gelatin and gelatin with low degree of modification CSM induced a decrease in bioink viscosity (e.g. 15 wt% GM2: 39.3 ± 3.6 mPa s versus 14 wt% GM2 + 1 wt% CSM: 32.9 ± 6.5 mPa s). In contrast to this, addition of CSM to bioinks made of gelatins with high

*Presentation only; no proceedings paper.

degree of modification, GM2A8 or GM10, induced an increase in solution viscosity (e.g. 15 wt% GM2A8: 5.2 ± 0.5 mPa s versus 14 wt% GM2A8 + 1 wt% CSM: 6.5 ± 1.0 mPa s).

The developed bioinks were proven to be suitable for bioprin-ting with viable mammalian cells, in this case porcine articular chondrocytes, and for fabrication of tissue models with intrinsic structure. Thus, biomaterials presented in this study can be used for biofabrication of artificial three-dimensional tissues with biomimetic organization, such as articular cartilage with its hierarchical structure.

10:40 **Thermal Inkjet System Enabling Biomolecule Dispensing for Life Science Research,**
Jeff Nielsen, Christie Dudenhoefer, Ken Duda, Michael Day, Dennis Esterberg, Ed Grenier, Dave Ochs, Matt Still, Debora Thomas, Ken Ward, and Joshua Yu, Hewlett-Packard Co. (USA) 402

A system designed to dispense small-molecule compounds dissolved in dimethyl sulfoxide (DMSO) into ANSI-standard microtiter plate was developed and commercialized by Hewlett Packard (HP) in 2011. This commercial system, which included the HP D300 Digital Dispenser and the T8 Dispensehead Cassette, was reported at the Digital Fabrication 2011 Conference and an early beta version of the system was reported at the Digital Fabrication 2006 Conference. The D300, based on HP's Scalable Printing Technology (SPT), has proven to be a useful tool for conducting pharmaceutical research with compounds in DMSO. The large dynamic range enabled by non-contact picoliter dispensing enables the rapid creation of dose-response experiments, including multi-level drug-drug interaction experiments.

In this contribution, we discuss key improvements to the system since commercial release, most importantly, the expansion of the capability of the system to enable the dispensing of various aqueous-based biomolecules, including proteins, DNA, lipids, and nanoparticles. We will discuss challenges in developing these new capabilities, especially around enabling DMSO and aqueous-based fluids to be dispensed accurately from a common dispensehead, and examples of the types of experiments that are now enabled. We will also discuss future directions to further expand the utility of the digital dispensing platform in pharmaceutical and life science research.

Exhibit Hall Opens at 10:30 AM
11:00 AM – 11:40 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

11:40 **Biopolymers for 3D Printed Bone Structure,** *Azem Yahamed, Michael Joyce, Paul D. Fleming, and Alexandra Pekarovicova, Western Michigan University (USA)* 406

Bone substitute materials can replace damaged bone structures and significantly reduce the surgery and recovery times. Three-dimensional (3D) printing is a new rapid method to make these substitutes with exact shape and structure, based on actual individual bones medical measurement data. The goal of this work was to investigate the influence of the printing orientation on the smoothness and the percentage of void volume on the mechanical properties of biocompatible and biodegradable thermoplastic materials that can be applied for three-dimensional printing of human bone structure substitutes. Fused Deposition Modeling (FDM) is used to produce 3D printed shapes of bones created from DICOM images of CT and MRI scans. Three samples of acrylonitrile butadiene styrene (ABS) were printed utilizing or having different number of layers. That is, one, two and three layers at a 45º (head angle) were printed. The angle is related to the direction of the printing, which is controlled automatically by MakerWare software of the 3D printer itself, without any external control from the operator or technician. Thickness and roughness for each sample were subsequently measured. One sample of polylactic acid (PLA) was printed with one layer at 45º and its thickness and roughness were measured. Two other samples of ABS, having one and two layers, were printed at 90º then thickness and smoothness were measured. Polyvinyl alcohol (PVA) was printed with one layer at 45º and 90º. Thickness and roughness of printed 3D samples were measured using a White Light Interferometer.

3D Printing and Additive Manufacturing con't.

Session Chairs: Trevor Snyder, 3D Systems; Martin Baumers, University of Nottingham; and Shinjiro Umezu, Waseda University

12:00 – 1:00 PM

12:00 **Digital Making: 3D Printing and Artisanal Glass Production,** *Aaron Oussoren, Philip Robbins, and Keith Doyle, Emily Carr University of Art + Design (Canada)* 411

Direct digital design and additive manufacturing are enabling new pathways for the design, development and distribution of material goods—radically redefining existing sites for knowledge exchange and our core assumptions of what makes a contemporary material practice. In the era of open source, democratized production, the relationships between an object, how it is made, what it is made of, where it is made, by whom

and when, are directed by the maker. For the last forty years, 3D printing has been used as an ideation tool to model what could be. The steady emergence of Direct Digital Manufacturing (Singer P. et al. 2011) has enabled us to manipulate true-life materials to directly achieve the final object. This paper will focus on emergent modes of making using legacy materials, leveraging work done in foundry and ceramics into glass, and how 3D printing provides room for innovation not only with these materials, but also with the requisite digital processes in terms of software, hardware, and workflow opportunities. This design-led creative research looks at opportunities for innovation in material practice and also seeks out the affinities and opportunities, which arise when design methodologies are implemented alongside an artisanal, craft-based approach to making.

12:20 **3D Printed Self-Glazing Ceramics: Process and Materials Development,** *David Huson and Katie Vaughan, University of the West of England (UK)* 416

David Huson, Katie Vaughan, and colleagues 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 final 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 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 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 paper will describe the development of a 3D printable ceramic body with a glaze precursor powder for the cementation glazing process. (the initial development work was described in a paper presented at DF2014) The process parameters, formulations and 3D printing settings required will be detailed and images and examples of artefacts made by this process will be included. 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 and designers to 3D print objects in a material that can be glazed and vitrified in one low temperature energy efficient firing process, a potential breakthrough for ceramic design and manufacture which will be applicable to the arts and wider industries.

12:40 **A Study on Reduction of Processing Time and Improvement of Strength by Using Photopolymer Resin in the 3DP Process with Powder Base,** *Dong Soo Kim and Sungwoo Bae, Hanbat National University (Korea)* 421

The 3DP technology is one of the additive manufacturing technologies that have recently come into the spotlight and are being applied to various fields. This technology has the advantage of enabling high speed printing which, is done on the basis of the ink-jet technology and the system to be constructed at a low cost. However, it has also the negative side that requires extra time for curing after 3D shape fabrication. On the other hand a post-processing period is meant to increase the mechanical strength of the product. Therefore, in this study, an innovative 3DP process is recommended to improve the strength of product without any post-processing. To verify the feasibility of the proposed process, a 3DP system was developed to test the mechanical strength experiment of the fabricated specimens. As a result, it was confirmed that the specimens fabricated by the proposed process had three times higher compression and yield strength than post-processed systems for improving the strength through the conventional thermal bubble jet process. To this effect, a proposed 3DP process would remarkably reduce the total fabrication time because there is no dry time and post-processing time after fabrication in the proposed process.

1:00 – 2:30 PM Lunch Break

Colloids and Colloidal Suspensions (Toner, Particles, Ink Formulation)

Session Chairs: Stanley May, University of South Dakota; Maik Müller, XaarJet AB; and Atsushi Tomotake, Konika Minolta Inc.

2:30 – 5:10 PM

2:30 **Pigmented Ink Technology to Enable HP PageWide XL Printer Capability,** *Jayprakash Bhatt, Larrie Deardurff, Vladimir Jakubek, Cory Ruud, Richard McManus, and Sundar Vasudevan, Hewlett-Packard Co. (USA)* 426

The recently announced HP Pagewide XL printer delivers high quality output at very high printing speeds. The breakthrough speed of Pagewide XL is delivered via an array of nozzles covering the entire paper width (an order of magnitude more nozzles than traditional scanning systems). All the drops are fired in a single pass, which leads to a heightened sensitivity to nozzle errors for output quality, and to servicing drops for print production costs. Robust and reliable operation, along with economical print production are enabled by an inkset developed for this application. First, the Pagewide XL inkset uses pigment colorants that are quickly immobilized when contacting paper surface, leading to high color saturation and high black optical density at lower levels of ink coverage. The pigmented colorants, along with HP's polymeric binders also deliver better resistance to water, highlighters, and light fade. Second, the inkset has an additive that migrates to the ink/air interface in the nozzle. This film-forming additive produces a vapor barrier that slows water loss and enables extended uncapped periods while maintaining good drop ejection. Finally, the ink components work together to minimize the need for servicing spits to keep nozzles healthy, which improves uptime, productivity, and reduces print production costs.

2:50 **Rheology and Stability of Functionalized Particle Loaded Inkjet Inks,** *Danny Lehmann, Klaus Krüger, and Vico Haverkamp, Helmut Schmidt University/University of the Federal Armed Forces Hamburg; Yaowapa Treekamol, Mauricio Schieda, and Iris Herrmann-Geppert, Helmholtz Centre Geesthacht (Germany)* 430

In this study, we investigate the rheological properties as well as the stability and the electrical properties of inkjet inks based on silane-functionalized TiO2-particles. At first, we describe the preparation of the surface modified TiO2-particles, the formulation of the inks and the measurement procedures. The results of the measurements are presented and mechanisms, which could explain the observed characteristics, are discussed. Based on these findings, we discuss the limits of application of the surface modified nanoparticle inks for functional inkjet printing. Furthermore, we show the successful application of a surface modified nanoparticle ink for inkjet printing of photo electrodes for photo assisted water splitting.

3:10 **Colorant Design for High Printing Quality on both Treated and Non-Treated Papers,** *Satoshi Tanaka, Isao Tsuru, and Daisuke Hamada, Kao Corportion (Japan)* 435

The pigment dispersion encapsulated by the polymer with electrostatic and steric repulsion group was known to provide high stability so that the dispersions do not aggregate soon after impacting on the paper. So, polymer dispersed pigment dispersion showed higher jetting stability and good performance of rub fastness on treated paper, but lower optical density on non-treated paper. On the other hand, a pigment with highly oxidized surface showed contrary performance. Thus, to provide higher print quality on both treated and non-treated paper by one ink, a different system needed to be considered. Two pigments with different surface characteristic dispersed together with polymer were found to provide higher jetting stability and higher print quality (optical density and rub fastness) on both treated and non-treated papers. It was concluded that higher optical density could be achieved by adjusting the ratio of two pigments to control the ink penetration into various papers.

3:30 **Systematic Ink Design and Solubility Enhancement via Genetic Algorithm for Nanoparticle-based Inkjet Inks (Focal),** *Jacob Sadie, Himamshu Nallan, Steven Volkman, and Vivek Subramanian, University of California, Berkeley (USA)* 439

Metal nanoparticle inks are the most commonly used material for creating conductive contacts via inkjet printing. While there are many commercial inks available, these inks may not be well-matched to individual systems or process flows. As such, the custom design of metal nanoparticle inks is a possible solution. However, the creation of a highly-loaded metal nanoparticle ink that exhibits reliable jetting behavior is a non-trivial process. In this paper we discuss a systematic method for designing metal nanoparticle inks using the fluid properties of both the unloaded and loaded ink to achieve reliable jetting behavior. In addition, we discuss the application of non-traditional experimental optimization methods, namely multi-objective genetic algorithms, to the search for highly soluble metal nanoparticles.

4:00 – 4:30 PM Coffee Break — in the Exhibit Hall, Oregon Ballroom Salon E

4:30 **Attenuation of Cracks Pattern in Dried Silica Colloidal Droplets by Anionic Surfactant Addition,** *Mahoulo Ahouansou[1], Simon R. Biggs[2], and Olivier J. Cayre[1], [1]University of Leeds (UK) and [2]The University of Queensland (Australia)* 443

The influence of the anionic surfactant sodium dodecyl sulfate (SDS) on the evaporation of drying silica colloidal droplets is investigated. The addition of SDS leads to an attenuation of cracks patterns after evaporation (i.e., the presence of cracks in the structure are dramatically altered). We understand that this phenomenon could be induced by radial Marangoni flows induced by the variation of SDS concentration along the air-water interface along with a depletion flocculation.

4:50 **Advanced LED UV Inkjet Inks for Industrial Applications,** *Hiroki Nakane, Mio Kumai, Masayoshi Hagi, and Kiyofumi Nagai, Ricoh Company, Ltd. (Japan)* 448

The technology of inkjet is used not only in house but also in commercial and industrial area. To expand business area, it is one of the main issues that ink is necessary to be used with nonabsorbent substrates such as plastic films. One of solution of this issue is UV ink. The market of UV curable inkjet have shown rapid growth in industrial area, especially in decoration market. We developed UV curable inkjet ink cured by LED lamp, which is able to be used in decoration with inkjet technology. The newly developed ink is superior in stretch to former UV inkjet ink for decoration, and it will be able to be used in forming process with higher curvature. Moreover, the newly developed ink also overcomes the difficulties that the hardness of former UV inkjet ink for stretch forming process is low, and curing coating film is broken off during punching process.

concurrent event

4:30 – 5:50 PM Colleague Connections—
Security Printing: Identifying the Opportunities Roundtable Discussion
see full details on page xxxv, Oregon Ballroom Salon A

7:00 – 9:30 PM Conference Reception
Portland Art Museum, Mark Building

THURSDAY OCTOBER 1, 2015

DIGITAL PRINTING TECHNOLOGIES

Oregon Ballroom Salon G

Ink Substrate Interactions

Session Chairs: Greg Herman, Oregon State University; Danny Lehmann, Helmut Schmidt University; and Takumi Suzuki, Canon Inc.

9:00 – 10:40 AM

9:00 **Adhesion and Electrical Properties of Low Temperature Processed Ag-PMMA-Films in Inkjet Printing,** *Andreas Rathjen, Jan Zimmermann, Vico Haverkamp, and Klaus Krüger, Helmut Schmidt University/University of the Federal Armed Forces Hamburg (Germany)* 452

A new simple to use approach for the measurement of adhesion strength of inkjet-printed films on their substrate is presented. The need for this new approach utilizing an ultrasonic bath is introduced by a brief explanation of existing methods. The ultrasonic bath method is evaluated by investigating different silver inks on different substrates (ceramic and glass-fibre reinforced plastic). Using the new ultrasonic bath method the temperature range for optimum adhesion on the substrate for different combinations of ink and substrate is evaluated. This temperature is shown not to be the maximum applicable temperature but rather a temperature in the middle section. At the optimum temperature, strong bonds between silver particles are formed without the sintering shrinkage breaking the bond to the substrate.

The influence of using poly(methyl methacrylate) in silver inks on adhesion and resistivity is also investigated and discussed. The organic material shows little impact on the resistivity of printed tracks for sintering temperatures above 150°C while changing the film adhesion temperature profile.

9:20 **Drop Coalescence on Non-Absorbent Coated Substrates,** *Jun Ma[1], David A. Mantell[1], Howard Mizes[2], Xin Yang[1], Paul McConville[1], and Hong Zhao[3]; [1]Xerox Corporation, [2]PARC, and [3]Virginia Commonwealth University (USA)* 457

Drop coalescence and ink reflow significantly affect the image quality in inkjet printing, especially on coated and non-absorbent substrates. In this study, the coalescence of inkjet-printed drops on a non-absorbent substrate was numerically simulated and compared with machine tests. Using a commercial software Flow-3D, the coalescing drop pairs are simulated by solving the mass and momentum conservation equations with Volume-of-Fluid method tracking the liquid-air interface. The effects of drop spacing and time interval on the geometry of coalescing drops are numerically investigated. Results show that when the second drop lands next to a pre-deposited drop, liquid in the second drop migrates towards the first drop driven by its internal capillary pressure and inertia. As a result, a geometrical shift towards the first drop and reduced drop spreading length are observed in the merged drop. The geometric shifts of coalesced droplets were qualitatively proved in a machine test using statistical image analysis. Both the reduced drop spreading length and the geometric shift contribute to the trailing edge displacement, defined as the wetting edge shift of the second drop away from its ideal location. It is also indicated in the simulation that drop spacing and time interval influence the geometric shift, drop spreading length, and thus trailing edge displacement. This trailing edge displacement plays an important role in determining the continuity of the printed lines, e.g. non-coalescence of printed drops due to large trailing edge displacement will lead to broken patterns or functional failures of printed electronics. This study provides valuable information in designing jetting sequence in the printhead, and optimizing printing processes for uniform line and solid formation.

9:40 **Anomalous Thermal Induced Pinning of a Liquid Drop on a Solid Substrate,** *Mandakini Kanungo, Xerox Corporation (USA); Srinivas Mettu, University of Melbourne (Australia); and Kock-Yee Law, Research and Innovative Solutions (USA)**

10:00 **Potential of Coating Comprising Hydroxypropylated Starch for Dye-based Inkjet Printing,** *Katriina Mielonen, Sami-Seppo Ovaska, and Kaj Backfolk, Lappeenranta University of Technology (Finland)* 462

The potential of hydroxypropylated starch–based composite coatings as inkjet receptive coatings was studied using water based inks with dye colorants. The variable in the development program was the proportion of various functional nanopigments such as kaolin and synthetic layered silicate. Also the effect of styrene-butadiene latex co-binder addition was investigated. From the viewpoint of print quality, the coated substrates

** Presentation only; no proceedings paper.*

showed excellent print density values, but low water fastness results, which was ascribed to dissolution of the coating-ink interface.

10:20 **New Media for 1-Pass Printing Applications,** *Charlie Zhou, Haowen Yu, Xulong Fu, Pere Canti, Ana de la Rosa, and Lisa Underwood, Hewlett-Packard Co. (USA)* 467

PageWide technology is an inkjet breakthrough that dramatically increases printing speed. The speed increases comes with some integration challenges. All of the ink is laid down in a single pass, so there is heightened sensitivity to missing nozzles, aerodynamics, and ink flux. Media is a key enabler for delivering customer requirements. In the CAD and GIS market, productivity is critical. With speeds up to 10x traditional inkjet, drytime and handleability are risk areas. HP's ColorPro technology enables excellent print quality with high Kod and saturated color, but with less ink. This helps both dry time and cost per copy. In the retail graphics and posters market, large uniform area fills are required, which is a challenge for 1-pass page-wide technology. HP's Production Poster technology has specially developed coating that tunes the dot size to deliver vibrant colors, while helping to hide missing nozzles, eliminating printing defects, and improving handleability. The result is a complete system where the ink, printer and media work together to deliver print quality at speeds not achievable with scanning inkjet technology.

10:40 – 11:10 AM Coffee Break — Oregon Ballroom Lobby

Colleague Connections— Late Breaking News/Success Stories and Confrence Highlights Forum

Session Chairs: Werner Zapka, XaarJet AB, and James Stasiak, Hewlett-Packard Co.

11:10 AM – 12:40 PM

Oregon Ballroom Salon A

Conference ends at 12:40 PM
Optional Tours—Preregistration required; buses leave at 1:45 PM

MATERIALS, METHODS, AND PERFORMANCE

Oregon Ballroom Salon A

Innovative Applications

Session Chairs: Grant Crawford, South Dakota School of Mines and Technology; Ashley Johns, Durham University; and Yasushi Hoshino, Tokyo Denki University

9:00 – 10:40 AM

9:00 **Halftone Structure Analysis for Classifying Print Processes,** *Shankhya Debnath, Independent Researcher (India)* 471

Estimating the source of a printing process is of primary importance for investigative and forensic purposes. This paper deals with development and application of a method for identifying and broadly classifying the print process from a given print sample, especially official forms and certificates. The developed method was not limited only to electrophotographic (EP) method, but was extended to conventional printing methods like offset and gravure. Various methods were previously tested on EP printed samples, but its use on conventional printing methods are being presented for the first time in this paper. A number of features were extracted from the print samples collected, which includes the various halftone structural transformations that inherently becomes a part of the printing process. Also, the halftone dots that forms a part of the image in any printing process were analyzed using Hough transform and the features thus collected were used to form a reference database. The features in this database formed as inputs to a neural network classifier, whereby the classifier was trained to obtain outputs and classify them into EP, offset or gravure classes. Once the trained network was formed newer test print samples were used to extract the same features and fed into the network for classification. The results obtained clearly showed that the outputs were correctly recognized and hence the method presented is quite promising.

9:20 **Using Emulsions to Overcome Problems Associated with the Inkjet Printing of High-Molecular-Weight Polymers in Solution,** *Ashley S. Johns and Colin D. Bain, Durham University (UK)* . 476

Emulsions were used to overcome problems with printing high-molecular-weight polymers in solution. A polymer is dissolved in an oil and dispersed in a surfactant solution. The surface tension of the oil/water interface opposes deformation of the oil droplets and thus the polymer chains are shielded from the high extensional strain rates that occur during inkjet printing. Consequently the elasticity of polymers under strain that inhibits jetting of pure polymer solutions is circumvented. The exemplar system is a 40 %wt discontinuous phase comprising a 9.5 %wt methyl benzoate solution of polystyrene (initial Mn = 487 kDa) dispersed in a 14.8 mM SDS solution. Drops were printed from a 50-μm nozzle and the drying process followed with a high-speed camera. The relative vapor pressure of the continuous and discontinuous phases is an important parameter in the drying process. Best results were obtained when the water evaporated first to leave a spherical cap of the polystyrene solution in oil. Limitations of the use of emulsions to print polymers are discussed.

9:40 **Characterization of Polymer and Silver Printed Thermoelectric Generators,** *Kristina Grunewald, Joachim Bahr, Florian Hofmann, Oleksandr Kravchuk, and Marcus Reichenberger, TH Nürnberg—Georg Simon Ohm (Germany)* 481

This work presents current results regarding environmental friendly and cost effective thermoelectric generators (TEG) produced by different printing techniques. Thermoelectric devices convert wasted heat into electricity. It is shown that a polymer-based printed thermoelectric generator provides a cost effective alternative to standard thermoelectric devices. TEG were printed by different printing techniques and realized with commercially available Poly(3,4-ethylenedioxythiophene) Poly(styrenesulfonate) (PEDOT:PSS) in combination with silver (Ag) legs on flexible foils (Polyethylene terephthalate (PET), Polyimide (PI)). For a thermoelectric generator of three thermal legs an open circuit voltage of 1 mV can be achieved with a temperature difference of 30 K. The output voltage can be multiplied by a serial connection of thermocouples or higher temperature differences. Moreover the power factor PF and the Seebeck coefficient α, which are suitable parameters for the evaluation of efficiency of thermoelectric material, are determined and will be presented.

10:00 **Inkjet Printed Hollow Silica Nanoparticles for Anti-Reflective Coatings,** *Yujuan He, Harrison R. Holzgang, Ki-Joong Kim, and Chih-Hung Chang, Oregon State University (USA)* 486

Patterned anti-reflective (AR) film using hollow silica nanoparticles (HSNPs) was achieved by inkjet printing technology. Various refractive indices for optimizing AR coating on different substrates were controlled by tuning the void space and wall thickness of HSNPs. Highly enhanced mechanical resistance could also obtained by combining HSNPs and its binder.

10:20 **Path to Low Cost Microfluidics,** *Alexander Govyadinov, Erik Torniainen, Pavel Kornilovitch, and David Markel, Hewlett-Packard Co. (USA)* 490

The paper describes a novel concept for a low cost microfluidic platform utilizing materials and processes used in low cost thermal inkjet printing. The concept re-purposes the jetting elements to create pumps, mixers, and valves all necessary components for the transport of fluids in a broad range of microfluidic applications.

10:40 – 11:10 AM Coffee Break — Oregon Ballroom Lobby

Colleague Connections—
Late Breaking News/Success Stories and Confrence Highlights Forum

Session Chairs: Werner Zapka, XaarJet AB, and James Stasiak, Hewlett-Packard Co.

11:10 AM – 12:40 PM

Oregon Ballroom Salon A

Conference ends at 12:40 PM
Optional Tours—Preregistration required; buses leave at 1:45 PM