

---

# Semiconductor Wafer Bonding: Science, Technology, and Applications 15

---

**Editors:**

**C. S. Tan**

**T. Suga**

**H. Baumgart**

**F. Fournel**

**M. Goorsky**

**K. D. Hobart**

**R. Knechtel**

**Sponsoring Division:**



**Electronics and Photonics**



Published by

**The Electrochemical Society**

65 South Main Street, Building D  
Pennington, NJ 08534-2839, USA

tel 609 737 1902

fax 609 737 2743

[www.electrochem.org](http://www.electrochem.org)

**ecstransactions™**

**Vol. 86, No. 5**

---

Copyright 2018 by The Electrochemical Society.  
All rights reserved.

This book has been registered with Copyright Clearance Center.  
For further information, please contact the Copyright Clearance Center,  
Salem, Massachusetts.

Published by:

The Electrochemical Society  
65 South Main Street  
Pennington, New Jersey 08534-2839, USA

Telephone 609.737.1902  
Fax 609.737.2743  
e-mail: [ecs@electrochem.org](mailto:ecs@electrochem.org)  
Web: [www.electrochem.org](http://www.electrochem.org)

ISSN 1938-6737 (online)  
ISSN 1938-5862 (print)  
ISSN 2151-2051 (cd-rom)

ISBN 978-1-62332-535-0 (CD-ROM)  
ISBN 978-1-62332-536-7 (USB)  
ISBN 978-1-60768-851-8 (PDF)

Printed in the United States of America.

---

## Table of Contents

*Preface* *iii*

### **Chapter 1** **Bonding of Wide Bandgap Semiconductors**

*(Invited)* Room Temperature Wafer Bonding of Wide Bandgap Semiconductors 3  
*F. Mu, Y. Wang, T. Suga*

Direct Wafer Bonding of GaN for Power Devices Applications 23  
*V. Dragoi, N. Razek, E. Guiot, R. Caulmilone, M. Liao, Y. S. Wang, M. S. Goorsky,  
L. Yates, S. Graham*

GaN LED on Quartz Substrate through Wafer Bonding and Layer Transfer Processes 31  
*K. H. Lee, Y. Wang, L. Zhang, S. J. Chua, E. A. Fitzgerald, C. S. Tan*

### **Chapter 2** **Fundamental and Characterization**

*(Invited)* Water Transport Along Si/Si Direct Wafer Bonding Interfaces 39  
*F. Rieutord, S. Tardif, I. Nikitskiy, F. Fournel, M. Tedjini, V. Larrey, C. Bridoux,  
C. Morales, D. Landru, O. Kononchuk*

Impact of Multiple Debonding on Adhesion Energy 49  
*F. Fournel, V. Larrey, F. Rieutord, C. Morales, C. Bridoux, G. Mauguen, S. Lobo*

Characterization of Wafer-Bonded Oxide-Free Silicon with Surfaces Treated with an  
Ion-Bombardment Procedure 55  
*M. Liao, C. Li, C. Flötgen, M. S. Goorsky*

**Chapter 3**  
**Adhesive, Anodic and Temporary Bonding**

|   |    |
|---|----|
| Benefits of Live View of Bond Formation and Alignment for Adhesive Bonding Characterisation<br><i>A. Draisey, T. Rogers, A. Malik</i> | 63 |
|---|----|

**Chapter 4**  
**Sensors and MEMS**

|  |     |
|--|-----|
| <i>(Invited)</i> Proximity Gettering Design of Hydrocarbon Molecular Ion Implanted Silicon Wafers Using Direct Bonding Technique for Advanced CMOS Image Sensors: A Review<br><i>K. Kurita, Y. Koga, R. Okuyama, T. Kadono, S. Shigematsu, A. O. Masada, R. Hirose, H. Okuda</i> | 77  |
| Multilayer Thin Film Getter for Sustainable Vacuum in MEMS Packaging<br><i>M. Wu, J. Moulin, A. Bosseboeuf</i>   | 95  |
| SiC Wafer Bonding and Deep Reactive Ion Etching Towards High-Aspect Ratio SiC MEMS Fabrication<br><i>L. E. Luna, K. D. Hobart, M. J. Tadjer, R. L. Myers-Ward, T. J. Anderson, F. J. Kub</i>   | 105 |
| Glass Frit Wafer Bonding for Encapsulating Monolithic Integrated CMOS-MEMS Devices<br><i>R. Knechtel, M. Zellmer, M. Schikowski, M. Behmueller, C. Van Buggenhout, A. Petropoulos</i>  | 111 |

**Chapter 5**  
**Packaging and Metal Bonding**

|  |     |
|--|-----|
| Room Temperature Bonding of Electroformed Cu Based-Heat Spreader in Atmospheric Air<br><i>T. Matsumae, Y. Kurashima, H. Takagi</i> | 121 |
|--|-----|

|   |     |
|---|-----|
| The Synergistic Roles of Temperature and Pressure in Thermo-Compression Bonding of Au             | 129 |
| <i>P. Ambhore, K. Mani, B. Beekley, N. Malik, K. Schjølberg-Henriksen, S. Iyer, M. S. Goorsky</i> |     |

|   |     |
|---|-----|
| Electrical Characteristics of Solder-Free SiC Die/Metal Foil/AlN Plate Junctions Fabricated Using Surface Activated Bonding | 137 |
| <i>S. Morita, J. Liang, N. Shigekawa</i>  |     |

## **Chapter 6 Integration and Dielectric Bonding**

|   |     |
|---|-----|
| <i>(Invited)</i> High Accuracy Aligned Wafer Bonding for Wafer-Level Integration  | 145 |
| <i>T. Plach, B. Rebhan, V. Dragoi, T. Wagenleitner, M. Wimplinger, P. Lindner</i> |     |

|  |     |
|--|-----|
| Influence of Composition of SiCN Film for Surface Activated Bonding  | 159 |
| <i>F. Inoue, L. Peng, S. Iacovo, A. Phommahaxay, J. Visker, P. Verdonck, J. Meersschaut, P. Dara, E. Sleenckx, A. Miller, E. Beyne</i> |     |

|   |     |
|---|-----|
| Ga <sub>2</sub> O <sub>3</sub> /Si and Al <sub>2</sub> O <sub>3</sub> /Si Room-Temperature Wafer Bonding Using in-Situ Deposited Si Thin Film | 169 |
| <i>H. Takagi, Y. Kurashima, T. Matsumae, T. Ito, H. Watanabe, H. Umezawa, S. Ohmagari</i>   |     |

## **Chapter 7 Si, SiGe and III-V Bonding**

|   |     |
|---|-----|
| <i>(Invited)</i> Monolithic Integration of Si-CMOS and III-V-on-Si through Direct Wafer Bonding Process | 177 |
| <i>K. H. Lee, L. Zhang, B. Wang, Y. Wang, W. Sasangka, K. E. Lee, E. A. Fitzgerald</i>                  |     |

|   |     |
|---|-----|
| The Role of Misorientation in Direct Wafer Bonded III-V Materials | 185 |
| <i>M. Liao, V. Tran, M. Yee, M. Seal, M. S. Goorsky</i>           |     |

|   |     |
|---|-----|
| Si-Ge Heterostructures Fabricated by Room Temperature Wafer Bonding | 191 |
| <i>N. Razek, V. Dragoi, A. Jung, H. von Känel</i>                   |     |

|   |     |
|---|-----|
| Room Temperature Bonding of Wafers Using Si and Ge Films with Extremely Low Electrical Conductivity | 199 |
| <i>M. Uomoto, A. Muraoka, T. Shimatsu</i>   |     |

**Chapter 8**  
**Low Temperature and Surface Activated Bonding**

|   |     |
|---|-----|
| Surface Activated Bonding of LiNbO <sub>3</sub> and GaN at Room Temperature | 207 |
| <i>R. Takigawa, E. Higurashi, T. Asano</i>                                  |     |

**Chapter 9**  
**Hermetic Packaging and Optical Devices**

|   |     |
|---|-----|
| Chemical Mechanical Polishing and Direct Bonding of YAG | 217 |
| <i>J. McKay, T. Bai, M. S. Goorsky</i>                  |     |

|   |     |
|---|-----|
| Collective Die Direct Bonding for Photonic on Silicon                         | 223 |
| <i>L. Sanchez, F. Fournel, B. Montmayeul, L. Bally, B. Szlag, L. Adelmini</i> |     |

|   |     |
|---|-----|
| Atomic Diffusion Bonding for Optical Devices with High Optical Density    | 233 |
| <i>G. Yonezawa, Y. Takahashi, Y. Sato, S. Abe, M. Uomoto, T. Shimatsu</i> |     |

|              |     |
|--------------|-----|
| Author Index | 247 |
|--------------|-----|