

## 1) 科学研究費補助金

平成 21～25 年度、科学技術研究機構 (JST) 戦略的創造研究推進事業 (CREST) 「異種接合 GaN 横型トランジスタのインバータ展開」

平成 21～24 年度、基盤研究(A) 「電子準位制御と新ゲート構造による窒化ガリウム系トランジスタの高信頼化」

平成 21～22 年度、特定領域研究 (公募研究) 「III 族窒化物半導体混晶の欠陥準位・表面準位の評価と制御」

平成 20～21 年度、日本学術振興会二国間事業共同研究、「半導体ナノワイヤ構造を利用した次世代集積回路の展開」、中国側代表者は呉南健教授 (中国科学院半導体研究所)

平成 19～20 年度、特定領域研究 (公募研究)、「III 族窒化物半導体混晶の欠陥準位・表面準位の評価と制御」

平成 17～18 年度、基盤研究(B) 「欠陥制御・界面制御に基づく窒化ガリウム系デバイス構造の高信頼化」

## 2) 招待講演 (2008 年以降)

1. T. Hashizume, Y. Hori and C. Mizue, (Invited) "Interface control technologies of GaN-based MOS structures for high-efficiency power switching transistors", Workshop on Dielectrics in Microelectronics (WoDiM 2010), Bratislava, Slovak, June 28-30, 2010.
2. T. Hashizume and K. Ohi, (Invited) "Current controllability and stability of multi-mesa-channel AlGaIn/GaN HEMTs", 2010 International Meeting for Future of Electron Devices, Kansai (IMFEDK), Osaka, May 13- 14, 2010.
3. T. Hashizume, (Invited) "Effects of plasma processing on surface properties of GaN and AlGaIn (Invited)", 2<sup>nd</sup> International Symposium on Advanced Plasma Science and its Applications for Nitrides and Nanomaterials (ISPlasma-2010), Mar. 8-10, Nagoya, Japan
4. T. Hashizume, (Invited) "Characterization and control of GaN and AlGaIn surfaces for high-performance GaN-based transistors", Huang Kun Forum, Chinese Academy of Science, Nov. 6, 2009, Beijing, China.
5. T. Hashizume, (Invited) "Surface control of GaN alloys for photonic and electronic devices", Society of Photographic Instrumentation Engineers (SPIE), Photonics West, San Jose, CA, Jan. 25-29, 2009.
6. T. Hashizume, (Invited) "Surface control structures for high-performance AlGaIn/GaN HEMTs", 7th International Conference on Advanced Semiconductor Devices and Microsystems (ASDAM 2008), Smolenice, Slovakia, October 12-16, 2008.
7. T. Hashizume, (Invited) "Surface control of AlGaIn for the stability improvement of AlGaIn/GaN HEMTs", 66th Device Research Conference (DRC-66), Univ. California, Santa Barbara, USA, June 23-25, 2008.
8. 橋詰 保、「窒化物半導体の表面・界面制御とパワートランジスタ展開」、日本学術振興会アモルファス・ナノ材料第 1 4 7 委員会第 1 0 8 回研究会、2010 年 7 月 9 日、主婦会

館、東京。

9. 橋詰 保、「AlGa<sub>N</sub>の深い電子準位と表面ポテンシャル」、応用物理学会応用電子物性分科会研究会、2010年5月21日、大阪大学銀杏会館、大阪。
10. 橋詰 保、「窒化物半導体の特徴とデバイス展開」、第27回無機材料に関する最近の研究成果発表会-材料研究の最前線から-、2010年1月25日、東海大学校友会館、東京。
11. 橋詰 保、「窒化物半導体のMIS界面電子準位」、日本学術振興会第154委員会・第162委員会合同研究会、2009年10月26日、東京。
12. 橋詰 保、「AlGa<sub>N</sub>の表面制御とトランジスタ応用」、電気学会超高速デバイス研究会、2009年3月9日、熱海。
13. 橋詰 保、「Ga<sub>N</sub>およびAlGa<sub>N</sub>の欠陥準位と表面準位」、科学技術交流財団第4回窒化物半導体応用研究会、2009年1月23日、名古屋工業大学。
14. 橋詰 保、「Ga<sub>N</sub>系トランジスタの現状と信頼性」、パワーデバイス用シリコンおよび関連半導体材料に関する研究会、2008年12月8-9日、新潟大学。
15. 橋詰 保、「AlGa<sub>N</sub>のバルク準位・表面準位とそのデバイス動作特性への影響」、日本学術振興会第162委員会ワイドギャップ半導体光・電子デバイス第59回研究会、2008年7月19日、東京。

### 3) 学術論文 (2007年以降)

1. N. Harada, Y. Hori, N. Azumaishi, K. Ohi and T. Hashizume, “Formation of recessed-oxide gate for normally-off AlGa<sub>N</sub>/Ga<sub>N</sub> HEMTs using a selective electrochemical oxidation”, Appl. Phys. Express **4**, Art. No. 021002 (2011)
2. C. Mizue, Y. Hori, M. Miczek, and T. Hashizume, “Capacitance-voltage characteristics of Al<sub>2</sub>O<sub>3</sub>/AlGa<sub>N</sub>/Ga<sub>N</sub> structures and state density distribution at Al<sub>2</sub>O<sub>3</sub>/AlGa<sub>N</sub> interface”, Jpn. J. Appl. Phys. **50**, Art. No. 021001 (2011).
3. E. Ogawa and T. Hashizume, “Variation of Chemical and Photoluminescence Properties of Mg-Doped Ga<sub>N</sub> Caused by High-Temperature Process”, Jpn. J. Appl. Phys. **50**, Art. No. 021002 (2011).
4. C.-Y. Hu, T. Hashizume, K. Ohi, M. Tajima, “Trapping effect evaluation of gateless AlGa<sub>N</sub>/Ga<sub>N</sub> heterojunction field-effect transistors using transmission-line-model method”, Appl. Phys. Lett. **97**, Art. No. 222103 (2010).
5. T. Yoshida and T. Hashizume, “Air-Gap Capacitance-Voltage Analyses of p-InP Surfaces Covered with Natural Oxide”, Appl. Phys. Express **3**, Art. No. 116601 (2010).
6. K. Ooyama, K. Sugawara, S. Okuzaki, H. Taketomi, H. Miyake, K. Hiramatsu, and T. Hashizume, “Deep electronic levels of Al<sub>x</sub>Ga<sub>1-x</sub>N with a wide range of Al composition grown by metal-organic vapor phase epitaxy”, Jpn. J. Appl. Phys. **49**, Art. No. 101001 (2010)

7. Y. Hori, C. Mizue, and T. Hashizume, "Process conditions for improvement of electrical properties of Al<sub>2</sub>O<sub>3</sub>/n-GaN structures prepared by atomic layer deposition", Jpn. J. Appl. Phys. **49**, Art. No. 080201 (2010). JJAP編集委員会より「SPOTLIGHTS」としてJJAPホームページで紹介される。 (<http://jjap.jsap.jp/spotlights/index.html>)
8. D. Gregušova, R. Stoklas, C. Mizue, Y. Hori, J. Novák, T. Hashizume, and P. Kordoš, "Trap states in AlGaIn/GaN metal-oxide-semiconductor structures with Al<sub>2</sub>O<sub>3</sub> prepared by atomic layer deposition", J. Appl. Phys. **107**, Art. No. 106104(2010).
9. M. Akazawa, T. Matsuyama, T. Hashizume, M. Hiroki, S. Yamahata, and N. Shigekawa, "Small valence-band offset of In<sub>0.17</sub>Al<sub>0.83</sub>N/GaN heterostructure grown by metal-organic vapor phase epitaxy", Appl. Phys. Lett. **96**, Art. No. 132104 (2010).
10. T. Kubo, H. Taketomi, H. Miyake, K. Hiramatsu, and T. Hashizume, "Variation of surface potentials of Si-doped Al<sub>x</sub>Ga<sub>1-x</sub>N (0 < x < 0.87) grown on AlN/sapphire template by metal-organic vapor phase epitaxy", Appl. Phys. Express **3**, Art. No. 021004(2010).
11. K. Ohi and T. Hashizume, "Drain current stability and controllability of threshold voltage and subthreshold current in a multi-mesa-channel AlGaIn/GaN high electron mobility transistor", Jpn. J. Appl. Phys. **48**, in press, (2009).
12. K. Sugawara, J. Kotani and T. Hashizume, "Near-midgap deep levels in Al<sub>0.26</sub>Ga<sub>0.74</sub>N grown by metal-organic chemical vapor deposition", Appl. Phys. Lett. **94**, Art. No. 152106-1-3 (2009).
13. M. Miczek, B. Adamowicz, C. Mizue and T. Hashizume, "Simulations of C-V-T Behavior of Metal/Insulator/AlGaIn and Metal/Insulator/AlGaIn/GaN Structures", Jpn. J. Appl. Phys. **48**, Art. No. 04C092-1-6 (2009).
14. T. Hashizume, N. Shiozaki and K. Ohi, "Surface control of GaN alloys for photonic and electronic devices (Invited) ", Proc. of SPIE, **Gallium Nitride Materials and Devices IV**, vol. 7216, 7216-0U-1, 2009.
15. N. Shiozaki and T. Hashizume, "Improvements of Electronic and Optical Characteristics of n-GaN-based structures by Photoelectrochemical Oxidation in Glycol Solution", J. Appl. Phys. **105**, Art. No. 064912-1-6(2009).
16. T. Kimura and T. Hashizume, "Effect of carbon incorporation on electric properties of n-type GaN surfaces", J. Appl. Phys. **105**, Art. No. 014503-1-5(2009).
17. C. Mizue, J. Kotani, M. Miczek, and T. Hashizume, "UV-induced variation of interface potential in the AlO<sub>x</sub>/n-GaN structure", Jpn. J. Appl. Phys. **48**, Art. No. 020201-1-3 (2009).
18. T. Tajima, J. Kotani and T. Hashizume, "Effects of native oxide formation on AlGaIn on DC characteristics of AlGaIn/GaN high-electron-mobility transistors", Jpn. J. Appl. Phys. **48**, Art. No. 020203-1-3 (2009).
19. T. Uesugi, T. Kachi, M. Sugimoto, T. Matsuyama, C. Mizue, and T. Hashizume, "Deposition of aluminum oxide layer on GaN using diethyl-aluminum-ethoxide as a precursor", J. Appl. Phys. **104**, Art. No. 016103-1-3(2008).

20. M. Miczek, C. Mizue, T. Hashizume, and B. Adamowicz, "Effects of interface states and temperature on the C-V behavior of metal/insulator/AlGaIn/GaN heterostructure capacitors", *J. Appl. Phys.* **103**, Art. No. 104510-1-11(2008).
21. K. Ooyama, H. Kato, M. Miczek, and T. Hashizume, "Temperature-dependent interface-state response in an Al<sub>2</sub>O<sub>3</sub>/n-GaN structure", *Jpn. J. Appl. Phys.* **47**, 5426-5428 (2008).
22. T. Tamura, J. Kotani, S. Kasai, and T. Hashizume, "Nearly temperature-independent saturation drain current in a multi-mesa-channel AlGaIn/GaN high-electron-mobility transistor", *Appl. Phys. Express* **1**, Art. No. 023001(2008).
23. J. Kotani, M. Tajima, S. Kasai and T. Hashizume, "Mechanism of surface conduction in the vicinity of Schottky gates on AlGaIn/GaN heterostructures", *Appl. Phys. Lett.* **91**, Art. No. 093501(2007).
24. E. Ogawa, T. Hashizume, S. Nakazawa, T. Ueda and T. Tanaka, "Chemical and Potential-Bending Characteristics of SiN<sub>x</sub>/AlGaIn Interfaces Prepared by *In Situ* Metal-Organic Chemical Vapor Deposition", *Jpn. J. Appl. Phys.* **46**, L590-592 (2007).
25. M. Kaneko, T. Hashizume, V. A. Odnoblyudov and C. W. Tu, "Electrical and deep-level characterization of GaP<sub>1-x</sub>N<sub>x</sub> grown by gas-source molecular beam epitaxy", *J. Appl. Phys.* **101**, 103707-1-5(2007).
26. N. Shiozaki, T. Sato and T. Hashizume, "Formation of Thin Native Oxide Layer on n-GaN by Electrochemical Process in Mixed Solution with Glycol and Water", *Jpn. J. Appl. Phys.* **46**, 1471-1473(2007).
27. T. Kimura, S. Ootomo, T. Nomura, S. Yoshida, and T. Hashizume, "Solid-Phase Diffusion of Carbon into GaN Using SiN<sub>x</sub>/CN<sub>x</sub>/GaN Structure", *Jpn. J. Appl. Phys.* **46**, L224-226(2007).

#### 4) 国際会議発表論文 (2007 年以降)

1. S. Okuzaki, K. Sugawara, H. Taketomi, H. Miyake, K. Hiramatsu and T. Hashizume, "Deep level characterization of MOVPE-grown AlGaIn with high Al compositions", 2010 International Conference on Solid-State Devices and Materials (SSDM2010), Tokyo, Sep. 22-24, 2010.
2. Y. Hori, C. Mizue and T. Hashizume, "Effects of fabrication processes on electrical properties of Al<sub>2</sub>O<sub>3</sub>/n-GaN structures prepared by atomic layer deposition", 2010 International Workshop on Nitride Semiconductors (IWN-2010), Tampa, USA, Sep. 19- 24, 2010.
3. K. Ohi and T. Hashizume, "Current Controllability and Stability in Multi-Mesa-Channel AlGaIn/GaN HEMT", 2010 International Workshop on Nitride Semiconductors (IWN-2010), Tampa, USA, Sep. 19- 24, 2010.
4. E. Ogawa and T. Hashizume, "Effects of Mg-doping density and high-temperature annealing on deep levels in Mg-doped GaN", 2010 International Workshop on Nitride Semiconductors (IWN-2010), Tampa, USA, Sep. 19- 24, 2010.

5. N. Harada and T. Hashizume, "A recessed oxide gate structure for threshold voltage control in AlGaN/GaN HEMTs by electrochemical process", 2010 International Workshop on Nitride Semiconductors (IWN-2010), Tampa, USA, Sep. 19- 24, 2010.
6. C. Mizue and T. Hashizume, "C-V characterization of ALD-Al<sub>2</sub>O<sub>3</sub> insulated gates on AlGaN/GaN structure", Workshop on Dielectrics in Microelectronics (WoDiM 2010), Bratislava, Slovak, June 28-30, 2010.
7. T. Yoshida and T. Hashizume, "Air-gap capacitance-voltage analysis of p-InP surfaces", 22nd International Conference on Indium Phosphide and Related Materials (IPRM2010), Takamatsu, May 31- June 4, 2010.
8. Y. Hori, C. Mizue and T. Hashizume, "Interface state properties of Al<sub>2</sub>O<sub>3</sub>/n-GaN prepared by atomic layer deposition", International Meeting for Future of Electron Devices, Kansai (IMFEDK), Osaka, May 13- 14, 2010.
9. K. Sugawara, T. Kubo, H. Taketomi, H. Miyake, K. Hiramatsu and T. Hashizume, "Characterization of Schottky interface properties and deep levels of Al<sub>x</sub>Ga<sub>1-x</sub>N (0.25<x<0.68) grown by MOVPE", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
10. K. Ohi and T. Hashizume, "Multi-Mesa-Channel Structure for Improvement of Gate Controllability and Current Stability in AlGaN/GaN HEMTs", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
11. E. Ogawa and T. Hashizume, "Mg accumulation and defect formation at p-GaN surfaces caused by a high-temperature annealing", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
12. C. Mizue, Y. Hori, M. Miczek and T. Hashizume, "Characterization of interface electronic states in ALD-Al<sub>2</sub>O<sub>3</sub>/AlGaN/GaN structures", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
13. M. Tajima and T. Hashizume, " Correlation between surface leakage current and operation degradation of AlGaN/GaN HEMTs", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
14. T. Kubo, K. Sugawara, H. Taketomi, H. Miyake, K. Hiramatsu and T. Hashizume, "Chemical and Electronic Properties of MOVPE-grown Al<sub>x</sub>Ga<sub>1-x</sub>N Surfaces (0.25 < x < 0.68)", 8th International Conference on Nitride Semiconductors (ICNS-8), Oct. 18-23, 2009, Jeju, Korea.
15. Y. Hori, C. Mizue, K. Ooyama, M. Miczek and T. Hashizume, "Chemical and electronic properties of ALD-Al<sub>2</sub>O<sub>3</sub>/AlGaN interfaces", 2009 International Conference on Solid-State Devices and Materials (SSDM2009), Sendai, Oct. 7-8.
16. N. Harada, N. Shiozaki, and T. Hashizume, "Electrochemical oxidation of GaN for surface control of GaN-based device structures, 2009 International Conference on Solid-State Devices and Materials (SSDM2009), Sendai, Oct. 7-8.
17. K. Ooyama, C. Mizue, Y. Hori and T. Hashizume, "Interface characterization of Al<sub>2</sub>O<sub>3</sub>/n-GaN structure prepared by atomic layer deposition", 2009 Asia-Pacific Workshop on Fundamental and Application of Advanced Semiconductor Devices (AWAD 2009), Jun. 24-26, 2009, Busan, Korea.
18. E. Ogawa and T. Hashizume, "Effects of high-temperature anneal on surface properties of

- Mg-doped GaN", 2009 International Meeting for Future of Electron Devices, Kansai (IMFEDK), Osaka, May 14- 15, 2009.
19. T. Kimura and T. Hashizume, " Characterization of GaN surfaces after high-temperature annealing and carbon diffusion", 2008 Asia-Pacific Workshop on Fundamental and Application of Advanced Semiconductor Devices (AWAD 2008), Jul. 9-11, 2008, Sapporo.
  20. K. Ohi, T. Tamura, J. Kotani and T. Hashizume, "Mesa-gate AlGaIn/GaN HEMTs having narrow-width channels", 2008 International Conference on Solid-State Devices and Materials (SSDM2008), Tsukuba, Sep. 21-23.
  21. K. Sugawara, J. Kotani and T. Hashizume, "Near-midgap deep levels in MOVPE-grown AlGaIn", 2008 International Conference on Solid-State Devices and Materials (SSDM2008), Tsukuba, Sep. 21-23.
  22. Nanako Shiozaki, Taketomo Sato, Tamotsu Hashizume, "Control of Electronic States at n-GaN Surfaces by Photoelectrochemical Oxidation in Glycol Solution", 2008 International Workshop on Nitride Semiconductors (IWN-2008), Montreux, Switzerland, Oct. 5- 10, 2008.
  23. Takshi Kimura and Tamotsu Hashizume, "Impurity incorporation and Ga outdiffusion at n-GaN surfaces during high-temperature annealing processes", 2008 International Workshop on Nitride Semiconductors (IWN-2008), Montreux, Switzerland, Oct. 5- 10, 2008.
  24. Chihoko Mizue and Tamotsu Hashizume, "Depletion layer modulation at the Al<sub>2</sub>O<sub>3</sub>/n-GaN interface under UV-illumination", 2008 International Workshop on Nitride Semiconductors (IWN-2008), Montreux, Switzerland, Oct. 5- 10, 2008.
  25. Eri Ogawa and Tamotsu Hashizume, "Variation of Mg density and conductivity at p-GaN surfaces caused by high-temperature anneal", 2008 International Workshop on Nitride Semiconductors (IWN-2008), Montreux, Switzerland, Oct. 5- 10, 2008.
  26. Masafumi Tajima and Tamotsu Hashizume, "Impacts of Surface of Oxidation and Oxynitridation on DC Characteristics of AlGaIn/GaN HEMTs", 2008 International Workshop on Nitride Semiconductors (IWN-2008), Montreux, Switzerland, Oct. 5- 10, 2008.
  27. Takahiro Tamura, Junji Kotani, Seiya Kasai, Tamotsu Hashizume, "Highly Thermal Stability of Drain Current in Multi-Mesa-Gate AlGaIn/GaN HEMTs", The 34th International Symposium on Compound Semiconductors (ISCS-34), Oct. 15-18, 2007, Kyoto.
  28. T. Kimura and T. Hashizume, "Effects of carbon diffusion on electrical and optical properties of n-GaN", 7th International Conference on Nitride Semiconductors (ICNS-7), Sep. 16-21, 2007, Las Vegas, USA.
  29. M. Tajima, A. Basile, J. Kotani, T. Hashizume, "Operation Robustness of AlGaIn/GaN HEMTs with an Ultrathin-Al-Layer Based Surface Control", 7th International Conference on Nitride Semiconductors (ICNS-7), Sep. 16-21, 2007, Las Vegas, USA.
  30. N. Shiozaki, F. Ishikawa, A. Trampert, H. T. Grahn, T.Hashizume, "High-quality native oxide of GaN for surface passivation formed by photo-enhanced electrochemical process", 7th International Conference on Nitride Semiconductors (ICNS-7), Sep. 16-21, 2007, Las Vegas, USA.
  31. E. Ogawa, M. Sugimoto, T. Kachi, T. Uesugi, N. Soejima, T. Hashizume, "Correlation between chemical and electrical properties of p-GaN surfaces subjected to halogen-based plasma", 7th

International Conference on Nitride Semiconductors (ICNS-7), Sep. 16-21, 2007, Las Vegas, USA.

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33. M. Miczek, C. Mizue and T. Hashizume, "The effects of interface states on C-V behavior of insulated gates on AlGa<sub>N</sub>/Ga<sub>N</sub> heterostructures", 7th International Conference on Nitride Semiconductors (ICNS-7), Sep. 16-21, 2007, Las Vegas, USA.
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36. T. Kimura and T. Hashizume, "Carbon diffusion into Ga<sub>N</sub> using Si<sub>N<sub>x</sub></sub>/CN<sub>x</sub> bilayer structure prepared by ECR-CVD", 2007 International Meeting for Future of Electron Devices, Kansai (IMFEDK), Oosaka, April 24 - 25, 2007.
37. C. Mizue, J. Kotani, M. Miczek, T. Hashizume, "Interface state characterization of insulating gates on AlGa<sub>N</sub> layers and AlGa<sub>N</sub>/Ga<sub>N</sub> heterostructures", 2007 International Meeting for Future of Electron Devices, Kansai (IMFEDK), Oosaka, April 24 - 25, 2007.
38. J. Kotani, M. Tjima, S. Kasai and T. Hashizume, "Analysis of lateral surface leakage in the vicinity of Schottky gates in AlGa<sub>N</sub>/Ga<sub>N</sub> HEMTs", 65th Annual Device Research Conference (DRC-65), University of Notre Dame, South Bend, IN on June 18-20, 2007.
39. N. Shiozaki and T. Hashizume, "Characterization of thin native-oxide layer formed on Ga<sub>N</sub> by photoelectrochemical process in glycol solution", 17th International Vacuum Congress (IVC-17), 13th International Conference on Surface Science (ICSS-13), International Conference on Nano Science and Technology (ICN+T 2007), Jul. 2-6, 2007, Stockholm, Sweden.
40. J. Kotani and T. Hahsizume, "Characterization of deep levels in MOVPE-grown AlGa<sub>N</sub> by capacitance transient spectroscopy", 17th International Vacuum Congress (IVC-17), 13th International Conference on Surface Science (ICSS-13), International Conference on Nano Science and Technology (ICN+T 2007), Jul. 2-6, 2007, Stockholm, Sweden.
41. C. Mizue, T. Matsuyama, J. Kotani, M. Miczek and T. Hashizume, "AlON insulated-gate structure on AlGa<sub>N</sub> prepared by ECR-CVD using an aluminum-ethoxide source", 17th International Vacuum Congress (IVC-17), 13th International Conference on Surface Science (ICSS-13), International Conference on Nano Science and Technology (ICN+T 2007), Jul. 2-6, 2007, Stockholm, Sweden.