東北大学 電気通信研究所

研究室外部評価資料

(2013 年度-2018 年度)

Activity Report of Research Laboratory for External Review

April 2013 - March 2019
(FY.2013-2018)

Research Institute of Electrical Communication
Tohoku University

誘電ナノデバイス研究室

Dielectric Nano-Devices

April 2013 - March 2019 (FY. 2013-2018)

A. 研究室名 / Research Laboratory

誘電ナノデバイス研究室
Dielectric Nano-Devices

B. 構成員 / Faculty and Research Staff (as of May 1, 2019)

※ 欄を適宜追加削除等調整して下さい．期間内に異動等があった場合には，在籍期間を記載して下さい．

教授 / Professor	
氏名 Name	長 康雄 Yasuo Cho (April 2001 -)
分野名 Research Field	誘電ナノデバイス研究分野 Dielectric Nano-Devices
准教授 / Associate Professor	
氏名 Name	山末 耕平 Kohei Yamasue (July 2016 -)
分野名 Research Field	誘電ナノ物性計測システム研究分野 Nanoscale dielectric measurement systems
助教 / Assistant Professor	
氏名 / Name	平永 良臣 / Yoshiomi Hiranaga (October 2006 -) 山末 耕平 / Kohei Yamasue（April 2010 - June 2016） 山岸 裕史 / Yuji Yamagishi (April 2017 -May 2018)
他 / Others	
	科研費研究員: 1 名 (November 2015 - February 2016)

C. 研究目的 / Research Purpose

本研究室は、ナノテクノロジーを駆使して、電子材料の誘電計測に関する研究の発展を図ることと、その成果を高性能次世代電子デバイスの開発へ応用することを目的としている。

Aaim and target of our research group are developing the research on the dielectric measurement of electronic materials using nano-technologies and applying its fruits to high-performance next generation electronic devices.

D. 主な研究テーマ / Research Topics

1. 超高分解能（原子分解能を持つ）走査型非線形誘電率顕微鏡
2. 新規半導体素子のドーパントプロファイル計測
3. 局所 DLTS 法を用いた絶縁膜/半導体界面の研究
4. 非線形誘電率顕微鏡を用いた強誘電材料・圧電材料の評価の研究
5. 非線形誘電率顕微法を用いた超高密度誘電体記録の研究

1. Scanning nonlinear dielectric microscope (SNDM) with super high (atomic-scale) resolution.
2. Visualization of dopant profile in semiconductor devices using SNDM.
3. Investigation of interface quality at the insulator/semiconductor interface using local-DLTS.
4. Evaluation of ferroelectric material and piezoelectric material using SNDM.
5. Ultra-high density ferroelectric data storage using SNDM.

E. 学術論文等の編数 / The Number of Research Papers							
	2013	2014	2015	2016	2017	2018	Total
(1) 査読付学術論文 Refereed journal papers	3	8	5	7	8	4	35
(2) 原著論文と同等に扱う 査読付国際会議発表論文 Full papers in refereed conference proceedings equivalent to journal papers	0	0	0	0	1	0	1
(3) 査読付国際会議 Papers in refereed conference proceedings	15	22	29	19	25	32	142
(4) 査読なし国際会議・シンポジウム等 Papers in conference proceedings	0	0	0	0	0	0	0
(5) 総説・解説 Review articles	0	0	2	1	2	1	6
(6) 査読付国内会議 Refereed proceedings in domestic conferences	2	3	7	3	4	4	23
(7) 査読なし国内研究会・講演会 Proceedings in domestic conferences	11	17	18	16	15	13	90
(8) 著書 Books	1	1	0	0	0	0	2
(9) 特許 Patents	0	0	0	0	0	0	0
(10) 招待講演 Invited Talks	3	5	5	5	5	5	28

F. 特筆すべき研究成果 / Significant Research Achievements (FY.2013-2018)

See Ref. 1.　"#" mark indicates research carried out at a former organization.

2013-2018 年度の研究成果（論文・特許など）のうち，前半（2013-2015 年度）と後半（2016-2018 年度）それぞれで代表的な数件（2-3 件程度ずつ）について，参考資料を引用して，その特徴と学術的意義などを簡単に紹介する．英文のみ，もしくは和文と英文で記載．
要約は 300 字程度．論文誌の要約/Abstract のコピー可．学術面での国際的インパクトならびに社会的影響を 100 字程度で記載．
必ずしも当該期間内に発表・出版したものに限るのではなく，例えば過去に発表したものでもこの期間内に成果が得られたり，評価されるようになったりしたものも含むものとする．
インパクトファクターや被引用件数など，できる限り第三者が定量的に評価できる指標を用いてアピールすること．それらの指標にはそぐわない場合には，その事情とそれに変わる適当な評価指標・尺度を示すこと．

[2013-2015]

1. Kohei Yamasue, and Yasuo Cho "Scanning nonlinear dielectric potentiometry", REVIEW OF SCIENTIFIC INSTRUMENTS, Vol.86, pp. 093704-1-8, 2015 [IF: 1.336]

Abstract: Measuring spontaneous polarization and permanent dipoles on surfaces and interfaces on the nanoscale is difficult because the induced electrostatic fields and potentials are often influenced by other phenomena such as the existence of monopole fixed charges, screening charges, and contact potential differences. A method based on tip-sample capacitance detection and bias feedback is proposed which is only sensitive to polarization- or dipole-induced potentials, unlike Kelvin probe force microscopy. The feasibility of this method was demonstrated by simultaneously measuring topography and polarization-induced potentials on a reconstructed Si(111)-(7 × 7) surface with atomic resolution.

International impact on both academic and social aspects: In this article, we proposed new potentiometory method termed scanning nonlinear dielectric potentiometry (SNDP) to the quantitative, nanoscale measurement of electrostatic potentials induced by spontaneous polarization or permanent dipoles on surfaces and interfaces. This method is selectively sensitive to spontaneous polarization and permanent dipoles rather than the contact potential difference (CPD) and fixed monopole charges, which cannot be distinguished by Kelvin probe force microscopy (KPFM).

2. Kohei Yamasue, Hirokazu Fukidome, Kazutoshi Funakubo, Maki Suemitsu, and Yasuo Cho "Interfacial Charge States in Graphene on SiC Studied by Noncontact Scanning Nonlinear Dielectric Potentiometry", PHYSICAL REVIEW LETTERS, Vol.114pp. 226103-1-5, 2015 [IF: 8.839]

Abstract: We investigate pristine and hydrogen-intercalated graphene synthesized on a 4H-SiC(0001) substrate by using noncontact scanning nonlinear dielectric potentiometry (NC-SNDP). Permanent dipole moments are detected at the pristine graphene-SiC interface. These originate from the covalent bonds of carbon atoms of the so-called buffer layer to the substrate. Hydrogen intercalation at the interface eliminates these covalent bonds and the original quasi-(6×6) corrugation, which indicates the conversion of the buffer layer into a second graphene layer by the termination of Si bonds at the interface. NC-SNDP images suggest that a certain portion of the Si dangling bonds remains even after hydrogen intercalation. These bonds are thought to act as charged impurities reducing the carrier mobility in hydrogen-intercalated graphene on SiC.

International impact on both academic and social aspects:　This is a first demonstration of the application of noncontact scanning nonlinear dielectric potentiometory (NC-SNDP) to reveal the interfacial charge (especially interfacial dipole moment) state. NC-SNDP imaging suggested the presence of permanent dipole moments at the interface of pristine mono layer graphene (MLG) on a 4H-SiC(0001) substrate. These dipoles are formed by C atoms covalently bonded to the substrate. Upon hydrogen intercalation, the quasi-(6×6) corrugations disappear, the topmost graphene layer is relaxed, assuming an extremely flat shape, and the dipole moments vanish.

These results indicate that the buffer layer becomes a second graphene layer and the Si dangling bonds are terminated by hydrogen, as expected. NC-SNDP images also suggest that some of the Si dangling bonds remain even after hydrogen intercalation. These bonds are believed to act as charged impurities significantly affecting electronic transport in hydrogen-intercalated graphene on SiC. These results indicate that the NC-SNDP is a first successful technique which can reveal the potential distributions induced by atomic scale dipole moment only.

[2016-2018]

3. Yasuo Cho "High resolution characterizations of fine structure of semiconductor device and material using scanning nonlinear dielectric microscopy" Jpn. J. Appl. Phys., Vol.56. pp.100101-1-10, 2017. [IF: 1.471]

Abstract: Scanning nonlinear dielectric microscopy (SNDM) can easily distinguish the dopant type (PN) and has a wide dynamic range of sensitivity from low to high concentrations of dopants, because it has a high sensitivity to capacitance variation on the order of 10^{-22} F/$\sqrt{Hz}$. It is also applicable to the analysis of compound semiconductors with much lower signal levels than Si. We can avoid misjudgments from the two-valued function (contrast reversal) problem of d*C*/d*V* signals. Under an ultrahigh-vacuum condition, SNDM has atomic resolution. As the extended versions of SNDM, super-higher-order SNDM (SHO-SNDM), local-deep-level transient spectroscopy (local-DLTS), noncontact SNDM (NC-SNDM), and scanning nonlinear dielectric potentiometory (SNDP) have been developed and introduced. The favorable features of SNDM originate from its significantly high sensitivity.

International impact on both academic and social aspects: This paper is an Invited Review Paper reviewing the high-resolution characterization of fine structures of semiconductor devices and materials using SNDM and its extended versions. First, the principle of SNDM was described, in which the mechanism underlying the high sensitivity of the order of 10^{-22} F/$\sqrt{Hz}$ was revealed. Also, characterization results for some semiconductor devices were introduced. Then, many newly developed SNDM methods (SHO-SNDM, local-DLTS, NC-SNDM, and SNDP) were briefly introduced and their applications to the characterization of several semiconductor devices and materials were described. The good measurement results indicate that SNDM and its extended methods are very powerful tools for the measurement of semiconductor devices and materials. Therefore, international impact on academic field and influence on society of this paper are very large.

4. Norimichi Chinone, and Yasuo Cho "Local deep level transient spectroscopy using super-higher-order scanning nonlinear dielectric microscopy and its application to imaging two-dimensional distribution of SiO2/SiC interface traps" J. Appl. Phys., Vol.122, pp105701-1-9, 2017 [IF:2.328]

Abstract: We propose a new technique called local deep level transient spectroscopy (local-DLTS), which utilizes scanning nonlinear dielectric microscopy to analyze oxide/semiconductor interface traps, and validate the method by investigating thermally oxidized silicon carbide wafers. Measurements of *C*-*t* curves demonstrate the capability of distinguishing sample-to-sample differences in the trap density. Furthermore, the DC bias dependence of the time constant and the local-DLTS signal intensity are investigated, and the results agree to characteristic of interface traps. In addition, the D_{it} values for the examined samples are estimated from the local-DLTS signals and compared with results obtained using the conventional high-low method. The comparison reveals that the D_{it} values obtained by the two methods are of the same order of magnitude. Finally, two-dimensional (2D) distributions of local-DLTS signals are obtained, which show substantial intensity variations resulting in random 2D patterns. The 2D distribution of the local-DLTS signal depends on the time constant, which may be due to the coexistence of multiple types of traps with different capture cross sections.

International impact on both academic and social aspects: A new technique called local-DLTS, which employs SNDM to analyze oxide/semiconductor interface traps has been proposed. The utility of the method was demonstrated. Similar to conventional DLTS, the proposed method measures capacitance transients generated in response to an applied pulse voltage. The measured *C*–*t* curves demonstrated the capability of distinguishing sample-to-sample differences in the trap density. Then, 2D distributions of the D_{it} were obtained, which showed substantial deviations in intensity that manifested as random 2D patterns. This implies that interface traps are inhomogeneously distributed at SiO_2/SiC interfaces. In addition, the 2D distributions depended on the time constant even though the feature sizes did not change, which may be due to the coexistence of multiple types of traps with different capture cross sections. These results show that local-DLTS is capable of measuring interface traps with high lateral resolution and is promising for acquiring microscopic lateral distributions with separated time constants. Lateral distributions of traps are expected to provide a wealth of information for identifying the physical origin of traps. Therefore, this newly proposed local-DLTS is a promising method to investigate MOS interfaces very precisely.

G. 特筆すべき活動 / Significant Activities (FY.2013-2018)

See Ref. 2-9. “#” mark indicates research carried out at a former organization.

研究室外部評価参考資料の 2 以降を参照しながら，2013-2018 年度のなどの活動の中から特筆すべきものを取り出し，前半（2013-2015 年度）と後半（2016-2018 年度）に分けて簡単に紹介する．英文のみ，もしくは和文と英文で記載.

[2013-2015]

1. Activities on committees of academic societies.

- Program committee member of Ferroelectric Materials and their Application (FMA) (FY 2006-) .
- Japan-Korea Conference on Ferroelectricity Organizing Committee (FY 2006-)

2. Editor and reviewer for academic journals.

- IEEE Transactions on Circuits and Systems II
- Journal of Vibration and Control
- Langmuir
- Applied Physics Letters ---etc.

3. Instruction and education for industry

- Hitachi High tech science
- Denso
- Toshiba
- ASRC
- Toyota motor co.

[2016-2018]

1. Activities on committees of academic societies.

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