Development of Novel Functional Si-based Devices Using Self-assembled Nanostructures for Multivalued Memory Operation, Ultimate Photo-sensing and Molecular Recognition

Seiichi Miyazaki(Professor, Graduate School of Advanced Sciences of Matter),
Mitsuhisa Ikeda (RCNS Researcher), Yudi Darma (Graduate School of Advanced Sciences of Matter, D2),
Taku Shibaguchi (Graduate School of Advanced Sciences of Matter, M1),
Seiichiro Higashi (Assoc. Prof., Graduate School of Advance Science of Matter),
Hideki Murakami (Research Associate, Graduate School of Advance Science of Matter)

1. Research Target

The serious limitations in down-sizing conventional MOS devices motivate us to develop novel functional devices operating with a few electrons and a few photons by means of an introduction of well-defined Si nanostructures into the MOS devices.

In this project, for the advanced information processing with a few electrons and photons, we focus attention on the device application of unique physical properties of Si nanocrystals associated with quantum size effects [1-2]and coulomb brocade [3] and have intensively studied MOSFETs with quantum dots (QDs) as a floating gate [4,5] which operate even at room temperature and low voltages. Based on a deep understanding of the multivalued capability of the QDs-floating-gate, we also plan to design and fabricate optically or chemically coupling QDs-floating-gate MOSFETs. For the optically coupling devices, the gate stack structures consisting of a semitransparent metal gate, a gate dielectric with a high dielectric constant (high-k), a QDs-floating gate and the bottom tunneling oxide will be investigated to achieve operations critical to the input of a few photons. And for the chemically coupling devices, porous metal gate will be combined with a high-k dielectric as control gate insulator to selectively adsorb specific molecules on the high-k gate dielectric.

In addition, from viewpoints of the synthesis of new tailor-made electronic materials, we will extend our research work to three dimensionally stacked structures of Si-based dots with a high areal density to control unique transport properties originating from electronic coupling among neighboring dots.

Major research issues are as follows:

1. Development of process technologies to control precisely the dot size, its distribution and position and fabrication of well-ordered array and high density stacked structures of dots
2. Characterization of carrier transport through coupling dots
3. Control of energy band structures with an introduction of Ge core to Si dots
4. Valence control with impurity doping to Si-based dots
5. Fabrication and characterization of QDs-floating-gate MOSFETs for multivalued operation, high photosensitive performance and molecular recognition

2. Research Results

2.1 Self-assembling Formation of Si-QDs by Low Pressure CVD

We have demonstrated that hemispherical single-crystalline Si-QDs with a fairly uniform size distribution and a high areal density (~10^{12}cm^{-1}) can be spontaneously formed on thermally-grown SiO_2 layers by controlling the early stages of LPCVD using a SiH_4 gas [6]. The temperature dependences of the areal dot density and the dot size in the early stages of LPCVD in the range of 560-700°C have shown that, for the dot formation on clean as-grown SiO_2, the Si-O bond breaking plays a role in the creation of nucleation sites and the dot size is rate-limited by the SiH_4 decomposition on Si and Si cohesive action. In addition, it has been found that surface Si-OH bonds if any act as reactive sites during LPCVD to efficiently promote the dot formation. Also, the SiH_4 pressure dependence of the areal dot density at 560°C show that, in the pressure region below 0.1Torr, a reduction in the SiH_4 pressure causes a marked decrease in the dot density, especially on as-grown SiO_2, suggesting that the thermal decomposition of small Si clusters before reaching the critical size for stable nucleation growth becomes significant under a low SiH_4 flux. The result indicates that, to obtain high selectivity of Si dot nucleation between as-grown and OH-terminated surfaces, the suppression of the spontaneous nucleation on as-grown SiO_2 is of great importance and the control of the SiH_4 pressure during LPCVD is one of critical factors. The formation of spherical Si QDs with a Ge core is also succeeded by controlling the selective deposition conditions in LPCVD using alternately SiH_4 and GeH_4.

2.2 Positioning of Si-QDs on SiO_2

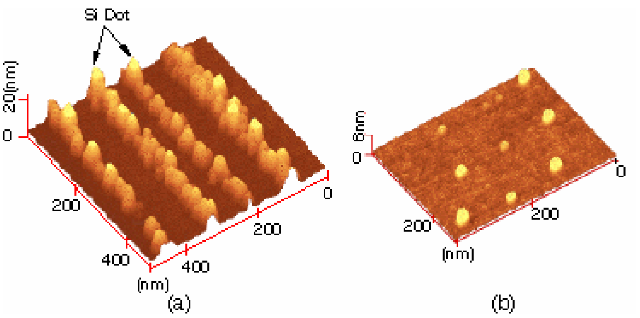
Based on the better understanding of the Si dot formation mechanism, the spatial control of OH termination on SiO_2 leads into positioning the nucleation site. In fact, the chemical or electrochemical surface modification on a nanometer scale by using AFM/STM probe techniques enables us to make regular arrays of Si dots as shown in Fig. 1, where the as-grown SiO_2 surface just before LPCVD was exposed to the electron beam from the a Pt (20%Ir) STM tip in H_2 ambient of 1x10^{-5}Pa[7]. Since H atoms are adsorbed on the clean Pt-tip surface through dissociative adsorption even at room temperature and emitted under a high electric field between the tip and the sample surface, reactive sites such as Si-H and Si-OH bonds are formed efficiently.

2.3 Evaluation of Charged States in Si-QDs

We have demonstrated that charges retained in the single Si dot covered with ultrathin SiO_2 are directly quantified from the change in the surface potential of Si dots induced by electron injection or emission through ultrathin SiO_2 as measured with an AMF/Kelvin probe technique [8]. For the Si dots in the range of 4.3-13nm in dot height, stable retention of single electron in each dot on 4nm-thick SiO_2 was confirmed from the comparison between measured surface potential changes on the charged dots with the calculated results in the equivalent circuit mode. For Si-QDs with a Ge core, we have also found that electrons and holes are retained in the Si clad and the Ge core, respectively as predictive in the type II band discontinuity between the Si clad and the Ge core.

2.4 Characteristics of MOS Capacitors with Si-QDs as a Floating Gate

Capacitance-voltage (C-V) and current-voltage (I-V) characteristics of Si QDs floating gate MOS capacitors exhibit unique hystereses which arise from charging and discharging in the Si QDs through the bottom tunnel oxide as shown in Fig. 2. For the case on p-Si(100) with an acceptor concentration of $3x10^{16}cm^{-1}$, the C-V curve measured from –3V to 3V is almost identical to the C-V curves for the case of uncharged Si-QDs floating gate. Similarly, the C-V curve measured from +3V to –3V for the case on n-Si(100) with an donor concentration of $1x10^{15}cm^{-1}$, is almost identical to the C-V curve for the uncharged floating gate. In both cases, a flat-band voltage shift of ~0.27V is observed and the capacitance peak, which is due to the emission of remaining charges to the substrate as seen in I-V characteristics, is measured around the corresponding flat-band voltage, namely the voltage separation of the peaks agrees well with the value expected from the difference in the Fermi level between p-Si(100) and n-Si(100). The results indicate that the dots act as memory nodes. In other words, we can rule out the contribution of traps with specific energy levels to the measured C-V hystereses. I-V characteristics shows multiple-step electron charging (or discharging) characteristics of the Si-dot floating gate are observable, suggesting that Coulombic force arising from charged dots efficiently suppresses the electron charging of neighboring neutral dots. When the floating gate consists of double-stacked dots instead of a single dot layer, the retention characteristics are improved significantly with keeping the tunneling oxide thickness constant for a high writing speed as represented in Fig. 3.



(a) (b)

Fig. 1 AFM image obtained after Si dot formation at 560ºC on the SiO_2 surface modified with spot and densely lined patterns by the STM tip. In the STM surface modification prior to LPCVD, the tip bias was applied at -10V with respect to the substrate.

2.5 Characteristics of Si-QDs Floating Gate nMOSFETs

Based on the characteristics of MOS capacitors with the Si-QDs floating gate, n-MOSFETs with adoubly-stacked Si-QDs floating gate. The drain current-gate voltage (I_d-V_g) curves show characteristics hysteresis arising from electron charging and discharging of the Si-QDs floating gate (Fig. 4). Distinct current bumps, which were observed in ramping up the gate voltage after complete discharging at -4V, indicate the multi-step electron charging to the Si-QDs floating gate caused by the Coulomb blockade effect. Considering that, in the region of 0-0.5V, a new current component emerges with increasing sweep rate, four steps of electron injection to the Si-QDs floating gate with an areal dot density of ~$6x10^{11}cm^{-2}$ are confirmed. In addition, the threshold voltage shift at each charging steps is not equal to that of the next charging step and slightly increase with progressive electron charging. This implies

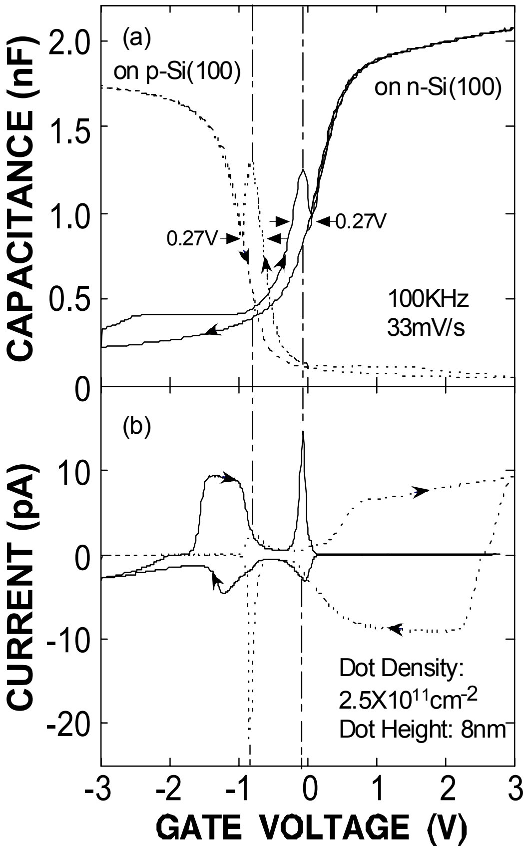


Fig. 2 Capacitance-voltage (a) and current-voltage (b) characteristics of Si-QDs floating gate MOS capacitors fabricated on p-Si(100) and n-Si(100).

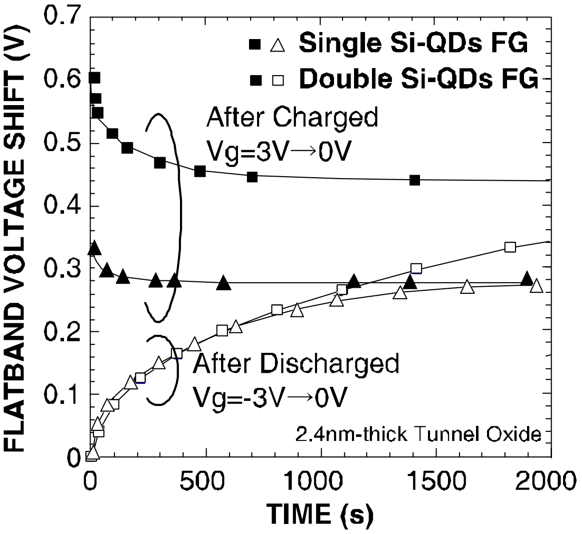


Fig. 3 Retention characteristics of MOS capacitors with the floating gate consists of double-stacked and a single-layer Si QDs.

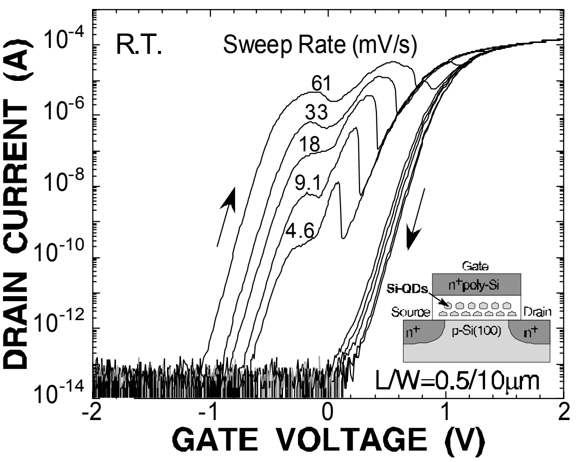


Fig. 4 Drain current vs gate voltage characteristics of a Si-QDs floating gate MOSFET, which were measured after fully discharged at a gate bias of -4V. The drain voltage was 50mV. The voltage sweep rate was changed in the range from 4.6 to 61mV/s. A cross-sectional view of a Si-QDs floating gate MOSFET is illustrated in the inset.

that the Coulomb interaction from the neighboring charged QDs play a subsidiary role on the electron tunneling form the channel to the Si-QDs. In other words, this can be interpreted in terms that the charging energy of the Si-QDs depends on not only charged states of individual Si QDs but also charged states of neighboring QDs. In general, since the charging time of the Si-QDs floating gate strongly depends on the gate voltage, faster the sweep rate is, higher the gate voltage for the charge injection becomes. In fact, with increasing sweep rate, the current bumps appear at higher gate voltages. Besides, the results of Fig. 4 implies that the charging voltage is affected by the redistribution of electrons in the Si-QDs floating gate during the gate voltage sweep as discussed later. Multi-step electron injection to the Si-QDs floating gate is also clearly seen in the temporal change in the drain current (I_d-t) at constant gate biases after complete discharging of the Si-QDs floating gate (Fig. 5). The threshold voltage after each current step corresponds to that of the scanned I_d-V_g characteristics. The distinct metastable state, in which the drain current is almost constant with respect to holding time, indicate that the total amount of effective charge in the Si-QDs floating gate remains unchanged in each of the metastable states. This result suggests that electron injected in the Si-QDs floating gate redistribution during each metastable state to reduce the effect of the Coulomb interaction among the charged QDs, namely to decrease the charging energy of QDs. The temperature dependence of Id-t characteristics measured at a fixed gate voltage show that a decrease in temperarture decelerates the electron charging and prolongs the metastable states, suggesting that the tunneling probability is increased with temperature for redistribution of electrons in theSi-QDs floating gate (Fig. 6). When the charging time (Δt_1 and Δt_2) and metastable time (Δt_3) are defined with a linearly extrapolation method and their reciprocal values are summarized in Arrehnius plots, the activation energy determined from the slope of the Arrehnius plot is found to be in the range of 0.23-0.31eV(Fig. 7). Base on the estimation of the sum of quantized and charging energies for QDs, we found that the obtained activation energy is almost equal to the energy separation between states for tunneling in QDs. It is likely that the electron tunneling between different energy states plays an important role on the observed multiple-step charging characteristics.

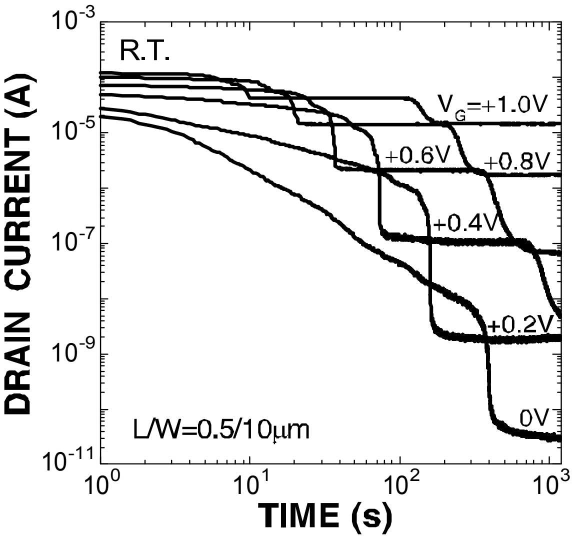


Fig. 5 Temporal change in drain current at various gate biases and a drain voltage of 50mV after complete discharging of a Si-QDs floating gate at a gate voltage of -4V.

The influence of light irradiation on electron injection characteristics in Si-QDs floating gate has also been studied.

The temporal changes of drain current (I_d-t) measured at constant gates in dark and under light irradiation were

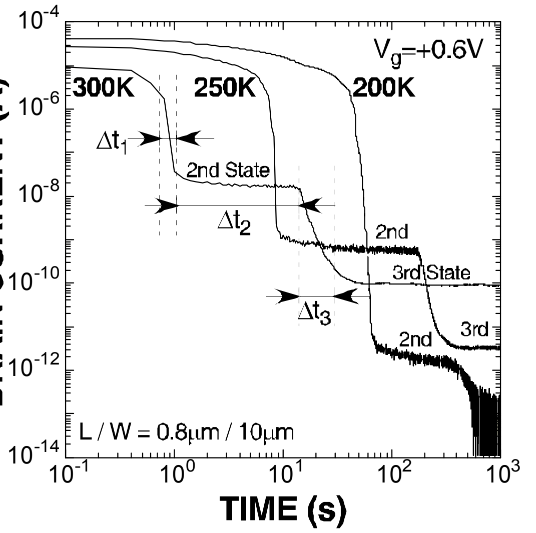


Fig. 6 Temperature dependence of I_d-t characteristics at a gate bias of 0.6V after complete discharging under the same condition of Figs 4 and 5. The drain voltage was 50mV. The definition of characteristics time (Δt_1, Δt_2 and Δt_3) is demonstrated in the curve at 300K.

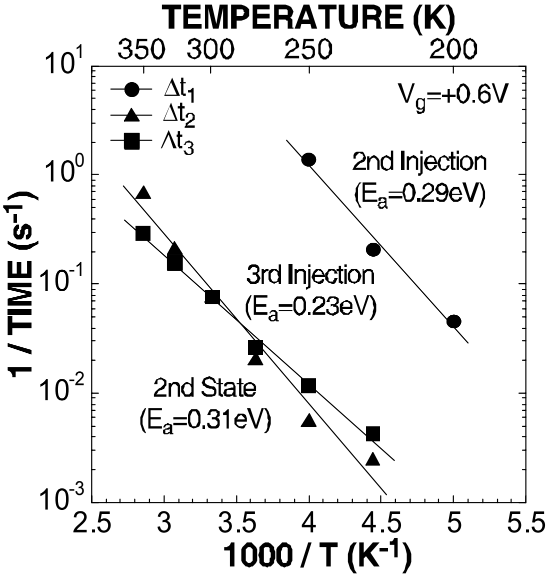


Fig. 7 Arrehnius plots of 2nd injection (Δt_1) and 2nd state (Δt_2) and 3nd injection (Δt_3) times from I_d-t characteristics.

compared as shown in Fig. 8. Although the current level is increased by 1.59eV light irradiation due to the photogenerated electron contribution, multistep electrion charging of the Si-QDs floating gate and a metastable state, in which a slight decrease in the drain current is observable, are still clearly observed as in the case measured in dark. Obviously, 1.59eV light irradiation promotes electron injection to the Si-QDs and reduces the period of the metastable charged state. Notice that when the light irradiation was turned off in the stable state achieved under light irradiation, the drain current coincides with the current level of the stable state obtained in dark. This indicates that the same amount of charges were injected finally into the Si-QDs floating gate in both cases under light irradiation and in dark condition. In other words, no excess electrons over a thermally equivalent level in dark is not injected to the dots under this light irradiation, which implies sufficient energy separation between the charged state and the next. We also found that the electron injection speed at the transition from the metastable charged state to the finally stable charged state is unlikely to be accelerated with increasing photon flux (Fig. 9) and in the photon energy (Fig. 10) although the time to the final stable state becomes shorter with higher photon flux and/or higher photon energy. The result implies that the light irradiation mainly accelerates the temporal change in the charging during the metastable charged states to trigger the transition to the final stable state. During the I_d-t measurement, when light irradiation was turned off in the early stages of metastable charged states, the drain current quickly decreases to some current level once and recovered partly due to the electron emission from the dots and then followed by the temporal change in dark (Fig. 11). Since the electron emission becomes hardly observed with the time spending in metastable states, the redistribution of electrons in the Si-QDs proceeds during the metastable charged state to further election injection Based on these results, we can suggest that the light irradiation plays an important role on the redistribution of electrons in the Si-QDs floating gate. Considering the fact that, by irradiation of photons with a sub-gap energy (0.8eV, 7×10^{17}cm^{-2}s^{-1}), no significant promotion in electron charging is observable, the contribution of the photoexcitation effect of injected electrons in the Si-QDs to the electron redistribution in the floating gate can be ruled out. The generation of hot electrons in channel with visible light irradiation is thought to be a crucial factor for the shorten metastable state, in which the electron tunneling

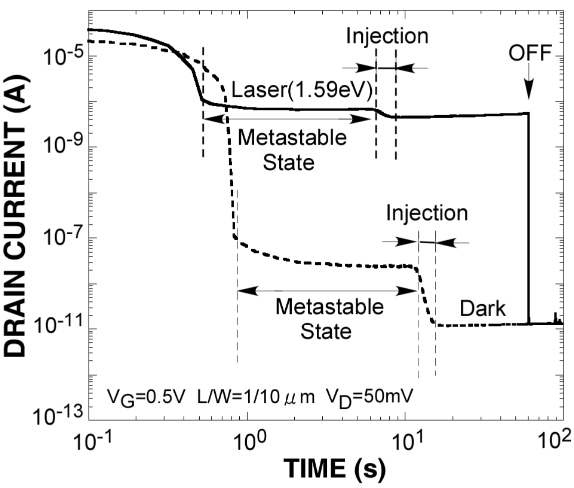


Fig. 8 Temporal changes in the drain current measured at V_g =0.5V under irradiation of 780nm (1.59eV) light and dark condition after complete discharging of the Si-QDs floating gate at $V_g = -4$V. Electron charging to the Si-QDs floating gate causes the threshold voltage shift resulting in the decrease in I_d.

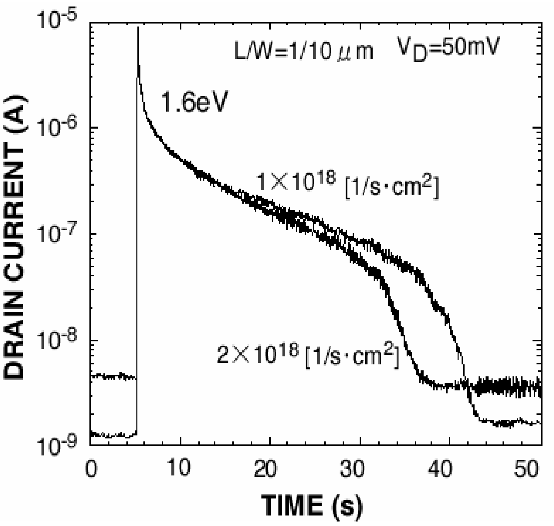


Fig. 9 The temporal changes in the drain current measured at V_G=0V under 1.59eV light irradiation with photon fluxes of 1x10^{18} and 2x10^{18} cm^{-2}/s after complete discharging of the Si-QDs floating gate at V_g=−4V.

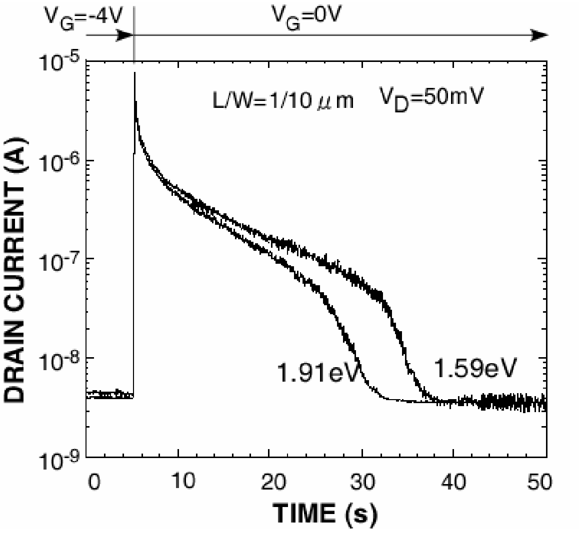


Fig. 10 The temporal changes in the drain current measured at V_g =0V under light irradiation of 1.59eV and 1.91eV photons with the same flux after complete discharging of the Si-QDs floating gate at V_g =−4V.

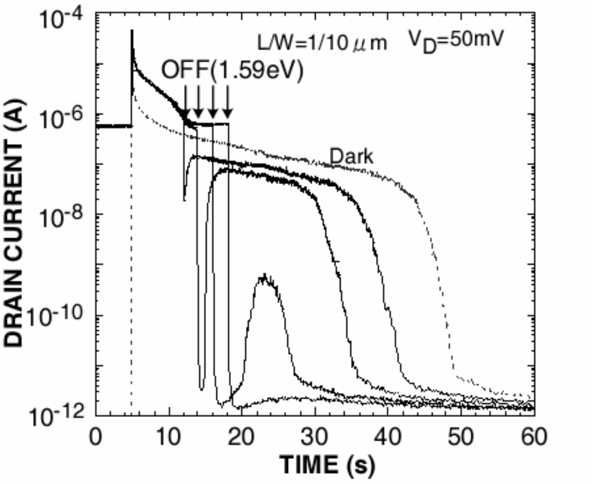


Fig. 11 Temporal change in the drain current, which was measured at V_g =0V when the 1.59eV light irradiation was turned off at various time as indicated by arrows. The result obtained without light irradiation anytime is also shown as a reference.

seems to be controlled by the charging and quantized energy in Si-QDs.

3. Summary

We have prepared nanometer-size Si dots with and without Ge core in a self-assembling manner by controlling the early stages in low pressure chemical vapor deposition on thermally-grown SiO_2. We have evaluated the surface potential change of each of Si dots due to charging or discharging one electron or a few by an AFM/Kelvin probe technique and demonstrated that, for dots consisting of Si clad and Ge core, electrons are stably stored in Si clad while holes in Ge core.

Multiple-step electronic charging and discharging characteristics of Si quantum-dots (Si-QDs) floating gates in the MOS capacitors and MOSFETs have been studied in the temperature range of 200～350K. The temporal change in the drain current at a constant gate bias after complete discharging in the Si-QDs floating gate shows specific stepwise reductions accompanied with metastable states in which the drain current also remain unchanged with time until the next quick current reduction. The result indicates that, in the metastable states, injected electrons redistribute in the Si-QDs floating gate with keeping the effective total charge density in the floating gate, and suggests that the Coulomb interaction among electrons stored in neighboring dots plays an important role on the stepwise behavior in electron charging. From the slope of Arrehnius plots of the time for both each electron injection and metastable state, it is likely that a thermal activation process with an energy of 0.3eV is involved in the electron charging to the Si-QDs floating gate. The activation energy (0.3eV) suggests the electron tunneling between different energy states among neighboring Si-QDs, considering the charging energy and quantization energy in Si-QDs. Also, we have demonstrated that the electron charging of the Si-QDs floating gate is accelerated by visible light irradiation and the accelerated charging is mainly attributable to the promotion of electron redistribution in the metastable charged states.

4. Future Research Issues in the COE Program

To further improve the performance of the Si-QDs floating gate MOSFETs, we focus on the precise control of the dot size distribution and the optimization of the dot stacked structure, especially the oxide thickness between the dots. In addition, we will extend our research to doping control of ionized impurities in Si-based dots for well-discrete charged states. Furthremore, we will fabricate photosensitive functional devices with the stacked Si QDs floating gate for optical interconnect.

Acknowledgements

This work was supported in part by Grant-in Aids for scientific research of priority area (A) from the Ministry of Education, Science, Sports and Culture of Japan.

The author wishes to thank Dr. H. Murakami and Assoc. Prof. S. Higashi for their assistance and M. Ikeda, T. Shibaguchi, Y. Daruma for their valuable contribution.

References

[1] M. Fukuda et al., Appl. Phys. Lett. 70 (1997) 2291.
[2] S. A. Ding et al., Appl. Phys. Lett. (1998) 3881.
[3] A. Dutta et al., Jpn. J. Appl. Phys. 39 (2000) 4647.
[4] S. Tiwari et al., Appl. Phys. Lett. 68 (1996) 1377, ibid 69 (1996) 1232.
[5] A. Kohno et al., Jpn. J. Appl. Phys. 40 (2001) L721.
[6] S. Miyazaki et al., Thin Solid Films 369 (2000) 55.
[7] S. Miyazaki et al., Proc. of the 25th Int. Conf. on Phys. of Semicond. (2001) p.373.
[8] N. Shimizu et al., Jpn. J. Appl. Phys. 39 (2000) 2318.

5. Published Papers and Presentations in International Conferences

[I] Published Papers on This Research

1. Yudi Darma, Hideki Murakami and S. Miyazaki, "Influence of Thermal Annealing on Compositional Mixing and Crystallinity of Highly-Selective Grown Si Dots with Ge Core", Appl. Surf. Sci. 224 (2004) 156-159.
2. K. Takeuchi, H. Murakami and S. Miyazaki, "Electronic Charging State of Si Quantum Dots formed on Ultrathin SiO$_2$ as Evaluated by AFM/Kelvin Probe Method" Proc. of ECS Int. Semicond. Technol. Conf. (2003) pp.1-8.
3. M. Ikeda, Y. Shimizu, H. Murakami and S. Miyazaki, " Multiple-Step Electron Charging in Silicon-Quantum-Dot Floating Gate Metal-Oxide-Semiconductor Memories", Jpn. J. Appl. Phys. 42 (2003) 4134-4137.
4. Y. Darma, R. Takaoka, H. Murakami and S. Miyazaki, "Self-Assembling Formation of Silicon Quantum Dots with a Germanium Core by Low- Pressure Chemical Vapor Deposition", Nanotechnology, 14 (2003) 413-415.
5. Y. Darma, H. Murakami and S. Miyazaki, "Formation of Nanometer Silicon Dots with Germanium Core by Highly-Slective Low-Pressure Chemical Vapor Deposition", Jpn. J. Appl. Phys. 42, 6B (2003) 4129-4133.

[II] International Conference Papers

1. Y. Darma and S. Miyazaki, "Characterization of Electronic Transport Through Si Dot with Ge Core Using AFM Conducting Probe", Dig. of Papers of 2003 International Microprocesses and Nanotechnology Conference (Tokyo, Oct. 29-31, 2003) pp. 22-23.
2. M. Ikeda, Y. Shimizu, T. Shibaguchi, H. Murakami and S. Miyazaki, "Multiple-Step Electron Charging in Si Quantum-Dot Floating Gate nMOSFETs", Extended Abst. of 2003 Int. Conf. on Solid State Devices and Materials (Tokyo, September 16-18, 2003) pp. 846-847.
3. Y. Darma, K. Takeuchi and S. Miyazaki, "Electronic Charged States of Single Si Quantum Dots with Ge Core as Detected by AFM/Kelviin Probe Technique" Extended Abst. of 2003 International Conference on Solid State Devices and Materials (Tokyo, September 16-18, 2003) pp. 300-301.
4. Y. Darma and S. Miyazaki, "Thermal Stability of Nanometer Dot Consisting of Si Clad and Ge Core as Detected by Raman and Photoemission Spectroscopy", Proc of 2003 Asia-Pacific Workshop on Fundamentals and Applications of Advanced Semiconductor Devices (Busan, June 30-July 2, 2003) pp. 145-149.
5. T. Shibaguchi, Y. Shimizu, M. Ikeda, H. Murakami and S. Miyazaki, "Analysis of Charging Characteristics in MOSFETs with a Si-Quantum-Dots Floating Gate", Prod of 2003 Asia-Pacific Workshop on Fundamentals and Applications of Advanced Semiconductor Devices (Busan, June 30-July 2, 2003) pp. 151-154.
6. Y. Darma, H. Murakami and S. Miyazaki, "Infuence of Thermal Annealing on Compotional Mixing and Crystallinity of Highly-Selective Grown Si Dots with Ge Core, Extended Abst. of 1st Intern. SiGe Technology and Device Meeting (Nagoya, Jan. 15-17, 2003) pp. 209-210.
7. Y. Darma, H. Murakami and S. Miyazaki, "Formation of Nanometer Silicon Dots with Germanium Core by Highly-Selective Low-Pressure Chemical Vapour Deposition", Dig. of Papers of Int. Microprocesses and Nanotechnology Conf. (Tokyo, Nov. 6-8, 2002 pp. 58-59
8. M. Ikeda, Y. Shimizu, H. Murakami and S. Miyazaki, "Multiple-Step Electron Charging in Si Quantum-Dot Floating Gate MOS Memories", Dig. of Papers of Intern. Microprocesses and Nanotechnology Conf. (Tokyo, Nov. 6-8, 2002) pp. 116-117.
9. Y. Darma, R. Takaoka, H. Murakami and S. Miyazaki, "Self-Assembling Formation of Silicon Quantum Dot with Germanium Core by LPCVD" Proc of 2002 Asia-Pacific Workshop on Fundamentals and Applications of Advanced Semiconductor Devices (Sapporo, July 1-3, 2002) pp. 307-310.

[III] Invited Talks in International Conferences

1. S. Miyazaki, "Charging/Discharging Characteristics of Silicon Quantum Dots and Their Application to Memory Devices", Joint Conf. of 7th Int. Conf. on Advanced Surf. Eng. and 2nd Int. Conf. on Surf. and Interface Sci. and Eng. (Guangzhou, May 14-16, 2004) p. 138
2. S. Miyazaki, "Self-Assembling of Si Quantum Dots and Their Application to Memory Devices" Int. Conf. on Polycrystalline Semiconductors (Nara, Sept. 10-13, 2002) I05.
3. S. Miyazaki, "Self-Assembling of Si quantum Dots and Their Application to Memory Devices", 2nd Vacuum & Surf. Sci. Conf. of Asia and Australia（Hong Kong, Aug. 26-30, 2002）Mo7.

[IV] Papers on Other Research Works

1. Teshima and S. Miyazaki, "A New Analytical Modeling for Photo-induced Discharge Characteristics of

Photoreceptors", Jpn. J. Appl. Phys., (2004) in press.

2. W. Mizubayashi, Y. Yoshida, H. Murakami, S. Miyazaki and M. Hirose, "Statistical Analysis of Soft and Hard Breakdown in 1.9-4.8nm-thick Gate Oxides",IEEE Electron Device Lett. (2004) in press.
3. A. Ohta, M. Yamaoka and S. Miyazaki, "Photoelectron Spectroscopy of Ultrathin Yttrium Oxide Films on Si(100)", Microelec. Eng., 72 (2004) 154-159.
4. M. Yamaoka, M. Narasaki, H. Murakami and S. Miyazaki, "Photoemission Study of Ultrathin Hafnium Oxide Films Evaporated on Si(100), Proc. of ECS Int. Semicond. Technol. Conf. (2003) pp. 229-236.
5. S. Miyazaki, H. Yamashita, H. Nakagawa and M. Yamaoka, "Photoemission Study of Interfacial Oxidation in ZrO_2/Sub-Nanometer SiONx/Si(100) Stacked Structures", Mat. Res. Soc. Symp. Proc. 747 (2003) 281-286.
6. S. Miyazaki, M. Narasaki A. Suyama M. Yamaoka and H. Murakami, "Electronic Structure and Energy Band Offsets for Ultrathin Silicon Nitride on Si(100)", Appl. Surf. Sci. 216 (2003) 252-257.
7. M. Yamaoka, H. Murakami and S. Miyazaki, "Diffusion and Incorporation of Zr into Thermally-Grown SiO_2 on Si(100)", Appl. Surf. Sci., 216 (2003) 223-27.
8. N. Kosku, F. Kurisu, M. Takegoshi, H. Takahashi and S. Miyazaki, "High-Rate Deposition of Highly Crystallized Silicon Films from Inductively Coupled Plasma", Thin Solid Films, 435 (2003) 39-43.
9. T. Kikkawa, N. Fujiwara, H. Yamada and S. Miyazaki, "Energy Band Structure of Ru/(Ba,Sr)TiO_3/Si Capacitor Deposited by Inductively- Coupled Plasma-Assisted Radio-Freqency- Magnetron Plasma", Appl. Phys. Lett. 81 (2002) 2821-2823.
10. S. Miyazaki, H. Takahashi, H. Yamashita, M. Narasaki and M. Hirose, "Growth and Characterization of Microcrystalline Silicon-Germanium Films", J. Non-Cryst. Solid 299-302 Part I (2002) 148-152.
11. S. Miyazaki, "Characterization of High-k Gate Dielectric/Silicon Interfaces", Appl. Surf. Sci. 190 (2002) 66-74.
12. H. Murakami, T. Mihara, S. Miyazaki and M. Hirose, "Carrier Depletion Effect in the n^+ Poly-Si Gate Side-Wall/SiO_2 Interfaces as Evaluated by Gate Tunnel Leakage Current", Jpn. J. Appl. Phys. 41 (2002) L512-L514.
13. W. Mizubayashi, Y. Yoshida, S. Miyazaki and M. Hirose, "Quantitative Analysis of Oxide Voltage and Field Dependence of Time-Dependent Dielectric Soft Breakdown and Hard Breakdown in Ultrathin Gate Oxides", Jpn. J. Appl. Phys. 41 (2002) 2426-2430.
14. S. Miyazaki, M. Narasaki, M. Ogasawara and M. Hirose, "Chemical and Electronic Structure of Ultrathin Zirconium Oxide Films on Silicon as Determined by Photoelectron Spectroscopy", Solid State Electronics, 16 (2002) 1679-1685.
15. Teshima and S. Miyazaki, "Improved Performance of Amorphous Silicon Photoreceptor by Using a Thick Surface Layer with a Graded-Band-Gap Structure", Jpn. J. Appl. Phys., 41 (2002) L1294-L1296.
16. S. Miyazaki, "Characterization of Ultrathin Gate Dielectrics on Silicon by Photoelectron Spectroscopy", Proc of 2001 MRS Workshop Series - Alternatives on to SiO_2 as Gate Dielectric for Future Si-Based Microelectronics (2002) pp. 8.1-8.7.

[V] International Conference Papers on Other Research Works

1. H. Kaku, S. Higashi, H. Taniguchi, H. Murakami and S. Miyazaki, "A New Crystallization Technique of Si Flms on Glass Substrate Using Thermal Plasma Jet", Abst. of 12th Int. Conf. on Solid Films and Surfaces (Hamamatsu, June 21-25, 2004).
2. K. Makihara, H. Deki, H. Murakami, S. Higashi and S. Miyazaki, "Control of the Nucleation Density of Si Quantum Dots by Remote Hydrogen Plasma Treatment", 12th Abst. of 12th Int. Conf. on Solid Films and Surfaces (Hamamatsu, June 21-25, 2004).
3. N. Kosku, H. Murakami, S. Higashi and S. Miyazaki, "Influence of Substrate DC Bias on Crystallinity of Si Films Grown at a High Rate from Inductively-Coupled Plasma CVD", Abst. of 12th Int. Conf. on Solid Films and Surfaces (Hamamatsu, June 21-25, 2004).
4. Y. Okamoto, K. Makihara, S.Higashi and S.Miyazaki, "Formation of Microcrystalline Germanium(μc-Ge:H) Films from Inductively-Coupled Plasma CVD", Abst. of 12th Int. Conf. on Solid Films and Surfaces (Hamamatsu, June 21-25, 2004).
5. K. Torii, T. Aoyama, S. Kamiyama, T. Tamura, S. Miyazaki, H. Kitajima, T. Arikado, "Dielectric Breakdown Mechanism of HfSiON/SiO_2 Gate Dielectric" 2004 Symp. on VLSI Technol. (Honolulu, June 15-17, 2004) 11.4.
6. H. Nakagawa, A. Ohta, F. Takeno, S. Nagamachi, H. Murakami, S. Higashi, S. Miyazaki, "Characterization of Interfacial Oxide Layers in Heterostructures of Hafnium Oxides Formed on NH_3-nitrided Si(100)", Extended Abst. of 2004 Int. Workshop on Dielectric Thin Films for Future ULSI Devices: Sci & Technol. (Tokyo, May 26-28, 2004) pp. 35-36.
7. A. Ohta, S. Miyazaki, H. Murakami, T. Kawahara and K. Torii, "Impact of Rapid Thermal O_2-Anneal on Dielectric Stack Structures of Hafnium Aluminate and Silicon Dioxide Formed on Si(100)", Extended Abst. of 2004 Int. Workshop on Dielectric Thin Films for Future ULSI Devices: Sci & Technol. (Tokyo, May 26-28, 2004) pp. 97-98.
8. A.Sakai, S. Sakashita, M. Sakashita, S. Zaima, Y. Yauda and S. Miyazaki, "Praseodymium Silicate Formation by Post-Growth High Temperature Annelaling, Fall Meegings of Mat. Res. Soc. (Boston Dec. 1-5, 2003) E3.23.
9. H. Nakagawa, A. Ohta, F. Takeno, H. Murakami and S. Miyazaki, "Characterization of Interfacial Oxide Layers in Heterostructures of Zirconium Oxides Formed on Si(100) and NH3-nitrided Si(100) surfaces", Abst. of 7th Int. Conf. on Atomically Controlled Surfaces, Interfaces and Nanostructures (Nara, Nov. 16-20, 2003) p. 253.
10. A. Ohta, S. Miyazaki, H. Murakami, T. Kawahara and K. Torii, "Characterization of Dielectric Stack Structures of Hafnium Aluminate and Silicon Dioxide formed on Si(100)", Abst. of 7th Int. Conf. on Atomi-

cally Controlled Surfaces, Interfaces and Nanostructures (Nara, Nov. 16-20, 2003) p. 255.

11. S. Miyazaki, “Photoemission Study of High-k Gate Dielectric/Si(100) Heterostructures - Chemical Bonding Features and Energy Band Alignment” Abst. of AVS 50th Inter. Symp. and Exhibition (Baltimore U.S.A, Nov. 3, 2003) DI-MoM7 (Invited).
12. M. Yamaoka, A. Ohta and S. Miyazaki, “Characterization of Hafnium Diffusion into Thermally-Grown SiO2 on Si(100)”, Extended Abst. of 2003 Int. Conf. on Solid State Devices and Materials (Tokyo, Sept. 16-18, 2003) pp. 810-811.
13. K. Makihara, Y. Okamoto, H. Nakagawa, M. Ikeda, H. Murakami and S. Miyazaki, “Local Characterization of Electronic Transport in Microcrystalline Germanium Thin Films by Atomic Force Microscopy Using a Conducting Probe”, Proc. of 2003 Asia-Pacific Workshop on Fundamentals and Applications of Advanced Semiconductor Devices (Busan, June 30-July2, 2003) pp. 37-40.
14. A. Ohta, M. Yamaoka and S. Miyazaki, “Photoelectron Spectroscopy of Ultrathin Yttrium Oxide Films on Si(100)”, Abst. of 13th Bi-annual Conf. on Insulating Films on Semiconductors (Barcelona, June 18-20, 2003) GS20.
15. A. Ohta, M. Yamaoka, S. Miyazaki, A. Ino, M.Taniguchi, H Namatame, M. Nakatake, A. Kimura and H. Sato, “Photoelectron Spectroscopy of Ultrathin Yttrium Oxide Films on Silicon”, Abst. of 7th Hiroshima Int. Symp. on Synchrotron Radiation (Higashi-Hiroshima, March 13-14, 2003) p.218.
16. K. Makihara, K. Takeuchi, M. Ikeda, H. Murakami and S. Miyazaki" Characterization of Nucleation and Growth of Ge Microcrystallites by AFM (Atomic Force Microscopy) with a Conducting Probe”, Proc of 20th Symposium on Plasma Processing (Nagaoka, Jan. 29-31, 2003) pp.321-322.
17. N. Kosku and S. Miyazaki, “Microcrystalline Silicon Films Form Inductively-coupled Plasma”, Proc of 20th Symposium on Plasma Processing (Nagaoka, Jan. 29-31, 2003) pp.319-320
18. S. Miyazaki, M. Narasaki and H. Murakami, “Electronic Structure and Energy Band Offsets for Ultrathin Silicon Nitride on Si(100)”, Abst of 4th Intern. Symp. on Control of Ssemiconductor Interfaces (Karuizawa, Oct. 21-25, 2002) A5-3.
19. M. Yamaoka, H. Murakami and S. Miyazaki, “Diffusion and Incorporation of Zr into Thermally-Grown SiO2 on Si(100)”, Abst. of 4th Intern. Symp. on Control of Semiconductor Interfaces (Karuizawa, Oct. 21-25, 2002) A4-3.
20. A. Suyama, H. Yokoi, M. Narasaki, W. Mizubayashi, H. Murakami and S. Miyazaki, "Photoemission Study of Aluminum Oxynitride/Si(100) Heterostructures-Chemical Bonding Features and Energy Band Lineup”, Extended Abst. of Int. Conf. on Solid State Devices and Materials (Nagoya, Sept. 17-19, 2002) pp.760-761.
21. H. Murakami, W. Mizubayashi, H. Yokoi, A. Suyama and S. Miyazaki, “Electrical Characterization of Aluminum-Oxynitride Stacked Gate Dielectrics Prepared by a Layer-by-Layer Process of Chemical Vapor Deposition and Rapid Thermal Nitridation”, Extended Abst. of Int. Conf. on Solid State Devices and Materials (Nagoya, Sept. 17-19, 2002) pp. 712-713.
22. N. Kosku, F. Kurisu, M. Takegoshi, H. Takahashi and S. Miyazaki, “High-rate Deposition of Highly- crystallized Silicon Films from Inductively-coupled Plasma”, Abst. of Joint Intern. Plasma Symp. of 6th APCPST, 15th SPSM, and 11th KAPRA (Cheju, July 1-4, 2002) p. 131.
23. S. Miyazaki, H. Takahashi, M. Sagara and M. Hirose, “Growth and Characterization of Amorphous and Microcrystalline Silicon-Germanium Films” 2002 MRS Spring Meeting (San Francisco, April 4, 2002) A18.1 (Invited).
24. N. Kosku, F. Kurisu, H. Takahashi and S. Miyazaki, "High-rate deposition of highly-crystallized silicon films from inductively-coupled plasma”, Extended Abst. of The 5th SANKEN Intern. Symp. (Osaka, March 14, 2002) pp.52-53.
25. S. Miyazaki and H. Murakami, “Characterization of Deposition Process of Microcrystalline Silicon- Germanium Films: In-situ Infrared Attenuated Total Reflection and Ex-situ Raman Scattering Studies”, Extended Abst. of The 5th SANKEN Intern. Symp. (Osaka, March 14, 2002) pp.65-66 (Invited).
26. M. Ichioka, S. Miyazaki, M. Taniguchi, H. Namatame, A. Kimura and H. Sato, "Characterization on As+ Heavily-Implanted Layer on Si(100) by X-ray Photoelectron Spectroscopy", Abst. of 6th Hiroshima Int. Symp. on Synchrotron Radiation (Higashi- Hiroshima, March 14, 2002) P-11.