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Light Induced Carrier Transfer in NiSi-Nanodots/Si-Quantum-Dots Hybrid FG in MOS Structures

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1. Introduction

The application of Si-quantum-dots (Si-QDs) and/or metallic nanodots to the floating gate (FG) of MOS structures has been attracting much attention because of their unique properties, which lead us development of novel functional memories [1-3]. The discrete charged states of the Si-QDs due to quantum confinement effect and charging energy play a role on multistep charging of the Si-QDs FG. And the charge storage characteristics of metallic nanodots depend on their potential depth determined by the Fermi energy. So far, we have demonstrated stable storage of many electrons and multistep electron injection in MOS capacitors with a NiSi-nanodots/Si-QDs FG [3]. The hybrid dots FG structures are also thought to be promising for optical response involving internal photoemission from metallic nanodots to Si-QDs.

In this work, we studied the effect of light irradiation on charge distribution in NiSi-nanodots/Si-QDs hybrid FG in MOS capacitors.

2. Experimental

Hemispherical and single-crystalline Si-QDs were self-assembled on a 4.8-nm-thick SiO_2 layer thermally grown on p-Si(100) by controlling the early stages of LPCVD of pure SiH_4 at 580°C. The average dot height and the areal dot density evaluated by AFM were 6nm and $2.1 \times 10^{11}cm^{-2}$, respectively. A ~3-nm-thick oxide layer was grown on the Si-QDs surface in O_2 at 850°C. To form NiSi-nanodots, the second Si-QDs layer was deposited under the same conditions with the formation of the first Si-QDs layer and a ~3nm-thick Ni film was evaporated on the second Si-QDs layer by electron beam. Subsequently, the sample surface was exposed to remote plasma of pure H_2 for 5min without any external heating [4]. After that, a ~3-nm-thick SiO_2 layer was formed at 350°C by inductively-coupled remote plasma CVD with SiH_4 and excited O_2/Ar. Then, the third Si-QDs layer was deposited under the same conditions. As for the control oxide, a ~21nm-thick SiO_2 layer was prepared by the remote plasma CVD. Finally, Al gates with a diameter of 1 mm were fabricated on top of the sample by thermal evaporation through a stencil mask (Fig. 1).

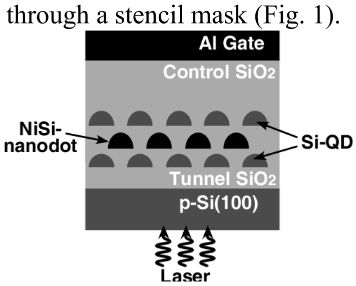

Fig. 1 Schematic of a MOS capacitor with a NiSi-nanodots/Si-QDs hybrid floating gate stack.

3. Results and Discussion

Figure 2 shows the capacitance-voltage (C-V) characteristics of the MOS capacitor with the hybrid FG stack, which were measured in dark with different ranges in gate voltage (Vg) swing. The calculated ideal C-V curve was also shown as a reference. After application of positive and negative gate biases, positive and negative flat-band voltage shifts, ΔV_{FB}, increase with the maximum applied |Vg| in each polarity (Fig. 3). Considering that the Fermi energy of the NiSi-nanodots locates at around midgap of Si-QDs, this result indicates that the amount of electrons and holes in the NiSi-nanodot increases with maximum |Vg|.

To study the influence of light irradiation on the charged states of hybrid FG, C-V characteristics were measured under light irradiation from the backside of the Si substrate. A 1310nm light from a semiconductor laser was used in this work to avoid electron-hole pair generation in the Si-QDs and Si substrate. When Vg was swept from +10V to -10V, positive ΔV_{FB} was decreased by 0.50V in comparison to the C-V curve measured in dark as shown Fig. 4(a). Noted that, since the electrons were stored in the NiSi-nanodots, the potential difference between the NiSi-nanodots and the third Si-QDs near the top control oxide is larger than that between the NiSi-nanodots and the

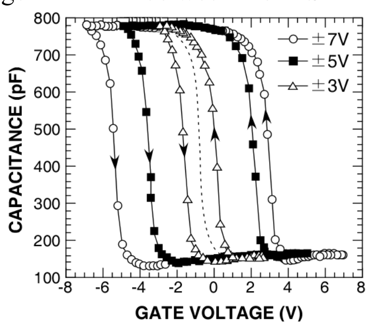

Fig. 2 Capacitance-voltage characteristics measured at 100kHz with a Vg sweep rate of 100mV/s. The gate voltage swing ranges were changed from ±3 to ±7V. The ideal C-V curve is also shown as a reference.

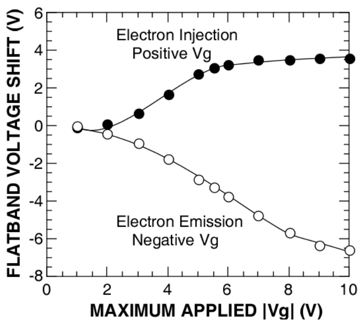

Fig. 3 The flat-band voltage shifts from the ideal C-V curve in Fig. 2 as functions of the maximum positive and negative applied gate voltage |Vg|.

first Si-QDs near the bottom tunnel oxide. This result can be interpreted in terms of the shift of charge centroid in the hybrid FG stack toward the gate side, which is mainly caused by transfer of photoexcited electrons from the NiSi-nanodots to the third Si-QDs as described later (Fig. 4(b)). On the other hand, when the Vg was swept from -10V to +10V, negative ΔV_{FB} was decreased by 0.49V from the C-V curve measured in dark, which implies the hole transfer from NiSi-nanodots to the third Si-QDs which can be induced by the tunneling of photoexcited electrons in the NiSi-nanodots to the first Si-QDs (Fig. 5).

The difference in the ΔV_{FB} between C-V curves measured in dark and under light irradiation was dependent on the maximum applied |Vg| as shown in Fig. 6. At the maximum applied |Vg| over 5V for positive gate bias and -7V for negative gate bias, the difference in ΔV_{FB} was increased with the maximum applied |Vg|, indicating the increase in the charge transferred by light irradiation. The difference in ΔV_{FB} induced by light irradiation was also found to be increased with charging time, namely the amount of charge in the NiSi-nandots, at constant gate biases of +5 and -7V as shown in Fig. 7. These results suggests that stored charges in NiSi-nanodots can be transferred to the third Si-QDs by photoexcitation when the potential difference between the NiSi-nanodots and the third Si-QDs becomes large enough by the gate biases and the charge injected to the NiSi-nanodots from the Si substrate.

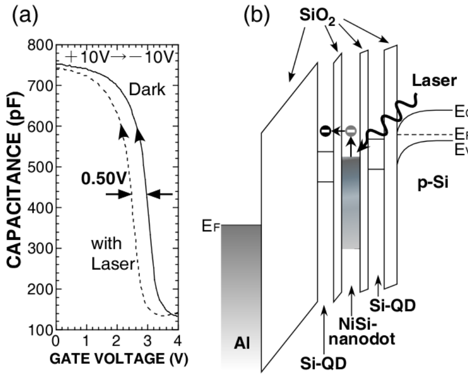

Fig. 4 (a) C-V characteristics measured in dark and under 1310nm light irradiation at 100kHz with a Vg sweep rate of 100mV/s. The gate voltage was swept from +10 to -10V. (b) Energy band diagram of a MOS capacitor with a NiSi-nanodots/Si-QDs hybrid floating gate stack for photoexcited electron transfer from the NiSi-nanodots to the third Si-QDs under light irradiation.

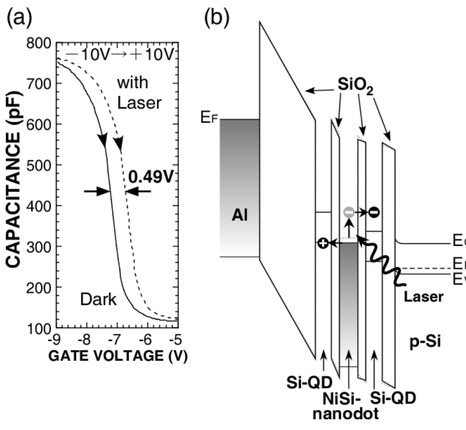

Fig. 5 C-V characteristics measured in dark and under 1310nm light irradiation at 100kHz with a Vg sweep rate of 100mV/s. The gate voltage was swept from -10 to +10V. (b) Energy band diagram of a MOS capacitor with a NiSi-nanodots/Si-QDs hybrid floating gate stack for photoexcited hole transfer from the NiSi-nanodots to the third Si-QDs under light irradiation.

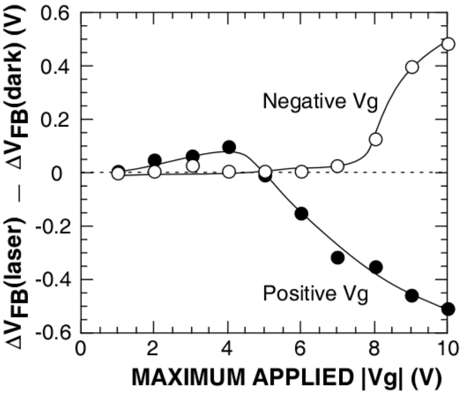

Fig. 6 The difference in the ΔV_{FB} between C-V curves measured in dark and under light irradiation as a function of the maximum applied |Vg|.

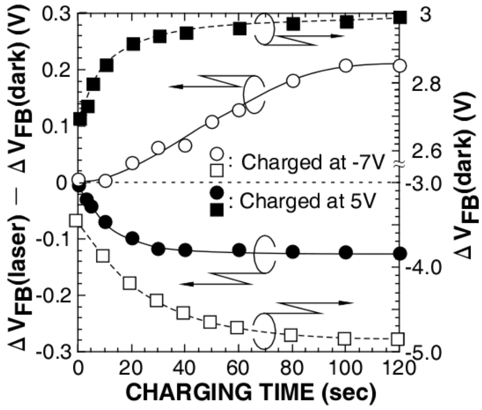

Fig. 7 The difference in the ΔV_{FB} between C-V curves measured in dark and under light irradiation, and the ΔV_{FB} in dark as a function of charging time at +5V and -7V.

3. Summary

We have studied optical response in the NiSi-nanodots/Si-QDs hybrid FG structures by using irradiation of 1310nm light. The observed optical response can be interpreted in terms of the shift of charge centroid in the hybrid nanodots FG caused by photo excitation of electrons in the NiSi-nanodots and transfer to the Si-QDs.

Acknowledgements

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