Charge Storage and Optoelectronic Response of Silicide-Nanodots/Si-Quantum-Dots Hybrid-Floating-Gate MOS Devices

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The application of silicon quantum dots (Si-QDs) and metallic nanodots (NDs) to a floating gate (FG) in MOS devices has attracted much attention because of their potential advantages over conventional FG MOS memories. In fact, multi-valued memory capability can be provided by discrete charged states of Si-QDs originating from the quantum confinement energy as demonstrated in a unique stepwise shift in the threshold voltage of MOSFETs with a Si-QDs floating gate [1-4]. On the other hand, enlarged and stabilized memory window can be achieved by a FG made of metallic NDs with an appropriate work function to form a deep potential well [5, 6]. Recently, we have proposed and fabricated hybrid stacked structures consisting of metallic NDs, Si-QDs and ultrathin interlayer SiO_2 to satisfy both multiple valued capability and charge storage capacity for a sufficient memory window and to open up novel functionality [7]. As for the functionality of such a hybrid nanodots FG, with near-infrared light irradiation, we have verified optical responses caused by transfer of photo-excited electrons from metallic NDs to Si-QDs [8].

Hybrid stacked structures consisting of NiSi-NDs, ultrathin interlayer SiO_2 and Si-QDs were fabricated through the following process sequence. Hemispherical Si-QDs were firstly formed on an ultra-thin thermally-grown SiO_2 by controlling the early stages of LPCVD of pure SiH_4 at 580°C. The areal dot density and the average dot size evaluated by AFM measurements were typically ~5nm and ~$3.5\text{x}10^{11}\text{cm}^{-2}$, respectively. And then, the Si-QDs surface was slightly oxidized in O_2 at 850°C, and followed by SiO_2 deposition from inductively-coupled remote plasma (ICRP) of SiH_4 and excited O_2/Ar at 350°C to obtain the designed thickness. Subsequently, to form NiSi-NDs, Si-QDs were grown again under the same conditions as the first formation of Si-QDs, and the surface was covered uniformly with a ~1.8nm-thick Ni layer by electron beam evaporation and successively exposed to remote H_2 plasma without external heating to enhance surface migration of Ni atoms and full-silicidation of Si-QDs. formed secondly. The 3rd formation of Si-QDs was preformed after ICRP-CVD of ultrathin SiO_2 on NiSi-NDs. Lastly, the top control oxide with a thickness of ~20nm, Al gates with a diameter of 1 mm and Al back contact with a window for light irradiation were sequentially fabricated to complete hybrid FG MOS structures (Fig. 1).

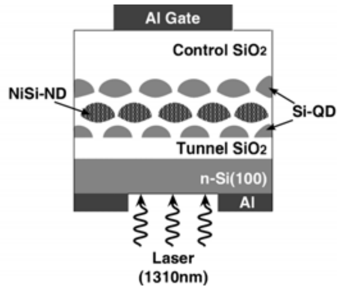

Fig. 1 Schematic of a MOS capacitor with a NiSi-NDs/Si-QDs hybrid FG.

High-frequency capacitance-voltage (C-V) characteristics of the MOS capacitor with the hybrid FG show positive and negative flat-band voltage shifts depending on the porality and the maximu magnitude of applied gate bias (Fig. 2), and cofirm stable charge strorage in a deep potential well in each of NiSi-NDs. Considering that electrons in NiSi-NDs can be excited by irradiation of infrared light of being not absorbed in the Si substrate and Si-QDs, such an infrared light irradation can cause electron trasnfer from NiSi-NDs to Si-QDs selectively (Fig. 3) and induces flat-band voltage shift as a result of the change in the charge centrode in the hybride FG. To investigate the response of photoexcited electrons in the hybrid FG stack to the change of gate bias, the transient current induced by pulsed gate voltages was evaluated by connecting the MOS capacitor with a 1 kΩ resistance in series and measuring the voltage drop across it with a lock-in amplifier. As shown in Fig. 4, a distinct change in the output voltage (V_{OUT}) of the lock-in amplifier was detected in synchronized timing of the infrared light irradiation under the application of periodic pulsed gate voltage. This result can be attributed to an increase in the displacement current mainly due to the photoexcited electron transfer from the NiSi-NDs to the top and bottom Si-QDs in response to pulsed gate voltage. Namely, the difference in V_{OUT} (ΔV_{OUT}) between in the dark and under light irradiation corresponds to the amount of charge transferred from the NiSi-NDs to the Si-QDs. The ΔV_{OUT} measured in each bias polarity as a function of pulse voltage is summarized in Fig. 5. The ΔV_{FB} almost linearly increased with pulse voltage over ±2.0V. This result indicates that the amount of transferred charge in each cycle is limited to a certain level determined by gate voltage and the signals proportional to gate voltage are associated with charging and discharging a capacitor as long as the photoexcited electron transfer can respond to pulsed gate voltage.

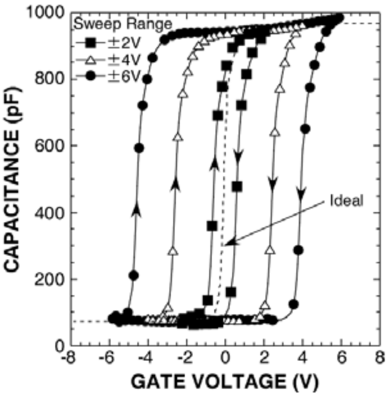

Fig. 2 100 kHz capacitance-voltage (C-V) characteristics of a MOS capacitor with the NiSi-NDs/Si-QDs hybrid FG. The gate voltage sweep rate was set at 100 mV/s. The ideal C-V curve is also shown with a dashed line.

Acknowledgments

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References

[1] S. Tiwari et al., Appl. Phys. Lett., vol. 68, pp. 1377-1379, 1996. [2] A. Kohno et al., Jpn. J. Appl. Phys. 2, Lett., vol. 40, pp. L721-L723, 2001. [3] M. Ikeda, et al., Jpn. J. Appl. Phys., vol. 42, pp. 4134-4137, 2003. [4] R. Matsumoto, et al. Jpn. J. Appl. Phys., vol. 47, pp. 3103-3106, 2008. [5] P. H. Yen et al., Appl. Phys. Lett., vol. 87, pp. 193504-1 -193504-3, 2005. [6] K. Shimanoe et al., IEICE Trans. Electron, vol. E92-C, pp. 616-619, 2009. [7] S. Miyazaki, et al., Thin Solid Films, vol. 518, pp. 530-534, 2010. [8] N. Morisawa, et al., Jpn. J. Appl. Phys., vol. 49, pp. 04DJ04-1-04DJ04-4, 2010.

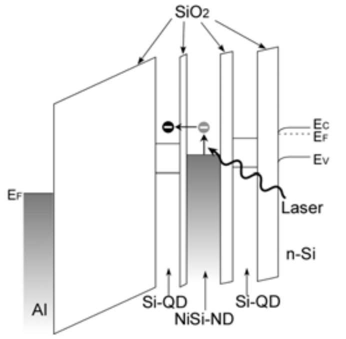

Fig. 3 Energy band diagram of the MOS capacitor with the NiSi-NDs/Si-QDs hybrid floating gate stack in which photoexcited electrons are transferred from the NiSi-NDs to the top Si-QDs with infrared light irradiation.

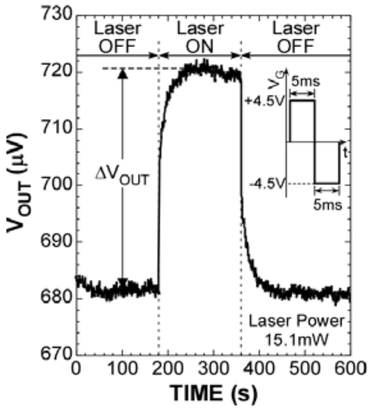

Fig. 4 The response of electrons excited by 1310 nm light irradiation in the NiSi-NDs/Si-QDs hybrid FG to pulsed gate voltage of ±4.5 V at a frequency of 100 Hz.

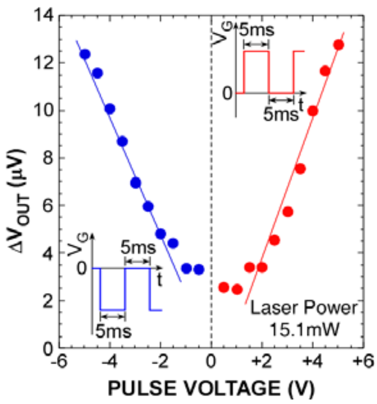

Fig. 5 The response of electrons excited by 1310 nm light irradiation in the NiSi-NDs/Si-QDs hybrid FG to pulsed gate voltage at a frequency of 100 Hz as a function of pulse voltage.