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Multistep Electron Injection in a PtSi-Nanodots/Silicon-Quantum-Dots Hybrid Floating Gate in nMOSFETs

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1. Introduction

The application of high density nanodots (NDs) to a floating gate (FG) in MOS memories has been attracting much attention because of its unique properties associated with quantum confinement effect and the Coulomb blockade effect, which leads to development of novel functional memories. So far, we have proposed the hybrid floating gate consisting of silicon-quantum-dots (Si-QDs) and metallic NDs to achieve both multivalued capability and stable charge storage [1]. In such hybrid FG, the discrete charged states of the Si-QDs due to quantum confinement energy and charging energy play a role on multistep charging and consequently the Si-QDs act as an energy filter in charge injection. In fact, we have demonstrated unique multistep threshold voltage shift in nMOSFETs with a Si-QDs FG at room temperature [2]. On the other hand, metallic NDs with an appropriate work function work as a charge storage node with large memory window because of its deep potential well suitable for stable charge storage [3].

In this work, we focused on the charge injection characteristics in an nMOSFET with a hybrid FG consisting of PtSi-NDs and Si-QDs.

2. Experimental

Hemispherical and single-crystalline Si-QDs were self-assembled on a 3.8-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 ~5 nm and ~3.5×10^{11} cm^{-2}, respectively. By dry oxidation at 850°C, the Si-QDs surface was uniformly covered with a ~2.7-nm-thick oxide layer. To form Pt-silicide NDs, the second Si-QDs layer was deposited under the same conditions and a ~2-nm-thick Pt film was formed on the second Si-QDs layer by Ar sputtering. Subsequently, the sample surface was exposed to remote plasma of pure H_2 for 5 min without external heating [4]. After that, a ~20-nm-thick SiO_2 layer was grown as a control oxide by inductively-coupled remote plasma CVD with SiH_4 and excited O_2/Ar at a substrate temperature of 350°C. Finally, an n^+poly-Si gate and source/drain junction were fabricated.

3. Results and Discussion

The formation of PtSi-NDs was confirmed from the photoemission spectra of core lines and the valence band excited with monochromatized AlKα radiation.

The drain current versus gate voltage (I_D-V_G) characteristics of the nMOSFET with the PtSi-NDs/Si-QDs hybrid FG gate, which were measured with different ranges in gate voltage swing, show unique hysteresis properties due to stepwise increase in the amount of stored electrons in the FG as shown in Fig. 1. After application of positive and negative gate biases, positive and negative threshold voltage shifts, ΔV_{th}, were clearly observed due to electron injection to and emission from the hybrid dots FG through a bottom tunnel oxide, respectively. In each V_G polarity, the ΔV_{th} increases with the maximum applied V_G (Fig. 2). Considering the areal dot density and control oxide thickness, one can estimate that one electron storage per ND causes the ΔV_{th} of 0.53V. Therefore, observed fairly large ΔV_{th} indicates the stable charged states due to the multiple electron injection to and emission from the hybrid dots FG. Since several electrons could not be retained stably in the Si-QDs, the injected charges must be stored in the deep potential well of the PtSi-NDs (Fig. 3). Note that, in sweeping the gate voltage from negative V_G toward the positive bias direction, multistep electron injection was clearly observed, in which electron injection proceeds at

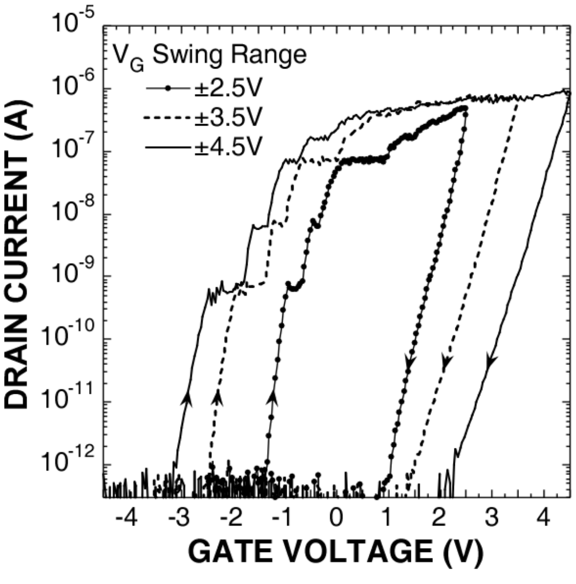

Fig. 1 Drain current - gate voltage characteristics of an nMOSFET with a PtSi-NDs/Si-QDs hybrid floating gate measured with three different Vg swing ranges. The gate length and width are 0.5 and 10μm, respectively. Drain voltage and V_G sweep rate were 1V and 1V/s, respectively.

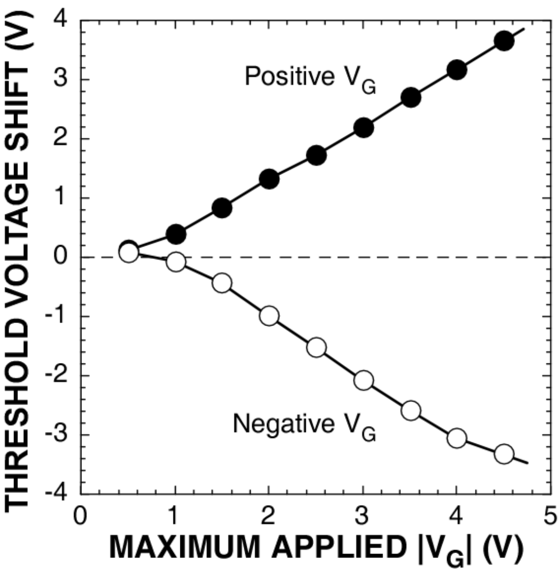

Fig. 2 The threshold voltage shifts seen in Fig. 1 measured as functions of the maximum positive and negative applied gate voltage |Vg|.

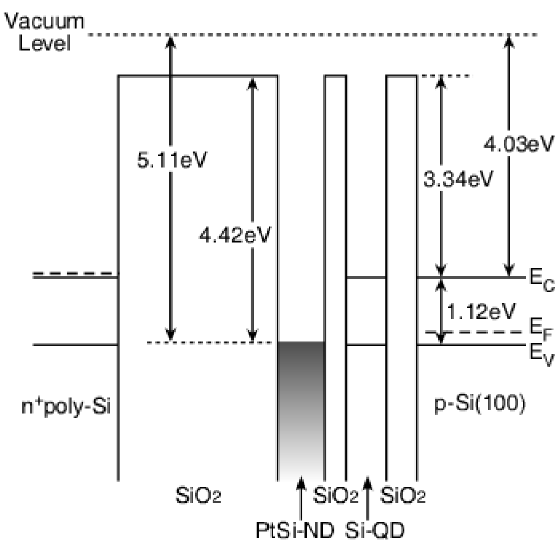

Fig. 3 Energy band diagram of a MOS structure with a PtSi-NDs/Si-QDs hybrid floating gate stack, which was simply drawn using measured work function of the PtSi-NDs.

specific drain current levels independent of V_G swing range, namely, initial amount of positive charges in the PtSi-NDs. This result can be interpreted in terms of electron injection to the PtSi-NDs through the Si-QDs with discrete charged states at specific tunnel oxide voltages.

To get an insight into the electron injection characteristics of the PtSi-NDs/Si-QDs hybrid FG, I_D-V_G characteristics were measured with different V_G sweep rates at a constant swing range as shown in Fig. 4. Unique multistep electron injection independent of sweep rate was also observed at specific drain current levels. With increasing sweep rate, the electron injections at each step occur at lower V_G because of the decrease in ΔV_{th} both at each electron injection step and at intermediate regions between them in which electron injections are not completely suppressed. The decrease in ΔV_{th} at each electron injection step with increasing sweep rate suggests that electron tunneling rate from the Si substrate to Si-QDs may be decreased with progress of electron charging to the Si-QDs layer due to the Coulomb repulsion among the neighboring charged Si-QDs.

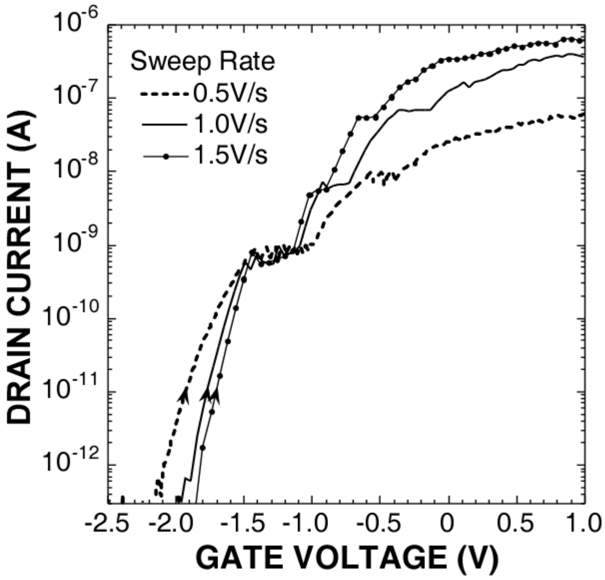

Fig. 4 Drain current - gate voltage characteristics measured with three different Vg sweep rates. The gate voltage was swept from -3V to +3V at a drain voltage of 1V.

4. Summary

The multistep electrons injection in the nMOSFET with the PtSi-NDs/Si-QDs hybrid floating FG has been demonstrated. The electron injection was observed at specific drain current levels independent of V_G swing range and sweep rate. This result can be interpreted in terms of the electron injection into the PtSi-NDs through the discrete charged states of Si-QDs.

Acknowledgements

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