Formation and Characterization of Hybrid Nanodots Floating Gate for Optoelectronic Application

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The application of high density nanodots (NDs) to a floating gate (FG) in MOS memories has been attracting much attention because of its potential advantages over conventional planar FG memories [1, 2]. In semiconducting nanodots, discrete charged states originating from quantum confinement and Coulomb blockade effect lead to multi-valued memory capability. On the other hand, metallic NDs with an appropriate work function to form a deep potential well provide practically large memory window. To satisfy both multiple valued capability and charge storage capacity for a sufficient memory window and to open up novel functionality, we have proposed and fabricated a hybrid nanodots FG in which Si quantum dots (QDs) and silicide nanodots are stacked with a very thin SiO_2 interlayer [3].

Hemispherical Si-QDs were grown firstly on an ultrathin SiO_2 layer by controlling the early stages of LPCVD of pure SiH_4 at 580°C [4]. The average dot height and the areal dot density, which were evaluated by AFM observations, were typically ~5nm and ~$3.5x10^{11}cm^{-2}$, respectively. High density silicide-NDs was prepared by full-silicidation of pre-grown Si-QDs, in which the Si dot surface was covered with either an ultrathin Ni layer by electron beam evaporation or an ultrathin Pt layer by Ar sputtering, and followed by a remote H_2 plasma exposure without external heating [5]. The silicidation of Si-QDs promoted by such a remote H_2 plasma treatment was confirmed from chemical shifts in photoemission spectra of core lines and distinct changes in valence band spectrum, and the work function values of the NiSi- and PtSi-NDs were determined to be 4.53±0.05eV and 5.11±0.05eV, respectively, from the cut-off energy in photoemissions. From surface potential measurements after scanning an electrically-biased AFM tip in a tapping mode, we confirmed electrical separation among silicide NDs and stepwise changes in the surface potential with the tip bias which indicate multistep electron injection into and extraction from the NDs. For the Si-QDs/silcide-NDs hybrid stack, the 2nd formation of Si-QDs after the surface oxidation of firstly grown Si-QDs was performed with the same condition as the 1st formation and followed by full-silicidation of the 2nd formed Si-QDs with ultrathin metal layer formation and subsequent remote H_2 plasma exposure. After that, a ~20nm SiO_2 layer as a control oxide was formed at 350°C by inductively- coupled remote plasma CVD with SiH_4 and excited O_2/Ar. Al top electrodes with 1mm in diameter were fabricated for MOS capacitors and n^+ poly-Si gates with a size of 0.5 x 10µm^2 for MOSFETs [5].

In electron charging and discharging characteristics measured with application of pulsed gate biases to MOS capacitors with a hybrid NDs FG, in which silicide-NDs were stacked on Si-QDs with an ultrathin SiO_2 interlayer, stepwise changes in the rates for electron injection and emission were revealed with increasing pulse width at room temperature. In addition, nMOSFETs with a hybrid NDs FG show unique hysteresis with stepwise changes in the drain current - gate voltage characteristics as shown in Fig. 1. This observed characteristics can be interpreted in terms that the electron injection and storage into silicide-NDs proceed through the discrete charged states of Si-QDs. For MOS capacitors with a triple-stacked hybrid NDs

FG fabricated by adding another Si-QDs, by 1310nm (~0.95eV) light irradiation from the back side of the Si substrate, a distinct infrared optical response in C-V characteristics was detected as shown in Fig. 2 (a). Considering almost no absorption of the 1310nm light in Si-QDs as well as the Si substrate, the result can be interpreted in terms of the shift of charge centroid in the hybrid FG stack due to transfer of photoexcited electrons from silicide NDs to the Si-QDs as indicated in Fig. 2 (b).

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References

[1] S. Tiwari, et al., Appl. Phys. Lett. 68 (1996)1377.

[2] M. Ikeda, et al., Jpn. J. Appl. Phys. 42 (2003) 4134.

[3] S. Miyazaki, ESC Trans. 41(7) (2011) 93.

[4] S. Miyazaki, et al., Thin Solid Films, 369 (2000) 55.

[5] N. Morisawa, et al., Jpn. J. Appl. Phys. 49 (2010)04DJ04.

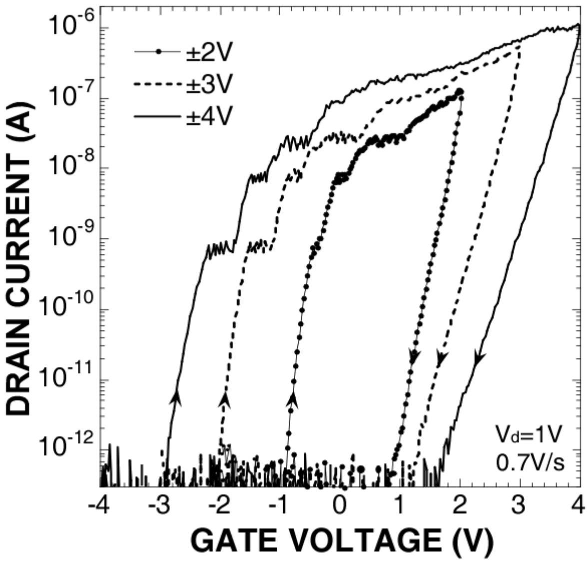

Fig. 1 Drain current - gate voltage characteristics of an nMOSFET with a Pt-silicide NDs/Si-QDs hybrid floating gate measured in three different ranges of gate voltage swing.

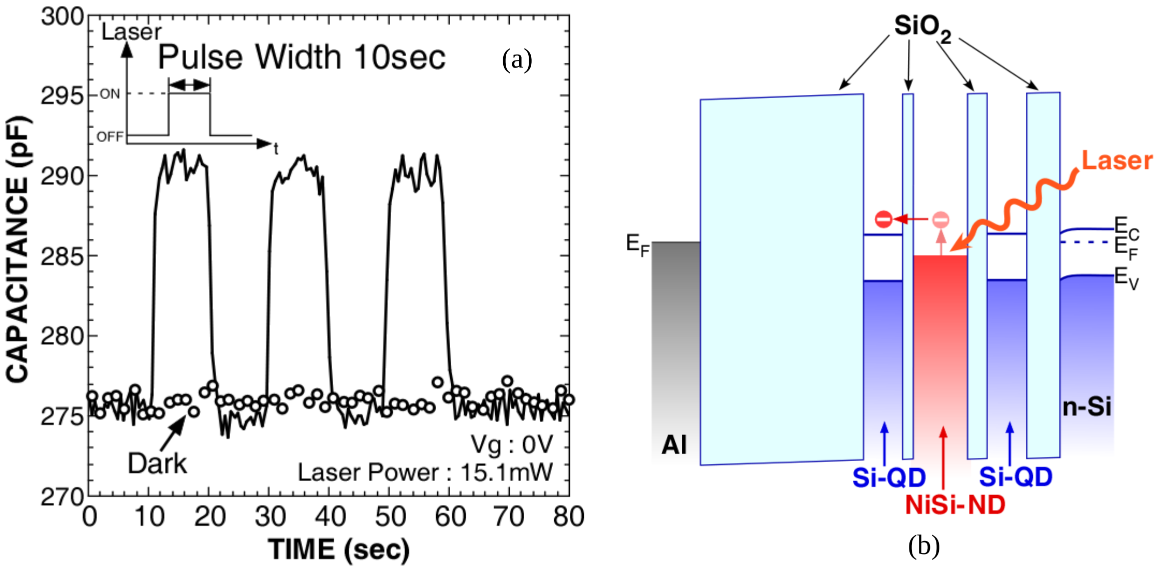

Fig. 2. (a) Optical response of an MOS capacitor with a Si-QDs/Ni-silicide NDs/Si-QDs FG on n-Si(100) and (b) energy band diagram to explain change in charge centroid induced by sub-gap light irradiation. The internal oxide thickness between Ni-silicide NDs and bottom Si-QDs or top Si-QDs was ~2.4nm or ~1.4nm, respectively.