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Photon-induced effect on single-charge-tunneling in a Si multidot Schottky FET

Ratno Nuryadi, Hiroya Ikeda, Yasuhiko Ishikawa and Michiharu Tabe

Research Institute of Electronics, Shizuoka University, 3-5-1 Johoku, Hamamatsu 432-8011, Japan
Phone: +81-53-478-1307 Fax: +81-53-478-1348 email: romtabe@rie.shizuoka.ac.jp

1. Introduction

Recently, in addition to application for quantum cellular automata [1], two-dimensional (2D) coupled-dot single electron (hole) tunneling (SET) devices have attracted interest in developing optical devices such as position sensing detector or photoimaging device [2]. One of essential issues in the optical device is how the photon (light) influences the electron (hole) tunneling through the tunnel junction. So far, photon effect has been studied experimentally in single [3] and double quantum dots structures [4]. However, the effect of photon on 2D multiple-junction structure has not been reported.

The purpose of this work is to study the electrical characteristics of 2D multidot Si SET devices focusing on the visible light irradiation effect. In this work, SET devices with 2D Si coupled dots were fabricated in a silicon-on-insulator (SOI) material. The coupled dots were formed by the nanometer-scale local oxidation of Si (nano-LOCOS) process [5], which enable us to fabricate a variety size of quantum dots.

2. Device Fabrication

Figure 1(a) shows the nano-LOCOS processes. First, a homemade SOI (18-nm-thick top Si(100)/90-nm-thick buried SiO_2/n^+-Si(100)) surface [6] was nitrided in a vacuum to form naturally ultrasmall SiN islands. Second, the surface was oxidized by conventional furnace oxidation. Since the SiN islands work as oxidation masks, Si coupled dots can be obtained by the oxidation. Third, the sample was dipped in chemical solutions to remove the SiN masks and SiO_2. Figure 1(b) shows a typical AFM image of fabricated coupled dots. The lateral size, height and density of Si dots are about 20 nm, 4 nm and $3x10^{11}$ cm^{-2}, respectively.

Then, the Si layer with coupled dots was patterned to form a Si channel. Finally, Al electrodes were deposited. Figure 2 shows (a) a schematic view of the final field-effect transistors (FETs) structure and (b) a cross-sectional view of the Si channel. Here, the n^+-Si substrate serves as a backgate and no top gate is prepared. The channel width and a distance between source and drain were about 0.2 and 0.8 μm, respectively. The channel/source and channel/drain contacts are Schottky contact. Thickness of interdot Si region ($t_{interdot}$) which works as a tunnel barrier was about 5 nm. The effect of visible light irradiation was examined using a halogen lamp.

3. Results and Discussions

A specific property of this device is that the carrier polarity in the channel can be controlled by applying backgate (substrate) voltage (V_{bg}), that is, ambipolar characteristics are observed. For positive V_{bg}, electrons are induced in the channel and the device acts as a single-electron device. In contrast, for negative V_{bg}, holes are induced and the device acts as a single-hole device.

Figure 3 shows the drain current (I_d) versus V_{bg} characteristics for (a) electron and (b) hole carriers at 15 K in dark condition. The current oscillations due to Coulomb blockade (CB) effect are clearly observed for both carriers. These results indicate that tunnel barriers are formed in both the conduction and valence bands as shown in Fig. 3. Probably, an electron (hole) percolation path between source and drain is formed in the channel as shown in Fig. 4 and the highest-resistance tunnel junctions dominate the carrier transport.

There are several photon-induced effects observed in single-hole-tunneling characteristics by the light irradiation for sample to sample, as shown in Figs. 5 and 6. Figure 5 shows I_d-V_{bg} characteristics for hole carrier at 15K in the dark and under continuous light irradiation. In this figure, the peaks of CB oscillations shift to lower $|V_{bg}|$ by the light irradiation. The most important photon-induced effect is probably assisted electron tunneling from the n^+-Si substrate into the overlying multidot layer. (Photo-absorption in the multidot layer may be the secondary effect because of its ultra-small thickness.) The electron injection into the multidot layer results in electron-hole recombination and, thus, reduction of the number of holes, previously stored in Si dots in the vicinity of the percolation path. This phenomenon should effectively enhance I_d, which is responsible for the result in Fig. 5.

Another photon-induced effect in Fig. 6 is more striking, i.e., a new current peak is generated as indicated by an arrow. Generation of new peaks is previously reported in an asymmetric Si SET [3], where photo-generated charges are responsible for this result. We believe that our result in Fig. 6 is also related to photo-generated charges but it must be reflecting the multidot structure.

4. Conclusions

Thus, we have successfully observed both single-electron and single-hole characteristics in the same Si coupled-dot SET devices fabricated in a SOI layer, and clarified photon-induced effect on the single-hole-tunneling characteristics.

Acknowledgements

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References

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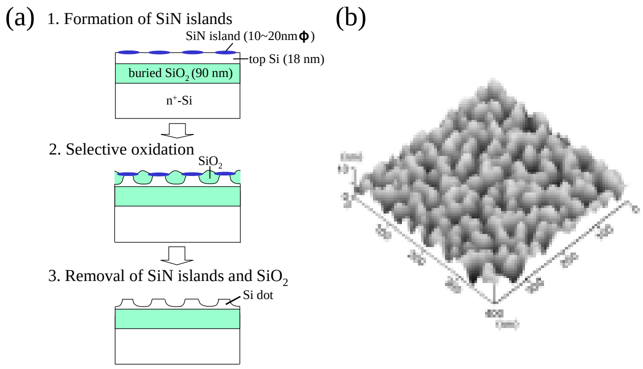

Fig. 1 Fabrication steps of Si coupled dots.

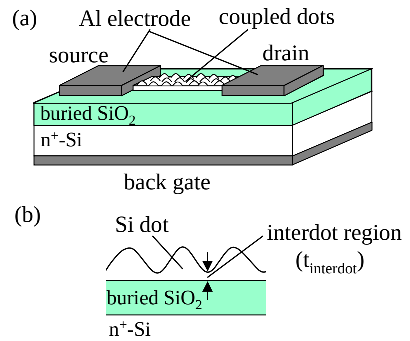

Fig. 2 (a) Schematic view of Si SET device and (b) cross-sectional view of Si channel.

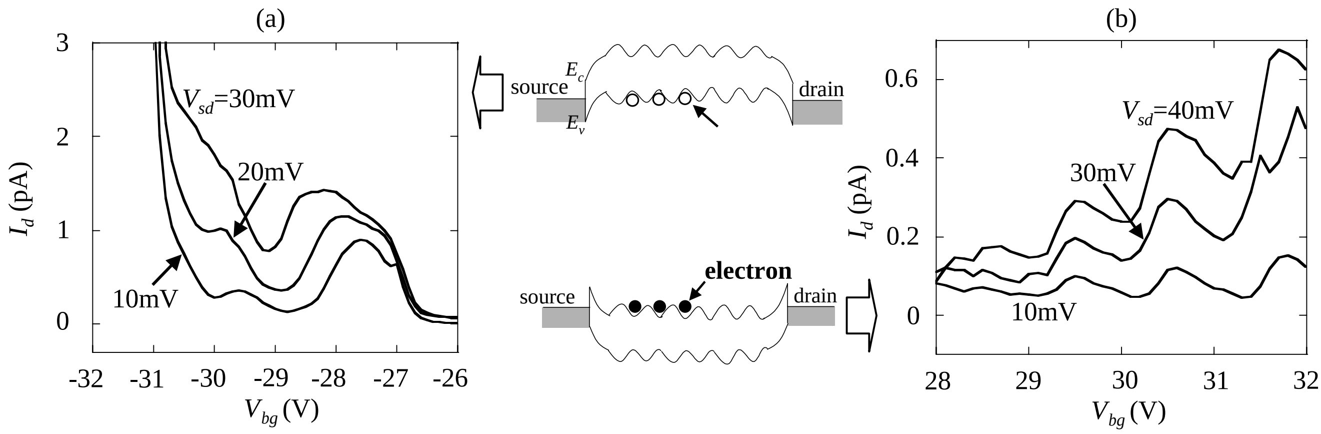

Fig. 3 I_d-V_{bg} of the (a) single-hole and (b) single-electron characteristics at 15K.

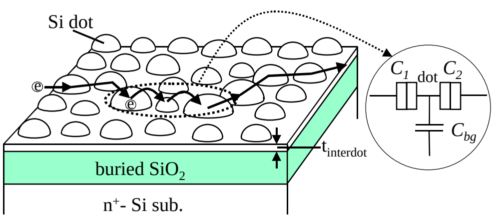

Fig.4 Single electron (hole) percolation path.

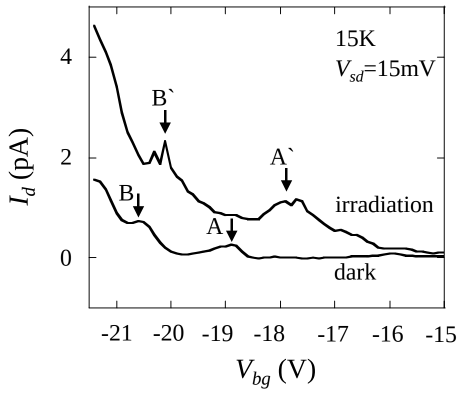

Fig. 5 I_d-V_{bg} characteristics at 15K in the dark and under light irradiation.

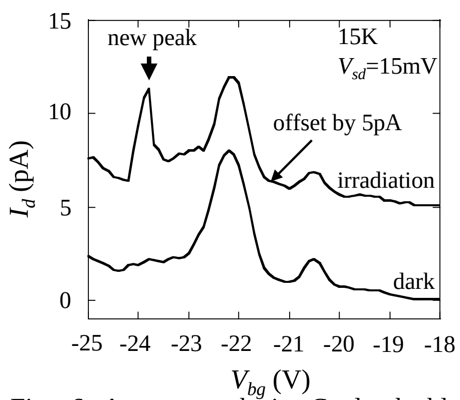

Fig. 6 A new peak in Coulomb blockade oscillations caused by light irradiation.