Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 816-817

A-8-2

Photo Illumination Effect on Single-Electron-Tunneling Current Through a Thin Bicrystal SOI FET

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1. Introduction

Nanometer-scale devices with multiple tunnel junctions (MTJ) have attracted much attention as a candidate for new functional devices such as photoimaging devices and quantum cellular automata. Recently, we have studied the interaction between single-hole-tunneling (SHT) current and photons on two-dimensional (2D) MTJ Si multidot field-effect-transistor (FET) fabricated on silicon-on-insulator (SOI) substrate [1]. The SHT current is modulated by the charging/discharging of Si dots due to the photon generated electron-hole pair in the dots.

In this work, we discuss the photon-induced charging effect on single-electron-tunneling (SET) current of SOI-MOSFET embedding 2D network of screw dislocations (so-called bicrystal FET). The dislocations are formed at a bonding interface of two Si (001) wafers when the in-plane crystalline direction is slightly misaligned between the wafers [2]. It is found that the threshold voltage (V_{th}) of SET current through the dislocations is modulated by the photon-generated holes near the interface of the Si and the buried SiO_2 (BOX) layer. The shift in V_{th} is linearly proportional to the wavelength of light, indicating that the shift depends on the number of photon-generated holes. This result provides a possibility of developing optical devices using dislocation network system.

2. Device structure

The device used in this experiment is an n-channel SOI-MOSFET, schematically shown in Fig. 1. In the channel, periodic dislocation network is formed by bonding of two SOI wafers with a twisted angle [3].

Figure 2(a) and (b) show typical cross-sectional and plan-view transmission electron microscope (TEM) images of the twist-bonded interface before device fabrication. Fig. 2(a) shows a successful bonding process, while Fig. 2(b) shows networks of screw dislocations (as in circle X). The periodicity of the dislocation network, *d* is determined to be ~6 nm, which agrees well with the theoretical period of *d*=5.5 nm for φ=4° [2]. Although the moiré pattern without dislocation network (as in circle Y) is also observed, we believe that it has no significant influence on the SET characteristics.

Figure 3(a) and (b) show a schematic 2D potential profile near bonding interface and 1D potential profile along the dislocation line. Spatially modulated potential may be induced by the strain due to the dislocation network.

3. Results and Discussions

Figure 4(a) shows a typical drain current (I_d) versus backgate voltage (V_g) characteristics at 16 K for drain voltage V_d = 5 mV in a dark condition. The I_d increases with increasing V_g. In region A, the current flows through the dislocations channel at the bonding interface, while in region B, the current mainly flows through the buried channel at Si/BOX interface (see Fig. 4(b)) [4]. The band-bending at bonding interface is probably due to the formation of donor-like gap states [5]. The presence of the current oscillations due to Coulomb blockade effect (see arrows in Fig. 4(a)), indicates the existence of multiple-junction structure formed by spatially modulated potential.

The effect of continuous monochromatic light illumination on I_d-V_g curves is clearly seen in Fig. 5. In this experiment, incident photon flux is kept constant. It is found that the threshold voltage (V_{th}) of the SET current is shifted when the wavelength of the light λ is varied. The plot of V_{th} as a function of λ is shown in Fig. 6. The increase in λ linearly increases the V_{th}.

The relationship between V_{th} and λ can be explained using Fig. 7. After the photon-generated electron-hole pair vertically separates from each other, the electrons move toward the dislocation channel, while the holes move toward the interface of Si/BOX layer. Then, the electrons flows through the channel due to the V_d. The holes, on the other hand, will remain near the Si/BOX interface, resulting in the modulation of the potential. This leads to the enhancement of the SET current. Since the optical absorption coefficient of Si increases with decreasing λ, the number of photon-generated holes should also increase. The number of the holes determines the shift in V_{th}. Thus, one can adjust the V_{th} values by light illumination with changing λ as a parameter.

4. Conclusions

We have investigated the effect of light illumination on the bicrystal FET. The threshold voltage of SET current through the dislocation channel can be modulated by the absorption photons. This opens up the application of the bicrystal system in new optical devices.

References

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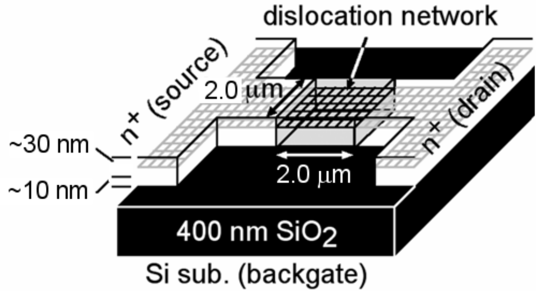

Fig. 1 Schematic view of Si bicrystal FET.

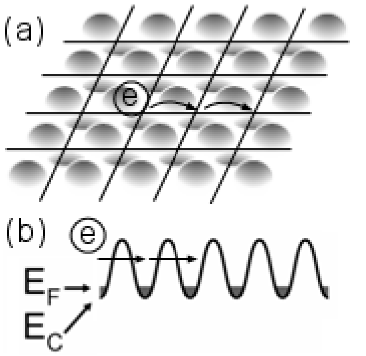

Fig. 3 (a) A schematic view of 2D potential profile near the bonding interface and (b) 1D cross-sectional view along the dislocation line.

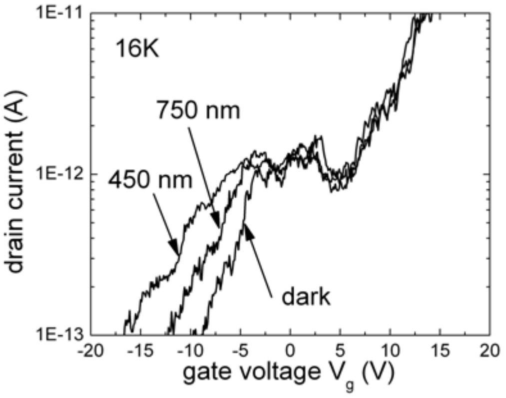

Fig. 5 I_d-V_g curve at 16 K for V_d = 5 mV in dark and under light illumination.

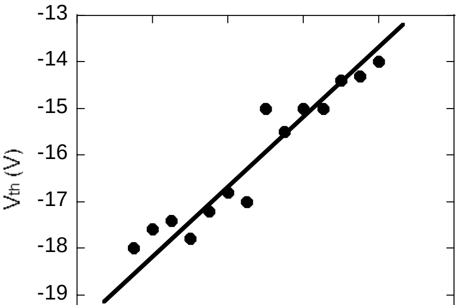

Fig.6 Threshold voltage V_{th} as a function of wavelength λ.

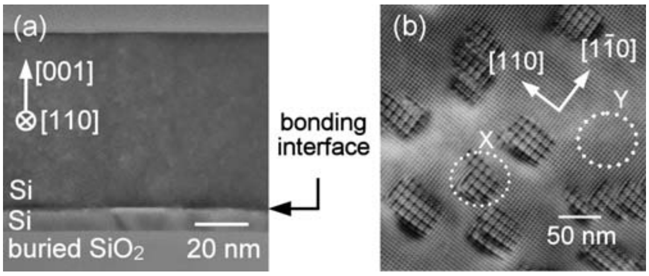

Fig. 2 (a) Typical cross-sectional and (b) plan-view TEM images of the interface before device fabrication.

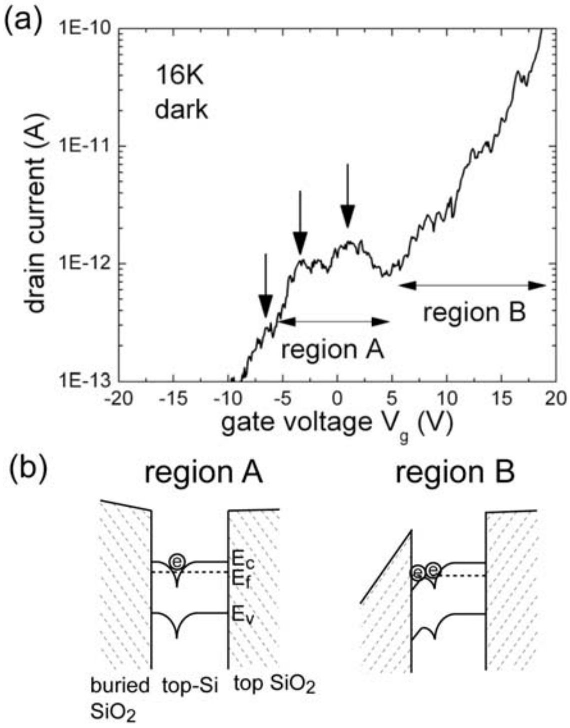

Fig. 4 (a) I_d-V_g curve at 16 K for V_d = 5 mV in a dark condition and (b) the schematic band diagram.

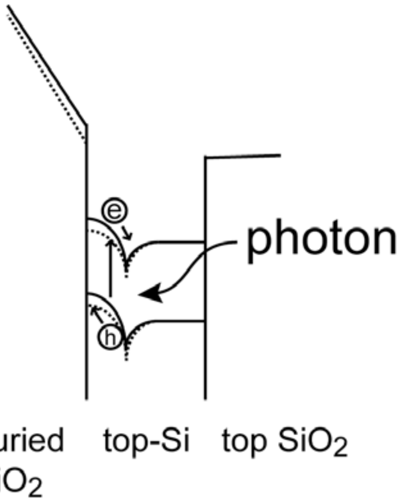

Fig. 7 Schematic illustration of the potential diagram.