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Photodetective Characteristics of Metal-Oxide-Semiconductor Tunneling Structure with Aluminum Grid Gate

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1. Introduction

Recently, attention to using optical technology is increased to improve the connection of devices on a single chip, and between chips or modules [1]. In the electrical system, the current logic circuit is mainly composed on a silicon substrate, and this trend will continue. Optical devices are preferred to integrate in silicon substrates. The $Al/SiO_2/Si$ tunneling structure has proposed as a photodetector fabricated through MOS compatible processes [2]. However, the Al gate electrode has not been efficiency-enhanced structure such as a grid gate electrode.

In this study, we have examined the photodetective characteristics of the MOS tunneling diode with Al grid gate, and have observed rapid change in on-off ratio. We also have discussed the mechanism of the change.

2. Experimental

The wafer was n-type Si(100) with a resistivity of 10-20 Ω·cm. The wafer was rinsed O_3 ultrapure water, cleaned with $HF/H_2O_2/H_2O$/surfactant solution under megasonic irradiation, rinsed with O_3 ultrapure water, etched with dilute HF solution, and rinsed with ultrapure water. The Si wafer was thermally oxidized at 1000℃ in oxygen gas of an atmospheric pressure. The thickness of an SiO_2 film was 2.6nm as measured by ellipsometry. The Al electrode was formed onto SiO_2 film by evaporation and was patterned to be grid gate by photolithography. Figures 1(a) and (b) show the optical microscope image and interference microscope image of the Al grid gate. The electrode area was $1.62\times10^{-3}cm^2$ and the thickness was about 30nm.

The current density(J) - gate voltage(V_G) characteristics and the gate capacitance(C_G) - gate voltage(V_G) characteristics of MOS diodes were measured under light irradiation. The light source was He-Ne laser (wavelength:632.8nm). The energy of the laser is larger than the band gap of Si so that the electron is excited from valence band to conduction band. The optical power density P_{in} was controlled from $1.8\times10^{-7}mW/cm^2$ to $3.9mW/cm^2$ with dark filters.

3. Results and Discussion

Figure 2 shows the J - V_G characteristics of the MOS diode with Al grid gate. The dark current density(J_{dark}) is saturated as negative voltage increases. The photo current densities(J_{photo}) are increased as negative voltage increases. As for low power densities, the current densities are hardly increased.

Figure 3 shows the relation between the on-off ratio and P_{in} when V_G is –2V. The on-off ratio was calculated from the ratio of the current density under light irradiation and under no light irradiation, defined as $10\log_{10}[J_{photo}(P_{in})/J_{dark}(P_{in}=0)]$. In the range of low optical power density ($P_{in}<10^{-4}mW/cm^2$), the on-off ratio is almost zero. With increasing P_{in}, it rapidly increases at about $10^{-4}mW/cm^2$, and in the range of high optical power density ($P_{in}>10^{-4}mW/cm^2$), it linearly increases.

The C_G - V_G characteristics of the MOS diode at 1MHz under light irradiation are shown in Fig. 4. The C_G is maintained relatively constant under light irradiation as negative voltage increases, while the C_G continuously decreases under no light irradiation.

The surface potential Φ_{SL} at the Si/SiO_2 interface as a function of gate voltage for optical power densities are shown in Fig. 5. The surface potential as a function of C_G was obtained from the C_G – V_G characteristics shown in Fig. 4 under depletion approximation, because C_G is modulated by photoexcited holes in the valence band in addition to the modulation by V_G through a variation of Φ_{SL} during the C_G – V_G characterization under light irradiation [3].

Figure 6 shows the difference $\Delta\Phi_{SL}$ of the surface potential between with and without light irradiation as a function of P_{in} when V_G is –2V. In the range of $P_{in}<10^{-4}mW/cm^2$, $\Delta\Phi_{SL}$ is almost zero. It rapidly increases at about $10^{-4}mW/cm^2$, then it linearly increases as P_{in} increases. This rapid change point of $\Delta\Phi_{SL}$ corresponds to that of the on-off ratio in Fig. 3. From these results, we can conclude that hole is not accumulated under lower optical power density than the threshold P_{in}.

Figures 7(a) and (b) show the energy band diagrams of MOS tunneling structure for low and high optical power density. For high optical power density, the accumulation of holes in the valence band decreases the surface potential (=$\Delta\Phi_{SL}$), and the increased oxide voltage V_{ox} increases the tunneling electrons from Al into the conduction band of Si at the constant gate voltage. On the other hand, the hole is hardly accumulated for low optical power density. This is probably due to that carrier lifetime of the excited hole is short.

4. Conclusions

We have demonstrated the photodetective characteristics of the MOS diode with Al grid gate. The on-off ratio rapidly changes at the threshold optical power density. Under lower optical power than threshold the hole is hardly excited. This characteristic is useful when the MOS tunneling structure is used as a detector in digital optoelectronic system, because the turning on or off for optoelectronic switch can be clearly identified.

References

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(a)

(b)

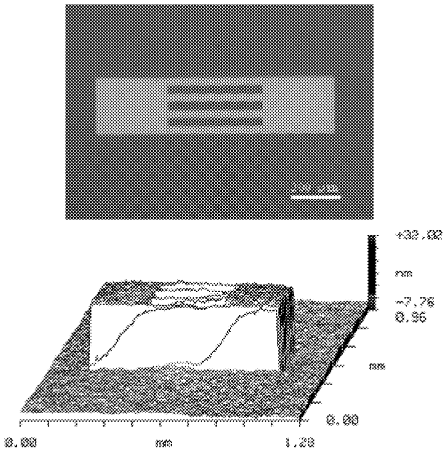

Fig. 1 (a) Optical microscope image and (b) interference microscope image of Al grid gate.

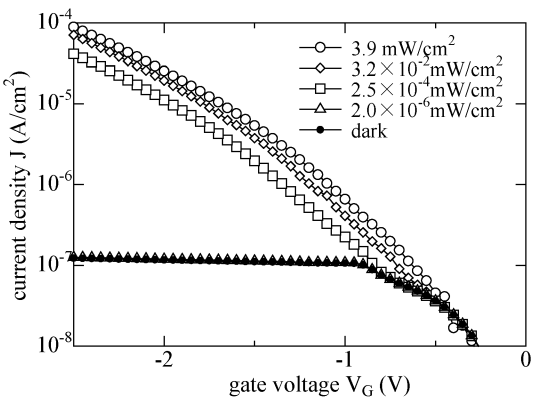

Fig. 2 Current density J - gate voltage V_G characteristics of MOS diode with Al grid gate for optical power densities P_{in}.

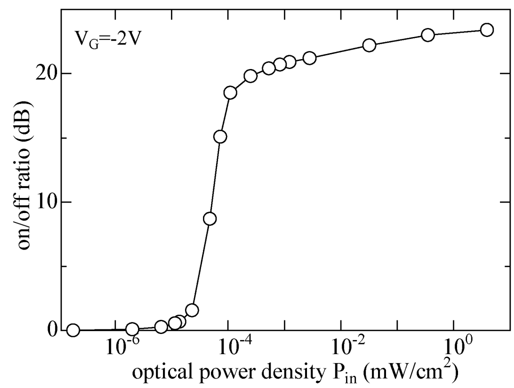

Fig. 3 Relation between on-off ratio and optical power density P_{in} when gate voltage V_G is –2V.

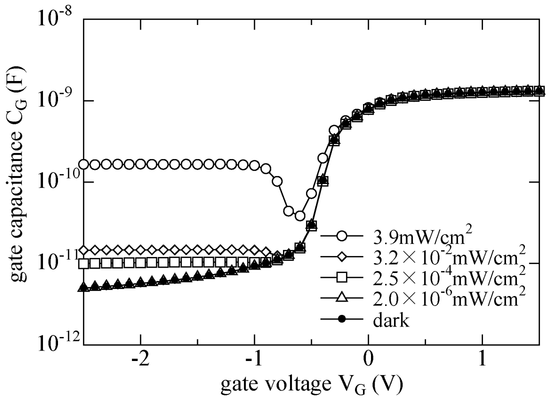

Fig. 4 Gate capacitance C_G - gate voltage V_G characteristics of MOS diode with Al grid gate for optical power densities P_{in}.

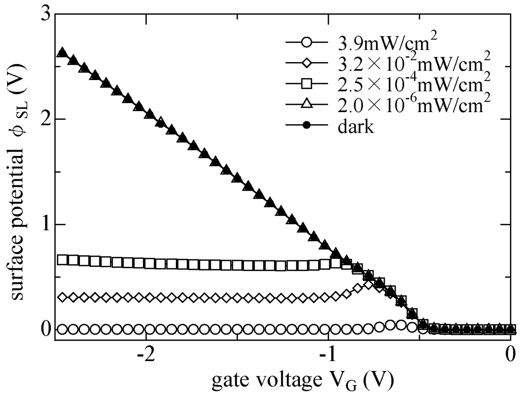

Fig. 5 Relation between surface potential Φ_{SL} and gate voltage V_G for optical power densities P_{in}.

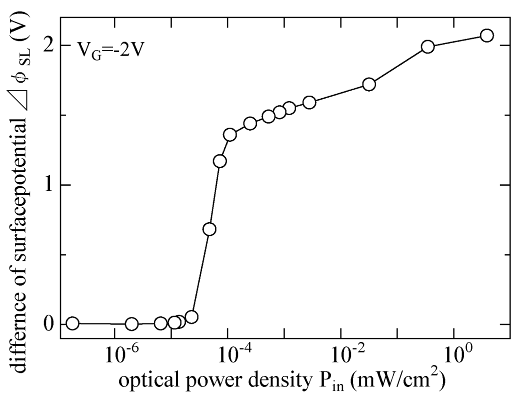

Fig. 6 Difference of surface potential Φ_{SL} between with and without light irradiation as a function of optical power density P_{in}.

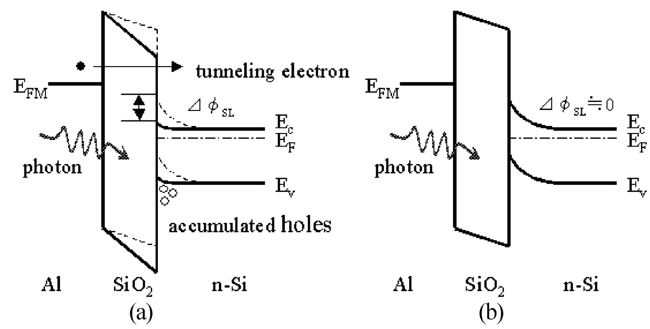

Fig. 7 Energy band diagrams of Al/SiO_2/n-Si tunneling structure at negative applied voltage for (a) high and (b) low optical power density.