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Ge/Si/Ge Potential Barrier Structure for Bolometer in Uncooled Infrared Image Sensor

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Abstract

A Ge/Si/Ge potential barrier structures were fabricated for a bolometer device in an uncooled infrared image sensor. An RF magnetron sputtering technique was used to deposit the device structures. The fabricated devices exhibited a decrease in resistance with an increase in temperature. The obtained temperature coefficient of resistance (TCR) was approximately 5-6 %/K. The magnitude of TCR values depended on the bias voltage.

1. Introduction

Uncooled infrared sensors are used in small and portable thermo cameras, and have attracted considerable attention. The applications of infrared cameras are spread into various fields, such as security, fire monitoring, quality control in factories, equipment degradation diagnosis, and medicine.[1)] Small infrared bolometer sensors are arranged in a two-dimensional structure for capturing infrared spectra. Although cooled sensors are highly sensitive, they must be cooled with liquid nitrogen, increasing their size and cost. Therefore, it is necessary to develop uncooled bolometers that have high sensitivity to increase the portability of infrared sensors. The required characteristics for a bolometer are a high temperature coefficient of resistance (TCR), a low noise-equivalent temperature difference, and high conductivity to facilitate connection with other electrical circuits and reduce the 1/*f* noise. One of the materials applied to an uncooled bolometer is VO_x, which has a high TCR and high conductivity.[2)] Amorphous silicon (a-Si) is also material applied to bolometers because it is used in a standard Si fabrication process. Reported TCR values of a-Si bolometer films are 2–4 %/K, which depend on resistivity. Other materials, such as SiGe, have been investigated intensively in attempts to obtain lower resistivity while maintaining a high TCR. A theoretical study of a potential barrier structure for use in a bolometer was reported.[3)] As thermal activation is necessary for carriers to flow over the potential barrier in this structure, the TCR value is expected to depend on the barrier height energy. The calculation results showed that a high TCR value and low resistance was expected for proper design of the structure.

In this study, we experimentally fabricated a potential barrier structure using stacked layers of Ge/Si/Ge for a bolometer device and characterized its electrical properties.

2. Experiments and results

The layered structure in this experiment is shown in Fig. 1. Every layer was deposited on a SiO_2 substrate using the RF magnetron sputtering technique. A Ti layer on the substrate with a thickness of 300 nm was deposited and a 500-nm Ge layer was deposited. A Si layer was deposited onto the Ge layer for potential barrier. A 500-nm Ge layer, a Ti film and a Pt film were deposited on the Si layer using a metal mask. All layers in this experiment were deposited by sputtering at 300 °C.

Indium (In) electrodes were formed on the sample in Fig. 1 by alloying In dots with the Si and the Ge layers at 350 °C. The electrical contact of In electrode to bottom Ti layer was confirmed by measuring resistance between the two In electrodes which value became approximately 20-30Ω.

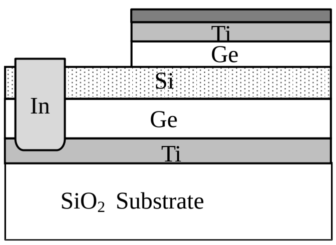

Fig.1 Layered structure of potential barrier for bolometer device.

The current flow for measuring the electrical characteristics is from the top Pt layer to bottom Ti layer through the Ti/Ge/Si/Ge layer. Then, it flows to an indium-alloyed electrode. The bottom Ti layer with sheet resistance of 20 Ω/sq was formed for decreasing parasitic resistance in lateral direction because the resistivity of Ge layer was 40 Ω·cm and not low. The basic electrical characteristics of a Si layer showed a high resistivity of 170MΩ·cm and a TCR of 3.9 %/K. The TCR of a Ge layer was 1.8 %/K.

As X-ray diffraction (XRD) analysis of Si and Ge film showed no peaks, it is expected that Ge and Si films have amorphous structures.

The current–voltage characteristics of a 100-nm-thick Si layer device are shown in Fig. 2. The relation between current and voltage is not linear. The current becomes larger than what would be predicted by a linear relation with the applied voltage. The temperature dependence of the current showed that when the temperature became higher, the current became larger.

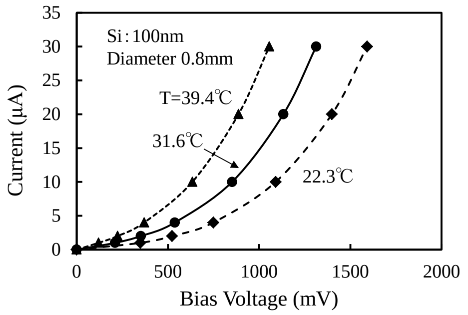

Fig. 2 Current–voltage characteristics of the 100-nm-thick Si layer device.

The resistance characteristics of a 100-nm Si layer device are shown as a function of the temperature in Fig. 3. The results show that the resistance decreases with increasing temperature. Comparing the resistance between applied currents to the device, the resistance for the case of the larger current was smaller than that of the lower current.

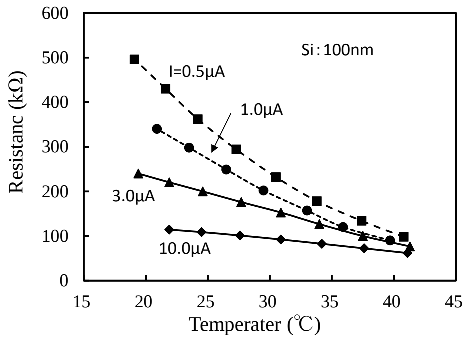

Fig.3 Temperature dependence of resistance of 100-nm-thick Si layer device.

TCR is derived using resistance, R, and temperature, T by the expression of $(1/R)\times dR/dT$ from the temperature dependence of the resistance. Magnitude of TCR values are plotted as a function of the electric field in the Si layer in Fig. 4. It is assumed here that the voltage is applied almost entirely at the Si layer because the resistances of the other layers (Pt, Ti, and Ge layers) are sufficiently low compared to the Si layer. As the current flows perpendicular to the Ge layer, and its thickness is 0.5 μm, the voltage applied in the Ge layer is low. Pt and Ti are metal, and their resistances are also low.

The magnitude of TCR values are high at low electric field and decrease as the electric field increases. The electric field dependences of the TCRs are similar for both the 50-nm and 30-nm barrier devices. The TCR value obtained is approximately 5-6 %/K at low electric field.

3. Discussions

The experimental results in Fig. 2 show that the currents do not linearly depend on the bias voltage; the resistances become low with increasing the bias voltage. The results in Fig. 3 show that the resistance of the device decrease with increasing temperature. The thermal activation of carriers for conduction is expected from the result.

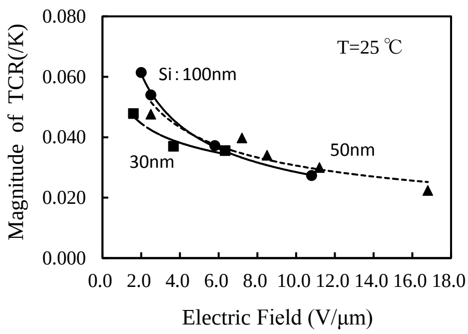

Fig.4 Magnitude of TCR values as a function of the electric field in the devices.

Carrier conduction in amorphous Si is usually hopping type one which is thermally activated from the carrier trapping state. When an electric field in amorphous Si is large, carrier conduction in it is explained by Pool-Frenkel model.[4)]As the thermal activation of carriers increase by the electric field in this model, the resistance becomes smaller at higher electric field.

The resistance of our device depended on the current as shown in Fig. 3, which mean it depended on the electric field. The TCR is also shown to depend on the electric field. However the TCR magnitude cannot be explained by only Pool-Frenkel type conduction in the Si layer. Though the single Si layer showed TCR of 3.9 %/K as previously described, the TCR values of our device in Fig. 1 were obtained to be 5-6% /K. They are larger than the single Si layer one. There should be some other mechanisms which lead to higher TCR value.

As the Si layer of our device is sandwiched with Ge layers. There is some potential barrier between Si and Ge layer. In this case TCR value is expected to become high because thermal activation is necessary for carrier to flow over the barrier. The thermionic current over the barrier and tunneling current at the top of the barrier energy when bias voltage is applied at the device will lead to high TCR value and its electric field dependence.[3)]

4. Conclusions

A Ge/Si/Ge potential barrier structure was fabricated for an uncooled infrared image sensor. The resistance of the device showed decrease with increasing temperature. The obtained TCR value was approximately 5-6 %/K.

References

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