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Ohmic Contact on N-type and P-type Ion-implanted 4H-SiC with Low-temperature Silicide-less Process

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Abstract

Forming ohmic contacts on n-type and p-type SiC regions with the same contact metal is a key process in regard to creating high-performance MOSFETs and IGBTs. Dependence of contact resistance on n-type and p-type SiC regions on ion species, dose, and implantation temperature was investigated. The investigated results revealed that amorphousization of the SiC surface and generation of 3C-SiC produces low contact resistance without the need for high-temperature silicidation process.

1. Introduction

4H silicon-carbide (SiC) is well known as a promising material for high voltage devices, due to its wide band gap, high electric field and high themal conductivity. To create low-loss and highly reliable SiC metal-oxide-semiconductor field-effect transistors (MOSFETs), forming an ohmic contact on n-type and p-type ion-implanted SiC epilayers is one of the key processes.

Nickel silicide is a popular contact metal, since it can be formed on n-type and p-type SiC in the same process. Several papers reported the mechanism of ohmic contact formation on n-type SiC with nickel silicide [1-3]. In paticular, they reported influence of nickel-silicide phase, precipitation of graphite in metal/semiconductor interface, and carbon vacancies at the SiC surface. All these papers reported that high temperature annealing over 950°C is required for forming ohmic contact with low contact resistance. On the other hand, high-temperature annealing degrades adhesion of the silicide/metal interface due to precipitation of graphite, and it increases oxide/semiconductor interface states density due to decomposition of interface passivation [4]. Therefore, low-temperature process for forming ohmic contact is required for SiC MOSFET with good performance and high reliability.

In this work, a low-temperature silicide-less ohmic contact was formed by using a high dose and heavy ion implantation and titanium electrode. Moreover the mechanism for forming ohmic contact at low temperature was revealed by investigating ion implantation dose, temperature, and work function of contact metal dependence of contact resistance on n-type and p-type SiC.

2. Sample fabrication

N-type and p-type regions were formed by nitrogen and/or phosphorus implantation and aluminum implantation on an n-type epi-layer with a doping concentration of 1.0×10^{16} cm^{-3}. Ion implantation temperature was 25°C or 350° C. After activation annealing at 1700°C in argon ambient, Kelvin patterns were formed. Contact metals are nickel silicide, formed by nickel deposition and silicidation annealing at 1000°C, or titanium. Contact resistance and sheet resistance were evaluated by using Kelvin patterns with contact area of 5.0 μm□.

3. Evaluation of contact resistance

Current-voltage characteristics and relationships between ion implantation dose and contact resistance of the nickel-silicide contact on n-type regions are shown in Fig. 1 (a) and 2, respectively. Ohmic behavior was observed in

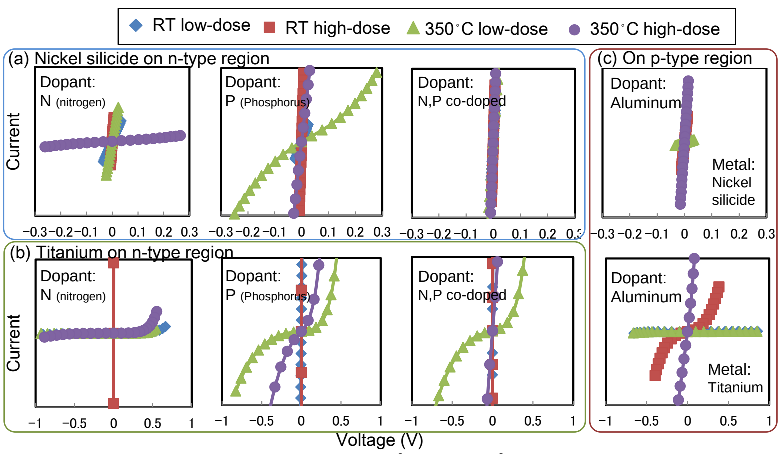

Fig. 1 Voltage-current characteristics of samples fabricated in various conditions. (Upper graphs: nickel silicide contact, Lower graphs: titanium contact)

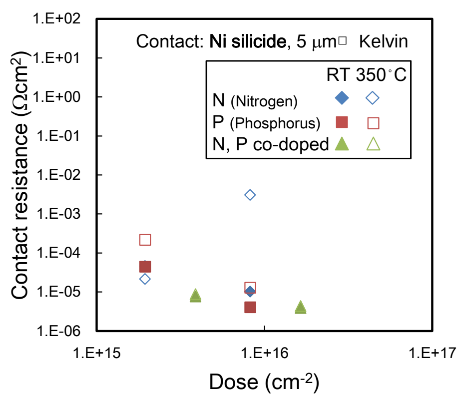

Fig. 2 Relationships between an ion implantation dose and the contact resistance on n-type SiC with Ni silicide.

almost all samples. The contact resistance of the nitrogen-implanted sample in the low-dose region is comparable to that of the phosphorus-implanted one, but it is higher in the high-dose region. This is because solid-solubility limit of nitrogen in SiC is lower than that of phosphorus. Co-implantation of nitrogen and phosphorus has no special effect on the contact resistance. The implantation temperature has little influence on the contact resistance in the case of nickel-silicide contacts. Next, current-voltage characteristics and relationships between ion implantation dose and contact resistance of the titanium contact on n-type regions are shown in Fig. 1 (b) and 3, respectively. All samples implanted at high temperature and low-dose nitrogen implanted at room temperature (Group B in Fig. 3) does not have ohmic behavior and have much higher contact resistance than the other samples (Group A), which has comparable contact resistance to that with nickel-silicide contacts. The lowest contact reistance on n-type SiC obtained in this work was 3.8×10^{-6} Ωcm^2 in the case of nickel-silicide contacts, and 3.7×10^{-6} Ωcm^2 in the case of titanium contacts.

Current-voltage characteristics and relationship between ion implantation dose and contact resistance of the samples with nickel-silicide or titanium contacts on p-type regions are shown in Fig. 1 (c) and 4, respectively. Clearly, implantation temperature has little influence on contact resistance in the cases of nickel-silicide and titanium contacts. The sample with nickel-silicide contacts has lower contact resistance than that with titanium contacts, since the work function of nickel-silicide is higher than that of titanium. Therefore, the barrier height for p-type region is lower in the case of nickel-silicide contacts than that of titanium contacts. The lowest contact resistance on p-type regions obtained in this work was 7.3×10^{-5} Ωcm^2 in the case of nickel-silicide contacts, and 2.7×10^{-3} Ωcm^2 in the case of titanium contacts.

4. Mechanism of low temperature ohmic contact

In general, contact resistance is determined by the barrier height at the contact metal/semiconductor interface and activated dopant concentration of the semiconductor surface [5]. The activated dopant concentration is approximately proportional to ion implantation dose. Therefore, if the barrier height in the contact metal/semiconductor interface is constant, the relationship with the ion implantation dose and the contact resistance should be on the same curve. Good correlation between the ion implantation dose and the contact resistance was observed in the Group A samples on n-type regions. Then, these samples seem to have constant barrier height. In contrast, the Group B samples have high contact resistance and bad correlation between the ion implantation dose and the contact resistance. Therefore, these samples seem to have high and quit-variable barrier height.

In consideration of the common element of the samples of Group A, implantation damage seems to affect contact resistance. Implantation with high ion mass, and high dose at room temperature increases the implantation damage. It was revealed by Monte Carlo simulation that all Group A samples were fully amorphousized by ion implantation. Then, 3C-SiC can be generated by activation annealing of these samples. The band alighnments of titanium/4H-SiC and titanium/3C-SiC are shown in Fig. 5. The conduction band level of 3C-SiC is lower than that of 4H-SiC, while the valance band level of 3C-SiC is comparable to that of 4H-SiC. Therefore, the existence of 3C-SiC lowers contact resistance on n-type SiC, but hardly lowers contact resistance on p-type SiC.

5. Conclusions

A low-temperature process for forming ohmic contact with a high dose and heavy ion implantation at room temperature for n-type regions and high temperature for p-type regions was developed, and contact resistance of 3.7×10^{-6} Ωcm^2 on n-type region and 2.7×10^{-3} Ωcm^2 on p-type region were obtained. The low contact resistance on the n-type regions seems to be related to barrier lowering by generation of 3C-SiC at the surface of the epilayer.

References

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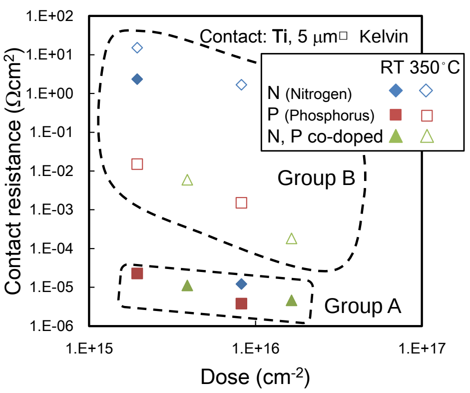

Fig. 3 Relationships between an ion implantation dose and the contact resistance on n-type SiC with Ti.

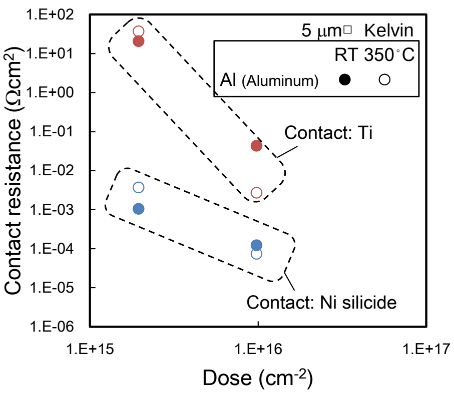

Fig. 4 Relationships between an ion implantation dose and the contact resistance on p-type SiC with Ni silicide and Ti.

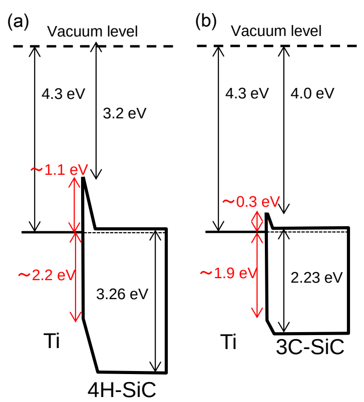

Fig. 5 Band alignment of 4H-SiC, 3C-SiC and titanium.