論文の要旨
（Thesis Summary）

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論文題目 Low Specific Contact Resistance and High-Temperature Reliability of Ni/Nb Ohmic Contacts on 4H-SiC for Harsh Environment Applications
(極限環境応用のための4H-SiC半導体上の低抵抗・高信頼Ni/Nbオーミック接触形成)

In this dissertation, the low specific contact resistance and high-temperature reliability of Ni/Nb ohmic contacts on 4H-SiC for harsh environment applications has been investigated.

In general, Ni is a good candidate for ohmic contact to n-type 4H-SiC because of low specific contact resistivity. However, the excess carbon atoms released from the SiC substrate are not controlled and thus cause the degradation of the contacts when operating in high temperature environment. By introducing Nb, these excess carbon atoms can be collected by the formation of Nb-C compounds during the annealing process and therefore improve the quality of the contacts. The experimental results show that though the Nb/Ni/4H-SiC had a low specific contact resistance after the fabrication process, it lost the ohmic behavior just 10-hour aging at 400°C. While the Ni/Nb/4H-SiC contact still exhibited good ohmic characteristics after being aged for 100 hours. The two-dimensional X-ray diffraction (2D-XRD), hard X-ray photoelectron spectroscopy (HAXPES), and transmission electron microscopy (TEM) analysis indicated that the Ni/Nb/4H-SiC sample had a better ability to collect the excess carbon atoms by the formation of Nb_6C_5 compound compared to the Nb/Ni/4H-SiC contact and thus improves the reliability of the contacts when operating in high temperature environment.

The low specific contact resistance as well as the high temperature reliability of the metal/SiC contacts not only depend on the metal structure, but also are strongly affected by the ratio of the metal elements to form the contact. Therefore, the influence of Ni and Nb thickness on the electrical properties as well as high temperature reliability of Ni(x)/Nb(100-x)/n-type 4H-SiC ohmic contacts, where x = 25, 50, and 75 nm, were investigated in this thesis. The 2D-XRD, HAXPES, and TEM analyses indicated that a high density of Ni leads to a high concentration of Ni_2Si formed at the interface of the contact and thus accounts for the low specific contact resistance of the Ni(75 nm)/Nb(25 nm)/4H-SiC contact. However, the lack of Nb leads to the excess carbon atoms are not well collected during the annealing process resulting the degradation of this contact when operating in high temperature environment. On the other hand, relatively high Nb density improves the ability to eliminate the excess carbon atoms and thus enhances the high temperature reliability of the Ni(75 nm)/Nb(25 nm)/4H-SiC sample. However, a low concentration of Ni leads to the low density of Ni_2Si formed at the interface of the contact and consequently increases the specific contact resistance. Considering both low specific contact resistance and high temperature reliability, the Ni(50 nm)/Nb(50 nm)/4H-SiC ohmic contact has been a potential candidate for high temperature and harsh environment applications.

In order to obtain both low specific contact resistance and high-temperature reliability, not only high concentration of Ni_2Si formed at the interface of the contact but also the

excess carbon atoms must be totally collected during the annealing process. In this thesis, the influence of CF_4:O_2 surface etching on the formation of Ni(75 nm)/Nb(25 nm) ohmic contact to n-type 4H-SiC bulk substrate was investigated. The SIMS, XRD, EDX, and TEM analyses indicated that CF_4:O_2 surface etching could eliminate the excess carbon atoms released from the SiC substrate by the formation of CO_x gases, and hence, a low concentration of Nb can totally collect the remaining excess carbon atoms. Moreover, the breaking and/or weakening the Si-C bonds during the etching process leads to Ni easily reacting with Si and thus improves the uniform formation of the Ni_2Si during the RTA process. As a result, by applying the CF_4:O_2 surface etching, not only the low specific contact resistance but also the high temperature reliability of the Ni(75 nm)/Nb(25 nm)/4H-SiC contact are improved.

The operation lifetime of 4H-SiC MOSFET is not only governed by the high defect density at the SiO_2/SiC interface but also strongly affected by the reliability of the gate metal. In this thesis, the high temperature reliability of 4H-SiC MOS capacitors with Al, TiN, TiC and mixture of TiN and TiC metal gate was investigated. The experimental results show that though TiC has a high melting point and the high temperature reliability, the SiO_2/4H-SiC capacitors based on TiC metal gate exhibited the degradation when operating in high temperature ambient. It is supposed that during the aging process at high temperature, the reaction of the gate metal (TiC and TiN:TiC) with a low quality of SiO_2 results in the carbon cluster and/or a higher defect states generated in the SiO_2 layer leading to the failure of the capacitors with TiC and TiN:TiC gate metal. Whereas, Al has a low melting point, the MOS capacitor with Al gate still exhibits good electrical characteristics after being aged at 400°C for 100 hours. After 100 hours of aging, the 4H-SiC MOS capacitor with TiN gate electrode shows not only good C-V characteristics with a low leakage current but also the flatband voltage is much higher than that of the Al gate metal. These results indicate that, for higher temperature applications, TiN can be a potential candidate.

In order to evaluate the applicability of 4H-SiC fabrication processes to build complex electronic circuits for harsh environment applications, the high temperature reliability of single stage amplifier circuit based on 4H-SiC MOSFET were investigated in this thesis. The experimental results show that the Ni/Nb/4H-SiC ohmic contact as well as the implanted load resistor exhibit a very stable after 100 hours of aging at 400°C. Though the carrier mobility and the threshold voltage of the single silicon carbide MOSFETs slightly shift after the first 25 hours of aging, these 4H-SiC MOSFETs remained fully operational after being aged for 100 hours. The stability of drain current, carrier mobility and threshold voltage of the 4H-SiC MOSFET account the stability of voltage gain of the single stage amplifier after 100 hours of aging at 400°C.

As the conclusion, in this thesis, SiC semiconductor process technologies with Ni/Nb/4H-SiC ohmic contact and TiN gate structure for high temperature electronics were developed and established. The high temperature reliability of 4H-SiC MOSFETs and electronic circuits with the process technologies were demonstrated.