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Ohmic contacts to polycrystalline 3C–SiC films for extreme environment microdevices

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Abstract

Ohmic contact characteristics were studied under the surface treatments of poly 3C–SiC films heteroepitaxially grown on SiO_2/Si wafers by APCVD. The poly 3C–SiC surface was polished to remove submicron-sized roughness and to get flat and smooth surface using chemical–mechanical polishing (CMP) process. However, some scratching marks on the poly 3C–SiC have remained surface due to the mechanical defect of CMP process. To remove a part of subsurface damage and scratching marks, the polished surface was oxidized by wet-oxidation furnace and it has been etched by diluted HF solution. Titanium tungsten (TiW) thin film was deposited on the surface treated poly 3C–SiC using circular transmission line model as a metallization process and it was annealed through the rapid temperature annealing (RTA) process to improve interfacial adhesion. The contact resistivity of the treated 3C–SiC surface was measured as the lowest $1.2 \times 10^{-5}\ \Omega\ \mathrm{cm}^3$ at 900 °C for 45 s.

Keywords: B. Surfaces; C. Electrical properties; D. SiC

1. Introduction

Silicon carbide-microdevices technology has rapidly been developing as next generation semiconductors in developed countries. Recently, the development of microelectromechanical system (MEMS) for the expected operational temperature over 500 °C is required at various industrial fields such as transportation machines, engine, space technology, environment technology and power plants [1].

Among many wide band gap semiconductors, the study of SiC has been mainly focused on nanoelectromechanical system (NENS) for RF, bio technology industries as well as MEMS for extreme environment applications because of its high temperature, high pressure, high power, high frequency, radiation-hard, corrosion-hard and superior mechanical properties [2].

The hexagonal 4H– and 6H–SiC wafers are currently fabricated in 2 in. diameter, but they are very expensive. Nevertheless, cubic (3C)–SiC grown on Si substrates still remains the only choice for low cost and large area applications. Single 3C–SiC membranes of proper thickness are currently not available because of the problems which have residual stress, cracks, thermal expansion coefficient (8%) and lattice mismatching (20%) of interfacial SiC/Si grown at high temperature over 1300 °C. On the other hand, polycrystalline (poly) 3C–SiC films deposited on insulating films on Si wafers can help to solve these problems [3]. Therefore, we should precede metallization studies with regard to a thermally stable electrode formation to develop M/NEMS applications for RF, bio, space and environment fields by using poly 3C–SiC with these excellent properties. However, some SiC devices make serious damages because of being submicro-sized roughness on the SiC surface grown by atmospheric pressure chemical vapor deposition (APCVD). That is why researchers are continually studying to solve these problems on the surface for metallization process [4,5]. The SiC surface has been polished by chemical mechanical polishing (CMP) to get more flat surface. Oxidation process also can improve the flatness of its surface, which may be formed into lower ohmic contact.

Recently, it has been working on ohmic contact for high temperature using thermally stable metals such as W, Ti, Ta and TiW of them is a suitable candidate for ohmic contact because it is thermally stable and phase changes do not occur at high temperatures [6].

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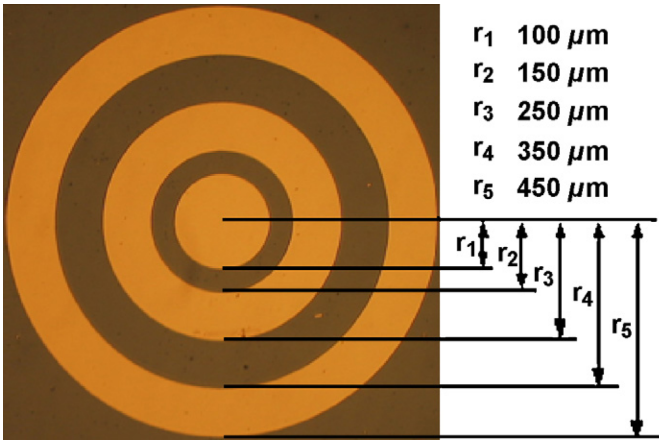

Fig. 1. Surface photography of TiW electrodes patterned by C-TLM method for contact resistivity measurement of TiW/poly 3C–SiC with r_{1-5} = 100, 150, 250, 350 and 450 μm.

In this work, poly 3C–SiC thin films heteroepitaxially grown on SiO_2/Si substrates were performed by surface treatment processes, such as CMP and wet oxidation process subsequently. And then, the TiW thin film as a thermally stable metallic material was deposited on the surface of poly 3C–SiC treated for ohmic contact as preceding study of development of extreme environment MEMS applications for high temperatures. Electrical, mechanical and physical properties of TiW/poly 3C–SiC, such as specific contact resistance, current–voltage (*I–V*) characteristics, flatness, and interfacial reaction according to annealing and surface treatments were investigated.

2. Experimental procedure

In this research, the poly 3C–SIC thin films of 2 μm thickness have been heteroepitaxially grown on SiO_2/Si substrates by APCVD at 1150 °C by adding single precursor such as HMDS ($Si_2(CH_3)_6$), which is easily decomposed in low temperature and has no risk of for explosions.

The grown poly 3C–SiC thin film was polished by CMP process in which colloidal silica slurry solution and diamond lapping films were used to remove submicro-sized roughness on their surfaces. And then the surfaces polished by CMP were oxidized by wet-oxidation furnace, they were etched in diluted HF solution again. The TiW thin films with the Ti/W ratio of 10/90 vol.% were deposited about 2000 Å on the polished poly 3C–SiC by RF magnetron sputter. In the last process, the TiW/poly 3C–SiC film was annealed in rapid temperature annealing (RTA) with Ar gas for 45 s.

Fig. 1 shows the surface photography of the patterned TiW/poly 3C–SiC with r_{1-5} = 100, 150, 250, 350 and 450 μm made in this study. After finishing the process of growth, CMP and oxidation subsequently, the surfaces of the treated poly 3C–SiC were observed by atomic force microscope (AFM), optical microscope. The TiW/poly 3C–SiC thin film was characterized by X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and scanning electron microscope (SEM), respectively to analyze interfacial mutuality diffusion and some cracks according to annealing. *I–V* characteristic of the circular-transmission line model (C-TLM) patterned TiW/poly 3C–SiC was also measured by the HP4155B semiconductor parameter analyzer and the four-point probe to evaluate specific contact resistance.

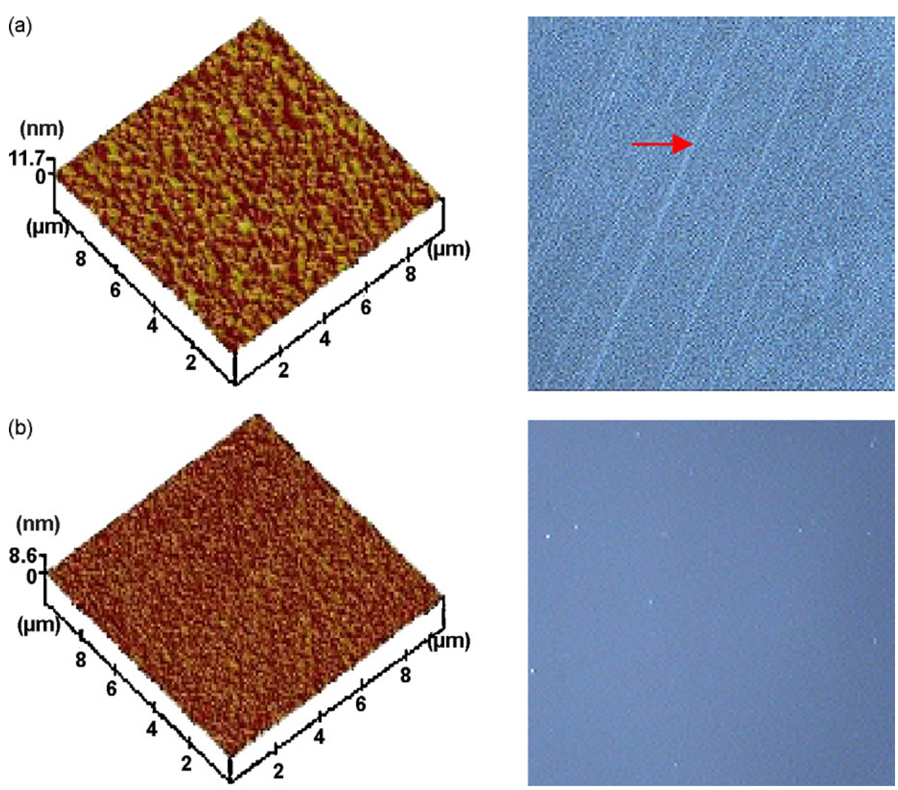

Fig. 2. Images of AFM and optical microscope according to surface treatments of the grown poly 3C–SiC thin film.

3. Results and discussion

Fig. 2 shows the images of the optical microscope and the 3D-surface of AFM according to surface treatments of poly 3C–SiC. The RMS of grown film surface was as over 27.6 nm. Fig. 2(a) shows the surface image that the poly 3C–SiC thin film was polished by CMP process. Roughness of the poly 3C–SiC was more than twice reduced to 11.7 nm of RMS. However, fine scratching marks remained on their surfaces due to mechanical defect of CMP process. Fig. 2(b) is the AFM image that the poly 3C–SiC thin film is oxidized and then is etched in diluted HF solution to remove a part of subsurface damages and scratching marks made by CMP process. Thus, we can see that surface of poly 3C–SiC is flat and smooth as decreasing to 8.6 nm of RMS roughness.

The crack of TiW thin films deposited on poly 3C–SiC substrates during annealing process was analyzed by SEM. It may happen to cracks between metal and semiconductor due to the difference of their thermal expansion coefficient. As the SEM images, before and after annealing at 900 °C, for 45 s, there were no cracks on the TiW thin films deposited on the poly 3C–SiC.

Fig. 3 shows that variations of the crystallization for TiW thin films are analyzed by XRD, which is set from 2° to 4° for an angle of incidence and is injected into the value of 2θ for a route of search to see diffraction peaks. These results of the XRD analysis on TiW thin films are shown in Fig. 3(a) and (b) by using these conditions such as (a) before annealing and (b) after annealing at 900 °C for 45 s with RTA process, respectively. The Ti peak is much stronger than the TiW peak before annealing. By annealing process, the Ti peak decreased, but the recombined TiW peak increased.

Fig. 4 shows the XPS depth-profile to analyze the interfacial mutuality diffusion and stability of the TiW/poly 3C–SiC before and after annealing. After annealing, it was found to be a stable state which hardly changed in the interfacial TiW/poly 3C–SiC. Fig. 4(a) showed little O_2 on the surface layer, but Fig. 4(b) showed much O_2 on TiW thin films is diffused outside by annealing. Increasing Ti as well as O_2 showed that they react on each other at high temperature. In the case of exposure of TiW thin films as ohmic contact at high temperature, it is considered that the contact characteristic is deteriorated owing to the oxidation of Ti. Therefore, it should be required to prevent the formation of the oxidation film for ohmic contact [7].

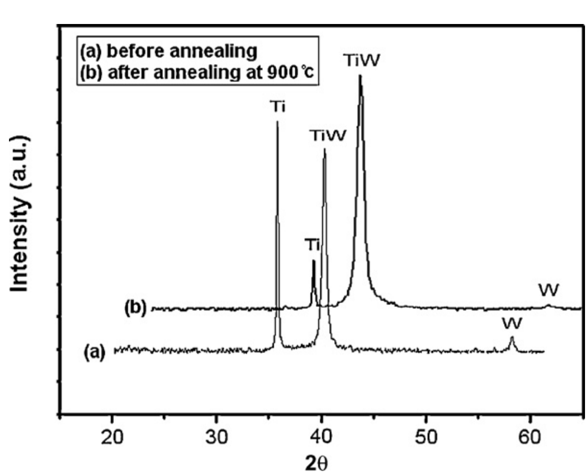

Fig. 3. Variations of XRD crystallization peak of TiW thin films (a) before and (b) after annealing.

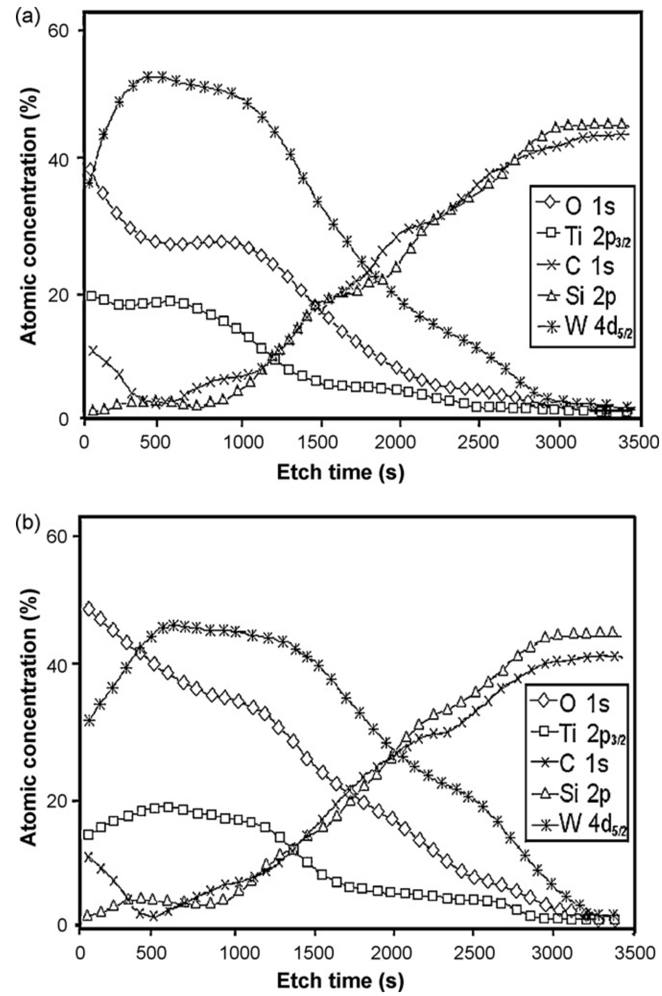

Fig. 4. XPS depth-profiles of TiW/poly 3C–SiC (a) before and (b) after annealing.

In this work, specific contact resistances of TiW/poly 3C–SiC are observed with the C-TLM method. The resistance (R_1) between the first inside circle and the second circle, resistance (R_2) between the second circle and the third circle were measured in Fig. 1, respectively. And then the specific contact resistance of the ohmic contact was calculated by using the C-TLM method as given by (1) [8].

$$p_c = \left[\ln\left(\frac{r_2'}{r_1}\right)R_1 - \ln\left(\frac{r_1'}{r_0}\right)R_2\right](r_0)^2\Delta \quad (1)$$

where, r_0, r_1, r_1' and r_2' are the radius of the various circles like a Fig. 1 and the value of Δ can be obtained by (2) as a function of the geometrical structure of these samples.

$$\Delta = \frac{[2\pi/(\alpha r_0)^2]}{\ln(r_2'/r_1)[E(r_0)/\alpha r_0 + 1/\alpha r_1(A(r_1,r_1')/C(r_1,r_1'))] - \ln(r_1'/r_0)[1/\alpha r_1(A(r_1,r_1')/C(r_1,r_1')) + 1/\alpha r_2(A(r_2,r_2')/C(r_2,r_2'))]} \quad (2)$$

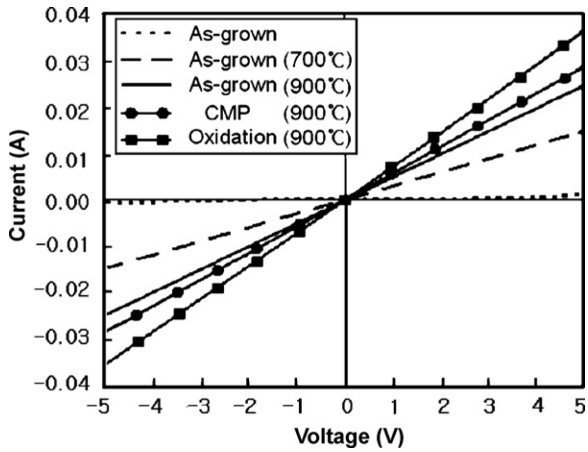

Fig. 5. *I–V* characteristics of TiW/poly 3C–SiC depending on surface treatments and annealing conditions.

The α parameter is then defined as (3)

$$\alpha = \sqrt{\frac{R_{sk}}{p_c}} \quad (3)$$

where R_{sk} is a sheet resistance under the TiW contacted on Poly 3C–SiC.

Fig. 5 shows *I–V* characteristic curves of TiW/poly 3C–SiC films under the surface treatments and annealing conditions. Before annealing, there was no electric current because it was not contacted perfectly at the interfacial TiW/poly 3C–SiC. However, it was linearly shown that ohmic contact was improved by interfacial adhesion according to increasing temperature with RTA process. When the poly 3C–SiC thin films are etched in diluted HF solution after CMP and wet-oxidation process, roughness and subsurface damage on their surface can be removed. Therefore, the *I–V* characteristics with regard to the surface treated of the poly 3C–SiC could become the lowest ohmic contact for 45 s at 900 °C. It has been shown that the lowest specific contact resistivity was $1.2 \times 10^{-5}\ \Omega\ cm^3$ at these time and temperature. The value of specific contact resistivity decreases when annealing temperature increases with RTA process. However, since the RTA process runs over 1000 °C, 1 min, it is important to control oxidation for the metal contact [9].

4. Conclusions

Poly 3C–SiC films grown by have still remained a problem such as fine roughness on its surface. To solve this problem, the surface of poly SiC was polished by CMP process in this study. Nevertheless, some scratching marks remained on the polished poly 3C–SiC surface due to mechanical defect of CMP process. After the polished poly 3C–SiC films finished oxidation process, some scratching marks and subsurface damage of their surfaces was removed perfectly. The result of the XRD analysis shows that crystallization of TiW thin films according to annealing was improved. It was found to exist in stable thin films of the interfacial TiW/poly 3C–SiC, which has no both mutuality diffusion and any cracks by XPS and SEM, respectively. It has been shown that the specific contact resistivity measured by C-TLM methods was the lowest value $1.2 \times 10^{-5}\ \Omega\ cm^3$ at 900 °C for 45 s. Therefore, surface treatments of poly 3C–SiC are significant to get better ohmic contact like preceding study for development of extreme environment microdevices.

Acknowledgments

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