Ti/WSi/Ni ohmic contact to n-type SiCN*

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Abstract: Ti/WSi/Ni contact to n-type SiCN was investigated using the circular transmission line method. Current–voltage characteristics, X-ray diffraction and X-ray photoelectron spectroscopy were used to characterize the contacts before and after annealing. It is shown that the conducting behavior of the contacts is dependent on the annealing temperature. After annealing at 900 °C or above, ohmic contacts with specific contact resistivity were achieved. The 1000-°C-annealed contact exhibits the lowest specific contact of 3.07×10^{-5} $\Omega\cdot\text{cm}^2$. The formation of ohmic contact with low specific contact resistivity was discussed.

Key words: SiCN; ohmic contact; electrical property
DOI: 10.1088/1674-4926/31/4/043003 **EEACC:** 2520

1. Introduction

Silicon carbon nitride (SiCN) has been considered as a promising semiconductor material for MEMS (micro-electro-mechanical systems) devices operated at high temperature because of its wide interesting physical characteristics, such as hardness, oxidation resistance, corrosion resistance, wide energy band dap, and good thermal conductivity[1−16]. To realize SiCN MEMS devices for high temperature, one of the most important problems is to obtain thermal dynamically stable ohmic contacts with low contact resistance between the films and electrode. However, during the past years, most of the studies of SiCN films have been focused on the preparation and characterization of the film[1−8, 14−16], while relatively few researches were on the contact properties of SiCN films[17]. Therefore, here we present our studies on the ohmic contacts of n type SiCN films.

Considering metal such as Ni has been shown to react with Si to form nickel silicides at temperatures lower than 600 °C, pure metal contacts to SiCN might be thermally unstable at relatively low temperatures. Therefore, like the case for GaAs, multilayered materials should be introduced into contacts on SiCN to form carbides and nitrides with the goal to constrain the excess carbon and nitrogen at the interface after annealing. In this paper, we report a low contact resistivity for Ti/WSi/Ni on n-type SiCN. Current–voltage characteristic of the contacts before and after rapid thermal annealing at temperatures ranging from 300 to 1000 °C are investigated and discussed, and the microstructure at the interface of the Ti/WSi/Ni-SiCN structure was analyzed using X-ray diffraction spectroscopy (XRD) and X-ray photoelectron spectroscopy (XPS) depth profiles.

2. Experimental

2-μm-thick P-doped SiCN films were grown on p-type (100) direction silicon wafer (resistivity, 4 °C 10 $\Omega\cdot\text{cm}^2$) with plasma enhanced chemical vapor deposition system. During deposition, the substrate temperature was kept at 1000 °C. CH_4, SiH_4, N_2, PH_3 were used as source materials for C, Si, N, and n-type dopant, respectively, and their flow rates were kept at 20, 20, 20, and 4 sccm, respectively. According to Hall measurements, the carrier concentration and mobility of the as-deposited n-SiCN films are about 9×10^{17} cm^{-3} and 221 $\text{cm}^2/(\text{V}\cdot\text{s})$ respectively.

The contact material Ni (20 nm), WSi (40 nm), and Ti (20 nm) were sputtered-deposited in sequence on the surface of the SiCN samples under a base pressure of 3×10^{-4} Pa. A standard photolithographic lift-off procedure was then conducted to obtain the CTLM (circular transmission line method) structure of the samples. The CLTM pattern, which consists of eight contact patterns with each one has a contact inner radius of 100 μm and a space (d) ranging from 10 to 80 μm between each inner and outer contact, was used for the measurements of the specific contact resistivity (ρ_c) and I–V characteristics between neighboring contacts. Finally, the resulted samples were annealed at different temperatures for 5 min in argon ambient.

XRD measurements were obtained on a Rigaku D/Max-IIIC X-ray diffractometer using CuKα_1 radiation. XPS measurement was conducted on a PHI-5702XPS/AES system using MgKα radiation of 1253.6 eV as an excitation source.

3. Results and discussion

Figure 1 presents the measured room-temperature I–V characteristics of Ti(20 nm)/WSi(40 nm)/Ni(20 nm) contacts to n-SiCN before and after thermal annealing. It can be seen the as-deposited sample shows rectifying behavior, indicating a Schottky-behaved contact. With enhancing annealing temperature, the I–V curves gradually proceed toward linear behavior. After annealing at 900 °C or above, the I–V characteristics become fully linear, which implies an ohmic contact were obtained. Compared with the sample annealed at 900 °C, the slope of the I–V curve for the sample annealed at 1000 °C increases, which suggesting the 1000-°C-annealed sample has lower ohmic contact resistance.

The average values of ρ_c for the samples before and after annealing were derived from CTLM, as listed in Table 1.

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* Project supported by the National Natural Science Foundation of China (No. 60606004).

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Received 9 December 2009

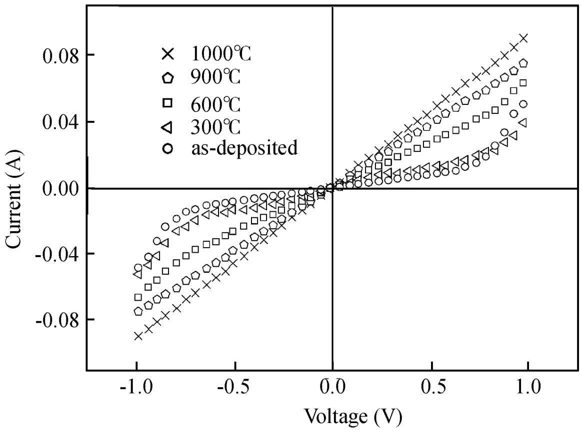

Fig. 1. I–V characteristics of Ti(20 nm)/WSi(40 nm)/Ni(20 nm) sample before and after annealing at different temperatures.

Table 1. Specific contact resistivity of the sample.

Annealing temperature (°C)	Specific contact resistivity (Ω·cm^2)
As deposited	—
300	3.32×10^{-2}
600	8.56×10^{-3}
900	6.25×10^{-5}
1000	3.07×10^{-5}

Compared with the as-deposited sample, the ρ_c value decreases from the range of 10^{-2} to 10^{-5} Ω·cm^2 by annealing. After annealing at 1000 °C, the contact with the lowest ρ_c value of 3.07×10^{-5} Ω·cm^2 was obtained.

To determine the microstructure of the above samples and to further investigate the compounds formed at the interface between Ti/WSi/Ni and SiCN after annealing, XRD analysis was performed on the contacts. Figure 2 shows the XRD results for the samples before and after annealing at 1000 °C. For the as-deposited sample, besides the diffraction peaks corresponding to SiCN, the reflection peaks corresponding to Ni, WSi, and Ti were observed. After 1000 °C annealing, five different peaks corresponding to TiN, Ni_2Si, WC, Ni_3Si_5, and TiN appear, while peaks corresponding to Ni, WSi, and Ti disappear. Among all the samples, note that the samples annealed at 900 °C or above show ohmic contact with low values of ρ_c, especially the 1000-°C-annealed sample exhibits the lowest ρ_c value of 3.07×10^{-5} Ω·cm^2. The significant improvement on ρ_c value of the contact system after annealing at high temperature should be attributed to the alloys suggested by XRD data.

To identify the compounds formed at the interface indicated by XRD results, we performed XPS depth profile measurement. Figure 3 depicts the XPS depth profiles of the Ti(20 nm)/WSi(40 nm)/Ni(20 nm) structure before and after annealing at 1000 °C. From the spectra for the as-deposited sample, the interfaces between the electrode materials and between electrode and SiCN can be seen clearly. For the Ti/WSi/Ni-SiCN contact annealed at 1000 °C, diffusion phenomenon appears obviously. At the beginning of sputtering, it can be seen O and C are present on the surface, which might come from the possible surface pollution and the surface layer of titanium oxide formed. Within the range of 0–5 min, Ti and N are detected, and the atomic concentration of titanium as well as nitrogen increases simultaneously and reaches their maximum respectively. With increasing sputtering time, contents of Ti and N keep decreasing and disappear simultaneously after nearly 15 min of sputtering. The results indicate that TiN is present in the 1000-°C annealed contact layers as supported by the XRD data. The region within 24–35 min of sputtering is characterized by the decreasing of both W and C as well as the increasing of Si and Ni, indicating that Ni_2Si, Ni_3Si_5, and WC present within this depth, as verified by the peaks corresponding to the alloys in XRD spectra. Within the range of 40–60 min, the Ni concentration falls gradually down to zero while concentrations of Si, C, and N increases from 16%, 6.3%, 6.1% to 39%, 33%, 28%, respectively, indicating that the SiCN surface is reached after nearly 60-min sputtering.

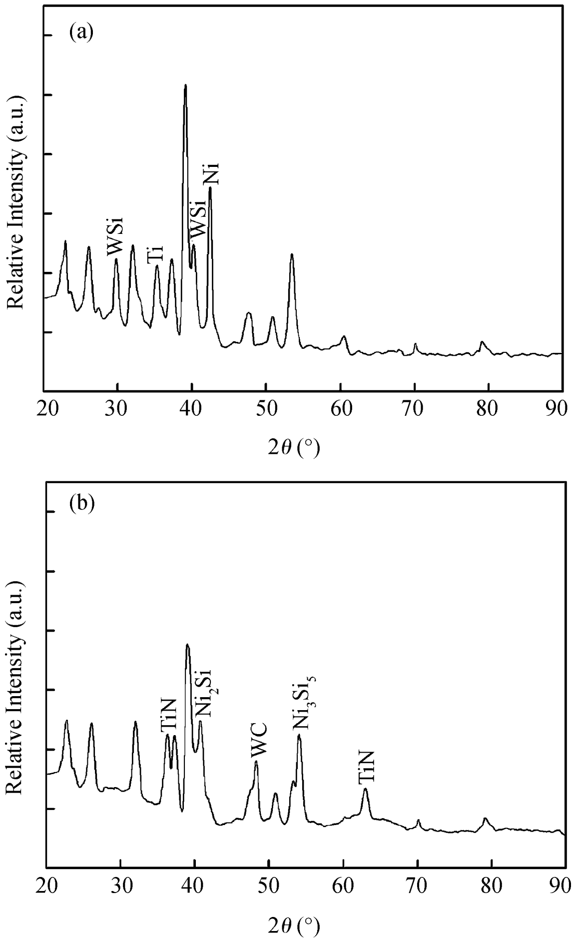

Fig. 2. XRD spectra of the Ti(20 nm)/WSi(40 nm)/Ni(20 nm) contact (a) before and (b) after annealing at 1000 °C.

Combining the XRD and XPS results mentioned above, it can be seen that the Ni atoms diffuse downward to Ti/WSi/Ni-SiCN interface and convert into nickel silicide layer in adjacent to the SiCN film. At the same time, the released carbon atoms and nitrogen atoms interact with W and Ti atoms to form WC and TiN layer respectively, which makes C and N atoms move far away from the contact interface. Therefore, the formation of the compounds at the interface should be responsible for the ohmic formation of the annealed contacts. As mentioned above, ohmic contacts with specific contact resistivity as low as 3.07×10^{-5} Ω·cm^2 have been achieved after thermal an-

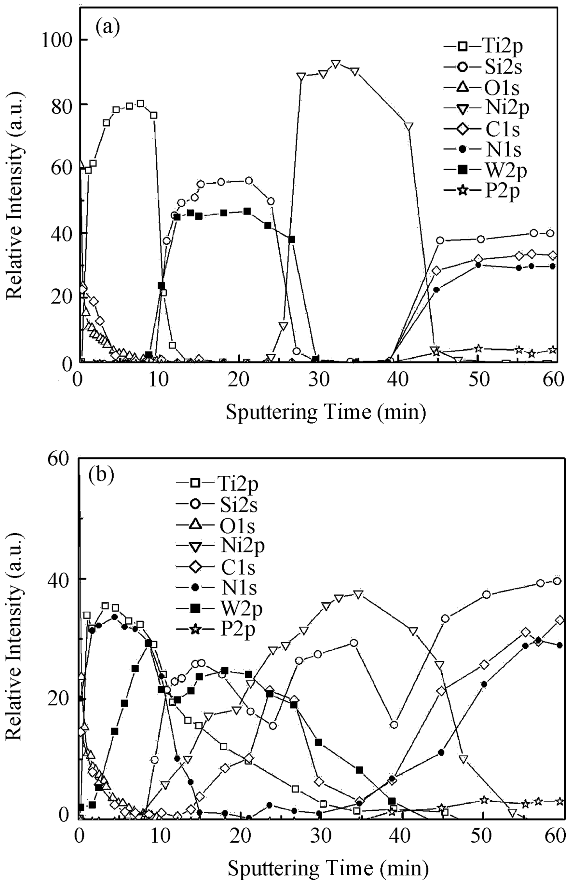

Fig. 3. XPS depth profiles of the Ti(20 nm)/WSi(40 nm)/Ni(20 nm) structure (a) before and (b) after annealing at 1000 °C.

nealing at 1000 °C. Thus, the addition of WSi and Ti into the Ni metallization scheme to n-SiCN restricted the accumulation of carbon and nitrogen atoms left behind during the nickel silicides formation, improving the electrical and microstructure properties.

4. Conclusions

In this paper, we have investigated Ti/WSi/Ni ohmic contact to n-SiCN. The conducting behavior is rectifying for the as-deposited contact, whereas ohmic contact with ρ_c value in the low $10^{-5}\Omega\cdot\text{cm}^2$ range was obtained after annealing at a temperature of 900 °C or above. XRD and XPS analysis suggest that Ni_2Si, WC, Ni_3Si_5, and TiN formed at the interfaces after annealing at a high temperature. The compounds should be responsible for the ohmic formation of the annealed contacts.

References

[1] Chen L C, Chen C K, Wei S L, et al. Crystalline silicon carbon nitride: a wide band gap semiconductor. Appl Phys Lett, 1998, 72: 2463

[2] Chang H L, Kuo C T. Properties of Si–C–N films prepared on Si substrate using cobalt interfacial layers. Mater Chem Phys, 2001, 72: 236

[3] Bhusari D M, Chen C K, Chen K H, et al. Composition of SiCN crystals consisting of a predominantly carbon-nitride network. J Mater Res, 1997, 12: 322

[4] Badzian A, Badzian T, Drawl W D, et al. Silicon carbonitride: a rival to cubic boron nitride. Diamond Relat Mater, 1998, 7: 1519

[5] Chang H L, Kuo C T. Characteristics of Si–C–N films deposited by microwave plasma CVD on Si wafers with various buffer layer materials. Diamond Relat Mater, 2001, 10: 1910

[6] Komateu S, Hirohata Y, Fukuda S, et al. Preparation and characterization of reactively sputtered SiC_xN_y films. Thin Solid Films, 1990, 193/194: 917

[7] Novikov N V, Voronkin M A, Zaika N I. Mechanical properties of thin ceramic coatings of the Si=C=N system deposited by reactive ion-plasma sputtering. Diamond Relat Mater, 1992, 1: 580

[8] Uslu C, Park B, Poker D B. Synthesis of metastable carbon-silicon-nitrogen compounds by ion implantation. J Electron Mater, 1996, 25: 23

[9] Liew L A, Zhang W, Bright V M, et al. Fabrication of SiCN ceramic MEMS using injectable polymer-precursor technique. Sensors and Actuators A, 2001, 89: 64

[10] Liew L A, Liu Y, Luo R, et al. Fabrication of SiCN MEMS by photopolymerization of pre-ceramic polymer. Sensors and Actuators A, 2002, 95: 120

[11] Liu Y, Liew L A, Luo R, et al. Application of microforging to SiCN MEMS fabrication. Sensors and Actuators A, 2002, 95: 143

[12] Gregori G, Kleebe H J, Brequelet H, et al. Microstructure evolution of precursors-derived SiCN ceramics upon thermal treatment between 1000 and 1400 °C. Journal of Non-Crystalline Solids, 2005, 351: 1393

[13] Barbadillo L, Gomez F J, Hernandez M J, et al. Nitrogen incorporation in amorphous SiCN layers prepared from electron cyclotron resonance plasmas. Appl Phys A, 1999, 68: 603

[14] Nakaaki I, Saito N. Optical, electrical and structural properties of amorphous SiCN:H films prepared by RF glow-discharge decomposition. Appl Surf Sci, 2001, 169/170: 468

[15] Chou Y C, Chattopadhyay S, Chen L C, et al. Doping and electrical properties of amorphous silicon carbon nitride films. Diamond and Related Materials, 2003, 12: 1213

[16] Probst D, Hoche H, Zhou Y, et al. Development of PE-CVD Si/CN:H films for tribological and corrosive complex-load conditions. Surface and Coating Technology, 2005, 200: 355

[17] Chang W R, Fang Y K, Ting S F, et al. The contact characteristics of SiCN films for opto-electrial devices applications. J Electron Mater, 2004, 33: 181