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Ohmic Contact Formation for n^+4H-SiC Substrate by Selective Heating Method Using Hydrogen Radical Irradiation

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Abstract

We developed an apparatus for producing high-density hydrogen plasma. We confirmed that the temperatures of transition-metal films increased to above 800˚C within 5 s when they were exposed to hydrogen plasma formed using the apparatus. We applied this phenomenon to the selective heat treatment of W/Ni films deposited on n^+4H-SiC wafers and formed nickel silicide electrodes. To utilize this method, we can perform the nickel silicidation process without heating the other areas such as channel regions and improve the reliability.

Keywords

Selective Heating, Nickel Silicide Electrode, Hydrogen Plasma, Ohmic Contact, SiC

1. Introduction

Silicon carbide (SiC) has properties such as wide band gap, high critical electric field, and high thermal conductivity. Therefore, SiC is a promising candidate for high temperature and high power semiconductor devices. To improve the performance of the devices, formation of ohmic contact on SiC is very important. Many metals have been researched for forming ohmic contact, and nickel is one of the strong candidates for fabrication of ohmic contact on SiC. The process temperature of Ni based ohmic contacts to SiC sometimes reaches approximately 1000˚C. Therefore, we must consider that heat treatment causes the degradation of SiC devices reliability.

In general, we use rapid thermal annealing (RTA) to shorten the processing time [1] [2]. SiC devices are heated for several minutes by RTA method and electrodes are formed on SiC devices. However, RTA method heats whole SiC wafers, which causes unnecessarily heating of areas such as channel regions.

To overcome these problems, we have proposed a simple heating method, in which transition metals can be heated selectively by exposing them to hydrogen plasma. Mozetič and coworkers [3]-[8] reported that the temperature of nickel was increased by the irradiation of hydrogen atoms and reached approximately 300˚C, and from this phenomenon they estimated the density of hydrogen atoms in hydrogen plasma. This phenomenon is attributed to the release of binding energy by the recombination of hydrogen atoms into molecules on nickel surfaces, and as a result, the nickel is heated. We previously reported that the temperatures of transition-metal films increased to above 800˚C within 5 s when they were exposed to hydrogen plasma [9]. We applied this phenomenon to the selective heat treatment of nickel films deposited on silicon wafers and formed nickel silicide electrodes [9]. In this paper, we report the application of the heating method to nickel silicide formation for SiC devices.

2. Experimental Methods

The schematic of an experimental apparatus with a self-tuning microwave plasma system [10] (SST Inc. JX0-1500-S1) is shown in **Figure 1**. This apparatus has four components: a reaction chamber, a 2.45 GHz microwave generator, a gas flow control unit, and a rotary pump evacuation system. The reaction chamber has four parts: 1) an outer cylindrical chamber made of a dielectric material, 2) a microwave coupling section mounted on the surface of the outer cylindrical

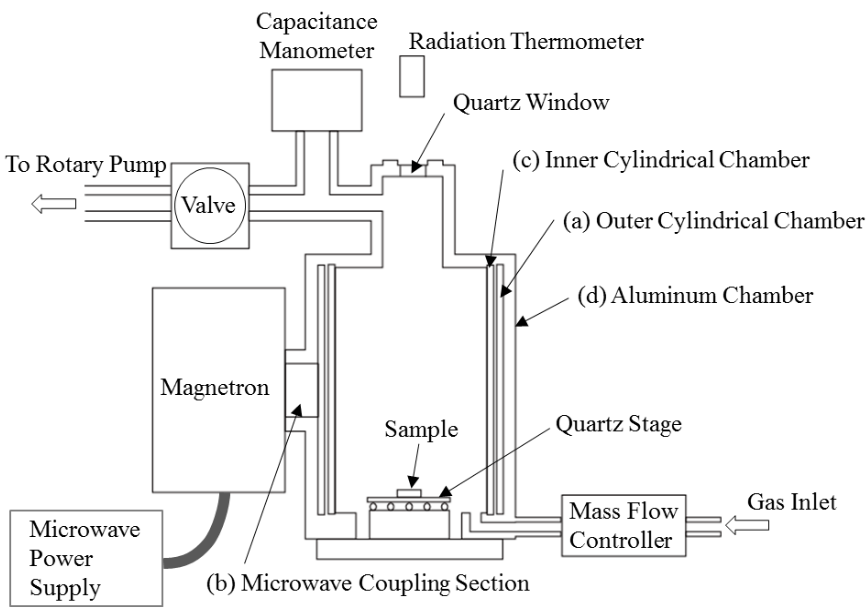

Figure 1. Schematic illustration of apparatus. The inner chamber has a diameter of 131 mm and a height of 206 mm.

chamber, 3) an inner cylindrical chamber made of quartz (diameter: 131 mm, length: 206 mm), and 4) an aluminum chamber that surrounds the outer cylindrical chamber except for in the microwave coupling section.

We set samples on a sample stage made of quartz and exposed to hydrogen microwave plasma. At that time, we evaluated the sample temperature using a radiation thermometer with a measuring wavelength ranging from 0.8 to 1.6 μm (Japan Sensor Corporation FTK9-P300R-30L22) through a quartz window.

For our experiment, W/Ni layers were deposited on the Si face of n^+4H-SiC wafers with an area of 400 mm^2 and a thickness of 400 μm by electron beam evaporation. The carrier concentrations of these wafers were approximately 3×10^{18} cm^{-3}. Ni layers were deposited on the SiC substrates and the thicknesses were approximately 60 nm. Since we could not obtain that the sample deposited Ni layer showed ohmic behavior after hydrogen plasma exposure, W layers (40 nm) were deposited on the Ni layers. The reason for the W layer deposited is that W layer temperature reaches higher than Ni layer under hydrogen microwave plasma exposure [9]. For current-voltage (I-V) curve measurement, we cut metallic regions of layers reacted between SiC and Ni into orthogonal equal- interval 3 mm meshes with the depth of 60 μm.

We studied the formation of nickel silicide by a scanning transmission electron microscope (FEI Company Tecnaei Osiris) with an energy dispersive x- ray analysis system (STEM-EDX).

In all the experiments, the input microwave power was 1000 W, the hydrogen gas flow rate was 20 sccm, and the pressure was 30 Pa.

3. Results and Discussion

Figure 2 shows the temperature profiles when W/Ni layers deposited on SiC wafers were exposed to hydrogen microwave plasma. After turning on the microwave power, we turned off the power after 7 s, 15 s, 30 s and 60 s. The temperature profile of 7 s exposure reached to approximately 550˚C and decreased to less than 350˚C within 10 s after turning off the microwave power. The temperature profiles of 15 s, 30 s and 60 s exposure reached to approximately 850˚C and decreased to less than 500˚C within 10 s after turning off the microwave power.

Figure 3(a) shows a cross-sectional STEM image of a sample of a W/Ni layer deposited on SiC wafer (as-deposited). **Figures 3(b)-(e)** show cross-sectional STEM images of samples after hydrogen plasma exposure for 7 s, 15 s, 30 s and 60 s.

Figures 4(a)-(e) show EDX line scan profiles of the sample in **Figures 3(a)-(d)**. The EDX profile after hydrogen plasma exposure for 7 s is hardly different from that of the as-deposited one except the concentration distribution of C. In the case of the sample exposed hydrogen plasma for 7 s, the concentration of C increased in the W layer. In the cases of 15, 30, and 60 s exposure, the concentration of C increased not only in the W layer but also in the nickel silicide layer with a maximal concentration near the interface between SiC and

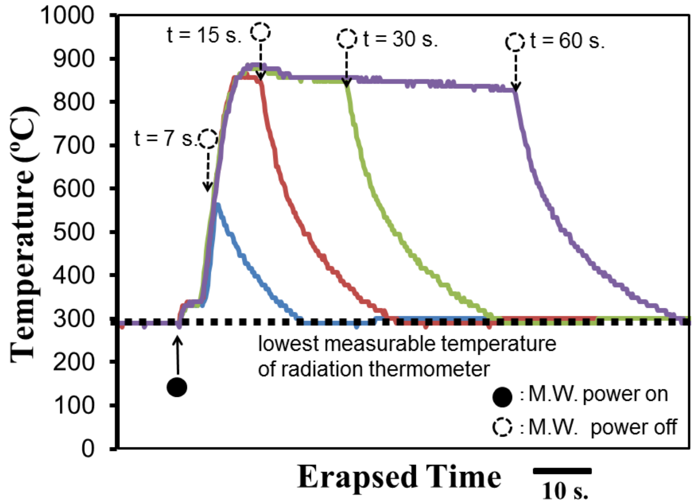

Figure 2. Temperature profiles when W/Ni layers deposited on SiC wafers were exposed for 7, 15, 30 and 60 seconds to hydrogen microwave plasma.

nickelsilicide layers. In the nickel silicide formation of Ni layer on 3C-SiC, A. Bächli and coworkers [11] reported that C diffused into Ni layer during the early stage of nickel silicide formation. With the nickel silicide formation, C accumulated in nickel silicide layer because nickel silicide was a diffusion barrier for carbon. Baud, L. and coworkers [12] reported that they never observed W_2C or WC X-ray diffraction signal from the sample of the W/3C-SiC through RTA method at 850˚C for 60 s. In our study, therefore, it is assumed that C diffuses through Ni layer and accumulates in W layer as carbon precipitate.

The I-V characteristics of W/Ni contacts on SiC after hydrogen microwave plasma exposure of 7, 15, 30 and 60 s are shown in **Figure 5**. After 7 s hydrogen plasma exposure, the I-V characteristic show rectifying behavior. After 15 s hydrogen plasma exposure, it is thought that the I-V curve has both the characteristics of Schottky and ohmic contacts. After 30 s hydrogen plasma exposure, the I-V characteristic becomes close to ohmic behavior. After 60 s hydrogen plasma exposure, the I-V characteristic shows ohmic behavior. Taking observations in **Figure 3** and **Figure 4** into consideration, it is not enough to show ohmic behavior that the nickel silicide is formed in the samples. This consideration agrees with the study of Crofton, J. and coworkers [13].

From these results, it can be seen that W/Ni layers form ohmic contacts to n^+4H-SiC after 60 s hydrogen plasma exposure. Furthermore, this heating time is as short as the process time by the RTA method. The heating method by hydrogen plasma exposure can heat selectively the areas of transition metals deposited on SiC wafers. Thus, it does not cause any heat damage to the areas which do not require heat treatment. Consequently, it can be expected that the reliability of SiC device is improved by this heating method.

4. Summary

In this study, we have developed an apparatus with a self-tuning microwave

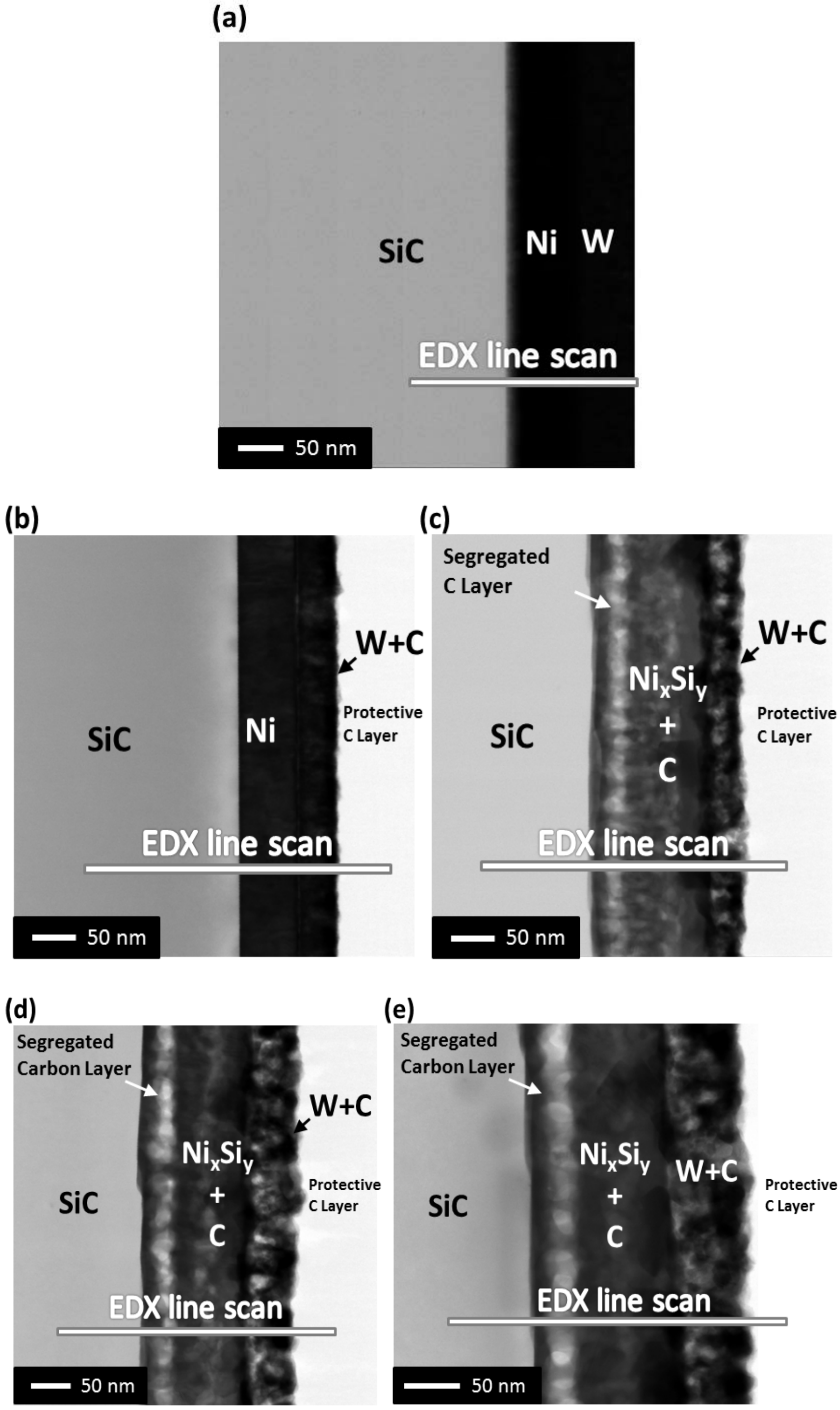

Figure 3. Cross-sectional STEM images of W/Ni layers deposited on SiC wafers samples before (a) and after hydrogen plasma exposure for 7 s (b), 15 s (c), 30 s (d) and 60 s (e).

plasma system to form high-density hydrogen plasma and we have confirmed that W/Ni/n$^+$4H-SiC can be heated at approximately 850˚C by exposure to high-density hydrogen plasma. We achieved the selective heating of W/Ni/n$^+$4H-SiC wafers by hydrogen plasma exposure and successfully formed ohmic

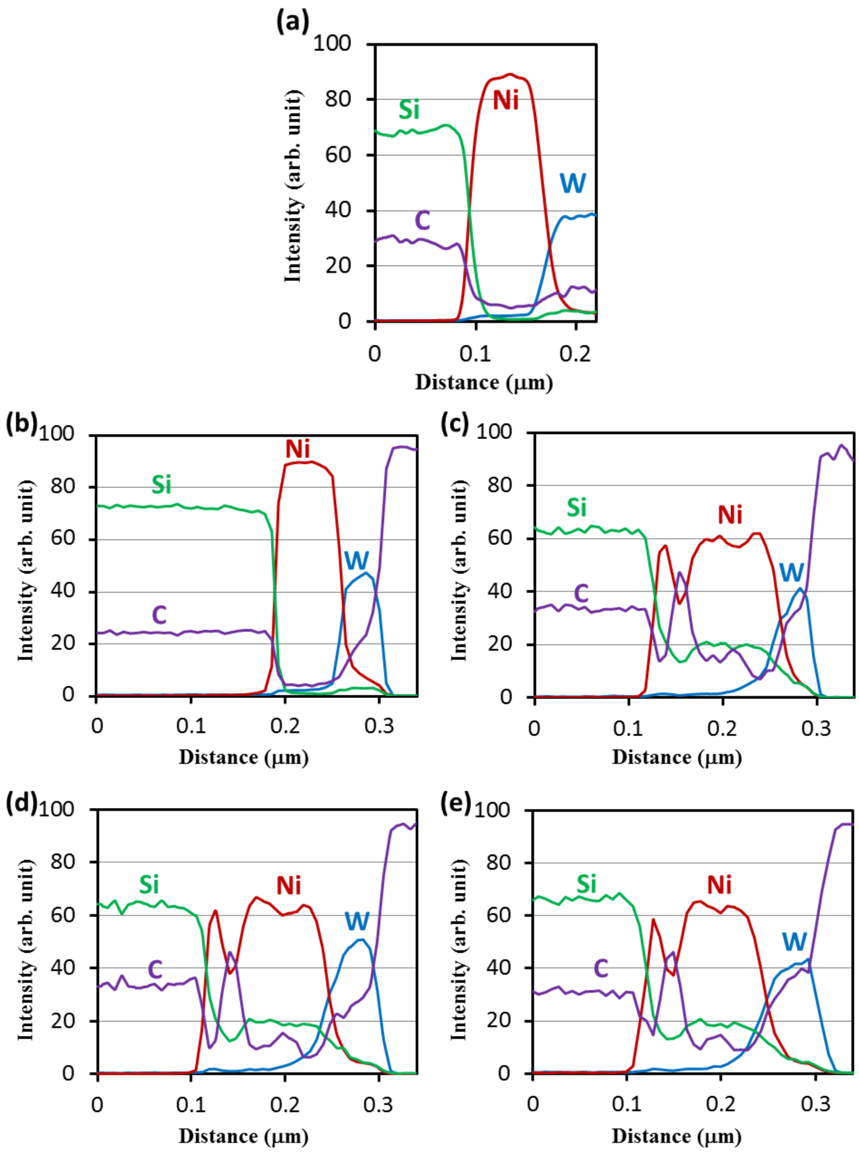

Figure 4. EDX line scan profiles of Si, C, Ni and W of the samples in **Figure 3**.

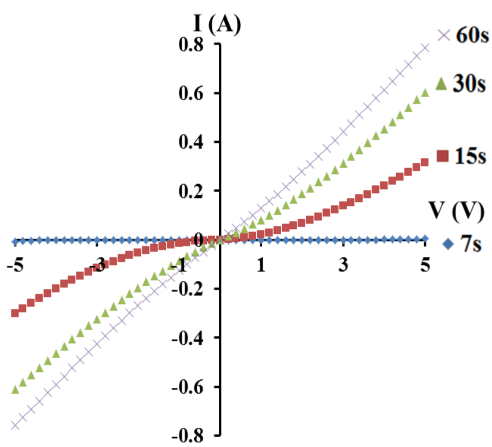

Figure 5. I-V characteristics of W/Ni/SiC contacts exposed hydrogen plasma at different time.

contacts in a short time. This heating method is suitable for the manufacturing of SiC devices.

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