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Effects of Ar^+ ion sputtering on morphology and electric conductance of 6H-SiC (0001) surface

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The paper reports surface modification of SiC by Ar^+ ion sputtering. Observations were performed with an ultra high vacuum atomic force microscope operating in the contact mode. The surface morphology and topography were investigated with simultaneous measurement of local changes in electric conductance. We show that the Ar^+ ion bombardment of the 6H-SiC wafer surface affects the surface stoichiometry, changing the character of a metal/SiC contact from the Schottky barrier diode type into an ohmic contact type.

Key words: *silicon carbide; metal contact; ion sputtering*

1. Introduction

Wide band-gap semiconductor silicon carbide SiC has been recognized as a very promising material for future applications in opto-, high-frequency, high-power, and high-temperature electronics [1–3]. In addition, the material is highly chemically resistant, even to hydrofluoric acid [4]. Preparation of SiC as an output material for a large-scale application in industry is still difficult, mainly due to the presence of numerous defects in single crystals of SiC and troublesome technology of surface-perfection preparation. Another problem occurs with the formation stage of the ohmic contact by deposition of metals and other materials onto this substrate. One of the means of processing the surface for a high cleanness and chemical resistance is ion bombardment. The ion-impact induced processes such as diffusion, segregation and surface diffusion can introduce considerable changes in substrate stoichiometry. Ion sputtering makes the surface disordered, roughened and flattened.

An improper morphology can degrade the quality of thin films grown on the surface and, in consequence, of the electronic components fabricated using the films. The chemical composition, cleanness and structure of the surface play an essential role in

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the formation process of the metal/semiconductor interface for technology of electronic devices [5]. Surfaces modified by ion sputtering show considerable changes in the conductance type of the contact probe/SiC(0001) surface. From this point of view we undertook this investigation of SiC surface preparation. In the present paper, we report the effect of the Ar^+ ion bombardment process on the topography and electric conductance of the 6H-SiC(0001) wafer surface.

2. Experimental

Samples, around 3×5 mm^2 in size, were cut out of the nitrogen-doped n-type (resistivity 0.065 Ω·cm) 6H-SiC single crystal (0001)-oriented Si-terminated wafers 0.25 mm thick (Cree Research Inc.). Supplier polished samples were degreased in acetone. 1.2 keV Ar^+ ion bombardment was applied from an ion gun with the 8 μA current at the pressure of 2×10^{-4} torr Ar, at room temperature for 2–25 min. Observations were performed at $\sim10^{-10}$ torr with the ultra high vacuum AFM (Omicron-made atomic force microscope) operating in the contact mode (nanosensors-made Pt/Ir tip with the force constant of 0.12 N/m). The surface morphology and topography were investigated with simultaneous measurement of the local changes in electric conductance of the probe/6H-SiC(0001) surface system. Next, the effect of Ar^+ ion bombardment of the sample was investigated by measuring of *I–V* characteristics. The area of probed region was 1 μm^2 covered by 6400 measurement points.

3. Results and discussion

AFM topography of the surface of a fresh commercial sample exhibits numerous, randomly oriented scratches of up to 20 nm deep and 200 nm wide, resulting from the polishing process. The ion bombardment process leads to considerable topographic changes of the surface. Figure 1 shows typical AFM images of the topography after 2 and 20 min of sputtering (Figs. 1a, b, respectively) and the corresponding images of the local conductance for the contact system of interest (Figs. 1c, d, respectively). Analysis of the topography showed that the roughness of the surface, as estimated by the RMS ripple parameter within the 1 μm^2 area frame, decreased with increasing bombardment time (Fig. 2). After a longer bombardment time of 20 min, the formation of grains on the surface was observed which may indicate the appearance of an amorphous layer [6]. The images in Fig. 1d, e, mapping the local conductance in the reverse bias mode show that after 2 min bombardment the surface is weakly and rather uniformly conducting, whereas after a longer exposure to ions the conductance behaviour essentially changes and after 20 min of bombardment the images are electrically non-uniform. The current images are grainy in structure which, however, is not reflected in the topographic image. The long-exposure originated grains reveal a higher conduction in the system of interest. The statistics on the population of these grains shows their diameters to be steady and the range between 0.4 and 0.6 nm, while the conduction of the system increases with increasing exposure time. For the exposures shorter than 5 min, the current images reveal a uniform and non-grainy structure whereas the surface becomes entirely grainy for longer exposure times. Changes in stoichiometry resulting from Ar^+ ion bombardment are not well understood so far; quite different results can be found in the literature. Preferential sputtering and the accompanying changes in SiC surfaces are reported. Detailed AES and XPS study on the Ar^+ sputtered SiC(0001) surface at room temperature revealed that the sputtering restored the surface stoichiometry [7]. Excess silicon [8] and excess carbon [6] surfaces were obtained after Ar^+ ion sputtering due to the different sputter rates of carbon and silicon.

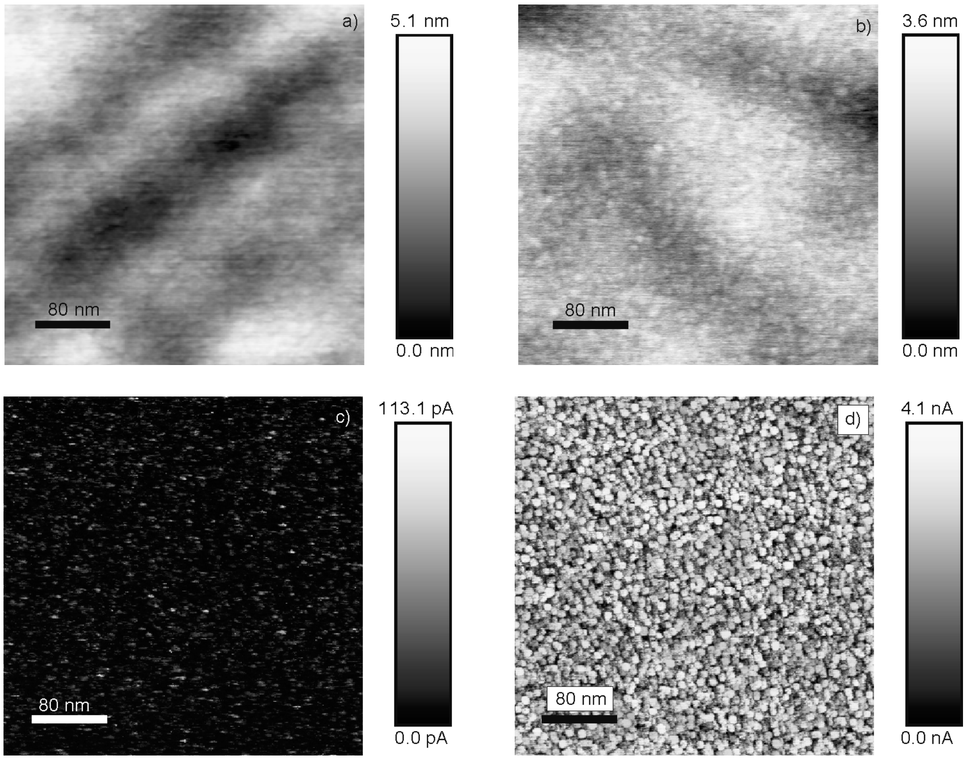

Fig. 1. AFM image of the 6H-SiC(0001) surface topography after 2 min (a), and 20 min (b) of Ar+ bombardment (1200 eV, 8 mA), and the corresponding electric conductance images 1.1 V(c) and 0.27 V (d)

Analysis of the *I–V* characteristics taken for different bombardment times shows, for the samples which were not subject to Ar^+ ion sputtering, a considerable difference in characteristics from site to site of the surface. Typical values of averaging are shown in Fig. 3. It is seen from these curves that the conductance character of the contact probe/6H-SiC(0001) surface changes from the diode type to the ohmic type.

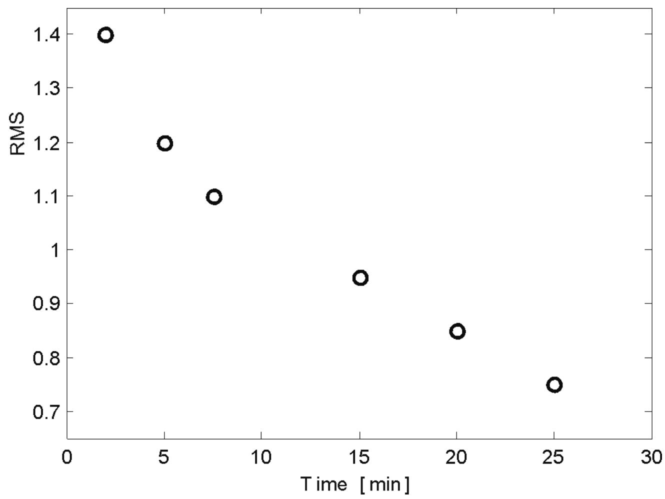

Fig. 2. The roughness of the surface (expressed by the RMS ripple parameter) vs. 1.2 keV Ar^+ ion bombardment time

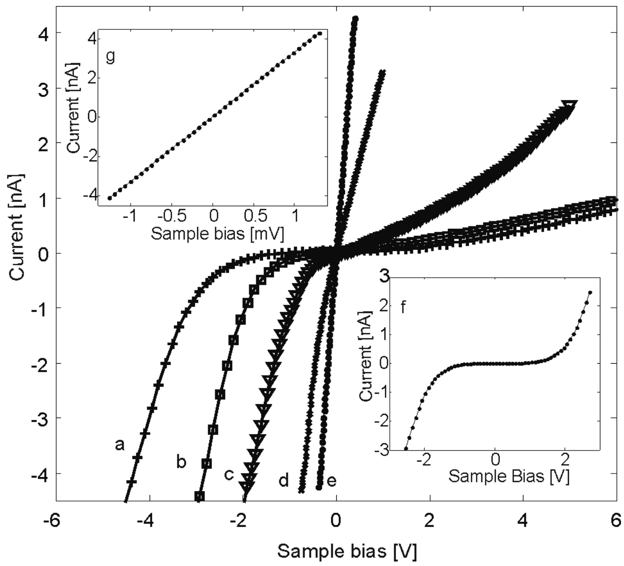

Fig. 3. Evolution of *I–V* characteristics for the probe/6H-SiC(0001) surface contact due to Ar^+ ion bombardment for 2 min (a), 5 min (b), 7.5 min (c), 15 min (d) and 20 min (e); *I–V* characteristics for the probe/Si(111) surface contact (f) and for the probe/HOPG surface contact (g)

For bombardment times up to 7.5 min, the contact is rectifying, and the characteristics are nonlinear like the case of measured on silicon (Fig. 3f). A crucial change appears for the times longer than 15 min of ion bombardment, and the obtained contact type becomes almost ohmic. Further bombardment leads to a very good ohmic contact. The linear characteristics, obtained after a longer exposure to Ar^+ ions, are typical of graphite (as that shown in Fig. 3g), which may be due to enriching the surface layer of the sample with carbon. Consequently, it is clear that the Ar^+ ion bombardment process is accompanied by preferential surface sputtering. This fact can be utilized for formation of the ohmic contact of metal/n-type SiC with the formation of the carbon intermediate layer that lowers the Schottky barrier at the interface [9].

4. Summary

It is shown that the roughness of the 6H-SiC(0001) surface is reduced with increasing time of Ar^+ ion bombardment. The remainders of the crystal polishing process such as the scratches can be efficiently removed. Moreover, the ion bombardment process essentially affects the surface stoichiometry, resulting in the change in conductance of the system of AFM probe/6H-SiC(0001) and, consequently, in the type of the contact from the rectifying one to the ohmic one. Ohmic contacts of metal/semiconductor used to be formed by high temperature annealing whereas the Ar^+ ion bombardment process can be utilized as another means of room temperature formation of such contacts.

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