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SiC Schottky-barrier diodes formed with TiB_x and ZrB_x amorphous layers

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Abstract. Electrical and structural properties of Schottky-barrier diodes formed with TiB_x and ZrB_x amorphous layers on *n*-6H-, 15R- and 4H-SiC (with epi-layer) were studied. High thermal stability of ideality factors and barrier heights in the formed contacts was explained by the thermal stability of an interface $TiB_x(ZrB_x)$-SiC after rapid thermal annealing at 800°C for 60 s.

Keywords: Schottky barrier, amorphous films, Auger spectroscopy, atomic force microscopy

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1. Introduction

Traditionally, SiC Schottky diodes technology utilizes polycrystalline films of refractory metals, their silicides and carbides and other high temperature compounds [1–5]. In spite of high conductance and thermal compatibility of those compounds, they degrade during high temperature operation. One of the possible degradation mechanisms is intergrain diffusion. Moreover, most of the used metals form various phases with SiC at relatively low temperatures, which results in formation of non-uniform interface [6].

One of the approaches to reduce diffusion at the interface metal–SiC is to use amorphous and nano-crystalline films of TiB_x and ZrB_x to form Schottky barrier to the SiC substrate [7, 8].

In this work, we studied the effect of rapid thermal annealing on the contact characteristics of ZrB_x-*n*-4H-SiC, $TiB_x(ZrB_x)$-*n*-6H-SiC and ZrB_x-*n*-15R-SiC.

2. Experiment

Three polytypes of SiC samples were used: (i) 4H-SiC substrates with n^+-buffer and n^--epitaxial ($n \sim 6 \cdot 10^{15}$ cm^{-3}) layers purchased from Cree Research Inc, (ii) Lely *n*-6H-SiC substrates, (iii) Lely *n*-15R-SiC substrates. Net doping concentration in the Lely samples was about 10^{18} cm^{-3}.

The Schottky diode structures were fabricated using planar technology with an insulating silicon dioxide film of 0.4–0.6 μm thick grown on Si-face of the SiC substrates. Contact windows in the oxide were 100–200 μm in diameter.

Amorphous and nano-crystalline films of TiB_x (ZrB_x) with the thickness 50 nm were deposited on SiC substrates by magnetron sputtering at the temperature of ~200°C followed by gold plating. Blanket ohmic Ni contacts (200 nm) were formed also by magnetron sputtering on *C*-faces of all samples followed by annealing at 1000°C for 90 s. Before gold plating, a part of the samples was subjected to rapid thermal processing (RTP) at 800°C for 60 s.

Auger spectroscopy was used to identify the atom profile depth distribution in the RTP-annealed and non-annealed structures. X-ray diffractometry was used to analyze crystallinity of the deposited films. Surface morphology of the contacts before and after RTP was studied by atomic force microscopy.

Current-voltage and capacitance-voltage characteristics of the formed diodes were also measured before and after RTP to determine the barrier heights and ideality factors.

3. Results and discussion

The Schottky barrier heights and ideality factors calculated from the forward I–V characteristics measured before and after RTP are summarized in Table 1. The voltage intercepts and net doping concentrations, $N_d - N_a$, extracted from $1/C^2$–V curves are also shown in the Table 1.

The results show that there was not any significant effect of RTP on the parameters of the formed Schottky diodes for each polytype of SiC substrates.

The diodes formed on n-n^+-SiC 4H substrate exhibited a leakage current of 10^{-4}A at the reverse bias of ~800V, while the diodes formed on 6H- and 15R-SiC substrates (without an n-epilayer) showed a leakage current of 10^{-4} A at ~40 V.

Specific contact resistances of ohmic contacts were in the range of $(0.9\ldots1.2)\cdot10^{-4}$ Ohm·cm^2 in all the samples.

Auger-electron spectroscopy was used in order to analyze an effect of RTP on the atom redistribution in the formed contacts (Fig. 1). The results show that the atom depth profiles were not significantly affected by RTP. Stoichiometry of all the deposited films was the same before and after RTP, and the RTP did not enhance the chemical interaction between the films and SiC substrate. This indicates a thermal stability of the contacts.

An X-ray diffractometry analysis showed that TiB_x and ZrB_x films had no crystalline phases before and after RTP, but had an amorphous or quasi-amorphous structure.

A surface morphology analysis performed by atomic force microscopy showed no significant difference between annealed and non-annealed TiB_x and ZrB_x contacts (Fig. 2). Mean surface roughness measured before and after RTP was about 0.5 nm. These data correlate with the results obtained in Ref. [7]. Note, a surface in the annealed samples became more uniform which might be explained by mechanical stress relaxationin the film after RTP.

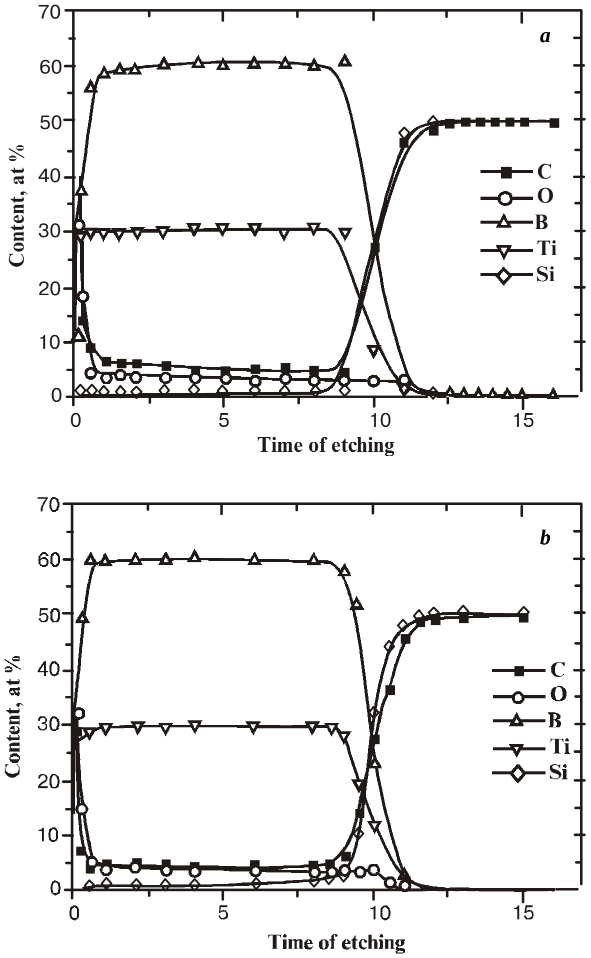

Fig. 1. Auger profiles of Si, C, Ti, B and O vs. depth in the TiB_x-n-6H-SiC contacts (a) before and (b) after RTP.

Table 1. The barrier heights, φ_B, ideality factors, n, and voltage intercepts, U_C^{C-V}, measured before and after RTP.

Diode structures	Parameters							
	Before RTP				After RTP			
	φ_B^{I-V},V	U_C^{C-V}, V	n	$N_d - N_a$, cm^{-3}	φ_B^{I-V},V	U_C^{C-V}, V	n	$N_d - N_a$, cm^{-3}
Au-ZrB_x-n-n^+-SiC 4H	0.83	0.87	1.2	$5\cdot10^{16}$	0.83	0.87	1.2	$5\cdot10^{16}$
Au-ZrBx-n-SiC 6H	0.79	0.87	1.2	10^{18}	0.80	0.87	1.2	10^{18}
Au-TiBx-n SiC 6H	0.82	0.85	1.2	10^{18}	0.82	0.85	1.2	10^{18}
Au-ZrBx-n-SiC 15R	0.78		1.58	$1.8\cdot10^{18}$	0.78		1.58	$2\cdot10^{18}$

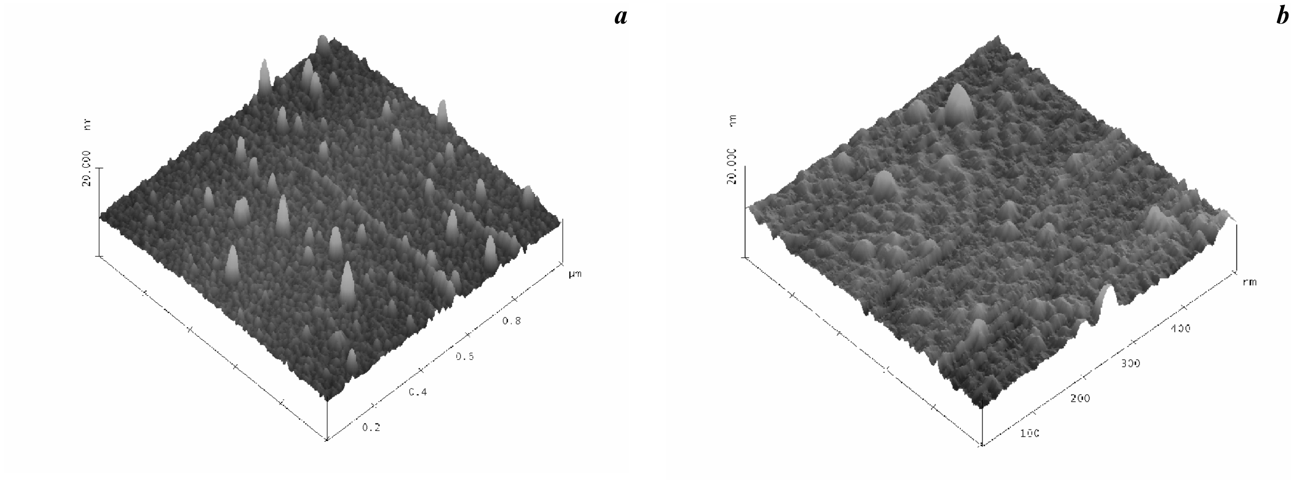

Fig. 2. AFM images of TiB_x-n-6H-SiC: *a* – without RTP; *b* – with RTP.

4. Conclusions

In this work, we have demonstrated that Schottky contacts based on amorphous or quasi-amorphous TiB_x and ZrB_x films form a thermostable (up to 800°C) interface with the 4H-, 6H- and 15R-SiC substrates. Thus, these contacts might be used in SiC devices operating at high temperatures with no degradation.

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