Structural characterization of alloyed Al/Ti and Ti contacts on SiC

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I. INTRODUCTION

Al-rich Al/Ti contacts on p-type SiC show good ohmic behaviour for a wide range of doping density after high temperature (> 950°C) post deposition annealing independently of the <0001> 4H- and 6H-SiC polytype [1, 2] employed. This ohmic contact behaviour appears to be closely related to the high Al content of the deposited metal layers. Several hypotheses have been proposed to explain the role of Al in such Al/Ti alloyed contacts mainly based on the doping effect of this element in SiC. However, Al/Ti-SiC alloyed contacts constitute a complex quaternary system where the formation and spatial distribution of different phases as well as loss of volatile Al could strongly affect the contact electrical characteristics. From recent structural investigations, two main experimental results deserve attention. On one hand, some of the phases expected from quaternary phase diagram based predictions have been identified in Al-rich Al/Ti-SiC alloyed contacts [3]. On the other hand, metallization spikes have been detected in this system. A high density of these metallic intrusions in the semiconductor is apparently bound to the ohmic behaviour and to the good contact-to-contact reproducibility observed [4]. Despite these experimental evidences several questions concerning the composition and the electrical behaviour of these contact regions are still open. Among these questions are the Al behaviour during the reaction that is not understood and the composition of the observed metallic spikes, suspected to enhance field emission, that is unknown. Additional structural investigations are thus needed to shed light upon these points. In this way, we report in this work a structural and chemical investigation of Al/Ti-SiC contacts.

II. EXPERIMENTAL

Al/Ti metal films with 72 wt. % Al were deposited on off-axis <0001> 4H- and 6H-SiC p-type homoepitaxial layers. Such a value was chosen because it gave the more reproducible electrical results [1, 2]. For comparison, a 80 nm thick Ti film was also deposited on a 4H-SiC homoepitaxial layer. All the samples were post annealed in vacuum at 1000°C for times ranging from 2 to 8 min. The RBS analysis chamber of the “Istituto Nazionale di Fisica della Materia” installed on one of the beam line of the accelerator AN2000 of the “Laboratori Nazionali di Legnaro” (Italy) was used for measuring the RBS-C spectra. Channelling and random spectra were measured for 2.0 MeV He ions backscattered at 170°.

XTEM observations were performed with a F.E.I. Tecnai F20 electron microscope operating at 200 kV and equipped with a PV9761/II super ultra thin window energy dispersive spectrometer (EDS). Scanning Electron Microscopy (SEM) observations were performed with a Philips XL30 electron microscope operating at 15 kV.

III. RESULTS

The main results of RBS-C analyses are summarised in Fig. 1. In this figure, random and <0001> channeling spectra of the Al/Ti (Fig. 1(a)) and Ti (Fig. 1(b)) contacts on the 4H-SiC samples alloyed in vacuum, are compared. In both cases an important channeling phenomenon at the metal-semiconductor interface is observed. This indicates that both the reacted layers are polycrystalline with most of the grains coherent with the c-axis of the underlying 4H-SiC structure. But, important differences in the structure of
FIG 2. TEM BF micrographs of cross-sectioned Al/Ti-6H-SiC alloyed contact. (a) low magnification micrograph; (b) metallization spike; (c) different phases marked with Roman letters

the two types of contact can also be seen. In fact, the presence of Si at the sample surface is uniquely observed in Fig. 1 (a), for the Al/Ti-SiC contacts. Moreover, in the Ti-SiC case, the reacted layer is characterised by a sharp interface while in the Al/Ti-SiC case a deep tail of the Ti signal towards the bulk SiC is visible. The latter finding could be due to spiking of the reacted layer into the semiconductor, or to the roughness of the reacted film. Also for what concerns the Al distribution, RBS-C results are not conclusive owing to the overlap of the Al and Si signals in the near surface region.

To solve these points XTEM analyses were employed on alloyed Al/Ti-6H-SiC samples. In the Bright Field (BF) micrographs reported in Fig. 2, the salient features of the contact layer morphology are reported.

As shown in the low magnification micrograph reported in Fig. 2 (a), the alloyed surface layer appears as a sequence of abrupt steps randomly distributed giving rise to a layer with pronounced thickness variations. Metallization spikes are effectively observed as intrusions of the alloyed layer into the semiconductor bulk, as shown in Fig. 2 (b). It is worth noting that the extension in depth of the spike observed in Fig. 2 (b) of about 50 nm is in keeping with those observed in the case of Al/Ti with similar wt % Al compositions [4]. In Fig. 2 (c), the different features identified by structural characterisation studies, are marked. From detailed electron diffraction observations, the region marked I corresponds to the dominant $\text{Ti}_3\text{SiC}_2$ phase in perfect epitaxial relationship with the underlying 6H-SiC substrate (region marked IV in Fig. 2 (c)) as already reported in [3]. The region marked II is a void and the porous nature of the contact has also been confirmed by SEM observations. From preliminary High Resolution Electron Microscopy (HREM) investigations regions like that marked III in Fig. 2 (c), occasionally found at the contact layer interface, appear to consist of grains with a cubic crystallographic structure and a well defined orientation relationship with the bulk 6H-SiC. The identification of the composition and of the precise crystallographic structure of these grains is currently underway. Finally, on top of the contact layer, large Si-rich Al agglomerates have been revealed by TEM and EDS analyses. These features probably result from the freezing of a Si-rich Al liquid phase during the cooling down of the samples. It is worth noting that the presence of crystalline $\text{Al}_4\text{C}_3$, expected from the study of equilibrium phase diagrams [5], has not been detected.

The results of a preliminary XTEM and EDS investigation on a sample consisting of a 80 nm thick Ti layer deposited onto 4H-SiC and annealed in vacuum at 1000 °C for 8 min can be summarised as follows. The reacted contact appears to consist of three layers of different composition. EDS analyses reveal that in the uppermost layer Ti and C are uniquely present, Si and Ti are the main component of the middle layer and Ti, Si and C are found in the layer adjacent to the 4H-SiC substrate. Preliminary micro-diffraction observations indicate that, in agreement with a previous work [6], TiC, $\text{Ti}_5\text{Si}_3$ and $\text{Ti}_3\text{SiC}_2$, are the main constituent of these layer, respectively. Moreover, in this case, the alloyed contact presents a uniform thickness as well as a flat interface with the underlying 4H-SiC substrate. These findings confirm and extend the above reported RBS-C results.

In parallel to this structural study, electrical measurements have been performed by our group [7], on transmission line model structures realised on heavy implanted SiC with the same Al/Ti, and Ti contacts described in this work. From these measurements it appears that with respect to the case of Ti contacts the use of the Al/Ti alloy improve the measured contact resistivity by about two orders of magnitude (at 290 °C, from about $10^{-2}$ to $10^{-4}\, \Omega\, \text{cm}^2$, respectively).

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