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COMPARATIVE CHARACTERISTICS OF 6H– AND 4H–SiC SURFACES IN DIFFUSION WELDING

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Abstract. The results of experimental investigations of diffusion welded (bonded) large area Al/SiC contacts are presented. The surface flatness of 4H–SiC structures with an epitaxial layer is investigated. New data on crystal surface quality of different producers are presented. The *U–I* characteristic of a large area Al–4H–SiC Schottky structure based on Sterling SiC is briefly discussed.

Key words: SiC, diffusion welding technology, SiC wafer surface quality, Al–4H–SiC Schottky structure.

1. INTRODUCTION

The first results on the diffusion welded Al/SiC contacts were presented in [1]. 6H–SiC used for this purposes was a donor doped n-type semiconductor substrate with polished upper C-face and with ground bottom Si-face. The results available by that time were preliminary and the diffusion welding conditions were examined purely qualitatively.

The purpose of this work is to give supplementary information on this problem and to demonstrate an adaptation of the diffusion welding technology for the 4H–SiC polytype.

2. MATERIALS AND METHOD

In our experiments aluminium has been used as the contact material because of its low melting point, relative inertia to solid state SiC, and its importance as a matrix material in metal/semiconductor composites. For the process, a 0.05 mm thick 99.99% Al foil has been used. The 6H– and 4H–SiC substrates were purchased from CREE Research Inc and Sterling Semiconductor Inc (both USA) with the following specification.

6H–SiC (CREE). The two wafers had a diameter of 35.0 mm and thickness 0.33 mm. The nitrogen dopant forms the n-type conductivity with net doping density (N_D–N_A) 3.6×10^{18} cm^{-3} and 1.3×10^{18} cm^{-3}, respectively. C-face was polished and Si-face ground.

4H–SiC (CREE). The wafer diameter was 35.0 mm and thickness 0.35 mm. The nitrogen dopant forms the n-type conductivity with net doping density of the substrate 8.5×10^{18} cm^{-3}. On the surface of the substrate, a 5 μm thick epitaxial layer was grown with donor concentration 2×10^{17} cm^{-3}. Si- and C-faces were both polished.

4H–SiC (Sterling). The wafer diameter was 35.0 mm and thickness 0.30 mm. On the Si-face of the substrate, a 6.75 μm thick epitaxial layer was grown with donor concentration 4.75×10^{15} cm^{-3}. Si-face was polished and C-face ground.

It should be mentioned that the thickness of the epitaxial layer, grown on the C-face of 4H–SiC, had rather irregular topology on the periphery of the wafer surface compared with the centre region of the wafer. Besides, over the whole surface, big rough impregnations (50 μm high) of disoriented 4H–SiC crystals as well as comparatively deep craters were observed. As an illustration, Fig. 1 shows the comparison of surface profiles in the periphery and in the central region of the epitaxial layer.

Such irregularities of the epitaxial layer may limit the fabrication of large area metal semiconductor contacts and, consequently, only the part of the wafers, cut out from the centre region of the latter, may be used for manufacturing properly functioning devices.

We have chosen for a detailed study the Sterling 4H–SiC epitaxial structure. Recently, the semiconductor producers have considerably developed growing of SiC. Recent reports tell about fabrication of a 75 mm wafer of the SiC single crystal. Nevertheless, the density of defects in the SiC wafer remains excessively great. According to the literature [2–4], the SiC wafers, containing high density of crystallographic defects, cause premature breakdown of the devices. Reduction of the defect density in SiC epitaxial material is the key issue in the development of SiC large area devices.

There are about 20 different types of macro- and microdefects to be determined. To reveal all of them, a high variety of techniques and apparatus is needed. Some of these techniques are considered in this paper.

Macroprofiles of the Si- and C-faces of the Sterling 4H–SiC epitaxial wafer are shown in Fig. 2.

The variation of the thickness of the ground C-face is about 10–15 μm. The Si-epiface is wedge-like with the variation of the thickness of about 20–25 μm. Such variation of the thickness is inadmissible by the diffusion welding process and under welding pressure circular cracks appear in the periphery of the wafer. Contrary to the CREE 4H–SiC wafer, in the Sterling wafer rough impregnation

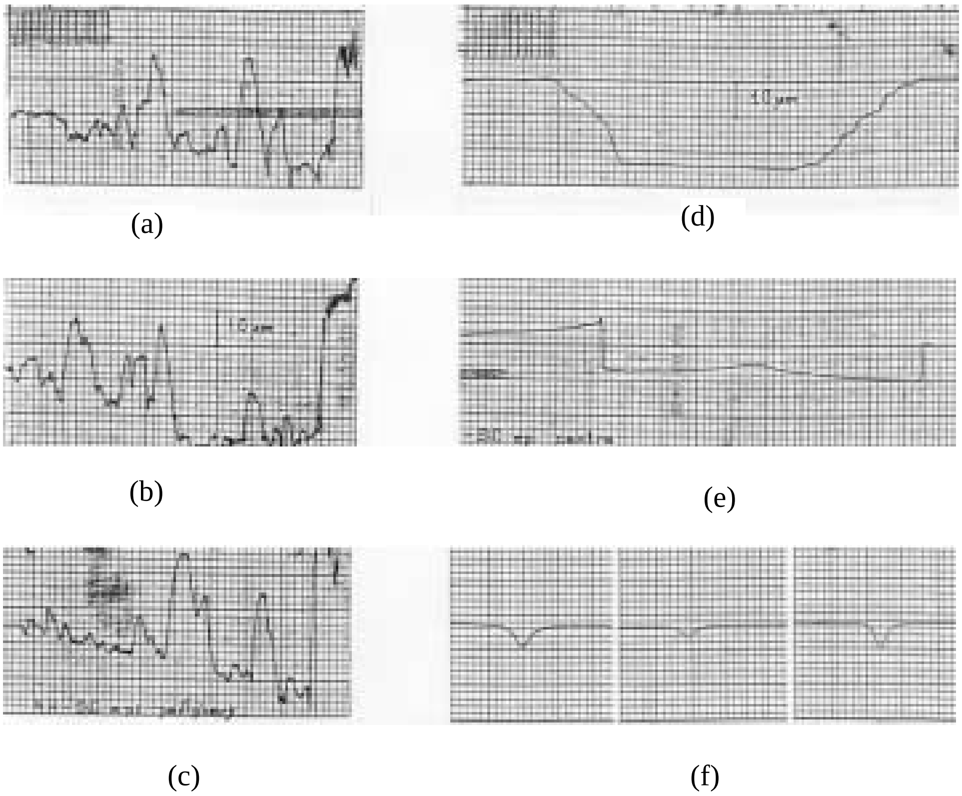

Fig. 1. Roughness of the surface of the epitaxial layer in the periphery (a)–(c) and in the centre region (d), (e) of the CREE wafer 4C–SiC; microprofile of the Sterling epiface with craters (f). Facsimiles of the automatic recordings.

over the episurface and irregularities of the topology were not observed. The diameter of craters is about 50 µm with the depth of about 8 µm. Figure 1f shows the microprofile of the Sterling epiface with craters; the map of macrodefects in the epitaxial Si-face of the Sterling 4H–SiC wafer is shown in Fig. 3.

The epitaxial layer of the Sterling wafer has considerably less crystallographic defects (for example, the number of Comet tails and Carrots is 57 for the total area while admissible is 75). The micropipes density is less than 100 cm^{-2}. The Schottky contact, formed in relatively free of defects area of the wafer with leakage current of 10 mA, has about 20 times as large reverse voltage than the Schottky contact in defected area of the wafer. However, the difference in donor concentration of the epitaxial layer must be also taken into account.

Chemical treatment of the material as well as the essence and method of the diffusion welding was in detail described in papers [1,5,6]. For all the samples, the diffusion welding process was carried out with the equipment UDS-6, specially developed for this purpose, and the diffusion welding procedure was realized at various combinations of the temperature and pressure.

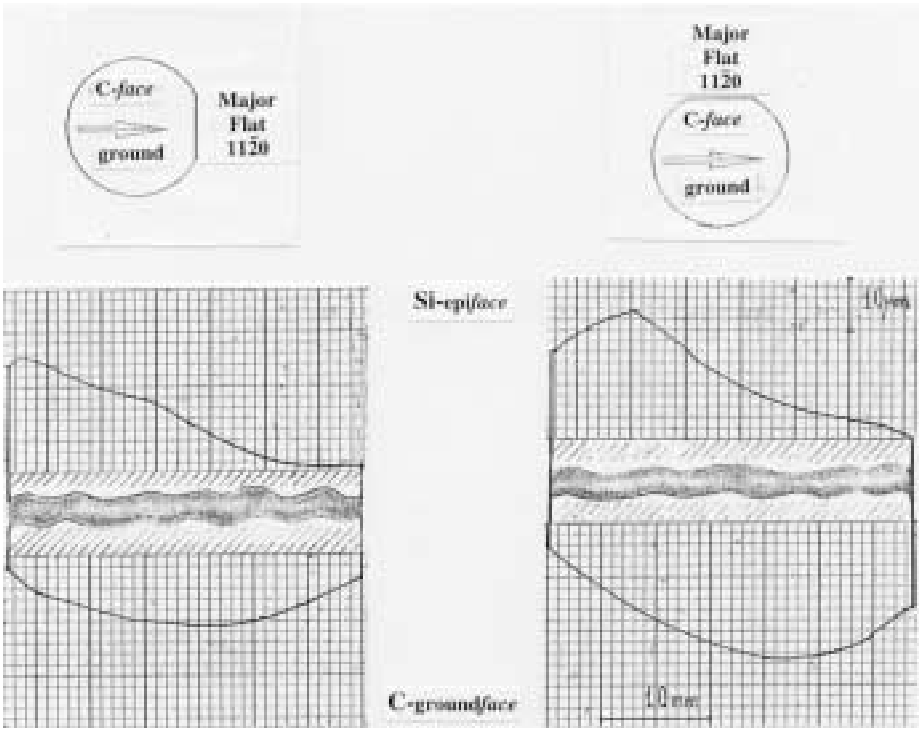

Fig. 2. Macro-profile of Si- and C-faces of the Sterling epitaxial wafer.

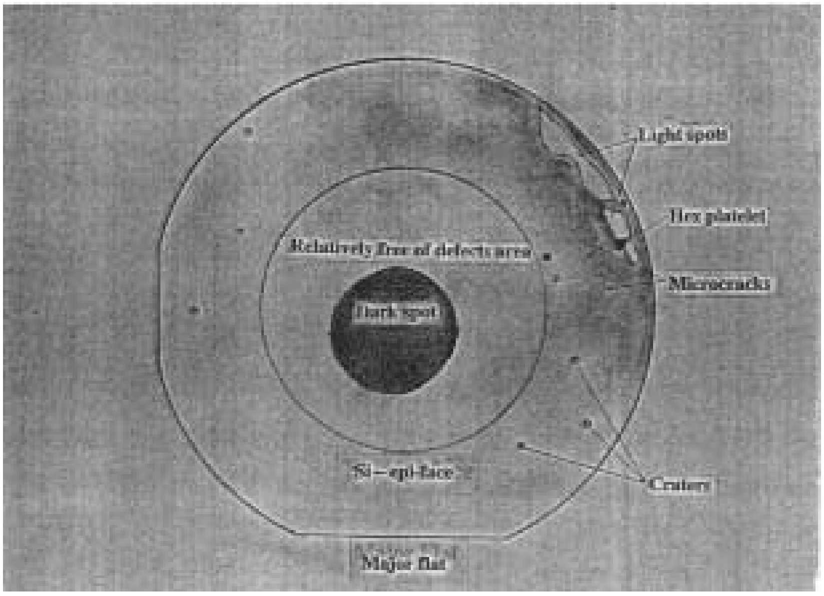

Fig. 3. The map of macrodefects in an epilayer of the Sterling wafer.

3. RESULTS

The binding strength test for Sterling Al–4H–SiC diffusion welded contact was carried out by means of a technique described in [6]. The tensile strength of the detachment of Al from SiC exceeds the breaking strength of annealed aluminium. Thus high adhesion of the diffusion welded metal layer irrespectively of SiC polytype was once again reaffirmed.

The preliminary rough estimation of the *U–I* characteristic of the Schottky welded contact was made on the 4H–SiC Sterling sample specially prepared for contact resistance measurement as shown in Fig. 4.

From the previous *U–I* tests it is known that such measurement of the Schottky contacts gives feebly marked asymmetry of the *U–I* characteristic, basically owing to the decrease of the reverse branch voltage. Figure 5 shows the comparison of the *U–I* curves for 6H– and 4H–SiC structures.

4. CONCLUSIONS

1. The diffusion welding techniques give the possibility to create reliable and homogeneous large area Al/SiC contacts. Today, the area of Me contacts is limited only by the dimensions of the provided SiC wafers. The bond strength of Al/SiC contact exceeds the breaking strength of annealed aluminium, irrespectively of the

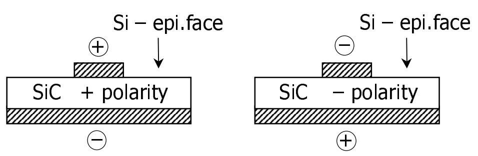

Fig. 4. Schematic picture of the measurement of the *U–I* characteristic.

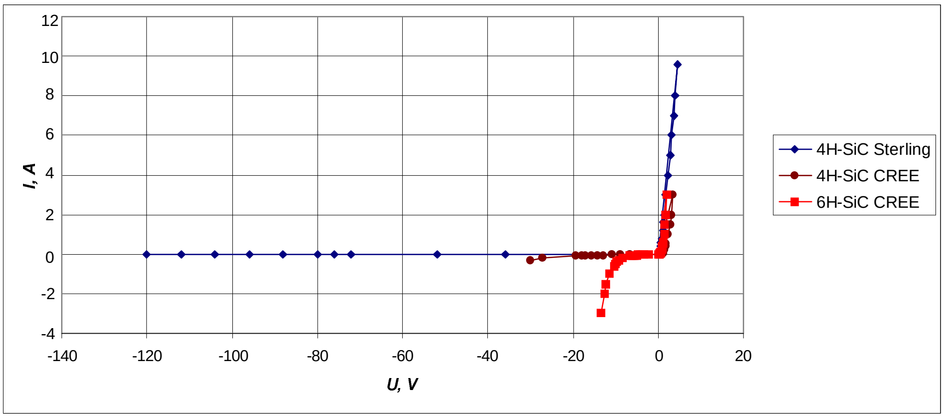

Fig. 5. *U–I* characteristics for 6H– and 4H–SiC structures.

SiC polytype. At the same time, from the point of view of mechanical strength, the interval of optimum diffusion welding conditions is large enough to enable to control the electrical properties of the Schottky contact.

2. Quality of the diffusion welded Al/SiC Schottky contacts strongly depends on the defect density in the surface layer of the SiC wafer. The Schottky contact, formed on a relatively free of defects area of the SiC wafer with leakage current of 10 mA, had 20 times as large reverse voltage than the contact manufactured in the defected area of the wafer.

ACKNOWLEDGEMENT

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6H– JA 4H–SiC PINDADE OMADUSTE VÕRDLUS DIFUSIOONKEEVITUSE PUHUL

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On esitatud difusioonkeevitusega valmistatud suurepinnaliste Al/SiC üleminekute eksperimentaaluuringute tulemusi, käsitletud 4H–SiC epikilede pinna ebatasasuse probleemi ning toodud uusi andmeid erinevate firmade valmistatud epikilega kaetud SiC plaatide pinna kvaliteedi kohta. Lühidalt on iseloomustatud firma Sterling 4H–SiC põhimikul valmistatud Al-Schottky struktuuride *U*–*I* karakteristikuid.