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Improvements in Pt-based Schottky contacts to 3C–SiC

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Abstract

Despite its structural shortcomings (stacking faults, twins and threading dislocations), 3C–SiC heteroepitaxially grown on Si still has potential for high temperature sensor applications for which stable electrical contacts are of extreme importance. Pt/Si multilayered metallisations were compared to conventional Pt ones in order to investigate the effect of excess Si to the metal/SiC interface and the possible improvements in the thermal stability. These contacts were annealed up to 750°C. Their electrical behaviour was analysed by I–V measurements while the interface between the metal system and the 3C–SiC surface was examined by transmission electron microscopy (TEM) and the formed phases were determined by X-ray diffraction (XRD).

Keywords: Multilayer metallisation; Platinum; Schottky contacts; Silicon carbide; TEM; XRD

1. Introduction

Silicon carbide has been attracting considerable attention [1–5] because of its high electron saturation velocity (2.5×10^7cm s^{-1}) and its thermal and chemical stability. These unique physical and electrical properties make SiC a viable material for high power, high frequency and high temperature device applications.

The thermal stability of ohmic and rectifying contacts of SiC electronic devices is of extreme importance. In the case of 3C–SiC/Si, the fabrication of good quality Schottky contacts is hindered by the large concentration of stacking faults, associated with the low stacking energy of this polytype, as well as with twins and threading dislocations occurring in heteroepitaxial films. Thus, the mediocre quality of 3C–SiC heteroepitaxial material and the availability of good quality 4H and 6H SiC substrates has turned the mainstream SiC research towards these SiC polytypes. However, there are still active research groups in 3C–SiC with the emphasis on high temperature sensors since the fabrication of sensing elements (e.g. membranes) can be achieved easier due to the etching selectivity between Si and SiC. Our present contribution adheres to that framework.

Several metals have been used as Schottky contacts to 3C–SiC [6] and platinum is one of them.

In the present study, platinum (Pt) contacts and platinum/silicon (Pt/Si) multilayer contacts have been compared. Pt/Si multilayer contacts (MLS) were employed to allow the formation of a platinum silicide layer at the top of the SiC with negligible consumption of the top SiC layer. Thus the generation of a detrimental to the contact, carbon layer [7], even at high annealing temperatures, can be avoided thanks to the total reaction between Pt and Si prior to the reaction between SiC and Pt. The carbon segregation can be avoided by supplying excess Si in the multilayer structure.

2. Experimental

The material used for the fabrication of the Schottky contacts was a 4 μm thick n-type CVD grown 3C–SiC on Silicon, unintentionally doped, with a donor concentration of 3×10^{17} cm^{-3} (SiC1) [8]. The sample was degreased by sequentially immersion in trichloroethylene, acetone and propanol followed by thorough rinsing in DI-water and blow-drying with high purity nitrogen. Then the surface was mechanically polished with diamond pastes of various diminishing sizes (smaller paste size 0.1 μm), and the surface

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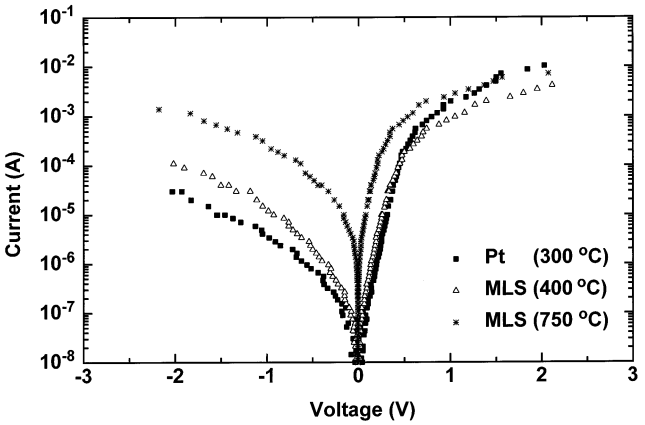

Fig. 1. I–V results for Pt (300°C) and MLS (400 and 750°C) Schottky diodes.

damage was removed by two consecutive dry oxidation steps at 1300°C for 2.5 h each. The formed oxides were then removed in (1:3) HF:H_2O solution. The resulted surface was examined by scanning electron microscopy (SEM) and FTIR-spectroscopy for its quality (smoothness and lack of surface defects) [9]. Due to the fact that the surface of the diodes is too small for either TEM or XRD observation, a piece of SiC1 was cut for that purpose (SiC2).

A chromium/titanium/platinum/molybdenum/gold metallisation strip on the one side of sample (SiC1) was used as the ohmic contact metallisation system [10]. Schottky circular dot arrays of 100 and 500 μm in diameter were then fabricated using standard contact positive resist photolithographic technique. On the one half of the sample 100 nm of Pt were deposited while during a second evaporation, the Pt/Si multilayer system (Pt 95A/Si 250A/Pt 180A/Si 250A/Pt 95A) was deposited. Sample (SiC2) was placed together with (SiC1) and half of it was totally covered by Pt while the other half was covered by the MLS. During both evaporations the samples were kept at 110°C to ensure good adhesion between the SiC surface and Platinum. The excess metal (SiC1) was removed by lift-off in acetone bath. Prior to all the evaporations, the SiC surfaces were treated in diluted HF. All the evaporations were performed at 2×10^{-7} Torr in a Temescal BJD1800 e-gun evaporator.

The contacts (SiC1) were then sequentially annealed for 1 h from 200 to 750°C at 100°C steps in a Carbolite horizontal furnace under nitrogen flow. After each annealing step the I–V characteristics of the diodes were measured and were compared with those of previous annealings.

Sample (SiC2) was scribed in three pieces initially. One piece was annealed at 400°C and the other was annealed at 750°C, both for 1 h under nitrogen flow. The third piece was kept as reference. Then each one of the three pieces was again scribed into two for TEM and XRD investigation respectively.

After the usual sample preparation by ion milling, the cross sectional TEM investigation was performed in a Philips CM20 TEM operated at 200 kV.

XRD investigation was performed in a Rigaku diffractometer with a thin film attachment. During the measurements, the samples were rotating in order to avoid errors induced by preferential orientations, of the analysed films [7].

3. Results

3.1. Electrical

For the Pt contacts the best results in relation to ideality factor and leakage current were obtained after annealing at 300°C (Fig. 1). The diodes remained rectifying up to annealing at 500°C but exhibited ohmic like behaviour following annealing at 600°C.

For the MLS contacts the best results in relation to ideality factor and leakage current were obtained after annealing at 400°C (Fig. 1). The diodes remained rectifying up to annealing at 750°C (Fig. 1).

The results are summarised in Table 1.

3.2. SEM

For both systems a rough but uniform and featureless surface was observed on as deposited layers. Upon annealing, the surface morphology changes. Above 400°C Pt and Pt_xSi tend to aggregate either into islands (Pt) or into dendrite like hillocks (MLS) (Fig. 2).

Table 1
Electrical results

Annealing temperature (°C)	Ideality factor (n_{Pt})	Ideality factor (n_{mls})	Leakage current L_{Pt} (A) at (−1 V)	Leakage current L_{mls} (A) at (−1 V)
As deposited	2.5	2.2	2.2×10^{-4}	1.6×10^{-4}
300	1.9	2.0	4.1×10^{-6}	2.0×10^{-5}
400	2	1.9	4.0×10^{-5}	1.0×10^{-5}
500	2	2.1	6.7×10^{-4}	2.0×10^{-5}
600	–	2.8	–	2.0×10^{-5}
750	–	2.1	–	2.7×10^{-5}

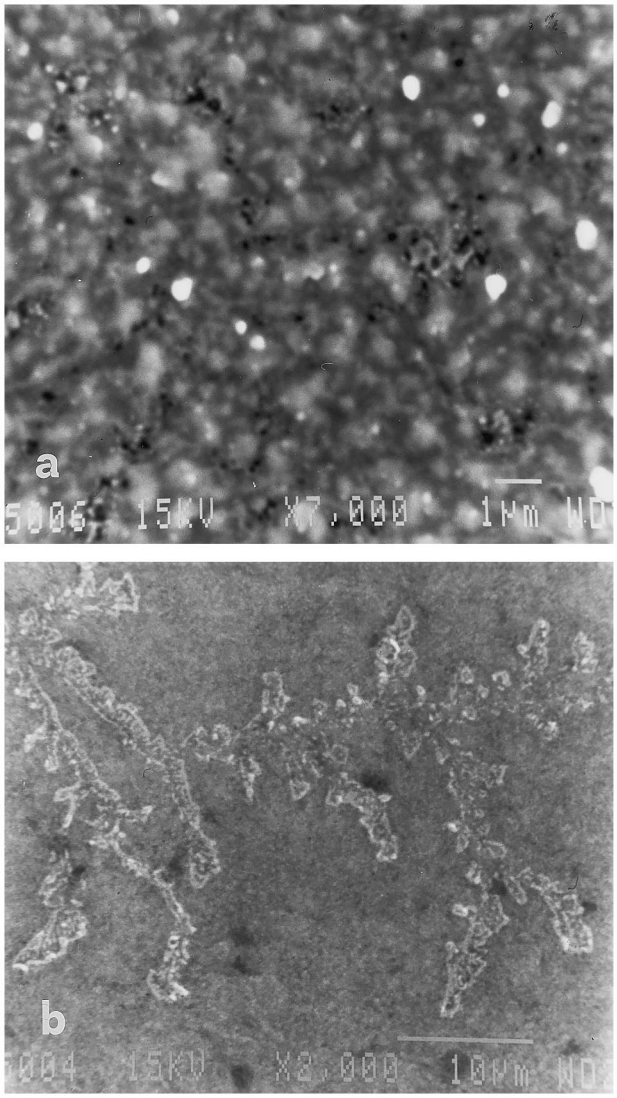

Fig. 2. SEM micrographs of Pt (a) and MLS (b), at 750°C.

3.3. TEM

For both systems the as deposited as well as the 400°C picture is of a polycrystalline metal layer without obvious interaction with the underlying SiC surface (Fig. 3).

The main difference is observed at 750°C:

In the Pt case, the metal layer exhibits a significant decrease of its thickness. This is attributed to the Pt consumption in forming large polycrystalline protrusions in the SiC. A typical protrusion is denoted as A in Fig. 3.

For the MLS a continuous polycrystalline layer is observed without any obvious reaction between the metallisation and the SiC surface (Fig. 4). However on top of the metallisation a thin amorphous layer was observed. This layer is believed to be silicon oxide since the EDS analysis identified silicon and oxygen but no platinum.

3.4. XRD

For the as deposited case the spectra for both metallisations are very similar, the only difference being the less signal for the MLS due to the smaller thickness of the metals. At 400°C, for the Pt case, there is no reaction between the metal and SiC while from the increase in the Pt peak, the higher crystalline texture of Pt can be deduced. For the same temperature, the picture for the MLS is quite different with the formation of the thermodynamically stable PtSi phase and the presence of unreacted Pt. At 750°C Pt forms Pt_2Si while the MLS form Pt_3Si. Both metallisations still have unreacted Pt left. Results are shown in Figs. 5 and 6.

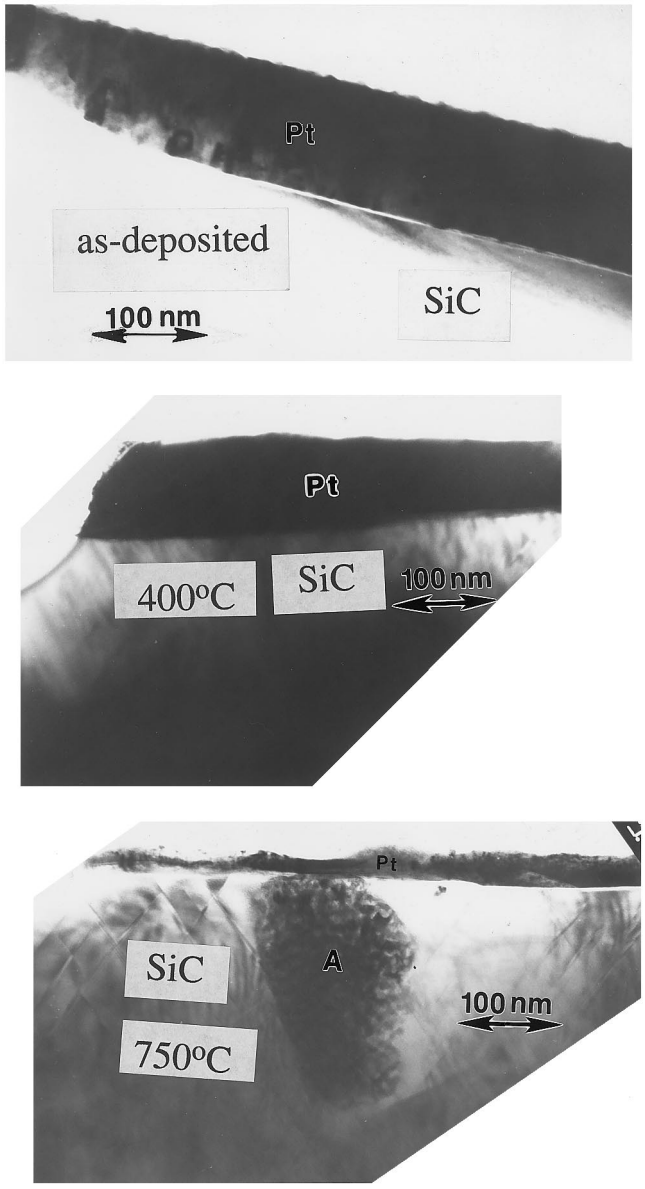

Fig. 3. TEM micrographs of Pt contact (as deposited, 400, 750°C).

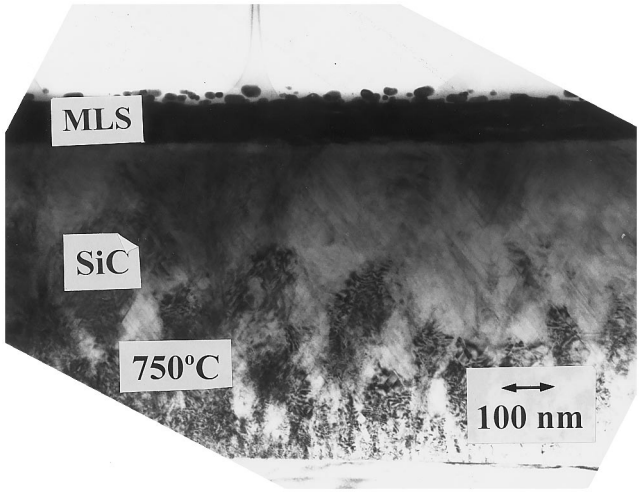

Fig. 4. TEM micrograph of MLS at 750°C.

4. Conclusions

It is thought that the Pt contacts could fail after a specific temperature due to the presence of a carbon layer following the reaction of Pt and SiC [5,7,11,12]. From our study of the Pt contacts it is obvious that at high temperatures large grains are created into the SiC due to Pt diffusion resulting in the degredation of the contact. The formation of Pt_xSi is generally accepted but there are different interpretations for the interfacial reaction and for the final structure [5,7,11–14].

From the analysis of the results for the MLS we can conclude that indeed the presence of the excess Si provided from the MLS assists the formation of a stable metal/SiC interface even at 750°C. Furthermore, from the XRD results at 400°C it is obvious that the excess Si helps the formation of the more thermodynamically stable PtSi phase [7,11] and which for pure Pt contacts usually forms above 1000°C [7]. This phase results in the minimum mismatch with 3C–SiC (001) [11]. From the TEM results of MLS annealed at 750°C it was concluded that there is no reaction between the MLS and the underlying SiC. Thus we can treat the MLS as a Pt–Si system. Furthermore also from the TEM results it was found that a thin amorphous silicon oxide layer forms on top of the silicide. The XRD results identified the presence of the Pt_3Si phase. A possible explanation for the formation of this Pt-rich phase is that Si from the MLS was consumed in forming the silicon oxide and the remaining silicon was not enough to form a silicon rich phase.

A general conclusion for both metal systems resulting from the XRD data is that 750°C is not a high enough temperature to induce the complete reaction of all Pt present.

Our concluding remarks are: (i) the reaction between the metallisation and the SiC substrate is avoided completely by applying MLS; (ii) MLS produce a thermally stable Schottky contact to 3C–SiC at temperatures at least as high as 750°C; (iii) MLS produce Schottky contacts to 3C–SiC at 400°C with the optimum electrical characteristics by forming the more thermodynamically stable Pt-Silicon phase; (iv) the effect of the Pt percentage in the MLS as well as ageing of the MLS must be performed in the future; and (v) annealing experiments in vaccum must be performed in order to

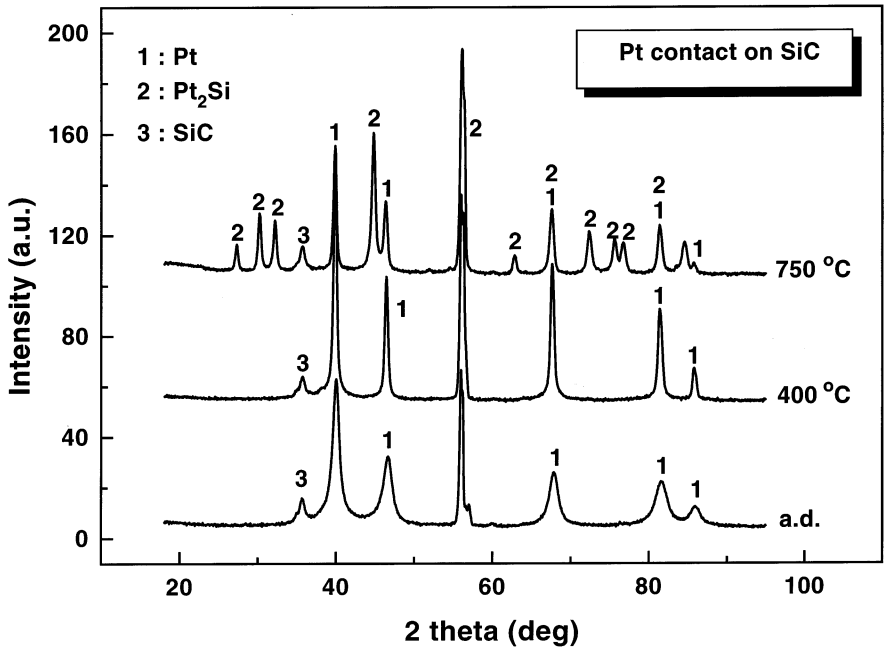

Fig. 5. XRD spectra of Pt contact (as deposited, 400, 750°C).

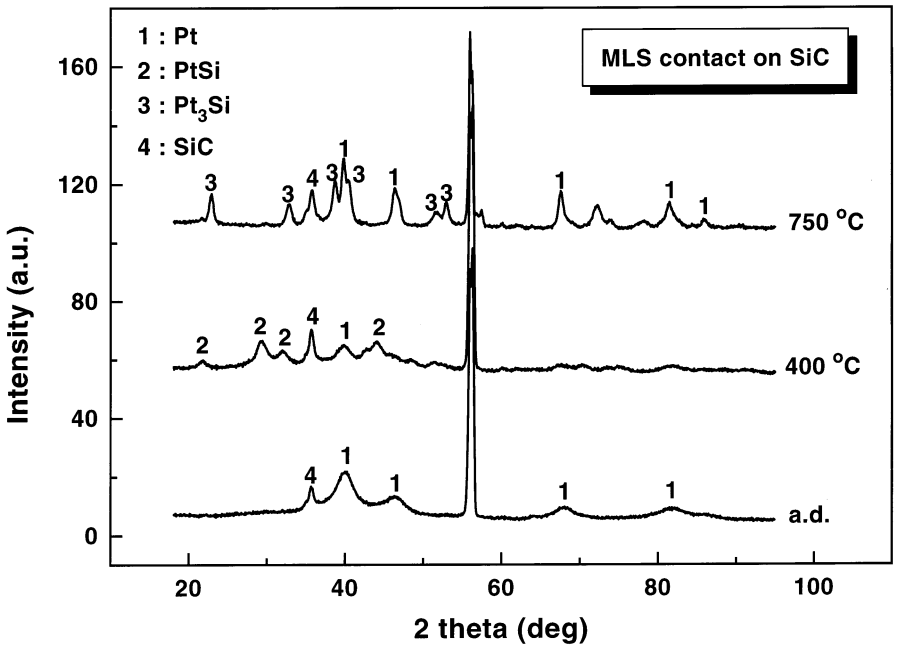

Fig. 6. XRD spectra of MLS contact (as deposited, 400, 750°C).

avoid the formation of the silicon oxide on top of the MLS at high temperatures.

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