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Micro-Raman spectroscopy applied in crystal structure analysis on the ESD failure mechanism of SiC JBS diodes

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ABSTRACT

This paper propose a novel reliability analysis approach for electrostatic discharge (ESD) stress on 4H-SiC junction barrier Schottky (JBS) diodes using the technology of Micro-Raman spectroscopy. Several conventional analysis are firstly used to determine the failure site after the JBS diodes are destructed by ESD stress, including optical microscope (OM), Photoemission microscopy (PEM) and scanning electron microscopy (SEM). Then, the Micro-Raman spectroscopy is applied to analyze element identification and crystal structure of micro failure site. The analysis reveals that high electric field and high temperature concentrate in the high-voltage termination, resulting in diode burnout and changing the physical microstructure of base SiC. Furthermore, in the micro failure site, 4H-SiC with different Raman spectrum from base 4H-SiC are clearly found, and carbon escapes out from base SiC by combustion, leaving a mixture of amorphous silicon and polysilicon, which is decomposed from the base SiC on the failure surface.

1. Introduction

Silicon Carbide Junction Barrier Schottky (SiC JBS) diodes are consist of Schottky and PiN diodes, which have been widely used in DC-DC converter, power factor correction (PFC), motor driver and so on [1–3]. The advantages of SiC JBS are low bipolar degradations, low turn-off losses, and high current capabilities [4, 5]. In 2006, the SiC JBS is released as Infineon's 2nd Generation of SiC diodes which are merged PN-Schottky diodes, in order to solve the limitation problem of surge current capability [6]. In recent years, the reliability issues of SiC JBS diodes have attracted great attention, such as, reverse avalanche stress [7, 8], forward stress [4, 9], high power and high temperature stress [10–12]. However, the reliability of SiC JBS under electrostatic discharge (ESD) stress is not well investigated [13]. In particular, the analysis of the micro failure site by ESD stress is still not well investigated.

In this paper, we analyze the failure site of the SiC JBS diode destructed by ESD, using optical microscope (OM), Photoemission microscopy (PEM) and scanning electron microscopy (SEM). Furthermore, the micro-Raman spectroscopy is applied to analyze the crystal structure and crystallographic orientation in the micro failure site, which will much improve the clarification of failure process and mechanism of SiC JBS diode, resulting from ESD stress.

2. Sample and experimental setup

The cross section schematic of the 4H-SiC JBS diode is shown in Fig. 1, which is designed and fabricated by ourselves. Tri-layer metallization of Ti/Ni/Al is used to form a backside contact. Titanium is used to form the front Schottky metal contact. The thickness of the Titanium is 0.16 μm, the thickness of the Al is 4.4 μm, and the thickness of passivation layer is 0.7 μm. The width of the p + ring and p-type junction termination (p-JTE) edge is 2 μm and 120 μm, respectively. The surface concentration and depth of p-JTE are $3 \times 10^{17}\,cm^{-3}$ and 0.8 μm to optimize the reverse breakdown performance. The spacing of the adjacent p + rings and the spacing between p + ring and p-JTE are both 4 μm. The width of the n-drift layer is 10 μm, and the doping concentration is about $8 \times 10^{15}\,cm^{-3}$, in order to block voltage more than 1200 V. In addition, the breakdown point is located at the p-JTE region. The rated breakdown voltage and forward operating current of JBS diodes are 1200 V and 10 A, respectively.

ESD stress is one of the main reasons to result in failure for most electronic devices. In this paper, the charges stored in a 100 pF capacitor with 8KV instantaneously discharged into the DUT SiC JBS diode samples, according to GJB-33A standard and human body model (HBM). Equipment of ESD simulator is from Oxry Instrument with EX-11000 of production model (Fig. 2). Five samples are stroked by ESD discharge with the alternately running 8 kV forward and reverse

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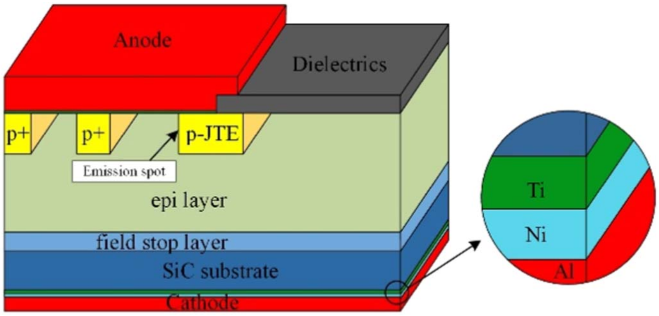

Fig. 1. Schematic cross section of the 4H-SiC JBS (include Emission spot).

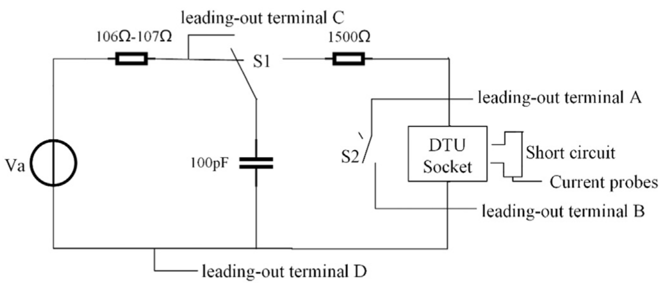

Fig. 2. Circuit schematic for ESD simulator.

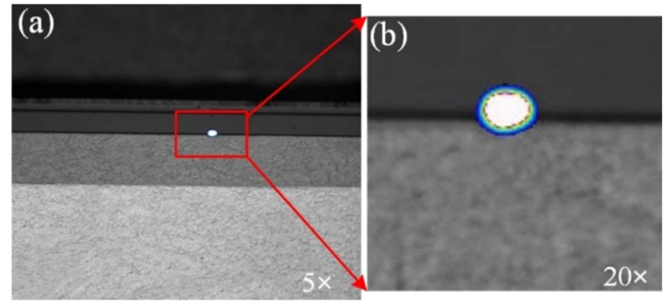

Fig. 4. (a) PEM image of the failure SiC JBS diode.

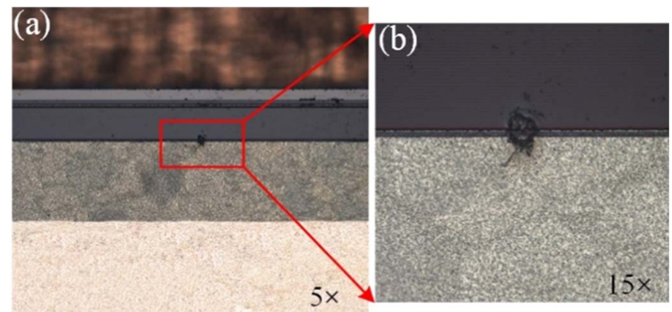

Fig. 5. OM micrographs of SiC JBS diode, at the black spot area indicated the failure site.

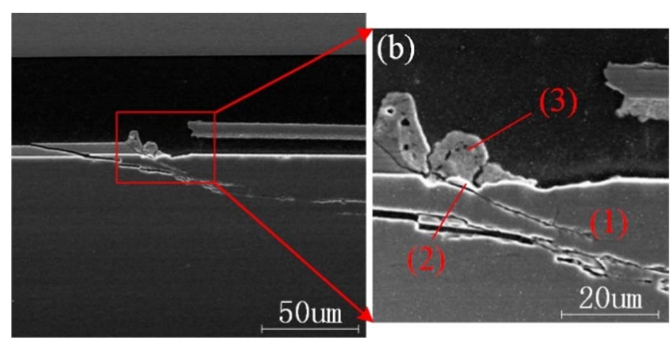

Fig. 6. (a) SEM micrographs of vertical FIB cut through the black spot area indicated as a red dashed rectangle in Fig. 5. (b) Shows the points where Micro-Raman spectroscopy analysis is performed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

voltage.

3. Results and discussion

Fig. 3 shows the I-V characteristics of five samples before ESD stress and one representative sample after ESD stress. The I–V curves of the samples are measured by Sony Tektronix 370A. The samples initially exhibit good electrical characteristics, but the reverse current sharply increases after ESD strike, indicating a behavior degradation and failure of the device.

Fig. 4 shows the PEM image of the sample. Clearly shining point bring to confirm failure site of the breakdown and current leakage, helping to further analyze the failure mechanisms. Fig. 5 shows the OM image of the destructed devices, also indicating that the failure site is in the interface of active area and termination as shown in Fig. 1.

Subsequently, the SEM and Micro-Raman analysis are carried out to clarify the physical process and failure mechanisms. Fig. 6 shows the micro structure of failure site by SEM. In the picture, (a) is the entire image containing the failure site and (b) is the close-up image at the failure site. It clearly demonstrates that the passivation layer at field plate (FP)'s terminal edge is entirely broken down and the SiC material adjacent to the edge of FP is also ruined. Resulting from instantaneous high electric field and temperature at failure moment, some molten compounds are generated and adhere to surface of failure site.

In order to further analyze the adhere compounds' element and crystal structure, we marked (1) to (3) points of the failure site in Fig. 6 (b) and carried out the micro Raman measurement. Actually, focused Ion Beam (FIB) millings at the three above demarcated points, then gathered SEM inspections. Prior to the Raman measurement, low-energy Ar ion milling is performed to remove possible damaged surface layer generated by SEM inspections.

Micro-Raman spectroscopy, by virtue of its micron-grade precision positioning and quantitative determination, provides a powerful means for SiC materials to analyze micro-failure mechanisms [14]. Based on the theoretic approach, a Raman detection platform called Micro-confocal Raman spectroscopy which combines Raman spectroscopy with microscopic analysis techniques is established to investigate SiC JBS diodes. In this work, Raman spectra is collected at room temperature, using a laser Raman spectrometer performed by confocal mode. The 514.5 nm line of an Ar ion laser is used for excitation. The spot diameter

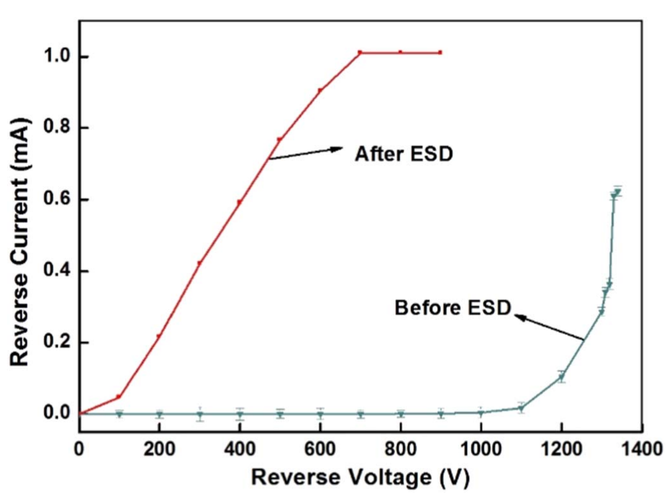

Fig. 3. Reverse I-V characteristics of the samples before & after ESD stress.