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Micropipes in SiC die Observed by Molten KOH Etching

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Abstract. The growing demand for wide-bandgap (WBG) materials in the microelectronics industry has led to increased investment in medium- and high-voltage power products based on SiC technology. SiC offers an excellent balance between high voltage blocking capability, high temperature operation and high switching frequencies [1]. One key step in preparing high-performance devices is improving the growth process of SiC ingot material by Physical Vapor Transport (PVT). Epitaxial growth occurs through the chemical vapor deposition (CVD) method [2]. However, this method is reported to generate extended defects such as Complex Stacking Faults (formerly referred to as carrots) and Polytype Inclusions (formerly referred to as triangles or comets) and propagate defects pre-existing in the bulk material, such as micropipes (MPs) and threading screw dislocations (TSDs), which have a very high killer ratio in SiC devices [3, 4]. In this work, the KOH molten etching method was used to investigate the nature of the defects that caused device failures; Raman spectroscopy was also employed to identify the spectroscopic correspondence of the peaks of interest.

Introduction

During the last decade the increasing demand for high-power devices has drawn attention to Wide-Bandgap (WBG) semiconductors. WBG materials include silicon carbide (SiC), gallium nitride (GaN), aluminum nitride (AlN) [5]. Among these, SiC exhibits characteristics that make it suitable for high power and high efficiency applications. However, the excellent prospects for using this material depend on its crystallinity. Crystal growth occurs through chemical vapor deposition (CVD), which ensures high-quality and high-purity SiC layers. Since the stacking of crystallographic planes can assume three different positions, this gives rise to cubic, hexagonal, or rhombohedral lattice structures called polytypes. Each polytype has unique electrical properties; 4H-SiC is the polytype with attractive properties for power devices due to its very high electron mobility, high breakdown field, and high thermal conductivity [6, 7]. However, the high concentration of structural defects, both extended and point defects, formed during ingot growth may lead to deterioration in the performance and reliability of semiconductor devices [8].

The dislocations commonly found in 4H-SiC can be classified as Threading Screw Dislocations (TSDs), Threading Edge Dislocations (TEDs), Basal Plane Dislocations (BPDs), and Micropipes (MPs) [9]. Some of these defects, such as MPs or TSDs spreading in the epi layer, cause fatal damage. Their identification and classification are a priority for using SiC devices. To study these types of defects present in substrates or the epitaxial layer of SiC, selective chemical etching in KOH is extensively used [10]. In this work, considering defect-preferred corrosion using molten KOH, three different failed dies were selected and analyzed.

For clarity, other extended defects propagated from dislocations are classified as Complex Stacking Faults (formerly referred to as carrots) and Polytype Inclusions (formerly referred to as triangles and comets). The detection and study of these defects have been extensively addressed [11, 12], as they are the cause of early electrical failure (usually no electrical stress or reliability tests are needed).

Experiment

Three different dies were selected from failed samples to analyze the defects that caused the burning. A nickel crucible filled with KOH pellets was used for etching the samples, and the temperature was set to 540°C for 12 minutes. After etching, the dies were cooled to room temperature and then washed with deionized water and isopropyl alcohol. A confocal microscope and scanning electron microscope (SEM) were used to observe the morphology of the etch pits on the surface. Raman spectroscopy was employed to identify the spectroscopic correspondence of the peaks of interest.

Results and Discussion

Three cases of failed dice were selected and treated with molten KOH.

In the first case (Fig.1a), the burn-in was revealed by optical inspection, showing that the failure seems to involve multiple defects. By zooming in on the region marked in red, it is possible to see one large defect (inside the green circle) accompanied by a small feature (inside the blue circle), connected to each other (orange circle). The FIB cuts (Fig.1b) performed in three different regions show the effect of the burn; however, they do not clarify the nature of the defect. Treating the sample with molten KOH (Fig.1c) reveals a micropipe (MP) on the surface, accompanied by another one highlighted by the green and orange traces. This phenomenon is due to the propagation of MPs generated in the substrate that evolve into the epitaxial layer, producing closed-core threading screw dislocations. Confirmation of the generation of closed-core threading screw dislocations is also provided by the presence of connections (orange circle) between the defects emerging on the surface. The two mechanisms involved during this propagation, which lead to the formation of closed-core screw dislocations, are reported in Fig. 2 [13].

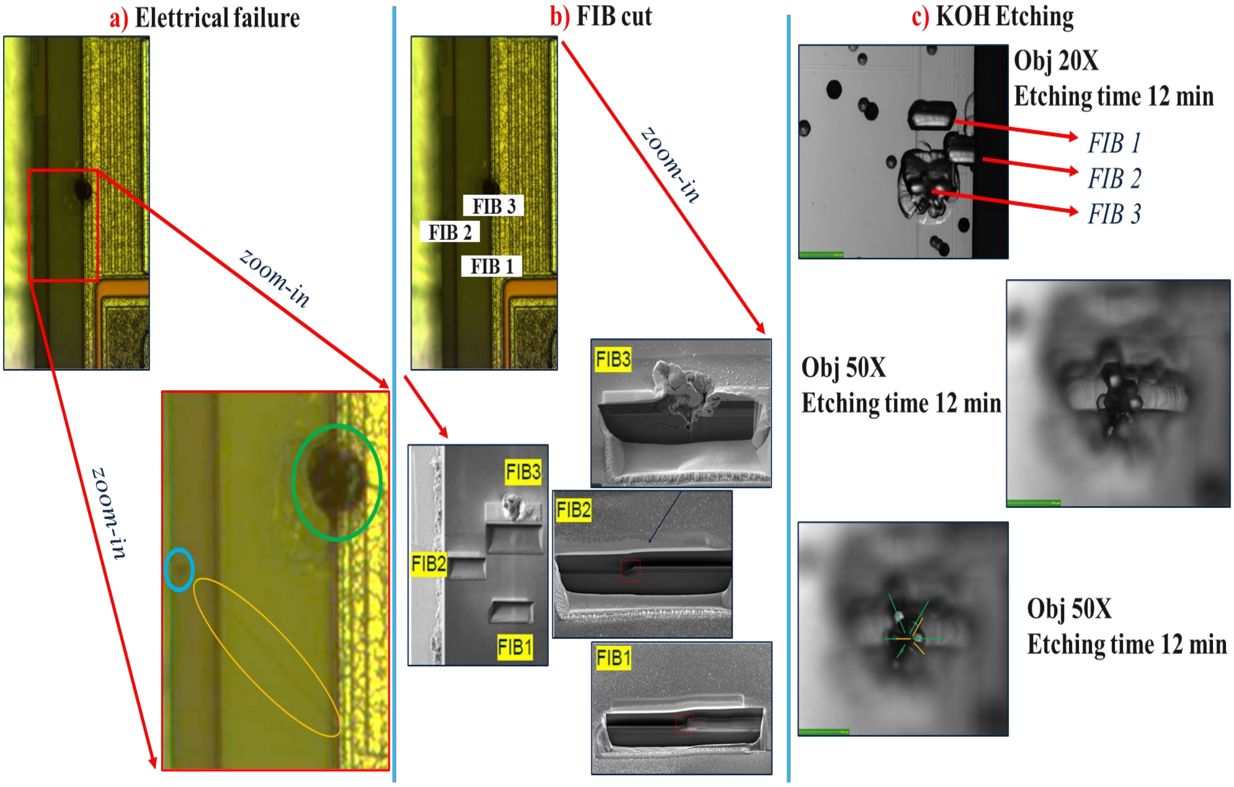

Fig. 1. In a) the electrical failure acquired with optical microscope with dissociation (orange circle) of the MP; in b) FIB cuts in three different regions (FIB 1, FIB 2, FIB 3) of the sample; in c) KOH etching of the die at temperature of 540°C, and time of 12 min detected by x20 and x50 obj.

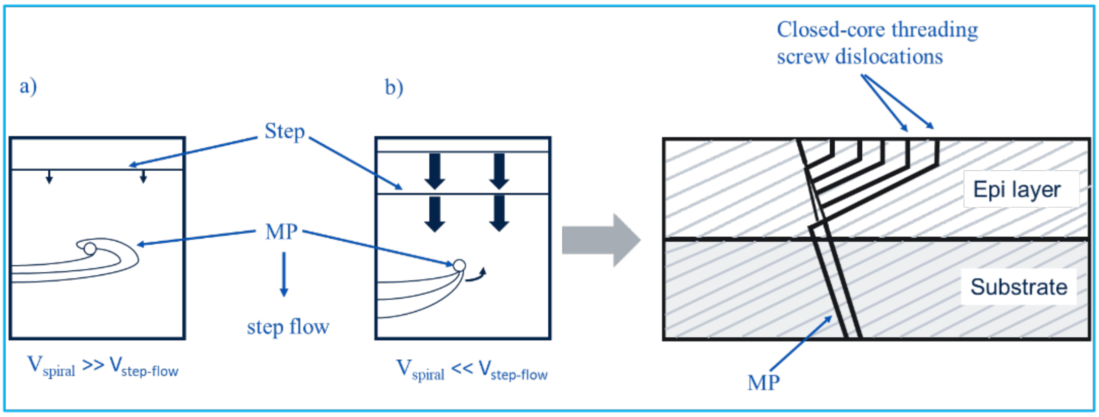

Fig. 2. Illustration of a micropipe evolution with no- dissociation and dissociation into several closed-core screw dislocations during epitaxial growth. In the case of $V_{Spiral}>>V_{StepFlow}$ (a) the MP does not experience dissociation. In case of $V_{Spiral}<<V_{StepFlow}$ (b) the MP undergoes dissociation [11].

The second case reported in Fig. 3 shows a symmetrical burn whose crystallographic nature is not immediately visible with optical investigation (Fig. 3a). However, by treating the sample in molten KOH (Fig. 3b), the characteristic morphology around the hole attributable to a MP, where each fingerprint is at 60° to the next, is visible and confirmed by SEM analysis (Fig. 3c). In this case, the MP does not experience dissociation into closed-core threading screw dislocations because the device is characterized by only one burn on the surface.

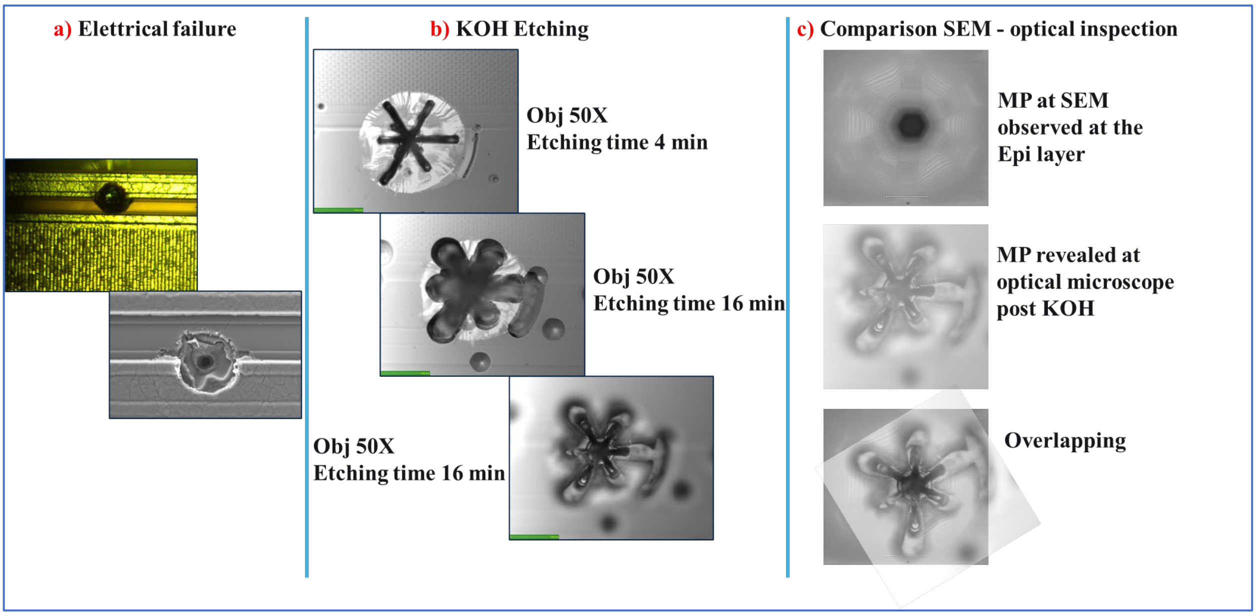

Fig. 3. In a) the electrical failure acquired with optical microscope; in b) KOH etching of the die at temperature of 540°C, and time of 12 min; in c) the comparison between the SEM acquisition and optical inspection of the MP.

In the third case shown in Fig. 4, the burn (Fig. 4a) detected through optical inspection does not show only a symmetric defect but also an additional feature (underlined in red). By subjecting the sample to KOH etching (Fig. 4b), a MP emerges from the inspected region, accompanied by additional features. To define the chemical nature of this feature, Raman analysis was conducted (Fig. 4c). The Raman spectrum of region 1, attributed to the micropipe, shows both the presence of 4H-SiC (777 cm^{-1}) and the presence of polytype (it can be assumed be 15R-SiC) due to the appearance of a pick between 780-790 cm^{-1}. Focusing on Fig. 4c, region 2, the Raman analysis shows peaks that determine the only presence of 4H-SiC. This excludes the involving polytypes in the detected area. Usually, the polytype is detected at the edge of the features, resulting from the electrical burning.

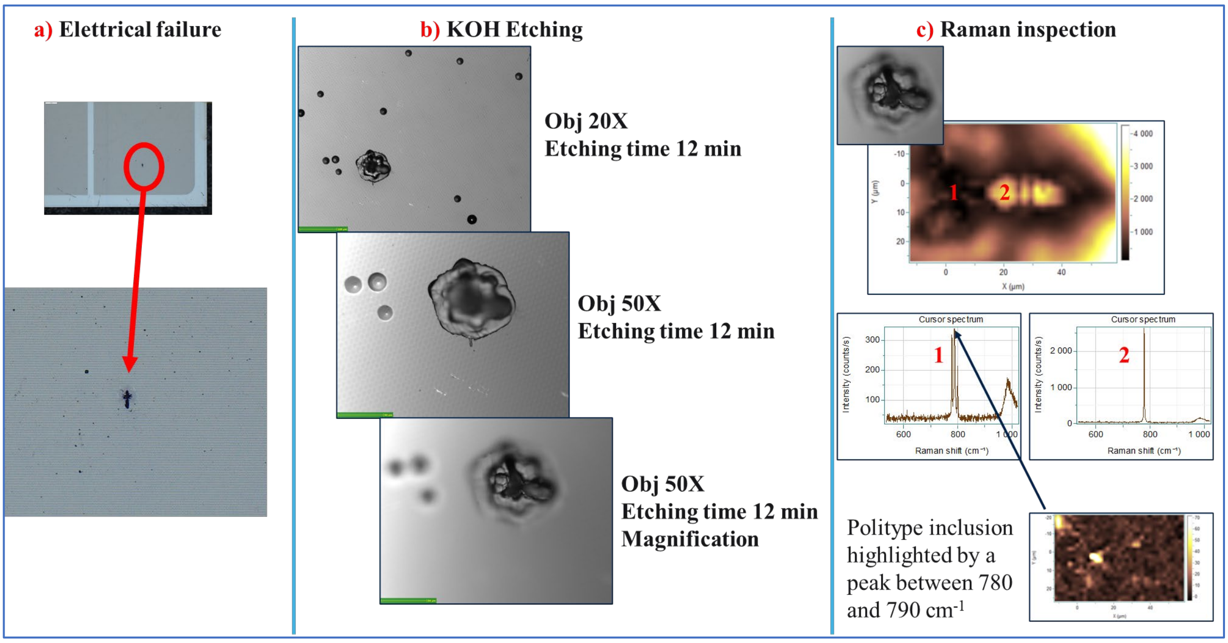

Fig. 4. In a) the electrical failure acquired with optical microscope; in b) KOH etching of the die at temperature of 540°C, and time of 12 min; in c) Raman inspection in regions 1 and 2.

Conclusion

The growth conditions of 4H-SiC bulk material present significant challenges, particularly due to the presence of various crystal defects such as MPs, TSDs, and basal plane dislocations (BPDs). Among these, it is well known that MPs affect semiconductor quality and device performance because they cause electrical failures. Results from molten KOH etching, combined with SEM and Raman analysis, contribute to the investigation of the formation and propagation of defects. Understanding the evolution of electrical failures helps clarify the mechanisms involved, with the aim of controlling and managing MP density to improve the electrical efficiency of devices.

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