

Evaluation of Basal Plane Dislocation Behavior near Epilayer and Substrate Interface

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Abstract. An essential silicon carbide (SiC) manufacturing procedure for eliminating bipolar degradation in a SiC device is the detection of the basal plane dislocation (BPD) causing the phenomenon. In this work, we employed the mirror electron microscope (MEM) technique, which has higher resolution than photoluminescence. The MEM provided results for the detection of short BPDs without conversion to threading edge dislocation at the epi/sub interface. In addition, a considerable number of short BPDs were observed in the epilayer grown with the improved method, and the conversion ratio around the buffer layer could be derived.

Introduction

The performance of power devices fabricated on silicon carbide (SiC) has for a few decades been expected to transcend that of Si-based devices owing to its excellent physical properties. SiC devices exhibit a lower specific on-resistance and higher breakdown voltage, however, several defects and dislocations in the epilayer and substrate make this difficult to achieve. In particular, basal plane dislocation (BPD) is a crucial defect due to the expansion of the stacking fault during a forward biased operation in a bipolar device [1]. In recent years, the BPD density in the epilayer has been reduced by improving the growth method with conversion to threading edge dislocations (TEDs) at the epi/sub interface [2], or the minority carrier recombination near the BPD at the epi/sub interface has been suppressed using the highly nitrogen-doped epilayer [3, 4].

The BPD detection technique has also been continually improved with a new inspection system realized that mainly uses photoluminescence (PL) and X-ray topography [5-7]. However, it is known to be difficult to completely determine the device yield using such detection methods, because short BPDs converted near the substrate could not be observed due to a lack of resolution. Figure 1 shows the location of several types of BPD to TED conversion: I. At the substrate/buffer layer interface, II. In the buffer layer, III. At the buffer/drift layer interface, IV. Without conversion. Two types of BPDs in the buffer layer, namely II and III, were too short to detect with conventional measurement methods. In this report, we detected short BPDs using a unique observation technique, and we compared the BPD to TED conversion in epilayers grown with the conventional and improved methods.

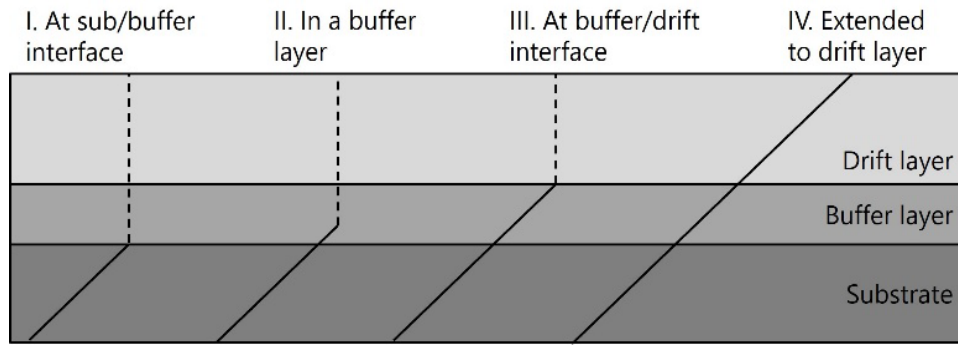


Fig. 1 Schematic diagram of several types of dislocation extended to the epilayer. Solid lines indicate BPDs and dotted lines indicate TEDs.

Experimental

The two kinds of epilayers used in this study were prepared from the same production lot; one was grown with both a buffer layer and a drift layer and the other was grown with just a buffer layer. 1 μm thick buffer layers doped with nitrogen at $1 \times 10^{18} \text{ cm}^{-3}$ and 4 μm thick drift layers doped with nitrogen at $1 \times 10^{16} \text{ cm}^{-3}$ were grown by chemical vapor deposition on commercially available n-type 4H-SiC (0001) substrates with a 4° off-cut angle in the [11-20] direction. To detect short BPDs in the samples, a mirror electron microscope (MEM) technique was used with a VM1000 (Hitachi High-Tech Corp.), which provides high resolution images comparable to those obtained with a scanning electron microscope that reflect the topographical distribution of an equipotential surface over a wafer [8].

Results and Discussion

BPD detection. Figure 2 shows the length distribution of short BPDs in the sample without a drift layer, and a typical BPD image, which appears as a diminishing dark line along the [11-20] direction when observed with an MEM, is shown in the inset. Negatively charged BPDs appears in dark contrast in the MEM image due to the distortion of equipotential surfaces, and the contrast decreased in the leftward direction because the electrical field by the BPD is less affected. The peak at 11 μm is reasonable because the penetration depth of MEM measurement is a little under 1 μm in the sample with nitrogen at $1 \times 10^{18} \text{ cm}^{-3}$. On the other hand, the penetration depth in the drift layer with the carrier concentration at $1 \times 10^{16} \text{ cm}^{-3}$ is approximately 4 μm . Figure 3 shows the mapping results obtained both with and without drift layer samples, which revealed thinning out with a coverage of approximately 0.3 %. No BPD was observed in Fig. 3(a) for an epi-wafer grown with both of a buffer and a drift layer. However, BPDs as dots in the inner region of the map of the epi-wafer grown with only the buffer layer can be seen in Fig. 3(b). These results reveal not only that all the BPDs were converted to TEDs before extending to the drift layer but also that a few BPDs remained in the buffer

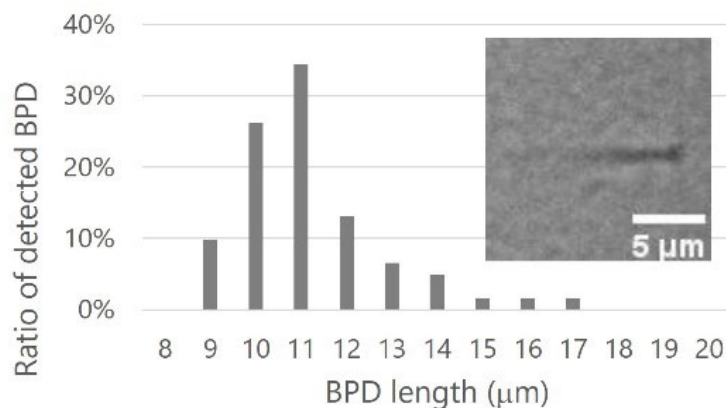


Fig. 2 Distribution of BPD length observed with MEM, as indicated in the inset.

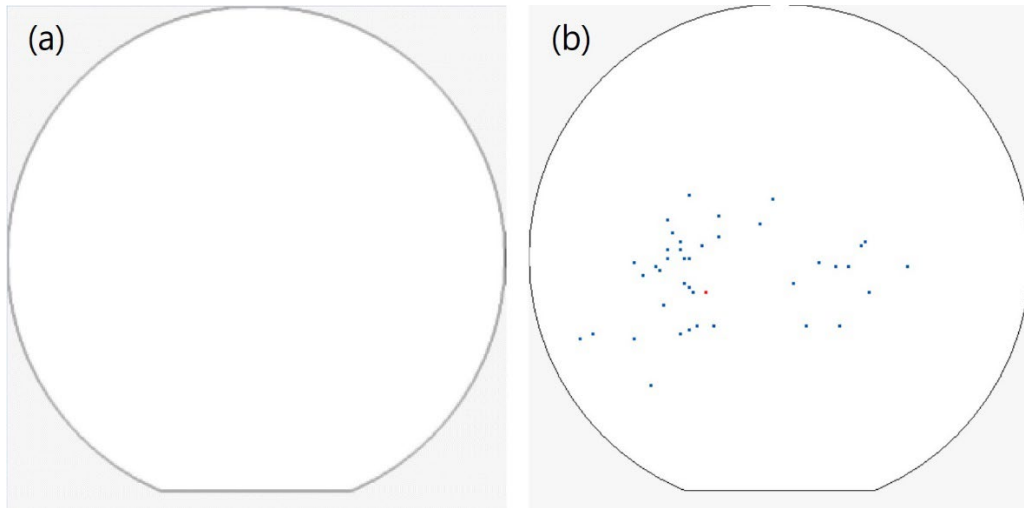


Fig. 3 Detection map of samples grown with (a) buffer layer and drift layer, and (b) just buffer layer observed with MEM.

layer without being converted at the epi/sub interface. Therefore, it was assumed that such short BPDs cause bipolar degradation on the epi-wafer without any BPDs being detected using conventional inspection methods. Figure 4 shows the PL map observed for the non-drift layer sample when using an NIR or NUV filter with a SICA88 (Lasertec Corp.). No BPDs were detected in the map because it was assumed that a BPD pattern with a length of $11\ \mu\text{m}$ is too short to be identified due to insufficient resolution even if the BPD could be observed with PL imaging.

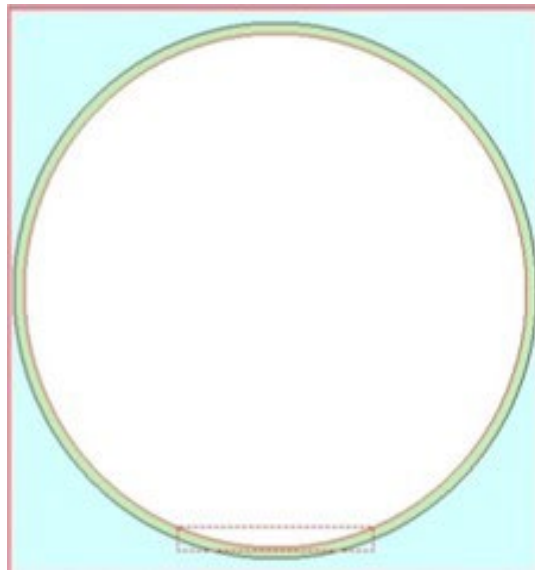


Fig. 4 Detection map of the sample observed with SICA88.

Investigation of conversion ratio. Figure 5 shows BPD maps obtained by MEM measurement at two epi-wafers with only a buffer layer; one was grown with the conventional method and the other with the improved method. In contrast to the BPDs over the entire map in Fig. 5(a), a significant number of BPDs were found in the epilayer grown with the improved method due to the almost complete conversion to TEDs at the epi/sub interface in Fig. 5(b). Moreover, it also shows that the conversion point from the BPD to the TED could be defined from the MEM results using the BPD length and several epilayer structures. Table I summarizes the conversion ratio in the prepared epi-wafer at every position mentioned above, namely I. At the substrate/buffer layer interface, II. In the buffer layer, III. At the buffer/drift layer interface, and IV. Without conversion, calculated from the results. It was found that there were a few types II or III BPDs with the conventional growth method because a type I conversion ratio of approximately 96 % is insufficient. On the other hand, almost all

the BPDs were conversion type I and BPDs converted by type II or III did not remain in the epilayer with the improved method. This means that the conversion point of the BPDs converted without the epi/sub interface causing bipolar degradation could be controlled and eliminated with the epi-grown method.

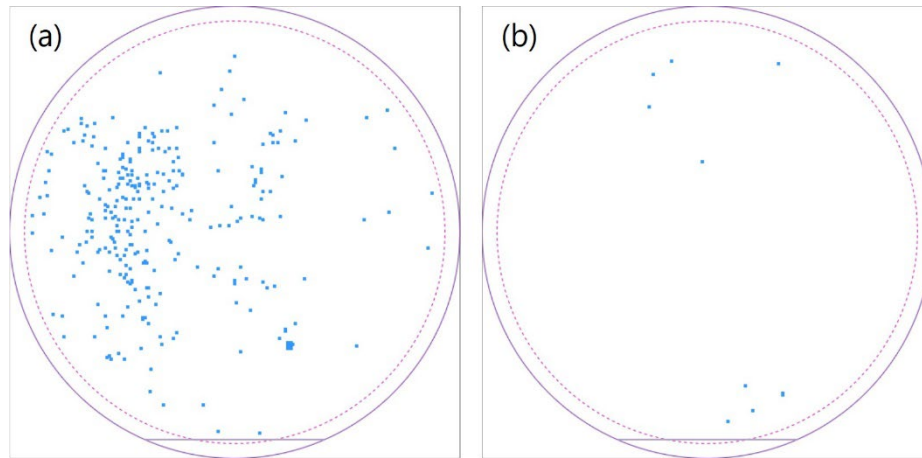


Fig. 5 Detection map of epi-wafer grown only buffer layer with (a) conventional and (b) improved method inspected by MEM.

Table I BPD to TED conversion ratio under several types of extension. (X is buffer layer thickness.)

Epi-grown method	I.	II.	III.	IV.
Conventional	96.07 %	51.80X %	99.50 %	< 0.01 %
Improved	99.99 %	-	-	< 0.01 %

Summary

Two developments are necessary if we are to overcome bipolar degradation, namely the elimination of the BPDs from the entire epilayer and precise detection. However, it was difficult to confirm that the BPDs were completely converted at the epi/sub interface because the previous measurement technique could not detect a short BPD. In this study, we showed that MEM imaging, which has been reported as a new inspection technique in recent years, could observe short BPDs in the buffer layer. In addition, we obtained information about where a BPD was converted to a TED around the buffer layer using this measurement. Therefore, this evaluation provides us not only a new technique with which to detect short BPDs but also knowledge about the conversion mechanism near the epi/sub interface.

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