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Effective Method (Selective E-V-C Technique) to Screen out the BPDs that Cause Reliability Degradation

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Abstract. We propose the new practical and effective method, called Selective E-V-C (Expansion-Visualization- Contraction) technique, to screen out the basal plane dislocations (BPDs) which might cause the forward voltage degradation of SiC devices. Since the method can be adopted at the epi wafer receiving inspection process in early stage of production line, it may replace the very time-consuming so-called "burn-in" operation currently utilized in some device manufacturers.

Introduction

Almost two decades have passed since the reliability issue of the forward voltage degradation of 4H-SiC devices was first reported [1, 2], and since then extensive studies on the issue have been carried out by many researchers, to prove that the degradation is caused by the nucleation and expansion of a single SSF (Shockley-type stacking fault) [3]. The origin of the SSF is a BPD (basal plane dislocation) which exists in the epilayer or near the epilayer and the substrate (epi/sub) interface. The SSFs are expanded by the electron–hole recombination energy when excessive minority carriers are injected into the regions in the vicinity of the BPDs, which is called REDG (recombination-enhanced dislocation glide) mechanism.

The density of BPDs has been drastically reduced mainly by raising the conversion ratio from BPDs in the substrate to benign TEDs (threading edge dislocations) during the epitaxial growth process. However, it was found in recent years that the converted BPDs also expand to SSFs from a BPD-to-TED conversion point [4]. Therefore, in order to prevent the SSF expansion from the conversion point, an introduction of a highly nitrogen-doped buffer layer has been proposed between the low doped drift layer and the substrate, which significantly shortens minority carrier lifetime to reduce the density of injected minority carriers around the epi/sub interface [5]. An adoption of the buffer layer has a great effect on suppressing SSF formation, but it is still never completely eliminated. This means that, among TED-converted BPDs in buffer layer, some tend to expand to SSFs, while others do not. Therefore, on mass production line, there is a strong need for screening out the "malignant" BPDs in buffer layer that will potentially expand to SSFs under forward bias operation. In some device manufacturers so-called "burn-in" screening is currently performed, in which the forward voltage degradation is checked, chip by chip, by applying forward current stress for a certain period. This is a very time-consuming process which raises a total cost of production.

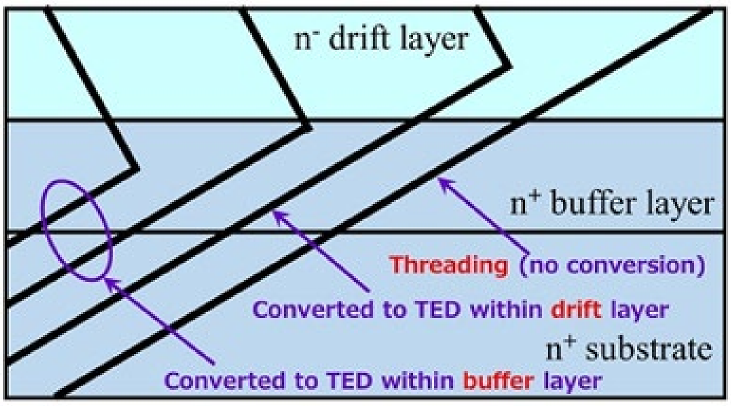
This paper focuses on how to capture TED-converted BPDs in buffer layer and also how to screen only BPDs that tend to expand, and using these methods, we propose the new practical and effective method, called Selective E-V-C (Expansion-Visualization-Contraction) technique [6].

In Selective E-V-C method, at the epi wafer receiving inspection stage, first, both threading BPDs and TED-converted BPDs are captured. Threading BPD means the BPD reaching drift layer surface and TED-converted BPD means the BPD which is converted to TED in drift layer or in buffer layer (including at drift/buffer layer interface). We capture the BPD in drift layer as straight bright line and the BPD in buffer layer as straight dark line by UVPL (ultraviolet photoluminescence) observation [Selection]. Second, UV irradiation is utilized to expand the BPDs to SSFs [Expansion], which is the same REDG phenomenon as in the case of forward voltage degradation by forward current stress. Third, the expanded SSFs are made visible by UVPL imaging [Visualization] and their distribution map is recorded, and finally the SSFs are contracted by heating under weak UV irradiation in order to return the SSFs to their original or near-original state of the BPDs [Contraction]. By referring to the recorded SSF distribution map, it is possible to accurately identify where on the wafer the defects that cause forward voltage degradation reside, without loading any excessive current that exceeds the maximum rating such as "burn-in" screening (acceleration test).

Experiment

For this work, the sample investigated was a commercially available n-type 100 mm Φ 4H-SiC substrate with a 4° off-cut angle, on which highly nitrogen-doped buffer layer (10 µm, 1 x 10^{18}cm^{-3}) and low doped drift layer (10 µm, 1 x 10^{16} cm^{-3}) were epitaxially grown. The total observation area was 17 mm^2.

First, the UVPL images on the BPDs present in the buffer layer as well as in the drift layer, were taken using 380 nm BPF (bandpass filter). Those BPDs can be captured as straight dark line by using NUV (near-ultraviolet) BPF , as reported in some previous papers [7,8]. Fig. 1 depicts observable types of BPDs by using 380 nm (NUV) BPF, and an example is shown in Fig.2A.



Drift layer thickness = 10 μm

Buffer layer thickness = 10 μm

Substrate thickness = 353 μm

BPD density = 1390 cm^{-2}

Fig. 1 Threading and TED-converted BPDs

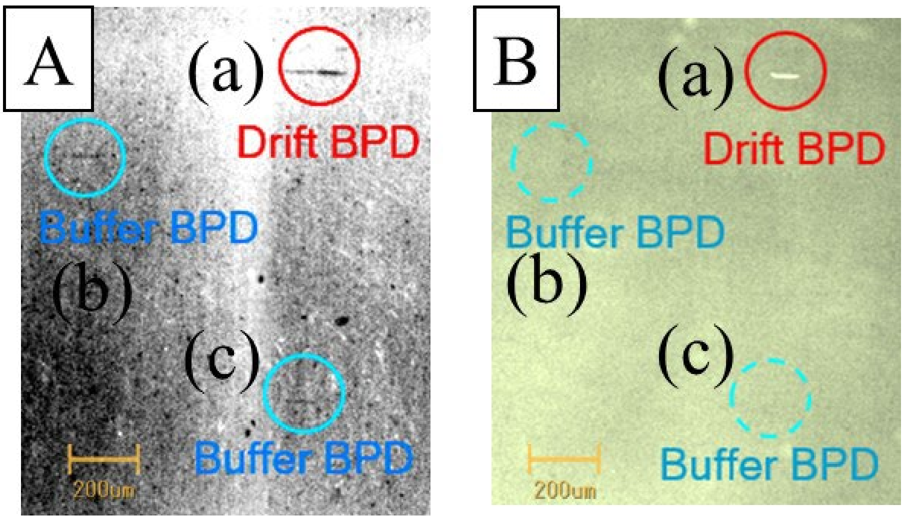


Fig. 2. UVPL image by excitation light (Mercury-Arc lamp 313 nm 50 mW/cm^2)
(a) A BPD converted to TED within drift layer.
(b) A BPD converted to TED near interface between drift layer and buffer layer.
(c) A BPD converted to TED within buffer layer.

Second, the UVPL image on the same area with over 700 nm LPF (long-pass filter) was taken, which is capable of only capturing BPD segments in drift layer (Fig.2B). By superimposing the first image and the second image, the BPD in buffer layer and that in drift layer was able to be separated. Third, for BPDs to expand, UV light from Hg-Xe lamps was irradiated over the sample through a quartz fiber with diameter of 8 mm. The irradiation conditions were approximately 3.5 W / cm 2 using a Hg-Xe fiber light source for 4 hours on a 25 ° C cool plate. After UV exposure, the expanded SSFs were examined by UVPL with 420 nm BPF(Fig.3A). Finally, in order to observe closely inside buffer layer, 10 µm drift layer was completely removed by planarly polishing of 11 µm from the surface (9 µm buffer layer remained), followed by UVPL observation with 380 nm BPF (Fig.3B).

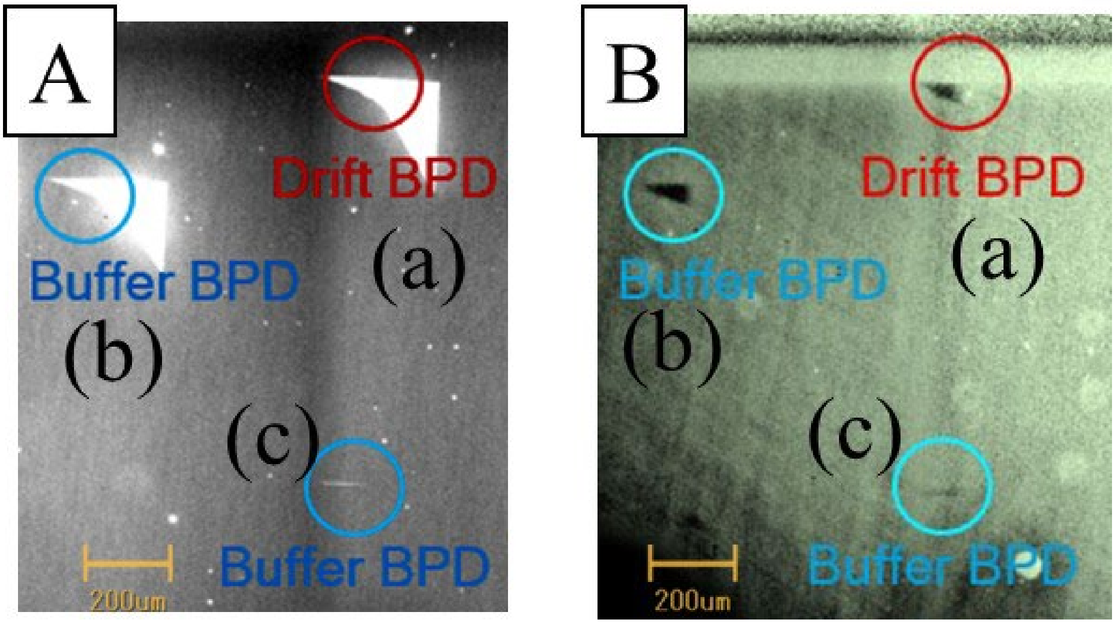


Fig.3. UVPL image by excitation light (Mercury-Arc lamp 313 nm 50 mW/cm^2)
(a) A BPD that converted to TED within drift layer expanded to SSF.
(b) A BPD that converted to TED near interface expanded to SSF.
(c) A BPD that converted to TED within buffer layer did not expand to SSF after 4 hours of UV irradiation.

Table I. Expansion Result

	Drift layer		Buffer layer
	Threading	Converted	Converted
Total	2	4	11
Expanded SSF	2	4	4
SSF	0	0	7

Total observed area was 17 mm^2, and Table I summarizes the observed BPDs and SSFs, and the following notable facts have been found.

● All the BPDs in drift layer (both threading and TED-converted) expanded, and the expanded area was extended into buffer layer in all cases. Because of different SSF expansion velocity between in drift layer and in buffer layer, double-shaped triangles were observed (Fig.4).

● On the other hand, some BPDs in buffer layer expanded and some did not. Even unexpanded one appeared as a bright line at 420 nm BPF, so it seemed that the BPD was dissociated into two partial dislocations, in a state of beginning of SSF expansion.

● From the length of dark line in buffer layer, the location of TED-converted point (namely, the depth from buffer/drift (b/d) interface) can be estimated. The BPD with deep converted point was expected to be hard to expand as compared with the BPD with the converted point near b/d interface because of short minority carrier lifetime within buffer layer. However, that was not always the case. This means that the ease of expansion cannot be determined by the depth of the converted point alone. Currently, it seems that the most practical way to determine if the buffer layer BPD expands or not is to simulate forward bias degradation with UV irradiation to identify SSF expansion.

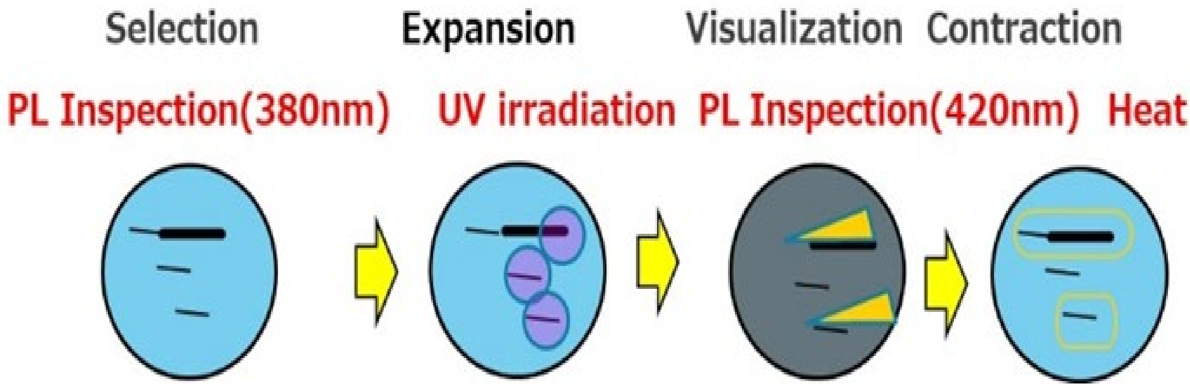


Fig. 4. Selective E-V-C technique

Based on these results, we propose a new practical and effective screening procedure to identify malignant BPDs within buffer layer, which expand to SSFs (Fig.4).

Step-1) BPD identification by UVPL with 380 nm BPF (UV irradiation area selected)

Step-2) UV irradiation over the selected area (expansion)

Step-3) SSF observation by UVPL with 420 nm BPF (visualization)

Step-4) Heating process (contraction of SSF and dissociated BPD)

Final heating process has an effect of contracting both SSFs and dissociated BPDs returning to their original or near-original state of the BPDs. In our experiment, almost all the expanded SSFs were contracted by 650 °C heating for 1 hour.

"In our experiment, we needed 4 hours for each SSF expansion by using Hg-Xe UV lamps. To shorten irradiation time, we recently changed the excitation source from UV lamps to UV laser, and roughly 100 to 1000 times faster expansion speed is obtained, so far."

Summary

The practical and effective way to screen out the BPDs which might cause the forward voltage degradation is presented, using UV irradiation and UVPL observation. We call it Selective E-V-C technique, and it has a potential to replace the time-consuming "burn-in" screening process.

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