Effects of Dislocations on Minority Carrier Lifetime In Dislocated Float Zone Silicon

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Abstract: We present a correlation of Microwave Photoconductance Decay minority carrier lifetime with dislocation density in high purity Float Zone silicon. Electron Beam Induced Current (EBIC) images were carefully aligned to lifetime maps and depth profiling of individual defect electrical activity was done by varying the bias of Schottky diodes. The data presented provides a relationship between lifetime variations and EBIC contrast, based on dislocation density and impurity decoration in the near surface zone.

INTRODUCTION

Although Float zone (FZ) Si ingots grown in NREL are pure and have the highest minority carrier lifetime [1], they suffer high yield losses due to breakage and mechanical failure during PV device processing. As a means to merge the benefits of both high lifetime FZ and the mechanically tougher CZ wafers, a joint NCSU/NREL program is underway using combinations of oxygen and nitrogen doping to maintain the high minority carrier lifetime, while improving the hardness by blocking dislocation movement. We report on longitudinal (parallel to growth axis) and radial changes in dislocation density and electrical activity in connection to minority carrier lifetime. Previously, dislocation "lineage" were revealed by x-ray topography (XRT) imaging and a correlation was established with Microwave Photoconductance Decay (μPCD) carrier lifetime [2]. As expected the highest lifetimes correspond roughly to areas of lowest dislocation density. In this poster, the dislocations are examined via EBIC imaging in connection with lifetime variations due to the level of dislocation impurity content.

RESULTS AND DISCUSSION

The measured lifetime distribution in the top portion of a longitudinal slug cut from a dislocated FZ Si ingot, on which a Schottky diode array was made, is given in Fig. 1. Note that most of the lifetime distribution is between 100 to 300 μs, while the maximum is about 400 μs. The EBIC images in Fig. 2 were obtained with a variable bias in a region with ~170 μs lifetime. Since the contrast of EBIC images is lowered in the bulk, see Fig. 2(d), we conclude that the dislocations in the near surface are contaminated. According to C-V measurements it appeared that the impurities introduced in the material at room temperature diffused about ~3 μm depth down the dislocations. Impurity free "clean" silicon dislocations are not expected to act as carrier recombination centers at room temperature [3, 4] and, therefore, are not visible with room temperature EBIC. The fact that the impurities were introduced during room temperature polishing of the surfaces limits their extent in the bulk, as verified with the variable bias EBIC. The extrinsic impurities were identified with DLTS, which showed that Fe exists at a level of 1E13 to 2E14 cm^{-3} and Cu at a level of 1E13 cm^{-3} [5].

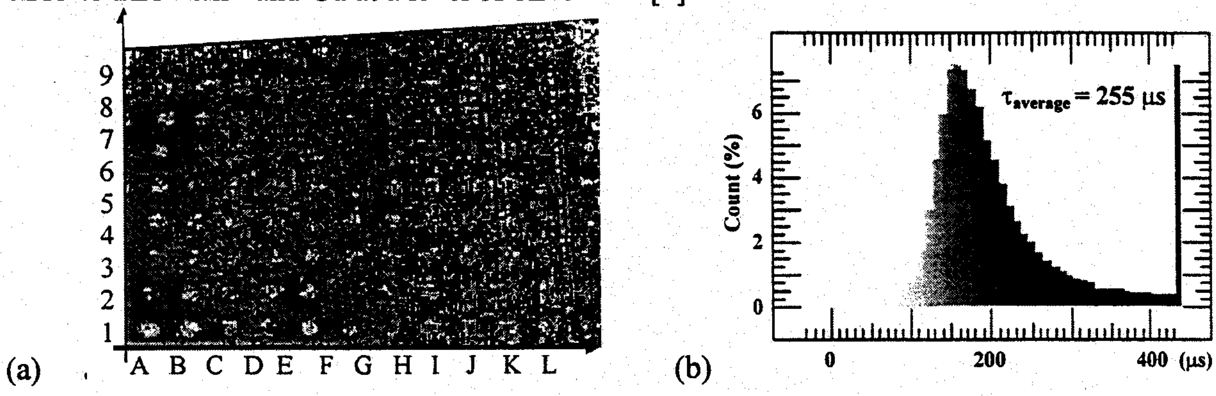

Fig. 1: (a) Lifetime map and (b) histogram of dislocated FZ sample cut from the region close to the ingot neck with superimposed the image of the diode array used in EBIC measurement. Note that the bar at 430 µs in the histogram represents the accumulated measured lifetimes above that value.

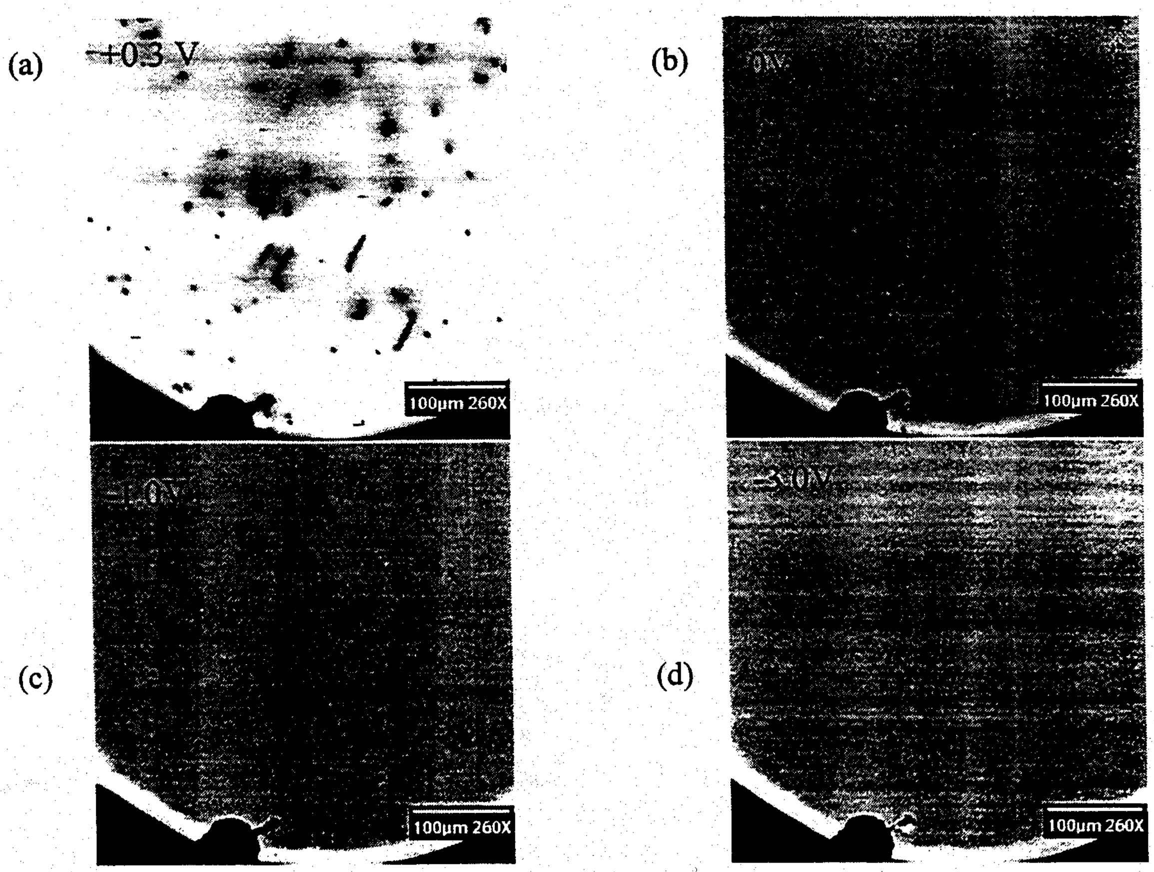

Fig. 2: EBIC images of a diode taken at different bias voltages. The diode is located in the ingot neck portion, in a region where the lifetime is about 170 µs, diode E2 in Fig. 1 (a).

The results obtained in the ingot bottom region differ slightly from the neck region in that low lifetime does not simply suggest a high dislocation density but also different type of dislocations leading to different characteristics of the EBIC contrast. Stronger EBIC contrast and wider extent of the recombination centers indicate dislocations with stronger impurity gettering ability. The shape and the contrast of the EBIC features can provide information on the dislocation character.

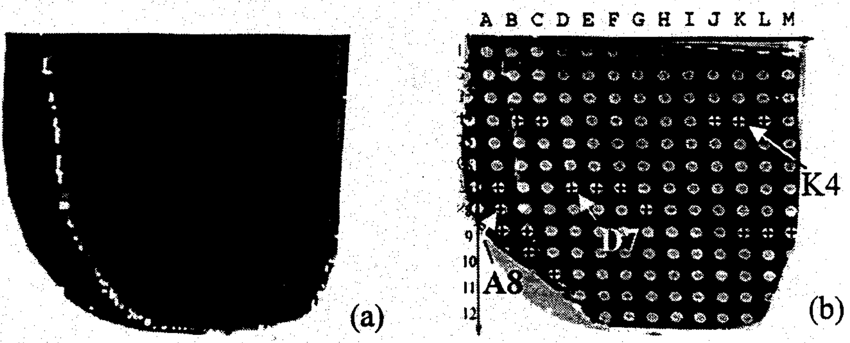

Fig. 3: µPCD Lifetime map of the bottom of an axial slug cut from an FZ ingot with a high density of dislocations. The gray scale in this map matches that of the histogram in Fig.1(b).

As shown in Fig. 3, the left side of the ingot is characterized with a low lifetime ~ 70µs (diode A8) and a high dislocation density [2]. Dislocation multiplication may have occurred by interaction with small impurity clusters which also reduce the lifetime and the EBIC baseline current, compare Fig. 4(a) to Fig. 4(c). The EBIC contrast of features in diode D7 appear sharper, many of which are circular or linear in shape, see Fig. 3(b), while the EBIC spots in diodes A8 and K4 appear weaker, and in the case of A8 more diffuse. It should be noted that the less sharp EBIC features (due to dislocations decorated with extrinsic impurities at the top portion) occur in a region (i.e., A8) where the lifetime is intrinsically low.

In the low dislocation area K4 the contamination is also present in the near surface (sensed by the dislocation carrier recombination activity) and the bulk is relatively cleaner than A8 region, according to the higher EBIC background current and the higher µPCD lifetime. Nonetheless, the shallow contamination partially screens the bulk lifetime component when measured by µPCD.

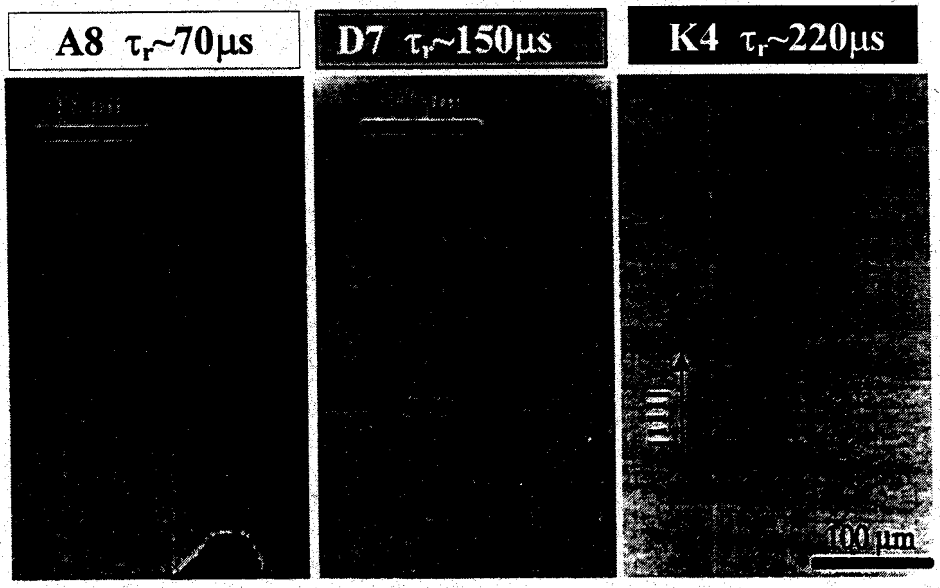

Fig. 4: Enlargement of portions of the EBIC images of diode A8 , D7 and K4 shown in Fig. 3 (b), where there is a clear lifetime variation (70, 150 and 220 µs respectively). Note that the [111] growth direction is parallel to the diode surface. The gray scale in the label boxes matches the lifetime gray scale provided in the histogram in Fig.1(b).

CONCLUSION

The minority carrier lifetime correlated previously with XRT images, is further studied in connection to EBIC data. The EBIC measurements at various biases have shown that a contamination occurred in the first 2-3 microns at most. This shallow contamination, was instrumental in decorating the dislocations which then allowed electrical evaluation of the dislocations strength and electrical activity field and the correlation with minority carrier lifetime. Indeed, the dislocation EBIC related features exhibited a characteristic shape that is location-dependent and varies with lifetime regions. In the highly dislocated region of the ingot neck, the lifetime is the lowest, while in region D7 of moderate lifetime (in the middle of the bottom of the ingot) dislocations appear as strong gettering center. Finally, in the low dislocation density region (K4) the lifetime is intrinsically high, due to a lower density of gettered impurities. Thus the lifetime degradation is proposed to be not caused by the dislocations only, but also to the distribution of impurities.

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