Abstract #1893, 224th ECS Meeting, © 2013 The Electrochemical Society

Unexpected Sources of Basal Plane Dislocations in 4H-SiC Epitaxy

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The suppression of basal plane dislocations (BPDs) in the epitaxiy of 4H-SiC devices is necessary for reliable and stable operation. During the forward-biased operation of bipolar devices such as PiN diodes, BPDs in the drift layer cause an upward drift in the forward voltage. Electron-hole recombination drives the faulting of the BPDs and the expanding stacking faults degrade the drift conductivity by a combination of suppressing carrier lifetime and introducing barriers [1-3]. Degradation also occurs in unipolar devices such as MOSFETS in which the body diode is forward biased [4]. The stacking faults that expand from the BPDs also increase the reverse-biased leakage [4,5].

Over the last decade, there has been a steady reduction in BPD density and that effort has concentrated on reducing BPDs within the epitaxially-grown device drift layer. Part of the reduction is due to improved wafers [6], but a majority of the improvement has been accomplished by increasing the fraction of BPDs that are converted into the more benign threading edge dislocations (TEDs) before reaching the drift layer. This is achieved by epitaxial growth conditions that increase the conversion fraction when growth is initiated and by converting most of the remaining BPDs within the more heavily doped buffer layer under the drift layer. In state-of-the-art epitaxy, a majority of the wafer area is free of BPDs within the drift area.

As large areas of the wafer have no BPDs extending from the substrate into the drift region of the epitaxy, other BPD sources become important. Two alternate sources are discussed in this presentation.

The first are BPDs created by epitaxial inclusions. Inclusions are formed during epitaxial growth and consist of a mixture of 3C and strongly misoriented 4H polytypes [7]. They distort the surface morphology and cause a local strain field that introduces BPDs in the immediate vicinity of the inclusion. A factor that amplifies the effect of these BPDs and that increases with epitaxial thickness is the slight lattice mismatch between the substrate and the drift layer due to the doping level difference between the two. As a result of the much lower doping level in the drift layer, it is typically in compression. One consequence is that BPDs glide long distances during epitaxial growth.

Figure 1, shows an example of an inclusion and induced BPDs in a 160 um thick drift layer. In addition to the dense cluster of BPDs in the immediate vicinity of the inclusion, a number of BPDs have glided up to 10 mm away from the inclusion. As the BPDs glide, they form half-loop arrays, which can introduce stacking faults along their entire length [8].

The second source of BPDs discussed here, which were previously not considered, are BPDs that propagate from the substrate into the epitaxial buffer layer but are converted into TEDs before entering the drift layer [9]. Recombination in the buffer layer is significantly weaker, and it has been widely assumed that BPDs not entering the drift layer could not be a source of stacking faults in the this layer. However, at sufficiently high currents or UV power, enough holes are injected into the buffer layer to initiate the faulting of BPDs. Once the fault expands to reach the drift layer, it rapidly expands through the drift layer.

Figure 2(a) shows a region with a single BPD within the drift layer inside the orange oval and multiple BPDs that converted to TEDs before propagating into drift layer. The latter show up as dark lines in Fig. 2(a) such as inside the yellow oval. After UV exposure at 351 nm at a power of 1000 W/cm^2, more that a dozen stacking faults spanning the drift layer are formed.

References:

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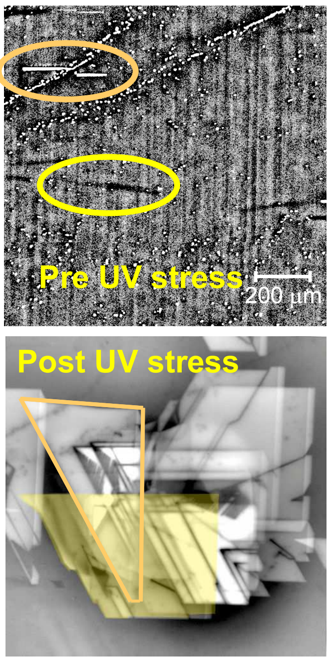

Fig. 2. UVPL images of (a) BPDs in the epitaxial buffer, (b) stacking faults in the drift layer after UV exposure at 1000 W/cm^2.

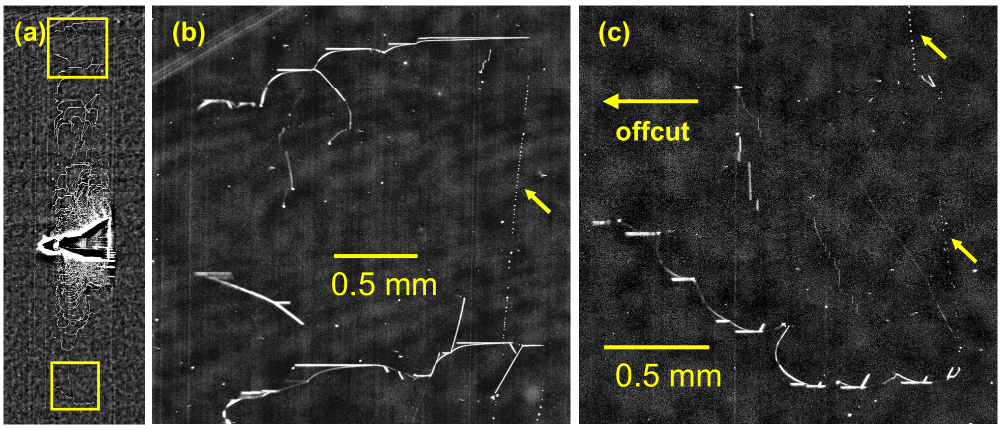

Fig. 1. Ultraviolet photoluminescence (UVPL) image of an inclusion and BPDs that it induces in the epitaxy: (a) is a 20 x 9 mm area, (b) and (c) are magnified views of the top and bottom boxes. The arrows point to series of dots due to half-loop arrays.