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Nucleation of In-Grown Stacking Faults and Dislocation Half Loops in 4H-SiC Epilayers Deposited at High Growth Rate

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There has been an increasing interest in growing 4H-SiC epilayers on substrates with an off-angle lower than 8° off-cut. Such growth is known to increase the probability of BPD conversion to electrically benign threading edge dislocations thus avoiding the formation of Shockley type stacking faults (SFs) that are detrimental to high voltage device performance. Reported epilayer growth rates on 4^o off-axis substrates with standard precursors (i.e. SiH_4 and C_3H_8) range from 2.5-10 μm/h. Increasing the supersaturation can increase growth rate but also can increase the density of extended defects in the epilayer.
In this work, a 4H-SiC homoepitaxial layer was grown by chemical vapor deposition on a 4^o off-axis substrate using SiH_4 and C_3H_8 at relatively high growth rate of 18 μm/h. Ultraviolet photoluminescence (UVPL) was used to map defects in the epilayer while defect-selective KOH etching was performed to delineate surface-penetrating dislocations. The structure of extended defects was assessed by TEM.
UVPL mapping revealed a very high density of in-grown stacking faults (SFs) (3×10^3 cm^{-2}) in the epilayer, as shown in Fig. 1(a). The density was substantially reduced to 30-50 cm^{-2} in other epilayers with the growth rate of 10 μm/h, or when growth started at 2 μm/h and increased to 18 μm/h over 10 minutes.

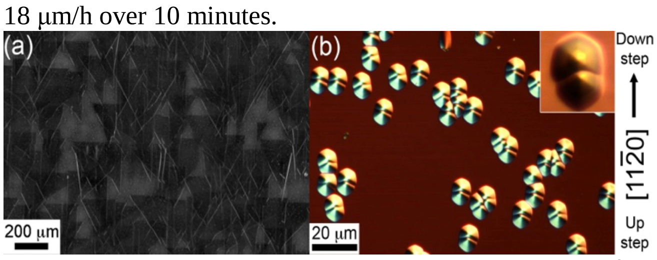

Fig. 1 (a) UVPL and (b) Nomarski optical micrographs of the epilayer grown at 18 μm/h. Inset in (b) shows 10 μm x 10 μm magnified view of the etch pits

High-resolution TEM revealed that the in-grown SFs (IGSF) are Shockley type faults consisting of a single unit cell of 8H polytype, as shown in Fig. 2. Stacking faults nucleated homogeneously in the epilayer (0.5-1 μm above interface) without any relation to any other defects.

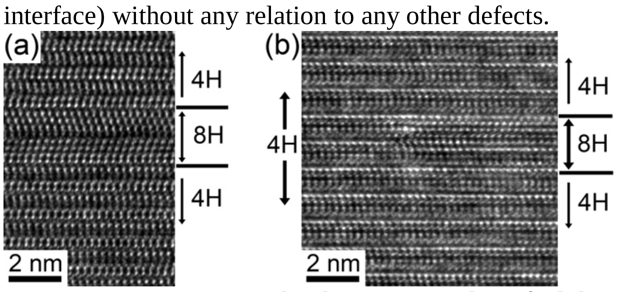

Fig. 2 HRTEM micrographs showing a stacking fault has (a) 8H stacking sequence, and is (b) Shockley type fault

The high density of IGSFs was correlated with a high density of dislocation half loops (5×10^5 cm^{-2}), which appeared as pairs of etch pits on the epilayer surface after KOH etching, as shown in Fig. 1(b). Areas of the epilayer with high density of stacking faults also have high density of dislocation half loops, and vice versa. TEM showed that the half loops consisted of 2 threading edge dislocations connected by a short BPD segment in the epilayer, as shown in Fig. 3. The Burgers vector of the half loop is in the basal plane, at a 60° off the step-flow direction.

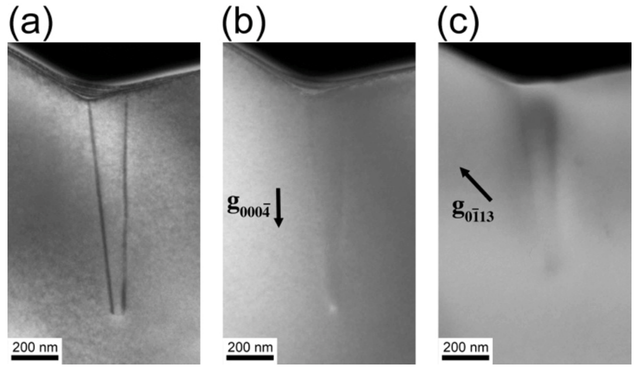

Fig. 3 (a) Bright-field TEM micrograph of a dislocation half loop, which nucleated 1.8 μm above interface. Step-flow direction is towards the right. Dislocation is invisible at (b) $g_{000\bar{4}}$ and (c) $g_{0\bar{1}13}$ two-beam diffraction conditions.

TEM results confirm that both types of defects (IGSFs and dislocation half loops) nucleated in the epilayer during growth and do not propagate from the substrate. There was no sign of second phase inclusions (such as Si droplets) or particulates.

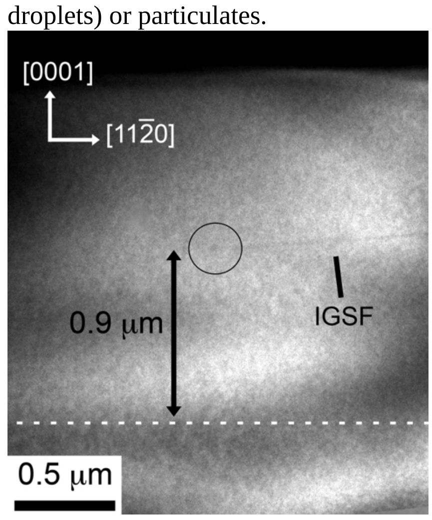

Fig. 4 Bright-field TEM micrograph at the [$\bar{1}2\bar{1}0$] zone-axis condition showing the nucleation of the in-grown stacking fault in the epilayer. The black circle shows the location where the stacking fault nucleated. The white-dashed line corresponds to the substrate/epilayer interface. The stacking fault nucleated in the epilayer (0.9 μm above the interface).

Dislocation half loops only appeared in the epilayer grown at 18 μm/hr, and did not appear in the other epilayers grown at lower growth rates.
We propose that the IGSFs and dislocation half loops are caused by nucleation of two-dimensional islands. The main difference between the epilayer grown at 18 μm/hr and the other epilayers is the higher supersaturation of precursors during initial stages of growth, which favors 2D nucleation. These observations are relevant to future high-growth rate attempts on even lower angle off-cut 4H-SiC substrates, where islanding and subsequent defect formation may prove even more problematic.