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Microscopic Investigation of SiC Epitaxial Layers on On-Axis 4H-SiC Substrates Using Kelvin Probe Force Microscopy

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We report on Kelvin probe force microscopy and electron backscatter diffraction measurements of 3C-SiC epitaxial layers grown on exactly oriented Si-face 4H-SiC (0001) substrates in a horizontal hot-wall chemical vapor deposition reactor, in the temperature range from 1150 °C to 1620 °C, under H_2 or H_2+SiH_4 atmosphere. The investigated layers were doped with nitrogen (for *n*-type) and aluminium (for *p*-type). The electron backscatter diffraction analysis revealed structure of polytype 3C blocks with a relative rotation of 60 and/or 120°. The Kelvin probe force microscopy measurements revealed cubic substructure as a equilateral triangle objects contrast which is characteristic of 3C silicon carbide polytype. The surface potential contrast was found to be dependent on the type and concentration of doping, which could be explained in terms of the impurities accumulation at block boundaries.

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1. Introduction

The improvement of crystalline structure of SiC epitaxial layers is still considered the most essential issue in enhancing the devices performance. The main problems that must be solved include polytype instability and basal plane dislocations (BPDs). In the case of high power bipolar electronic devices, the BPDs are reported to act as a source of expanding stacking faults (SF) formation in the basal plane during bipolar injection [1]. The application of epitaxial layers grown on on-axis substrates would allow to avoid BPDs generation. However, the growth on on-axis oriented substrates is connected with polytype instability. The coexistence of cubic (3C) and hexagonal (4H) polytype is usually observed in the epitaxial layers on on-axis substrates. The 3C-SiC polytype nucleates spontaneously on hexagonal (0001) on-axis surface for the temperature below $\approx 1650\,^{\circ}$C [2]. Another common and characteristic property of such layers is high density of double position boundaries (DPBs) [3] which result from simultaneous and random nucleation of 60° and/or 120° rotated 3C-SiC islands.

2. Experimental details

The growth was carried out in the horizontal hot-wall chemical vapor deposition (CVD) reactor (Epigress VP508GFR). The *in situ* on-axis Si-face (0001) 4H-SiC surface etching at 1620 °C, under H_2 or H_2+SiH_4 atmosphere was used to obtain a morphology composed of an array of steps. High purity H_2, propane C_3H_8 and silane SiH_4 gases were used, respectively, as a carrier gas and precursors for the SiC growth. The growth was started in different temperature (from 1150 to 1620 °C). The precursors flows were increased with C/Si ratio from 1 to 1.8. The slow SiH_4 flow changes — gradual growth rate increase — affected the better polytype stability. The pure nitrogen and trimethylaluminum (TMAl) were used for doping. The measured *C–V* concentrations in 3C-SiC epitaxial layers were contained in the range 2.8×10^{15}–2×10^{17} cm^{-3} for *n*-type and 2×10^{17}–1.6×10^{18} cm^{-3} for *p*-type, correspondingly.

The layers were characterized by electron backscatter diffraction (EBSD) for polytype identification and Kelvin probe force microscopy (KPFM) for analysis of surface potential distribution and revealing of cubic substructure. The EBSD technique is primarily utilized for determination of phase and orientation through recording and indexing of electron diffraction patterns. It is performed using a commercial scanning electron microscope (SEM) [4]. This system allows direct determination of the crystallographic orientation of inversion domains in 3C-SiC epitaxial layers. KPFM [5, 6] is a technique used for mapping of surface potential defined as a work function per electron with a setup of tapping mode atomic force microscopy (AFM). The principle of operation is based on a Kelvin probe — a capacitor consisting of a conducting AFM tip and the sample, formed due to moving the tip parallel to the surface. Measurements done using compensation technique give contact potential difference which reflects the surface potential or work function. Topography and potential are measured simulta-

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neously “line by line” and thus allow correlation between morphology and electrical properties.

3. Results and discussion

The variation of C/Si ratio in the function of the growth time and temperature has permitted to receive polytypically homogeneous 3C-SiC epitaxial layers. The EBSD system has been utilized to investigate polytypism in SiC epitaxial layers grown on on-axis substrates. Representative Kikuchi maps by the 3C-SiC islands orientation combinations are presented in Fig. 1. Indexing of the specific crystallographic planes at Kikuchi band intersections are marked on the picture. Each orientation is rotated ≈ 60° about the [111] axis relative to other based on the Kikuchi patterns.

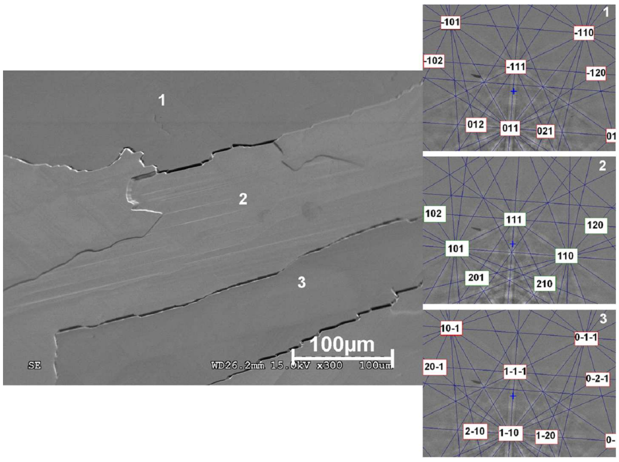

Fig. 1. Diffraction patterns obtained by EBSD for 3C-SiC epitaxial layer on on-axis 4H-SiC substrate.

The KPFM measurements revealed details of two kinds of potential contrast observed for the doped 3C-SiC epitaxial layers: one related to the atomic steps (Fig. 2b,d) and the other related to the triangle 3C-SiC islands boundaries (Fig. 3b). The results of topography (AFM) and surface potential (KPFM) for 3C-SiC n-type and p-type epilayers are presented in Fig. 2. In the case of the potential on the atomic steps the doping differences are revealed by surface potential measurements by KPFM. The light steps (Fig. 2b) (higher value of measured potential) correspond to lower value of the work function characteristic of n-type samples. The contrast is consistently reversed for the p-type sample (Fig. 2d).

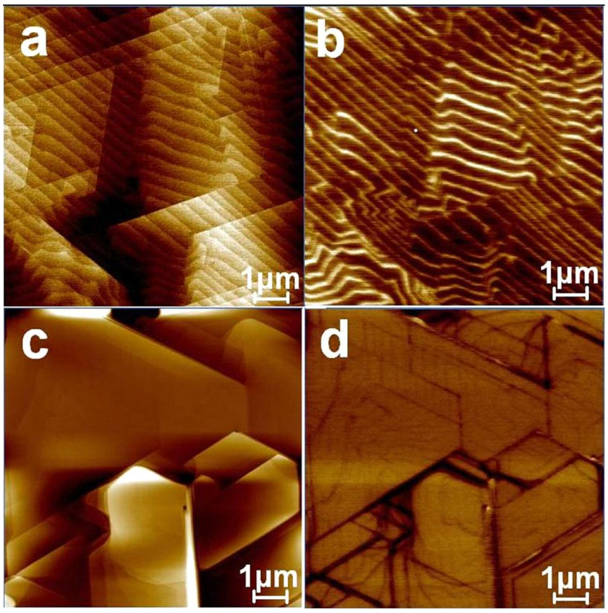

Fig. 2. The 3C-SiC epitaxial layers images of different n-type (a,b) and p-type (c,d) conductivity measured by (a), (c) tapping mode (Z range correspondingly 2 nm and 50 nm) and (b), (d) Kelvin probe (Z range 0.1 V) force microscopy.

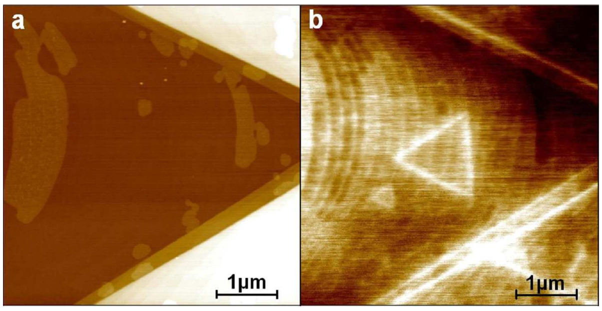

Fig. 3. The n-type 3C-SiC epitaxial layer images measured by (a) tapping mode (Z range 40 nm) and (b) Kelvin probe (Z range 0.1 V) force microscopy.

The higher nitrogen concentration was observed in triangular substructure of 3C-SiC epitaxial layers. Triangular features are clearly discernible by KPFM (Fig. 3b) but not all of them on AFM-TM (tapping mode — Fig. 3a) topography imagines. These triangular features get higher surface potential contrast on epitaxial layers with higher nitrogen concentration. The district light lines (equilateral triangle) are suspected to arise from partial dislocations bounding triangular stacking faults [7] or from the double position boundaries (DPBs) — twins.

4. Conclusions

EBSD and KPFM proved to be valuable characterization tools for non-destructive investigations of the polytype structure and morphological properties of 3C-SiC epitaxial layers. Various SiC polytypes could be identified and indexed by EBSD. Various SiC epitaxial layers surface could be resolved by AFM-TM, their surface potential related to the substructure by KPFM. The different doping of epitaxial layers surface potential measurements influenced contrast in the surface potential. This contrast could be explained in terms of of the segregation of impurities at atomic steps and block boundaries.

Acknowledgments

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