Approach of enhancing the crystal perfection in subsurface layer of *epi-ready* ($\bar{2}01$) β-Ga_2O_3 substrates

P.N. Butenko[1,2*], M.E. Boiko[1], M.D. Sharkov[1], A.V. Almaev[2], L.I. Guzilova[1], V.M. Krymov[1], A.A. Zarichny[1,3], V.I. Nikolaev[1]
*pavel.butenko@mail.ioffe.ru
[1] Ioffe Institute, 194021 Saint Petersburg, Russia
[2] Tomsk State University, 634050 Tomsk, Russia
[3] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

Metal-oxide-semiconductors (MOS) are being actively studied as the candidates for the development of novel semiconductor devices. β-Ga_2O_3 is one of the most promising materials of this class, has ultra-wide-band-gap (E_g=4.8eV), high breakdown field, high dielectric constant, high carrier mobility and as a result, a high Baliga figure of merit (BFOM) exceeding that of Si, SiC, GaN. Nowadays we see activity in research and development of bulk gallium oxide-based devices: metal-oxide-semiconductors field-effect transistors (MOSFETs), modulation-doped field-effect transistors (MODFETs), fin-array field-effect transistors (finFETs) and Schottky barrier diodes (SBD). In all of them, Ga_2O_3 acts as a substrate. However, the high density of structural defects and the limited crystal perfection of β-Ga_2O_3 crystals restrain the development of gallium oxide electronics.

We report a new technique for improving the crystal perfection of ($\bar{2}01$) β-Ga_2O_3 substrates. They were cut out from the *epi-ready* commercial 650μm-thick 2-inch single-crystal wafer as 5mm x 6mm rectangular samples. The region of the substrate was investigated in vicinity of 1000 μm from the cutting lines.

X-ray diffraction (XRD) study of the initial substrates in the θ-2θ mode revealed the splitting of the curves, indicating thus the presence of a disorientated block structure withing the sample and consequently, existence of nonstoichiometric phases. XRD ω-scanning showed a non-Gaussian-like shape being a characteristic of slightly disordered mosaic (1 arcmin discrepancy of block orientation). Using selective wet etching, we found an increase in the density of etch pits by 6 times as we approach the edge of the substrate at a distance of 1000 μm.

By selecting modes for combining thermal annealing with selective wet etching we have found the optimal one. The best result was achieved upon annealing at 1100°C for 11h in air and subsequent etching at 250°C for 10 min in (85%wt.) H_3PO_4. This procedure led to changes in the surface relief towards to its homogenization. Neither θ-2θ curves nor ω-scanning ones contained any splitting or non-Gaussian broadening around all the $\bar{2}01$-fold reflections.

The improvement can be explained, firstly, by the mobilization of the defect structure of the substrate subsurface layers by means of annealing at temperatures close to dissociation ones. Secondly, due to removal of the upper part of the substrate subsurface layer, predominantly mechanically initiated defects are annihilated. These structural defects were acquired by the substrate at the stages of post-growth processing and cutting and are more mobile than growth ones.

Thus, a reduction in the number of etch pits, indicates a decrease in the number of structural defects coupled with their redistribution. This fact is accompanied by non-stoichiometric phases disappearance and enhancing crystal perfection.