β-Ga_2O_3 microtube and nanomembrane fabrication by Cr implantation

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Monoclinic gallium oxide, β-Ga_2O_3, has recently gathered a renewed interest from the science and industry communities alike, due to its potential as a semiconductor for future applications. This material is particularly well-suited for transparent devices due to its wide bandgap of ~4.9 eV at room temperature, and for power electronics, thanks to its high breakdown electric field of 8 MV/cm, which makes it highly attractive for energy-efficient devices and power savings. Additionally, one of the key mechanical properties of this semiconductor is the (100) easy-cleavage plane, which allows thin flakes to be produced by conventional mechanical exfoliation techniques.

In this work, we propose and comprehensively explore a novel method based on ion implantation in (100)-oriented β-Ga_2O_3 single-crystals to produce microtubes and nanomembranes. In particular, the implantation-induced stress/strain profiles promote the rolling-up of a thin surface layer, thus creating a microtube. The unrolling of the microtubes can be triggered by thermal annealing, forming nanomembranes with bulk-like crystalline quality. Compared with traditional exfoliation methods, this method profits from improved reproducibility and control of parameters such as the membrane thickness. Being based on ion implantation, this method allows the optical, magnetic or electrical properties to be enhanced during the membrane production step, which can be tailored to the envisaged application. Moreover, this process contributes to savings of critical raw materials, namely gallium, allowing a large number of nanomembranes to be produced out of a single crystal which can then be transferred to a more abundant substrate such as silicon for device processing.

In short, this work encompasses a detailed study of β-Ga_2O_3 samples implanted with different Cr fluences, and combines experimental techniques such as X-Ray Diffraction, Rutherford Backscattering Spectrometry in the Channelling Mode and Positron Annihilation Spectroscopy with Molecular Dynamics simulations. The excellent consistency between both approaches allowed the defect profiles and subsequent stress/strain fields to be probed and correlated with the anisotropic nature of the monoclinic system in order to explain the physical processes leading to exfoliation.

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