High-quality AlN grown on nano-patterned sapphire substrates prepared by nano-imprint lithography

Peking University researchers have recently greatly improved the quality of heteroepitaxial AlN films by using nano-patterned sapphire substrates prepared by nano-imprint lithography.

Researchers from China's Peking University (PKU) have demonstrated high-quality aluminium nitride (AlN) grown on nano-patterned sapphire substrate (NPSS) prepared by nano-imprint lithography. Due to the application of NPSS and matched strategy for controlling threading dislocation density (TDD), the crystalline quality of AlN grown on sapphire has been greatly improved [L. S. Zhang, F. J. Xu, B. Shen, et al, Sci. Rep. 6, 35934 (2016)]. The best x-ray diffraction ω-scan full width at half maximum values for (0002) and (10$\bar{1}$2) reflections are 171 and 205 arcsec, respectively, and the calculated TDD is below 4×10^8cm^{-2}. Besides, by further balancing size of the pattern and lateral growth rate of AlN during epitaxy, an atomically flat surface with a root mean square (RMS) roughness of 0.096nm and straight and parallel steps were obtained, and the coalescence thickness was controlled to be less than 3μm (as shown in Figure 1).

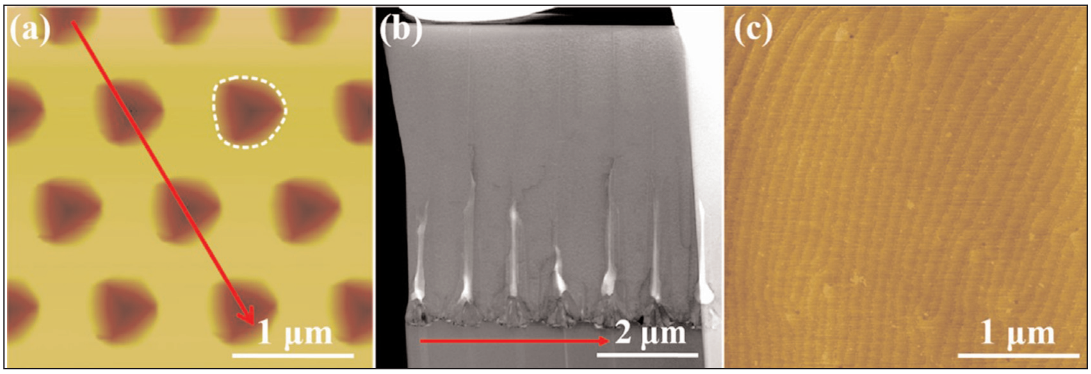

Figure 1. (a) AFM image of a typical NPSS (3mm x 3mm). (b) Cross-sectional STEM image for this chosen sample, fabricated by focused ion beam. (c) Typical AFM image of the surface morphology of the AlN sample on NPSS with 650nm hole patterns (3mm x 3 mm).

The PKU team believes this technique is promising. Although many techniques have been proposed to reduce the TDD of AlN grown on sapphire, a reliable method for obtaining AlN with TDD of the order of 10^8cm^{-2} is still scarce. The need for qualified AlN templates is urgent for research and volume production of deep ultraviolet (DUV) optoelectronic devices. The PKU team therefore developed this convenient technique for high-quality AlN epitaxy, including the NPSS fabrication process and matched

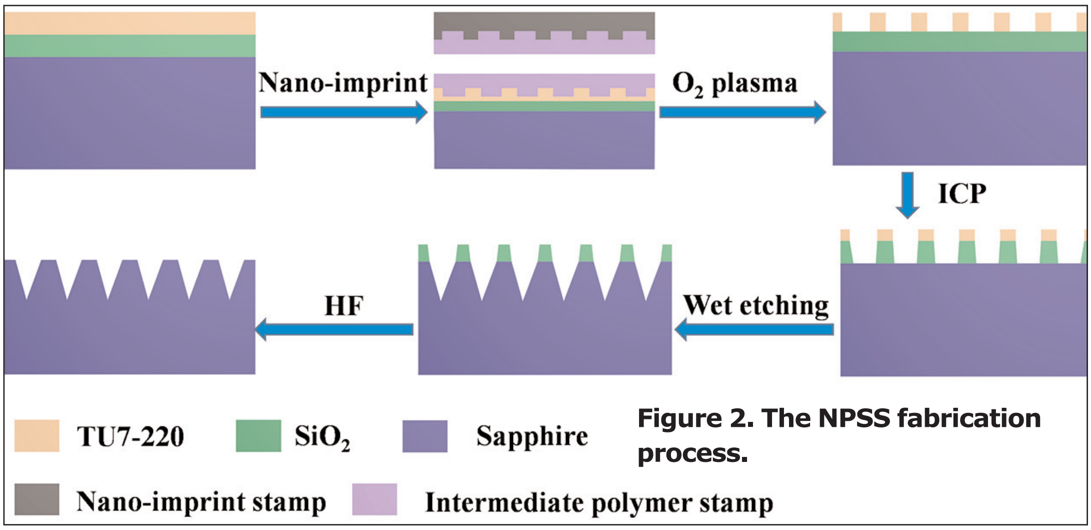

Figure 2. The NPSS fabrication process.

strategy for defect control on NPSS.

The NPSS fabrication process is illustrated in Figure 2. Stabilization and modification of the process can be ensured by benefiting from the mutual technologies of nano-imprint lithography, plasma-enhanced chemical vapor deposition (PECVD) and inductively coupled plasma (ICP).

During AlN epitaxy on the NPSS, the researchers found that there were three main competing processes influencing the TDD (shown schematically in Figure 3). The first is process A, where a large number of TDs are generated at the AlN/sapphire interface due to the large lattice mismatch. The second is process B, where TDs near the voids tend to bend towards the void side-walls driven by the image force, which can effectively decrease the TDs on the mesa regions. The third is process C, where some TDs are generated around the boundaries during coalescence caused by misorientations between the adjacent regions. When width of the growth mesa is decreased, process B will gradually become the dominant one and nearly all of the TDs originating from process A can be eliminated. In this case, the TDD in the AlN epilayers is mainly determined by the dislocation generation in process C. As such, a strategy for decreasing the TDD of AlN grown on NPSS is proposed, which means suppressing TDs from process A via process B with the optimized pattern size, and then decreasing TDs in process C. These suggest that, to gain a deeper insight into the role of NPSS in AlN epitaxy, both the effect of image force and impact of misorientations should be taken into account. In particular, process C had better be accomplished adopting a low lateral growth rate to avoid large misorientation and dislocation generation.

Ideally, almost all of the TDs in AlN grown on this NPSS locate above the hole patterns on the substrate, as shown schematically in Figure 4(a). The white discs represent regions with high TDD and the black dots represent dislocation outcrops. In order to verify how reasonable the schematic model is, the AlN grown on NPSS is characterized by wet etching in molten KOH/NaOH. The AFM images in Figure 4(b) and (c) show the post-etch surface morphologies of AlN. The relationship in relative position between Figure 4(c) and the simplified outlines of holes on the NPSS is determined according to the reference edge of the sapphire, as shown in Figure 4(d). As illustrated in Figure 4(d), most of the TDs are distributed in the outlines, which is only 38% of the total area of the substrate. This distribution feature of TDs roughly corresponds to the schematic model.

The great advantage of this technology is that not only can it improve the crystalline quality of the AlN drastically but it also will benefit the light extraction efficiency of DUV light-emitting diodes (LEDs) in the long term. ■

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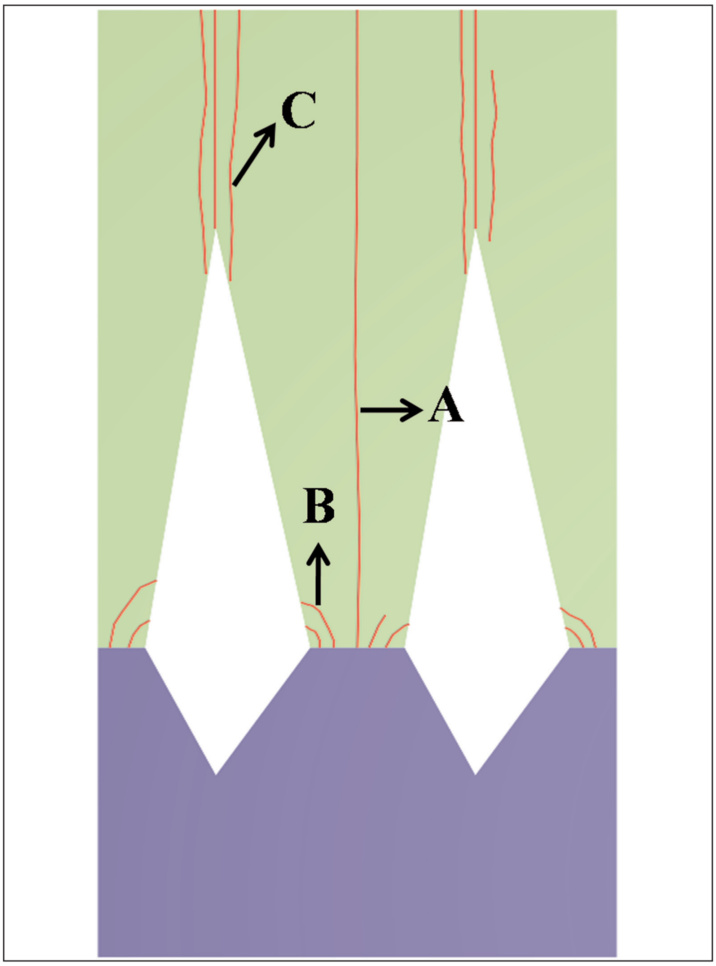

Figure 3. The three main competing processes influencing the TDD in AlN epilayers on NPSS.

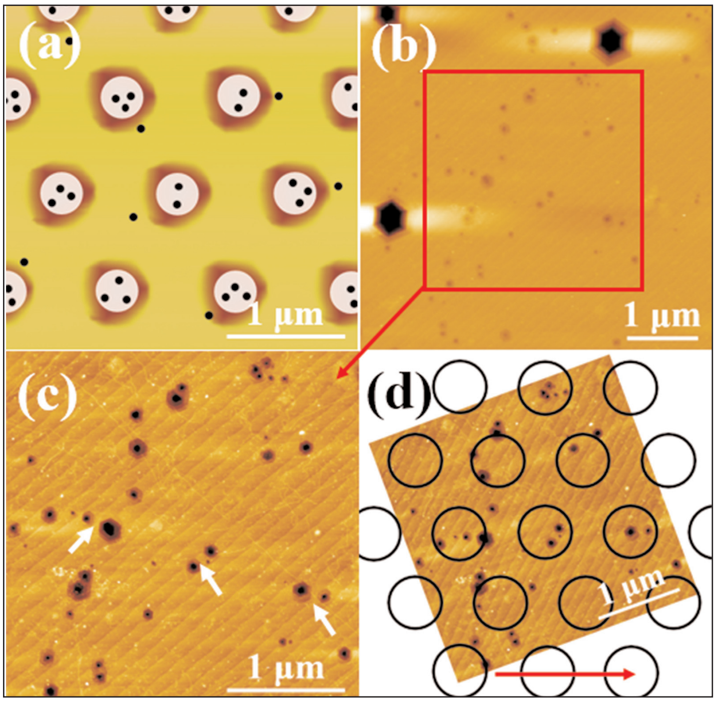

Figure 4. (a) Schematic of dislocation distribution above the NPSS. AFM images of the post-wet-etch AlN (b) in 5μm x 5μm, (c) in 3μm x 3μm. (d) Relationship between the positions of etching pits with the hole type patterns on the NPSS.