E-beam nanopatterning for the selective area growth of III-V nitride nanorods

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GaN/InGaN nanorods have attracted much scientific interest during the last decade because of their unique optical and electrical properties [1,2]. The high crystal quality and the absence of extended defects make them ideal candidates for the fabrication of high efficiency opto-electronic devices such as nano-photodetectors, light-emitting diodes, and solar cells [1-3]. Nitrides nanorods are commonly grown in the self-assembled mode by plasma-assisted molecular beam epitaxy (MBE) [4]. However, self-assembled nanorods are characterized by inhomogeneous heights and diameters, which render the device processing very difficult and negatively affect the electronic transport properties of the final device. For this reason, the selective area growth (SAG) mode has been proposed, where the nanorods preferentially grow on pre-defined sites on a pre-patterned substrate [5].

Surface pre-patterning can be achieved by e-beam lithography (EBL), colloidal lithography, or focused ion beam. In this work, we present substrate nanopatterning results using EBL followed by dry etch to pre-pattern a metal mask on GaN substrate with ordered arrays of nanoholes. We find EBL one of the most promising substrate nanopatterning techniques because of the highest ordering that can be achieved over areas of hundreds of micron, with high versatility and extreme reproducibility. By varying the e-beam exposure parameters (current, time), the thickness of the photoresist, and the etching recipe/time, we could achieve final masks with densely packed and highly ordered nanoholes with diameter down to 30 nm and pitch (center-to-center distance) down to 100 nm (Figures 1 and 3). Subsequent MBE growth on these patterned masks shows perfectly ordered GaN/InGaN nanorods that nucleate and grow with 100% selectivity inside the nanoholes, independently of the particular mask geometry (Figures 2 and 4). These nanorods exhibit perfect hexagonal cross section and periodicity (Figure 4). TEM analysis of these nanorods shows optimal crystal quality and absence of extended defects, proving that the nanohole patterning process was ideal. Finally, we advice on the main critical issues that might occur in the mask nano-patterning, mainly the presence of residues either from the etch process (etched material) or from the post etch residue removal (plasma-hardened photoresist), or both.

In summary, we demonstrate that specific and optimized e-beam processes can produce high quality nano-patterned masks with extreme resolution and reproducibility. These qualities, and the high ordering and periodicity over large areas, make these masks suitable for the fabrication of high efficiency devices based on nano-structured nitride materials.

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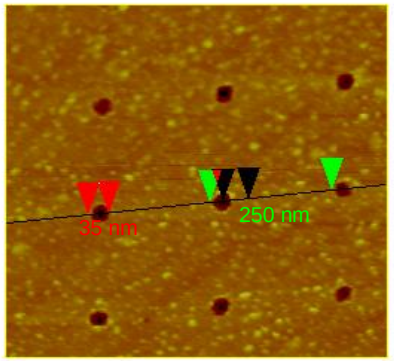

Figure 1. AFM image of typical nanoholes obtained by EBL on a titanium mask on GaN. Holes diameter: 35 nm; pitch: 250 nm.

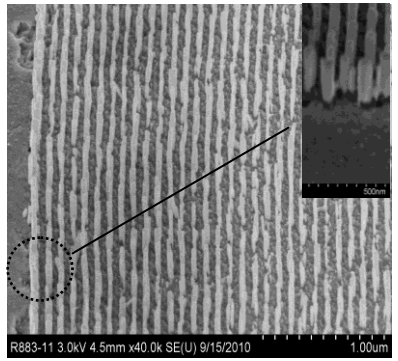

Figure 2. HR-SEM pictures of ordered arrays of GaN nanorods grown by MBE on the mask in Figure 1. Inset: zoom of the area in the circle.

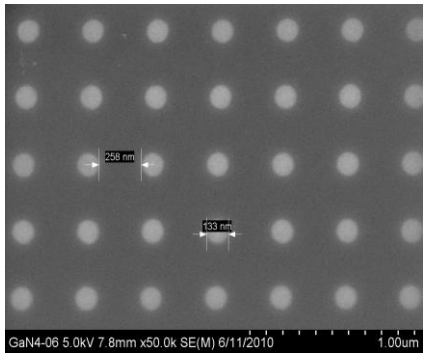

Figure 3. HR-SEM image of large nanoholes obtained by EBL on a titanium mask on GaN. Holes diameter: 130 nm; hole-to-hole distance: 250 nm.

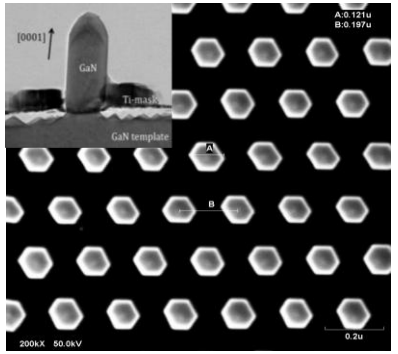

Figure 4. SEM top-view of the GaN nanorods grown on the mask in Figure 3, showing the typical hexagonal section. Inset: TEM image of a single nanorod displaying the high crystal quality.