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GaN nanostructuring for the fabrication of thin membranes and emerging applications

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Abstract: We present a review of technological methods developed in recent years for the purpose of gallium nitride nanostructuring, with the main focus on fabrication of thin GaN membranes. In particular, we report on traditional methods of wet etching undercutting for membrane manufacturing, technologies applied for the fabrication of photonic crystal structures based on GaN nanomembranes, double side processing, and surface charge lithography. Prospects of membrane applications in photonic devices, sensors, and microoptoelectromechanical and nanoelectromechanical systems are discussed, taking into account the advantageous piezoelectric, optical, and mechanical properties of GaN and related III–V nitride materials.

Key words: GaN nanomembranes, wet etching, photoelectrochemical etching, dry etching, liftoff techniques, e-beam lithography, surface charge lithography, photonic crystal membrane nanocavities, sensors

1. Introduction

Gallium nitride is currently considered one of the most important semiconductor materials for practical applications. GaN and related III-nitride compounds are nowadays widely used in the fabrication of short-wavelength light-emitting devices [1–4] and heterostructure field-effect transistors (HFETs) for high-frequency/high-power applications [4–7]. More sophisticated devices like blue vertical cavity surface emitting lasers (VCSELs) may find implementation in high-resolution printing and bio-sampling [8,9]. Recently, III-nitride–based blue vertical cavity surface emitting lasers using defect-free highly reflective AlInN/GaN distributed Bragg reflectors grown on c-plane free-standing GaN substrates have been demonstrated [10]. Lasing was achieved at room temperature under pulsed electrical injection.

Apart from these traditional applications, 2 new fields of applications are under development for the III-nitride group of materials. The first one is related to photonic crystals (PCs), which have been studied and applied to active optoelectronic devices including light emitting diodes (LEDs) and PC lasers [11,12]. The PC defect lasers employing the photonic bandgap effect could confine the photons in the defect nanocavities with a thin membrane suspended in the air and achieve a high quality factor with a small mode volume [13]. The realization of optical cavities presenting a high quality factor and a small mode volume is of major interest for the observation of cavity quantum electrodynamics effects in solid-state systems and the realization of novel photonic devices such as thresholdless lasers and single photon emitters. Previously, the PC defect lasers were commonly realized in GaAs- or InP-based material systems because the suspended thin membrane structure, which is

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