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The impact of nanoperforation on persistent photoconductivity and optical quenching effects in suspended GaN nanomembranes

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We report on fabrication of suspended ~15 nm thick GaN membranes nanoperforated in an ordered fashion using direct writing of negative charges by focused ion beam and subsequent photoelectrochemical etching of GaN epilayers. Both continuous and nanoperforated membranes exhibit persistent photoconductivity (PPC), which can be optically quenched under excitation by 546 nm radiation. Optical quenching of PPC occurs also under relatively intense intrinsic excitation of nanoperforated membranes by 355 nm radiation at $T < 100$ K. The proposed explanation is based on strong surface localization of charge carriers in nanoperforated membranes and UV-induced reactions occurring at surface states under intense intrinsic excitation. © *2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4847735]

Due to its advantageous properties such as wide bandgap and pronounced chemical and thermal stability, III-V nitrides are currently considered as one of the most important semiconductor compounds for practical applications. They are nowadays widely used for fabrication of short-wavelength light-emitting devices and heterostructure field-effect transistors for high-frequency/high-power applications.[1] Another emergent field of applications is related to fabrication and implementation of microelectromechanical, microoptoelectromechanical, and nanoelectromechanical systems.[2] Müller *et al.*[3] fabricated 500 nm thick membranes mechanically strong enough to support thin-film bulk acoustic resonator (FBAR) structures for frequencies up to 6.3 GHz with a very high quality factor. It is important to note that novel applications of GaN-based resonator structures require ultrathin membranes with thicknesses in the sub-100 nm or even in the sub-10 nm range. A decrease of the resonator structure thickness is needed to achieve an increase of the resonance frequency. Thus, GaN ultrathin membranes can serve as an excellent solution for increasing the resonance frequency of FBAR filters. Besides, a rise of the operating frequency is also important for FBAR based sensors, as their sensitivity is proportional to the square of the resonance frequency.[4]

The realization of reliable ultrathin GaN membranes with designable nanoarchitecture still remains a major technological challenge. III-nitride based materials suffer from several processing difficulties induced by their intrinsic properties. Due to the high chemical stability of GaN, its nanostructuring is usually based on inductively coupled plasma reactive ion etching (ICP-RIE) through lithographically opened windows. Electron beam lithography and dry etching techniques including focused-ion beam milling employed to pattern the GaN layer and to fabricate suspended thin membranes through wet etching of sacrificial films are rather expensive, and are generally not suitable for achieving veritable ultrathin membranes. Recently,[5] the formation of GaN nanomembranes providing a thickness of 200 nm was demonstrated through the coalescence of buried cavities during high-temperature annealing of nanoporous GaN prepared using electrochemical etching techniques. However, this approach is likewise not suitable for manufacturing ultrathin membranes.

In recent years, we have proposed and developed a cost-effective technology for GaN micro- and nano-structuring, the so-called surface charge lithography (SCL),[6,7] which opened wide possibilities for a controlled fabrication of GaN ultrathin membranes.[8–10] SCL is a maskless approach based on direct writing of negative charges on the surface of a semiconductor by a focused ion beam. These charges shield the material against photoelectrochemical (PEC) etching. Ultrathin GaN membranes suspended on specially designed GaN micro- and nano-structures have been fabricated using a technological route based on SCL with two selected doses of ion beam treatment.[10] In this paper, we demonstrate the applicability of SCL for the fabrication of nanoperforated GaN ultrathin membranes with a regular arrangement of holes. Along with this, we present the results of a comparative analysis of persistent photoconductivity and optical quenching (OQ) effects occurring in continuous and nanoperforated ultrathin GaN suspended membranes, and assess the mechanism behind these phenomena.

The wurtzite n-GaN samples were grown by metal–organic vapor phase epitaxy (MOVPE) in a Thomas Swan $3\times2''$ vertical closed coupled showerhead reactor.

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