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ELECTRICAL PRECISION
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# Application of Surface Charge Lithography to Nanostructuring of GaN Epilayers[1]

**V. Iu. Popa[a], O. Volciuc[a], I. M. Tiginyanu[a], A. Sarua[b], and P. Heard[b]**

[a] *National Center for Materials Study and Testing, Technical University of Moldova, bulv. Stefan cel Mare 168, Chisinau, MD-2004 Republic of Moldova*

*Institute of Applied Physics, Academy of Sciences of Moldova, ul. Academiei 5, Chisinau, MD-2028 Republic of Moldova*

[b] *H.H. Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol, BS81TL United Kingdom*

*e-mail: popa_sl@yahoo.com*

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**Abstract**—It is shown that treatment of GaN epilayers by a low energy low dose focused ion beam with subsequent photoelectrochemical etching represent an efficient tool for GaN nanostructuring. Direct "writing" of a surface negative charge trapped by radiation defects allows one to fabricate thin GaN walls with a thickness as low as 100 nm using focused ion beam treatment. The obtained results show that the undercut etching inherent to GaN etching through windows defined by surface charge lithography depends on the depletion length in the doped GaN material and does not occur in the structures below a critical size of 200 nm in our case.

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## INTRODUCTION

Recently, we demonstrated that low-energy $Ar^+$ ion beam treatment of n-GaN epilayers with subsequent photoelectrochemical etching (PEC) in an aqueous solution of KOH can be used for material microstructuring [1]. The low-energy ion beam treatment creates surface defects that trap electrons, thus generating a surface layer of negative charge. The ion-beam-induced surface layer of trapped negative charge shields the GaN against PEC etching. The new approach is called surface charge lithography (SCL), taking into account the possibility to design and exploit the surface charge trapped by ion-beam-induced radiation defects as a lithographic mask for the purpose of manufacturing GaN mesostructures [1]. We found that the mesostructures fabricated by using ion beam treatment with subsequent PEC etching of n-GaN epilayers exhibit an undercut of about 200 nm determined by the hole diffusion length [1]. The reason is that, due to lateral diffusion of minority carriers, partial etching occurs under the mask, which is the top area damaged by the ion beam. The undercut etching made questionable the ability to fabricate GaN mesostructures with transverse dimensions less then the hole diffusion length. In this work, we demonstrate the possibility to fabricate GaN nanowalls with transverse dimensions as low as 100 nm using direct "writing" of protective masks by a focused ion beam (FIB) with subsequent subjection of the samples to photoelectrochemical etching in an aqueous solution of KOH.

[1] The text was submitted by the authors in English.

## EXPERIMENT

The GaN layers used in our experiments were grown by low-pressure metalorganic chemical-vapor deposition (MOCVD) on (0001) c-sapphire. A buffer layer of about 25-nm-thick GaN was first grown at 510°C. Subsequently, a 0.5-μm-thick n-GaN film followed by an Si-doped $n^+$-GaN film and a top n-GaN layer with a 2.0 μm thickness each were grown at 1100°C. The concentration of free electrons in the top n-GaN layer was $1.7 \times 10^{17}$ cm$^{-3}$, while the density of the threading dislocations was in the range of $10^9$–$10^{10}$ cm$^{-2}$.

An FEI Strata FIB 201 focused ion beam system was used for exposure of the gallium nitride samples. This instrument produces a focused gallium ion beam of 30 keV energy with beam currents in the range of 1 pA to 12 nA and corresponding beam diameters of 8 nm to 500 nm. For the exposure of the gallium nitride here, a beam current of 150 pA was used. The exposure pattern was created in a bitmap form with a 1024 × 1024 pixel format covering an area of 122 μm square on the sample. An exposure time of 1 μs per pixel gave a total exposure time for the pattern of 0.48 s and a corresponding exposure dose of $6.6 \times 10^{12}$ cm$^{-2}$. Stopping range calculations predict the main projection range of the Ga ions in the GaN layer at about 14 nm under these conditions.

PEC etching was carried out in a stirred 0.1 mol aqueous solution of KOH under in situ UV illumination provided by focusing the radiation of a 350 W Hg lamp on a spot about 5 mm in diameter on the GaN surface exposed to the electrolyte. No bias was applied to the sample during the etching. The morphology of the