Cathodoluminescence microscopy and spectroscopy of GaN epilayers microstructured using surface charge lithography

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Cathodoluminescence (CL) microscopy and spectroscopy have been used to investigate the optical properties of GaN microstructures patterned by Ar^+ ion irradiation and subsequent photoelectrochemical (PEC) etching. Monochromatic CL images and CL spectra reveal an enhancement of several defect-related emission bands in a 10 μm wide area around each microstructure. In addition, columnar nanostructures and nanoetch pits were found in the PEC etched areas. CL emission of the nanocolumns is dominated by free electron to acceptor transitions, while excitonic luminescence prevails in the rest of the etched GaN layers. Investigation of the sidewalls of the microstructures reveals that a CL emission band centered at about 3.41 eV, attributed to excitons bound to structural defects, is effectively suppressed after PEC etching only in the observed nanocolumns. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2214210]

I. INTRODUCTION

GaN and related ternary alloys are important wide band gap semiconductors for a broad range of applications as high-frequency/high-temperature electronics and visible and ultraviolet emitters and detectors. Further improvement in device performance hinges on several factors, including understanding and reduction of point and extended defects and the development of micro- and nanoscale patterning techniques. Etching of these materials, which is an important process for the fabrication of optimal device structures, is difficult due to their chemical inertness. However, photoelectrochemical (PEC) etching, encompassing light-induced electrochemical reactions of semiconductors in contact with liquids, has been shown to be capable of rapid,[1] dislocation-selective,[2] dopant-selective,[3] or band-gap-selective[4] etchings of GaN and related ternary compounds. In addition, different kinds of nanostructures, such as nanowires and nanocolumns, have been fabricated by PEC etching of thin GaN films and related to the dislocation structure of the samples.[5]

The observation that mechanical damage inhibited the PEC etching of GaAs, led Yamamoto and Yano[6] to pattern the surface of *n*-GaAs wafers for selective material removal with the damage induced by ion bombardment. Such damage inhibited subsequent PEC etching by enhancing the recombination rate of the photogenerated holes in the irradiated areas. The method was then extended to pattern *n*-type GaAs, InP, InGaAs, and InGaAsP by direct writing with a focused ion beam.[7–9] Recently, fabrication of GaN microstructures following a similar approach has been reported.[10] Defects created at the surface of *n*-type GaN films using an Ar ion beam lead to the formation of a layer of trapped negative surface charge shielding the material against PEC etching. This surface charge can be exploited as a lithographic mask for cost-effective manufacturing of GaN microstructures.

In the present work, cathodoluminescence (CL) in the scanning electron microscope (SEM) has been applied to investigate the effects of irradiation and subsequent PEC etching processes in the optical and structural properties of undoped GaN films. CL measurements reveal that the effects of irradiation extend to a 10 μm wide region that surrounds the microstructures patterned following the procedure described above. Furthermore, a direct correlation between the morphology and the radiative recombination properties of individual nanostructures created after PEC etching in such region has also been established.

II. EXPERIMENT

GaN layers used were grown by low-pressure metalorganic chemical vapor deposition (MOCVD) on sapphire substrates. A buffer layer of 20 nm thick GaN was first grown at 510 °C. Subsequently, a 2 μm thick, nominally undoped, top GaN layer was grown at 1100 °C. The concentration of free electrons in the top layer was 1.8×10^{17} cm^{-3}. Selected areas of the samples were irradiated using 2 keV Ar^+ ions at a fluence of 3×10^{12} cm^{-2}. PEC etching was carried out in a stirred 0.1 M aqueous solution of KOH for 10 min under *in situ* ultraviolet illumination provided by a 200 W Xe lamp focused on the GaN surface exposed to the electrolyte. No bias was applied to the sample during etching.

The morphology of the samples was studied using a Leica 440 Stereoscan SEM or a Jeol JSM-6335F field emission SEM (FSEM). CL investigations were carried out in a

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