The Role of Alternating Current in Photo-Assisted Electrochemical Porosification of GaN

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Abstract -- **In this paper, we report the formation of porous GaN films under a novel alternating current (sine-wave a.c. (50 Hz)) photo-assisted electrochemical (ACPEC) etching conditions. The ACPEC formed porous GaN with excellent structural and surface morphology. Field emission scanning electron microscope (FESEM), atomic force microscopy (AFM) and high resolution X-ray diffraction (HR-XRD) phi-scan and rocking curves measurements evidenced important features of the pore morphology and nanostructures. According to the FESEM micrographs, the spatial nanoarchitecture of the porous structures exhibits pores with perfect hexagonal shape. The AFM measurements revealed an increase in the surface roughness induced by porosification. X-ray diffraction phi-scan showed that porous GaN sample maintained the epitaxial features.**

Index Terms -- **Porous GaN, Alternating current photo-assisted electrochemical etching (ACPEC), FESEM, AFM, HR-XRD.**

I. INTRODUCTION

The wide band gap semiconductor GaN and related materials have received increasing attention in recent years due to their potential applications for optoelectronic devices operating in the spectral region from the blue to near-UV and in electronic devices such as high temperature, high power and high frequency transistors [1-3]. Note that GaN devices are capable to operate in hostile and harsh environments [4], while GaN nanostructuring induces an increase in the radiation hardness of the material [5]. Additionally, GaN has emerged as important material for high power electronics devices owing to its high breakdown field.

Since the unearthing of porous Si shows augmented luminescence efficiency in 1990 [6], initial efforts to make porous GaN were motivated by the desire to realize similar effect with an ultraviolet (UV) band gap material. Porous GaN exhibits high surface area, shift of band gap, luminescence intensity enhancement, as well as efficient photoresponse as compared to bulk. Thus, the expectation is that porous GaN can be tailored to fabricate novel sensing devices.

Porous GaN can be prepared through dry-etching techniques, such as ion milling, chemical-assisted ion beam etching, reactive ion etching, and inductively coupled plasma reactive ion etching. However, these methods could induce surface damage; moreover, they lack the desired selectivity for the morphology, dopant, and composition [7]. The most feasible and cost-effective method to prepare porous GaN is the direct current (dc) photo-assisted electrochemical etching. To gain a high porosity layer, the most common technique is to use dc conditions with a constant and relatively high current density. Although dramatic research has been conducted to understand the formation of porous GaN prepared by the common technique, substantial fundamental properties are still not well understood [8-14].

The goal of this study is to prepare porous GaN by a novel technique, namely by alternating current photo-assisted electrochemical etching (ACPEC) [15]. Results of systematic morphological, structural and surface studies of porous GaN samples are reported.

II. EXPERIMENTAL METHODS

The commercial unintentionally doped (UID) n-type GaN film grown by metalorganic chemical vapor deposition (MOCVD) on a two inch diameter sapphire (0001) substrate was used in the formation of porous GaN by the ACPEC etching techniques. The thickness of GaN film is 3 μm with carrier concentration of ~ 6.05 x 10^{17} cm^{-3} as determined by Hall effect measurements. The ac etching process was performed with a current density of 25 mA/cm2 in 4 % concentration of KOH electrolyte under illumination of 500 W ultra-violet for 45 and 90 minutes etch time. The porous GaN samples were characterized by using FESEM, AFM and HR-XRD.

III. RESULTS AND DISCUSSION

FESEM images of the porous GaN samples generated under different etching durations are shown in Fig. 1. The FESEM images in Fig. 1 show well-defined network of pores with different sizes grown in the monocrystalline epilayer of GaN. The average pore size for 45 and 90 min samples were of about 35-40 and 55-60 nm, respectively. The average pore size varies significantly as a function of the quality of the starting GaN epilayers.

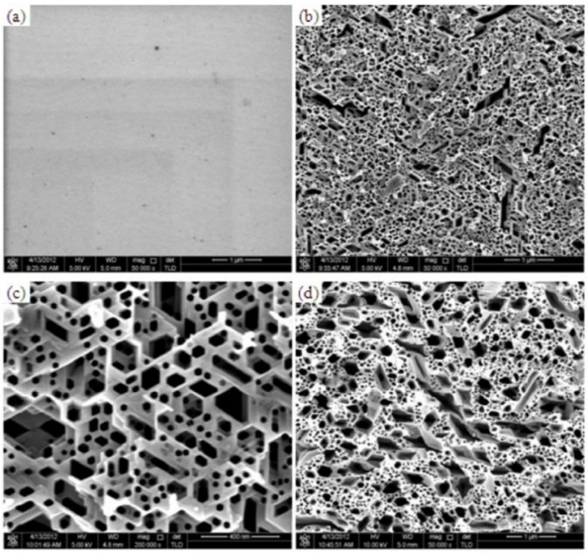

Fig. 1. FESEM image of the as grown and porous GaN formed under different etching durations: (a) as grown; (b) 45 minutes, (c) 45 minutes for high magnification, and (d) 90 minutes [15].

The AFM measurements revealed that the surface roughness over a 5 μm x 5 μm scan area increased in the porous GaN samples. These results were further supported by FESEM images in Fig. 1. The crystalline quality and lattice parameters were assessed and determined by using HR-XRD. The Phi-scan on asymmetric GaN (10$\bar{1}$2) reflection plane showed six-fold azimuthal symmetry for both as-grown and porous GaN samples. Six-fold symmetric is consistent with the wurtzite (hexagonal) crystal structure [16].

IV. CONCLUSION

In summary, a novel, simple and cost-effective alternating current PEC (ACPEC) etching was demonstrated to be an effective technique to form nano-porous GaN with excellent properties. According to FESEM images, the etching duration has significant impact on the size of the pores. AFM measurements evidenced that surface roughness increased in porous samples. The obtained results hint at the possibility to prepare high quality nano-porous GaN layers with tuneable stress. We strongly believe that further refinements of the sine-wave ac electrochemical processing technologies will enhance their role in semiconductor nanotechnology and nanoelectronics in the near future.

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