A Gallium Nitride Distributed Bragg Reflector Cavity for Integrated Photonics Applications

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***Abstract*— A deep etched 1D Distributed Bragg Reflector cavity in GaN-AlN-Sapphire has been analytically modeled and simulated using 2D FDTD. A structure fabricated using a hybrid Electron Beam- Focused Ion Beam method was assessed using microphotoluminescence.**

I. Introduction

Gallium Nitride (GaN) is a promising material system for a number of integrated photonics applications since it is transparent across most of the visible spectrum and can be grown in thin epitaxial layers allowing for integrated photonic component fabrication [1]. Additionally, GaN and its alloys can emit blue/green light and have useful non-linear properties. GaN is widely used in LED and laser applications, but has only recently begun to be assessed as a potential material system for technologies such as Photonic Crystal based circuits and applications [2-4]. A promising area is the use of GaN as a platform for fluorescent and label-free biosensing, where an optical microcavity could enhance the fluorescence from dyes. This paper shows analytic and numerical modelling results for a deep etched 1D DBR cavity and goes on to show a fabricated device using a hybrid E-beam, Focused Ion Beam(FIB) etching process. Finally a micro PhotoLuminescence(PL) study is performed to show that FIB etching has not induced large amounts of excess losses.

II. Analytical Solution and Modeling in FDTD

The Distributed Bragg Reflector shown in Figure 1 was analytically characterized using the Transfer Matrix Method(TMM) with a 1D effective refractive index for the vertical layer structure, the resulting wide stopband is shown in Figure 2. To enable a more accurate model of the structure a 2D Finite Difference Time Domain model was also used [5], with the full cavity structure shown in Figure 1. This will allow for effects such as finite hole depth and non-ideal hole shape to be studied in detail. Figure 2 shows that good agreement is obtained with the simple TMM model, with the slightly lower transmission outside the stopband being caused by diffraction losses that will be accounted for by the FDTD model. Figure 2 also shows the results when a cavity is formed by bringing two DBRs together. Here a resonant wavelength of 676nm is obtained with a Q factor of 356.

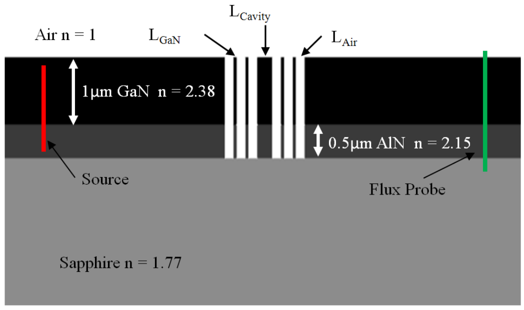

Figure 1. FDTD simulation, LGaN = 67nm, LAir = 159nm, LCavity = 586 nm, FDTD mesh=17nm

It can be seen that the Q factor is unaffected by changing from an etching depth through all layers to etching just to the AlN / Sapphire interface. This is due to the strong confinement of light in the upper GaN layer. The cavity simulated here will need to be modified slightly in order to make it more amenable to nanofabrication by using longer GaN sections in the Air/GaN DBRs. The grating shown is a simple first order case, moving to 3rd order GaN sections will allow easier fabrication, with the penalty of slightly higher diffraction losses and reduced stopband width.

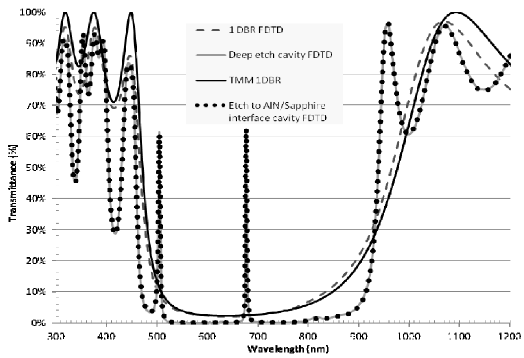

Figure 2. FDTD and analytical transmission plot of Cavity and single 3 period grating

III. FABRICATION AND QUALITY ASSESSMENT

A device based on the above modeling was then fabricated. In order to give lateral as well as vertical confinement to the modes a ridge waveguide was fabricated using Electron Beam lithography and Hydrogen Silsesquioxane (HSQ) resist and BCl3 Inductively Coupled Plasma etching. A typical ridge structure can be seen in Figure 3. The pitting observed in the FIB image is believed to be due to preferential etching of small defects within the GaN and AlN layers and as such we believe these should not be present in the unetched ridge. FIB etching was then used to define the deep etch grating [6] and a current of 70pA was used, the resulting device can be seen in Figure 3. In this initial case a depth of approximately 1µm was achieved. The use of hard metal masks and gas assisted etching will allow much deeper etches to be achieved in future device iterations.

In order to assess quality of the GaN that has been exposed to FIB etching, micro-Photoluminescence(PL) analysis was carried out and results are shown in Figure 4. HeCd 325 nm pumping was used and the results show that there is a small reduction in PL emission from the etched regions and these results suggest that the amount of FIB induced damage could be acceptable here.

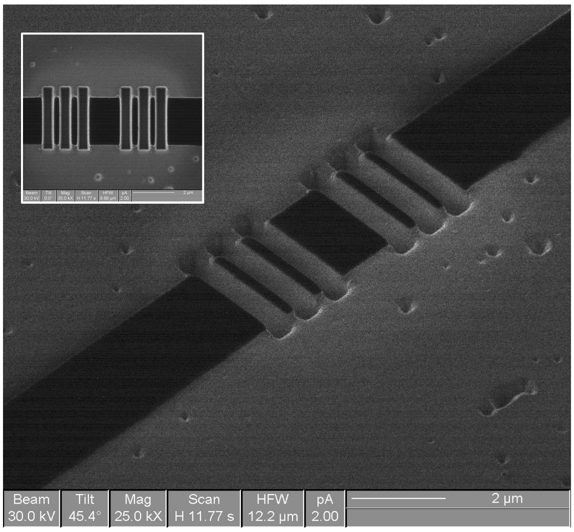

Figure 3. FIB image of grating in ridge waveguide, top view (inset) and tilted sideview

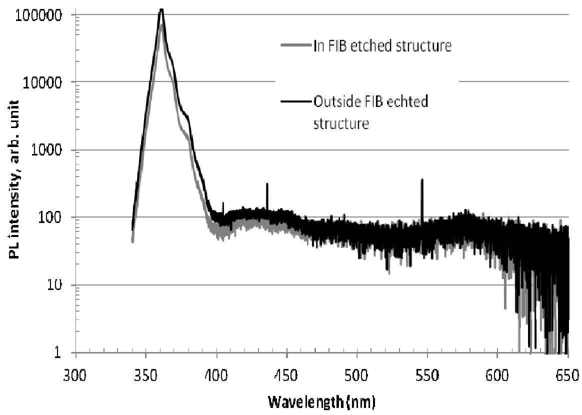

Figure 4. micro-PL analysis of etched and unetched structure

IV. CONCLUSIONS

This paper has presented modeling, fabrication and micro-PL assessment of a deep etched 1D DBR cavity structure. 2D FDTD modeling gives an estimated Q factor of 356 and future work will assess 2D photonic crystal structures which are predicted to allow much higher Q factors. In terms of fabrication, the paper shows a hybrid approach combining E-beam and FIB which allows rapid prototyping of structures embedded in predefined ridge waveguides. FIB induced damage can be an issue and full E-beam based fabrication of devices is being pursued in parallel with this work. These structures will find application in lab-on-a-chip Laser Induced Fluorescence analysis and integrated quantum photonics allowing for the potential integration of blue/green light sources directly on-chip.

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