Pergamon

0038-1101(95)00177-8

Solid-State Electronics Vol. 39, No. 2, pp. 311-313, 1996

0038-1101/96 $15.00 + 0.00

NOTE

GROWTH AND FABRICATION OF GaN–InGaN MICRODISK LASER STRUCTURES

(Received 27 March 1995; in revised form 29 May 1995)

Whispering gallery-mode microdisk lasers have optical modes strongly confined in a direction perpendicular to the quantum wells comprising the disk[1,2]. Various methods have been reported for directional coupling of light output from these lasers, including patterned asymmetries in the shape of the microdisk resonators[3], and use of a double-disk structure[4]. A variety of different materials systems have been utilized to realize these low-threshold devices, including InGaAs/InGaAsP[1–4], InGaAs/InGaP[2], GaAs/AlGaAs[5] and ZnSe/ZnCdSe[6].

There is interest in the use of GaN and related alloys for blue/u.v. emitters and detectors, sparked mainly by the development of highly luminescent light-emitting diodes[7]. To date, the requisite dry and wet etching processes or, indeed, the growth of the necessary InGaN quantum wells have not been available to produce a microdisk structure in the nitrides. In this note we report the growth of a GaN–InGaN multiple quantum well layer structure by metal organic molecular beam epitaxy (MOMBE), and a controlled two-stage etching process for fabrication of a micro-resonator.

The samples were grown on Al_2O_3 substrates in an Intevac Gas-Source Gen II. Figure 1 shows cross-sectional transmission electron micrographs of the entire structure (top) and of the three InGaN (70 Å)/GaN (200 Å) quantum wells (bottom). A low temperature AlN buffer was grown at 425°C for 5 min. The temperature was then raised to 700°C where the rest of the AlN buffer layer was grown at a rate of $0.35\,\mu m\ h^{-1}$. Dimethylethylamine alane and atomic nitrogen from an electron cyclotron resonance (ECR) Wavemat MPDR 610 were used as sources. The MQW layers were grown at 500°C using triethylgallium (TEG), trimethylindium (TMI) and ECR generated N. There is a clear planarizing of the growth front after deposition of the AlN, producing InGaN quantum wells of good structural quality. As expected from the lattice mismatch between AlN and Al_2O_3, there is a high density of stacking faults and dislocations; however, all of the layers are single-crystal as determined by selected area diffraction. The AlN and GaN were insulating for our growth conditions, whereas the InGaN was *n*-type with a carrier concentration of approximately $10^{20}\,cm^{-3}$, as determined from van der Pauw Hall measurements on thicker calibration samples. The InN mole fraction was approximately 0.33. Double crystal X-ray diffraction measurements confirmed that the component layers in the structure were hexagonal in phase.

A schematic illustration of the process sequence is shown in Fig. 2. After lithographically patterning circular photoresist masks, microcylinders are formed by ECR plasma etching at 170°C in a $Cl_2/CH_4/H_2/Ar$ discharge (flow rates of 10, 3, 15 and 10 sccm, respectively) at 1 mTorr pressure and a microwave power of 850 W. Additional r.f. power of 150 W was applied to the sample position to increase the ion energy to approximately 175 eV and thereby improve the etch anisotropy. These conditions produced smooth non-selective etching of all of the nitride layers in the structure, at rates between approximately $1000\,Å\ min^{-1}$ for AlN and $2200\,Å\ min^{-1}$ for GaN. The AlN is then selectively wet etched in AZ400K developer solution for approximately 30 min at 85°C to produce an undercut and leave the InGaN/GaN disk supported on an AlN pedestal. The active ingredient in the developer solution is KOH which etches AlN at a rate of approximately $330\,Å\ min^{-1}$ at 85°C. There was no measurable etching of GaN or InGaN under these conditions. We have found that the AlN wet etch rate is strongly dependent on the crystalline quality of the material, with much higher rates (up to approximately $1\,\mu m\ min^{-1}$ for polycrystalline AlN). Figure 3 shows a SEM micrograph of a typical microdisk after this two-step etching procedure. It is important to note that other layer structures are also feasible, including the use of AlGaN/InGaN quantum wells on a thick GaN buffer. However, there have been no reports of a controlled selective wet etch for GaN with practical rates at this stage.

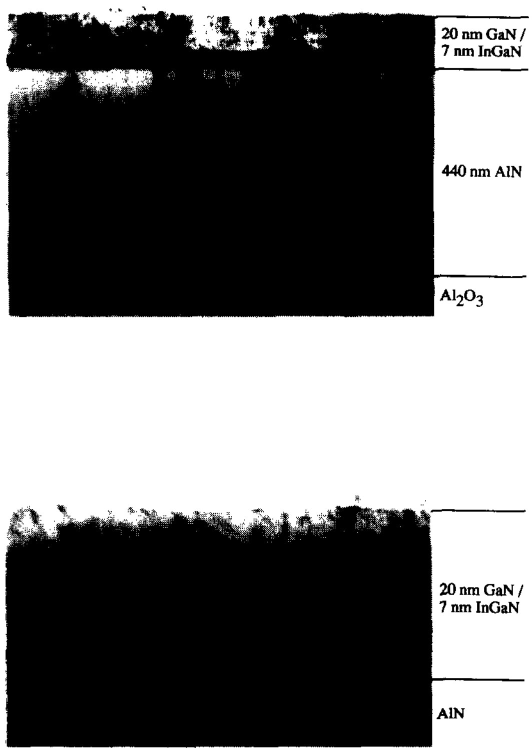

Fig. 1. TEM micrographs of full layer structure (top) and quantum wells (bottom).

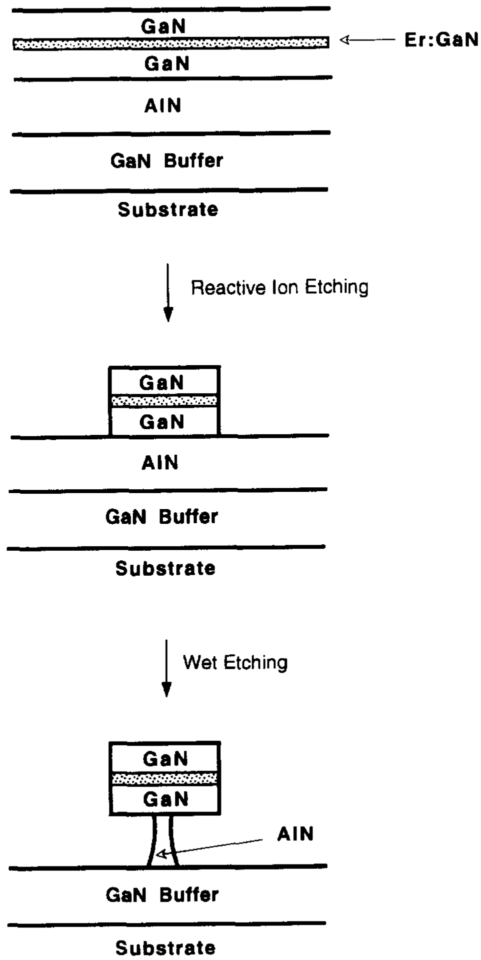

Fig. 2. Schematic diagram of process sequence for microdisk structure.

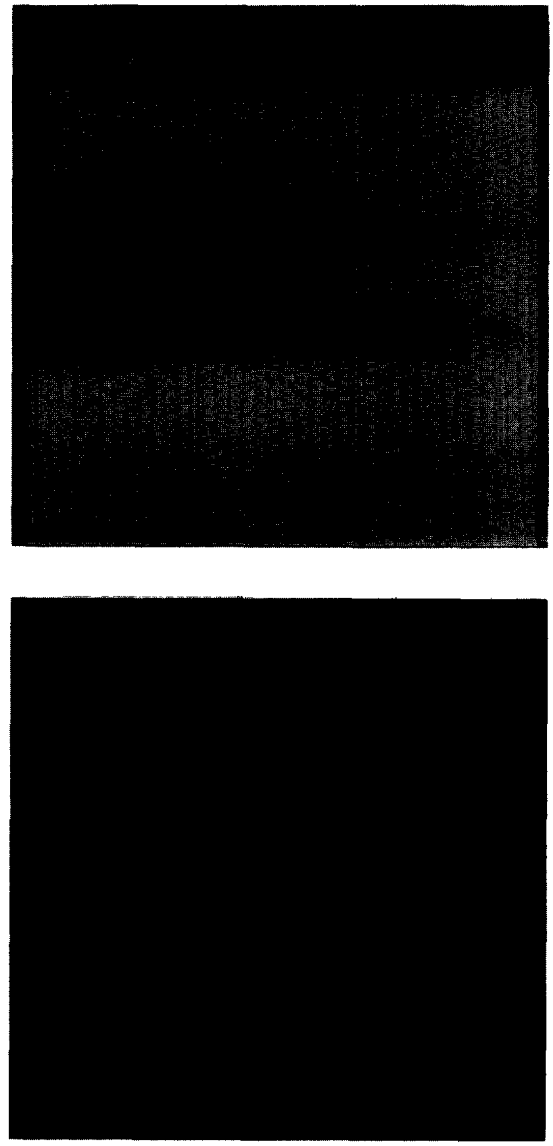

Fig. 3. SEM micrographs of microdisk structure.

The ECR plasma etch step is not expected to induce significant sidewall damage in the quantum wells based on our past experience with dry etching of III–V photonic device structures, and the resistance of the nitrides to damage based on our observations during both ion implantation and ion milling experiments. Detailed optical characterization experiments will be reported later.

In summary, we have developed an epitaxial growth procedure and a two-step etching sequence for the creation of GaN-based microdisk laser structures. These developments should expand the range of wavelengths accessible with microresonators.

Acknowledgements—The work at UF is partially supported by an AASERT grant from the U.S. Army Research Office and a National Science Foundation contract from the Division of Materials Research. The help of the staff of the Microfabritech facility is gratefully acknowledged. The work at Sandia National Laboratories is supported by the U.S. Department of Energy under Contract No. DE-AC04-94AL85000. The assistance of P. L. Glarborg at Sandia is also greatly appreciated.

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