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The Fabrication of the Circular Ring Laser Resonators by Excimer Laser Assisted Etching at Cryogenic Temperature

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1. Introduction

Semiconductor ring laser (SRL) has received much attention for its performance in single mode and single wavelength output. Similar laser structure with novel resonators for wavelength filtering, output coupling, and light wave traveling have been reported1-6. Since, semiconductor ring laser is not necessary to cleave mirror facets for the optical resonator that it is possible to integrate the laser source with other passive components monolithically. There are several approaches to fabricate the structure of the ring laser resonator, for example, by ridge waveguide etching, barrier diffusion, and grating formation. In fact, the etching method is believed to be the most reliable way to achieve an idea laser resonator with required current injection and waveguide confinement properties. Plasma base etching technique such as reactive ion etching, ion beam etching, and chemical assisted ion beam etching all have a potential damage to the etched surfaces due to bombardment of the energetic particles, and these damages is contributed to increase optical loss along the resonator7-8. The high photon energy(6.2 eV) of the ArF excimer laser combine with the high flux of the high pulsed laser is very efficient to activate surface reaction and desorption mechanism for initiating the etching process. In addition, the negligible momentum of the impinging photon causes almost no damage to the etched surface. We have developed the excimer laser assisted etching at cryogenically cooled substrate temperature at 140 K to achieve anisotropic etching with high resolution and no damage to the etched side wall.

2. Device Fabrication and Characterizations

The laser material is an MOCVD grown InGaAlP multiple quantum wells structure, and Figure 1 shows the detailed material structure of the laser substrate. The circular ridge-waveguide resonator is 10 μm in width, diameter of 100 μm -200 μm, and with a 500 μm long output coupling section. At the first step of the ring laser device processing, a sacrificial polymer layer (150F, Filmtronics) is spun on the laser substrate, and annealed at 150 C for 15 minutes to enhance the interfacing properties. Then a second layer of conventional photoresist(AZ4903) is spin coated on the top of the sacrificial layer. A g-line mask aligner (Karl Suss MA45) operating at contact mode is used to expose the pattern of the ring laser resonator structure. Since the developing of the sacrificial polymer layer in AZ4000K developer is faster than AZ4903 photoresist. An idea undercut structure for lift-off process can be achieved by controlling the difference of the developing time between the top photo-resist and the button of the sacrificial layer. An Au(2000A)/Cr(100A) layer used for etching resist mask and electrical contact for current injection purpose is deposited by an e-beam evaporator and patterned by a subsequent lift-off process.

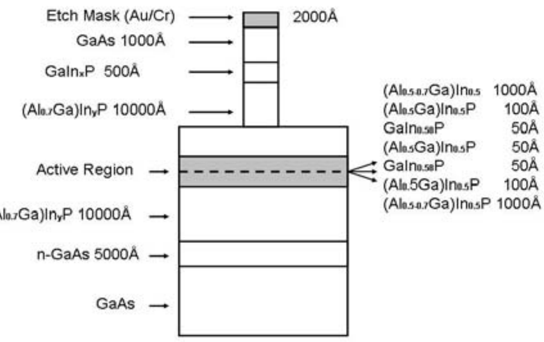

Figure. 1 The MOCVD grown InGaAlP multiple quantum wells structure.

For etching of the circular ring resonator, the ArF excimer laser assisted etching system was developed. Figure 2 shows the sketch of the etching system. The etching chamber is pumped to 10-5 Torr by a turbo molecular pump. The chemically cleaned sample is then transferred to the etching stage by a load-locking mechanics. The etching stage is cooled by liquid nitrogen, and maintained at 140 K by using the Omega CN2011 temperature controller with resisted heating. The electronic grade chlorine gas was introduced into the etching chamber and the pressure was maintained at 0-10 mTorr by a micro-leakage valve. The chlorine molecules will be condensed on the sample surface while the temperature below condensation. The ArF excimer laser system(Lamda Physik LPX 100) lasing at 193 nm with pulse width of 30 ns is running at 20 KV, and 10 Hz repeating rate. UV optics are used to project a uniform illumination area of laser beam on to the sample at fluences range 40-80 mJ/cm2. The key role of the laser fluence is to activate significant surface chlorine dissociation and at meanwhile to achieve moderate surface heating for disrobing surface chloride compounds. Figure 3 shows the SEM pictures of the etched ridge waveguide structure of the ring resonator by this etching.

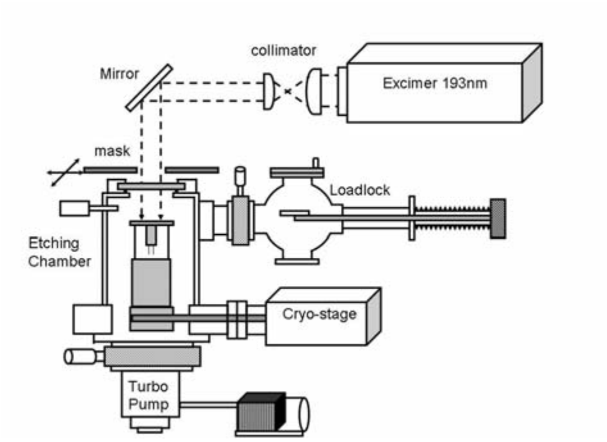

Figure 2. The sketch of the excimer laser assisted cryo-etching system

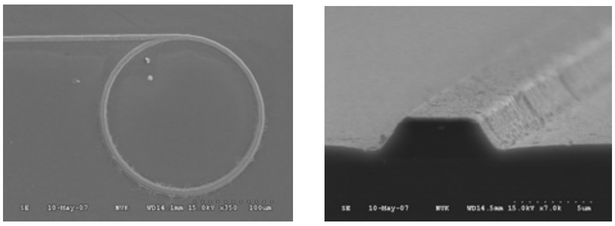
Figure 3. SEM pictures of the etched ridge waveguide structure by excimer laser assisted chlorine etching at 140 K.

The A silicate based spin on glass spin on glass (SOG) dielectric layer (ACCUGLASS 214) of $0.2\,\mu m$ is used for electrical isolation and optical confinement. A thick Au metal layer of $0.2\,\mu m$ is deposited by e-beam evaporator for electrode contacting.

Figure 4 shows the L–I characteristics of a circular ring laser with dimension described above. The calculated threshold current density 300 A/cm2 is very close to the idea linear ridge waveguide laser, and output power as high as 5 mW has been achieved at 80 mA injection current of CW operating. We have also measured the output spectrum of the ring laser by using a Jobin Yvon SPEX 500 spectrum analyzing system with 0.01 nm resolution, and showed single wavelength lasing at 638.84 nm.

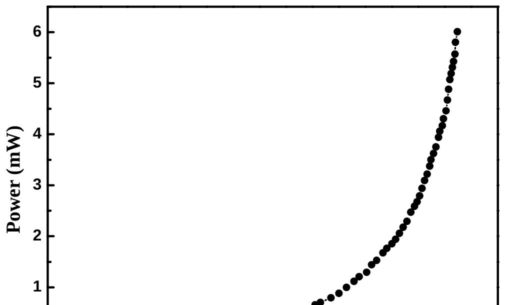

Figure. 4 L–I curve of the fabricated circular ring laser, the threshold current is around 70 mA.

3. Conclusions

We have demonstrated the fabrication of a circular ring resonator by the excimer laser assisted chlorine etching at cryogenic substrate temperature. The high photon energy (6.2 eV) of the ArF excimer can effectively dissociate the layer of condensed phase chlorine on the cryogenic substrate producing high reactive surface localized chlorine atoms to form chloride compounds which will be desorbed by surface heating under 193 nm irradiation. Since the momentum of photon is insignificant to damage the etched surface, it will maintain the electrical and optical properties of the resonator structure. Experiments of the etching of GaAs(100) and GaAs(110) orientations and Al1-xGaxAs compounds semiconductors show that the etching is non-crystallographic and non-selective etching. Since the surface compounds are removed by laser pulse that is able to achieve good depth control in etching. The threshold current density of the ring laser is comparable to those linear lasers fabricated by this etching technique. Further experiments of applying this etching technique to fabricate a waveguide structure of width close to the optical resolution of the laser wavelength is essential for developing the opto-electronic integrated devices.

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