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Using Substrate Removal Technique for GaAs-Based VECSEL Optimization

A combination of two types of etching mechanisms: physical etching which relies on physical interaction of particles that erode the surface, and wet/dry etching that relies on chemical reactions to erode the surface, is used to remove substrates with thickness between 300 and 500µm. First, the substrate is mechanically thin down to about 100µm and then wet etching or dry etching is applied. The substrate removal of GaAs was successfully achieved as verified in the x-ray diffraction etch analysis.

Keywords: VECSEL; Semiconductor laser; Substrate removal; Optoelectronics
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1. Introduction

There are basically three types of lasers: gas lasers, solid state lasers, and semiconductor lasers. Gas lasers have different uses that are determined by wavelength and power out. For example, Helium-Neon lasers are usually low power but operate in the visible spectrum and make good alignment lasers, CO_2 lasers are higher power and operate at a wavelength of 10.6µ in the IR range and they are good for cutting and welding metals, Argon lasers are good for pumping other lasers dye and chemical lasers it can be used to optically excite other lasers; it also makes good hologram slides. Solid-state lasers, such as ruby rod, and Nd:YAG operate in the near IR wavelength. These lasers use a crystal doped with an ion which provides the wavelength of the light that the laser operates at. The military has used ruby rod lasers in rangefinder applications, they have also used Nd:YAG lasers as rangefinders, but they are most commonly used in the medical field in surgery. The next types of lasers are the Semiconductor lasers. There are several kinds of semiconductor lasers and they operate differently than solid state lasers and gas lasers. Semiconductor lasers have an engineered band gap instead of a traditional active medium. The photons that are released are spontaneous and most will combine to be in phase, highly coherent, monochromatic light. Those photons that are not emitted are absorbed by the diode as heat energy making the diode very hot which can lead to a breakdown in the diodes structure. The internal heating can also interfere with the diodes ability to lase and maintain a population inversion. Edge emitting diode lasers which are the first semiconductor lasers that were used in mass quantities, also the first semiconductor lasers invented, are pumped by electrical current which itself is a source of heat. Another type of semiconductor laser is the Vertical External Cavity Surface Emitting Laser (VECSEL).

The lasers mentioned here all have one thing in common, that is that they are all very inefficient when it comes to power use (which is power out over power in). The best that most lasers can hope for is about 10-30% especially in gas and solid state lasers. Semiconductor lasers are about 50% efficient with some high power semiconductor lasers having 60-70% efficiency. The reason that lasers are so inefficient is that the energy that is not emitted as light is converted into heat. Therefore, elimination of this heat is crucial to improve laser efficiency. It is especially true for semiconductor lasers where excessive heat can lead to structural break down.

Figure (1) shows the basic functions of the VECSEL components. High energy incident pump photons are absorbed into pump absorbing region [4]. Carriers diffuse to the quantum wells where electrons are excited and relaxed emitting photons with energy equal to the quantum well band-gap energy [4].

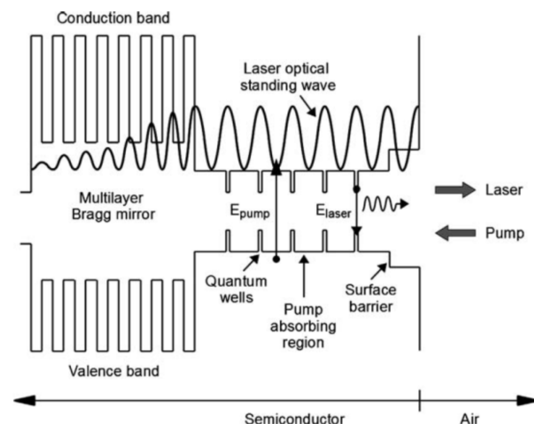

Fig. (1) Operating principles of optically pumped VECSELs [4]

The generated photons travel back and forth in the cavity. These photons stimulate more electrons

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in high energy levels to drop to lower energy levels and generate more photons with same wavelength and phase emitting coherent light [4-6].

2. Experimental Procedure

The samples were cleaved in squares of 1cm x 1cm for easy handling. Cleaving is performed using a diamond scriber. The wafer is placed epitaxial side up on a clean room wipe sheet. With a ruler on the straight side of the sample 1cm is measured and marked by scribing a small line. Then the wafer is placed over a straighten out paper clip so that the scribe line aligns with the paper clip and by applying equal pressure to both sides of the wafer with the ends of two tweezers the sample fractures in a straight line. The same procedure is repeated until the maximum possible $1cm^2$ chips are obtained from one wafer.

The next step is to chemically clean the sample to remove any impurities that may reside on the wafer surface. Each sample was soaked in acetone, isopropanol, and methanol for 2 minutes in each solution. Then the sample was rinsed with deionized (DI) water and dried with a Nitrogen gun. Nomarski images of the clean surface were taken before the bonding procedure.

Microscope glass slides were cut into three pieces. A pinch of ApiezonW ® wax was placed on top of the glass slide and then the slide was placed on a hot plate at a temperature of 150°C. Once the wax was melted, the sample was placed on the wax with the GaSb layer facing down. Slight pressure was applied on the sample to assure even contact, free of air bubbles, with the wax. Then the sample was removed and allowed to cool.

Since there is no etch stop layer, it is essential to know with precision the rate at which the etchant solution will etch GaAs as well as GaSb. To measure the etch rate on GaAs, the sample bonded to glass was measured with a micrometer before and after etch at five spots as shown in the diagram in Fig. (2).

Etch rate is equal to the thickness removed per unit time. The etch time was set for forty minutes. The etch rate for each of the five spot in the sample was calculated and averaged with the other to have a better estimate of the whole $1cm^2$ surface. To measure the etch rate on GaSb, the sample bonded to glass with the GaSb layer facing up was etched monitoring the time it took to etch the 3μm GaSb layer. The sample was measured and you can see the measurements in microns. The top number is the before measurement the bottom number is the after measurement. The bottom number is subtracted from the top number which tells us how many microns were etched in that spot. After determine how many microns were etched we take that number and calculate the etch rate; which is thickness / time. We do this for each spot measured, add the results and divide by five, which gives us and overall average of how much substrate was removed.

Fig. (2) Diagram of measuring positions

The etchant solution of NH_4OH: H_2O_2 at a volume ratio of 1: 33 was used. It was prepared by mixing 500ml of H_2O_2 and 15ml of NH_4OH. The sample was placed and secured on the jet etcher sample holder as shown in Fig. (3). The jet etcher is a homemade etcher that uses a pump to circulate the etchant solution and to keep a constant flow falling on the sample. Once the sample and the solution were ready, the pump was turned on and the valve open. The etch process was monitored through all the etch time to assure a steady stream and therefore an even etch. When the etch time was expired, the etch was stop by quenching the sample in DI water. The surface was dried with nitrogen gun and its surface was analyzed under Nomarski microscope.

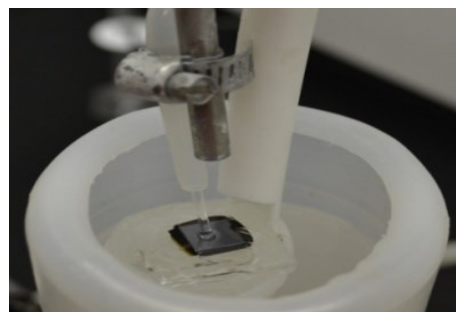

Fig. (3) The jet etcher setting

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4. Results and Discussion

There exist two types of etching mechanisms: physical etching which relies on physical interaction of particles that erode the surface and wet/dry etching that relies on chemical reactions to erode the surface [9]. Typically a combination of both methods is used to remove substrates with thickness between 300µm and 500µm. First, the substrate is mechanically thin down to about 100µmand then wet etching or dry etching is applied [7-8, 10-11]. However, dry etching is highly associated with surface damaging since it uses bombardment of ions from reactive gases to disassociate the substrate [9]. In view of the fact that a VECSEL surface must be smooth, dry etching is undesirable leaving us with wet etching as the reminding option.

Wet etching is the process by which layers of material are removed by using liquid chemical solutions. A wet etching process usually involves a three step reaction mechanism as shown on Fig. (4) [12]. First step, the reactants diffuse to the semiconductor surface. Second step, the chemical reaction occurs at the surface by oxidation reduction. Third step, reaction products diffuse from surface to dissolve into the solution. Therefore, the reaction chemistry between the semiconductor material and the etchant solution must be compatible.

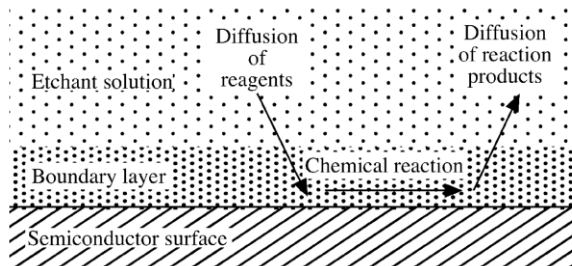

Fig. (4) Reaction mechanism for a wet etching process

Wet etching systems for GaAs had been studied extensively [11, 13-15]. A typically GaAs system is shown in Fig. (5). Usually, the etchant solution is composed of an oxidizing agent such as hydrogen peroxide, H_2O_2, and a solvent agent such as ammonium hydroxide, NH_4OH, or citric acid, $C_6H_8O_7$ [13]. These etchant solutions have a higher selectivity for GaAs material than for AlGaAs which means GaAs is etched at a much faster rate than AlGaAs [13-15]. Therefore, AlGaAs acts as an etch stop layer. Once, the etchant solution reaches AlGaAs the etch rate becomes so slow that the layer is conserved and it is an indication that the substrate has been removed. In addition, AlGaAs layer can be etched in seconds with Hydrofluoric acid which has an extreme selectivity for AlGaAs over GaAs [14]. Nonetheless, in this experiment the system is GaSb/GaAs as shown in Fig. (5b) and the selectivity of etchant solutions for GaAs over GaSb must be determined.

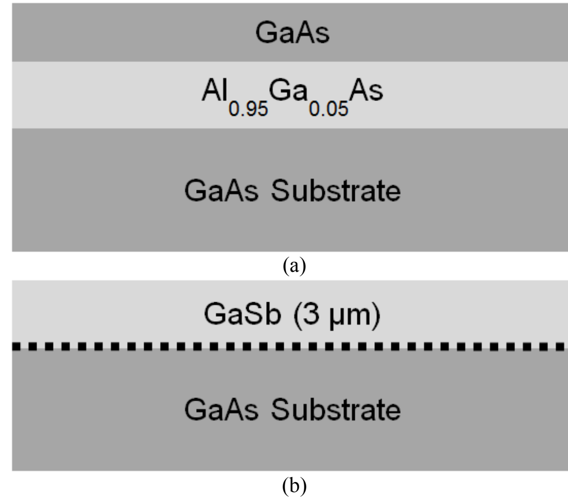

Fig. (5) Structure of etching systems for (a) GaAs and (b) GaSb/GaAs

The substrate removal of GaAs was successfully achieved as it can be verified in the XRD Etch analysis. Figure (6) shows the results from omega-two theta X-Ray diffraction study of the sample before (red curve) and after (black curve) the etch process. It can be clraerly notice that the substrate peak in the black curve, post etch, is completely gone leaving behind only the GaSb layer peak. This is an indication that the NH_4OH: H_2O_2 1:33 ratio has a higher selectivity for GaAs than for GaSb.

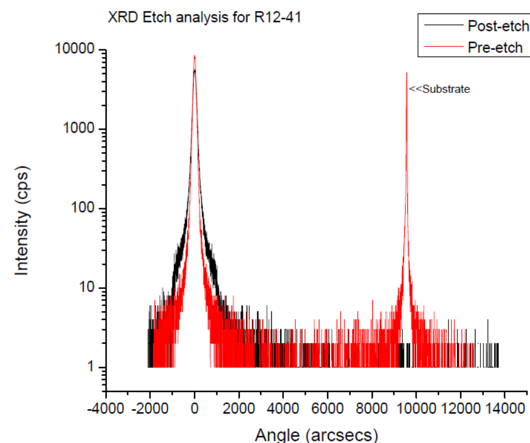

Fig. (6) Omega-two theta x-ray diffraction (XRD) study of the sample before (red curve) and after (black curve) the etch process

Nomarski microscope was used to analyze the surfaces of GaSb epi-layer before and after the etch. Figure (7) shows the Nomarski images results which shows almost no difference in surface quality. Therefore, further analysis need to be done to determine the roughness of the surface.

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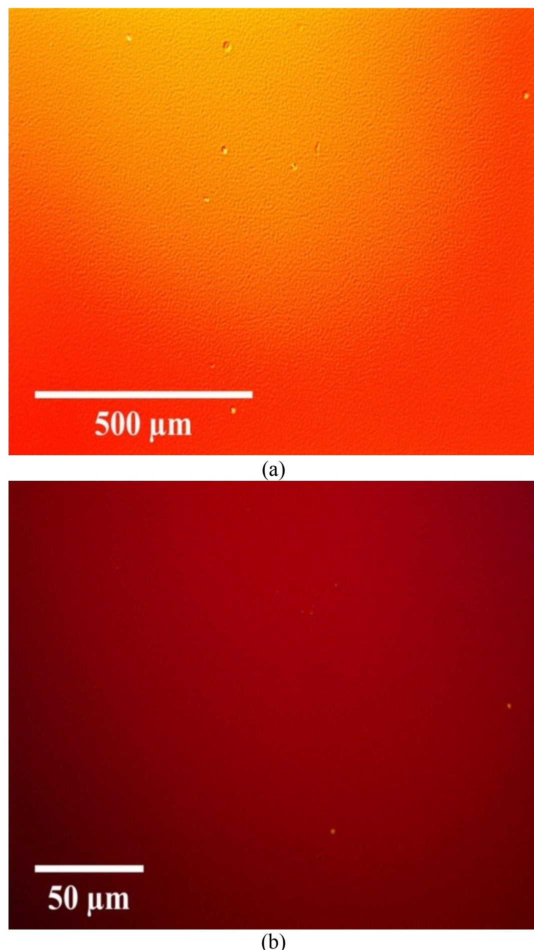

(a)

(b)

Fig. (7) Nomarski images of GaSb surfaces (a) before etch, and (b) after etch

References

[1] Schulz, N., et al. "Optically pumped GaSb-based VECSEL emitting 0.6 W at 2.3 µm." *Photonics Technology Letters, IEEE* 18.9 (2006): 1070-1072.

[2] Bellis, Mary. "History Of Lasers." *About.com Inventors*. N.p., n.d. Web. 23 Mar. 2013.

[3] "History of Lasers" *History of Lasers*.N.p., n.d. Web. 23 Mar. 2013.

[4] "Nano-Photonics Materials and Technologies for Multicolor High-Power Sources (NATAL)." *AG Bimberg: NATAL*. N.p., 0.2 Sept. 2010. Web. 26 Mar. 2013.

[5] O.G. Okhotnikov, *Semiconductor Disk Lasers: Physics and Technology*, Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, Apr. 2010.

[6] "Stimulated Emission." *HyperPhysics*. N.p., n.d. Web. 14 Apr. 2013.

[7] Tropper, A. C., et al. "Vertical-external-cavity semiconductor lasers." *Journal of Physics D: Applied Physics* 37.9 (2004): R75.

[8] Perez, J. P., et al. "Technologies for thermal management of mid-IR Sb-based surface emitting lasers." *Semiconductor Science and Technology* 25.4 (2010): 045021.

[9] Jacquemet, Mathieu, et al. "Single-frequency cw vertical external cavity surface emitting semiconductor laser at 1003 nm and 501 nm by intracavity frequency doubling." *Applied Physics B* 86.3 (2007): 503-510.

[10] Arokia, Nathan. "Etching and Chemo-Mechanical Polishing."N.p., 2005. Web. 14 Apr. 2013.

[11] Clayton, F., R. Westerman, and D. Johnson. "Characterization of a Manufacturable High Rate GaAs Via Etch Process." *GaAsMantech, Conference*. 2002.

[12] Yeh, Hsi-Jen J., and John S. Smith. "Integration of GaAs vertical-cavity surface emitting laser on Si by substrate removal." *Applied physics letters* 64.12 (1994): 1466-1468.

[13] Barron, Andrew R. "Formation of Silicon and Gallium Arsenide Wafers." *Connexions*.N.p., 21 Sept. 2012. Web. 14 Apr. 2013.

[14] Novak, J., et al. "Wet chemical separation of low-temperature GaAs layers from their GaAs substrates." *Materials Science and Engineering: B* 40.1 (1996): 58-62.

[15] Yablonovitch, Eli, et al. "Van der Waals bonding of GaAs epitaxial liftoff films onto arbitrary substrates." *Applied physics letters* 56.24 (1990): 2419-2421.

[16] De Salvo, Gregory C., Ron Kaspi, and Christopher A. Bozada. "Citric Acid Etching of GaAs1− x Sb x, Al0. 5Ga0. 5Sb, and InAs for Heterostructure Device Fabrication." *Journal of The Electrochemical Society* 141.12 (1994): 3526-3531.

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