Progress in Etched Facet Technology for GaN and Blue Lasers

A A Behfar, M R Green, J Hwang, A J Morrow, A T Schremer, and C B Stagarescu
BinOptics Corporation, 9 Brown Road, Ithaca, New York 14850, USA.

Abstract Several years ago, a new technology was pioneered at Cornell University in which the laser facets were formed using a process based on chemically assisted ion beam etching (CAIBE). BinOptics has developed InP-based lasers using this proprietary Etched Facet Technology (EFT). The devices are characterized by precisely located mirrors with quality and reflectivity equivalent to those obtained by cleaving. The use of EFT also eliminates losses that result from mechanical facet cleaving, allows wafer-scale testing and coating, and enables monolithic integration. BinOptics has now developed a modified version of its EFT for GaN materials and blue lasers where mechanical cleaving losses can be even more problematic. The relatively high defect density of currently available GaN materials creates an additional yield advantage for EFT: it allows the formation of shorter cavity devices with fewer defects per device. The first etched facet GaN devices are Fabry-Perot type ridge waveguide lasers emitting at 405nm for optical storage applications. However, as demonstrated in InP, it is planned to extend the technology to horizontal-cavity surface-emitting lasers (HCSELs) with integrated monitoring photodetectors (MPDs). A surface-emitting blue laser will allow two-dimensional arrays for high power applications and monolithic integration of additional functions. For example, the integration of a blue HCSEL with a receive detector will enable the creation of a compact optical head.

1. Background and Introduction

One of the key requirements for a laser to produce stimulated emission is to have optical feedback. This optical feedback is usually achieved through the use of reflecting mirrors. In semiconductor lasers, cleaving facets in the semiconducting crystal forms the mirrors. The vast majority of semiconductor lasers produced today are based on GaAs and InP. The zinc-blend lattice structure of GaAs and InP based lasers is ideal for forming cleaved facets that are parallel to one another. However, the cleaving process is a mechanical process that causes the wafer to be broken into bars and is incompatible with monolithic integration. Handling delicate bars for facet reflectivity modification, as well as for testing, is costly. Nevertheless, in view of the relative ease of cleaving GaAs and InP, and the lack of a strong market pull for monolithic integration, cleaved facet lasers dominate present-day fabrication of lasers in such material systems.

Nichia Chemical first demonstrated GaN-based blue lasers on sapphire substrates in 1995 and has subsequently been able to produce commercially available CW lasers [1]. Nichia uses cleaving to form the facets of its blue lasers, but prices of such lasers have remained very high. Cleaving sapphire to form the GaN-based laser facets is particularly difficult since sapphire has many cleave planes with approximately equal cleave strength within a small angular distance of each other. As such, the fracture interface can easily be redirected from one cleavage plane to another, even when perturbations during the cleaving process are small. Despite these problems, sapphire has been the substrate of choice for nitride growth because it is relatively inexpensive and stable during the high temperature processes required for GaN deposition. Both sapphire as well as more expensive SiC substrates are significantly lattice mismatched to GaN, producing high defect densities in the grown material. Freestanding GaN substrates are a partial solution, and are just now becoming available. But unlike GaAs and InP, GaN is hexagonal in crystal structure and much harder to cleave.

There is tremendous interest in fabricating inexpensive 405nm-emitting GaN based lasers for next generation DVD applications. If improvements can be obtained in the fabrication yield of these lasers, it would be a significant enabler for the next generation DVD market.

2. Etched Facet Lasers

An alternative to cleaving is to etch the laser facets. Over the years, many etching techniques have been reported for GaAs/AlGaAs-based lasers which include wet etching [2,3] and hybrid wet and Reactive Ion Etching (RIE) [4].

However, typical facets produced by such techniques resulted in reflectivity values that inferior to cleaved ones, until etched facets were formed through a process based on Chemically Assisted Ion Beam Etching (CAIBE) at Cornell University [5]. These laser devices are characterized by precisely located mirror facets with quality and reflectivity equivalent to those obtained by cleaving. BinOptics Corporation proprietary Etched Facet Technology (EFT) is based on this work.

CAIBE [6] uses an inert gas like Ar in an ion source to generate an ion beam, which is directed towards the sample. This is done in conjunction with a flow of a reactive gas like Cl_2 near the sample. The ion beam provides the physical component of the etching process, while the reactive gas provides the chemical component. There is independent direct control over both the physical and chemical components of the etch. This independent control allows the possibility of very high selectivity between the etch mask and the material that is etched. As etching only takes place in the direction of the ion beam, the etch is very anisotropic. Further development of appropriate etch masks [7] in conjunction with the unique capabilities of CAIBE resulted in excellent etched facets for semiconductor lasers.

The EFT allows lasers to be fabricated on the wafer in much the same way that integrated circuit chips are fabricated on silicon. Etched facet lasers are monolithically integratable with other photonic devices on a single chip [8] and can be tested inexpensively at wafer-level [9]. Facet Reflectivity Modification (FRM) can be used to modify the reflectivity of the etched facets through deposition of dielectric coatings with the wafer intact. Figure 1 shows a side-by-side comparison of lasers formed through EFT with lasers fabricated through the use of a conventional cleaved facet.

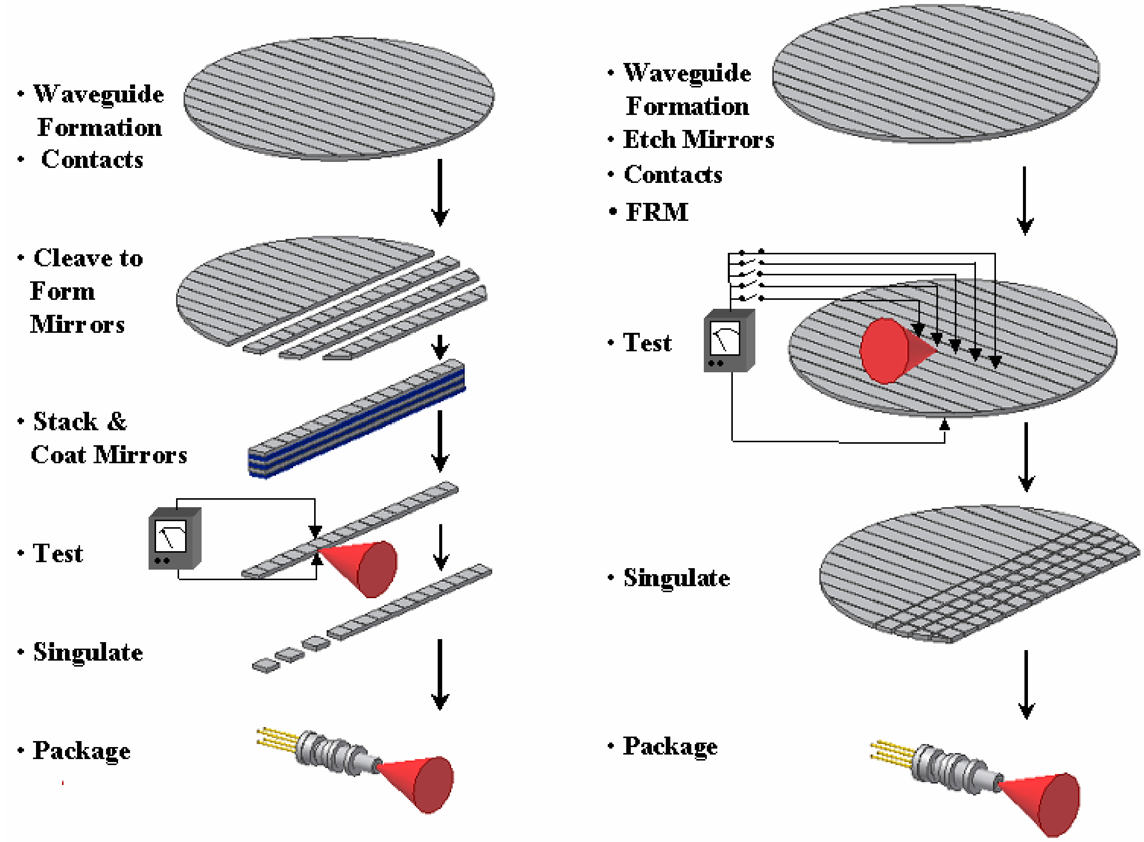

Figure 1. Conventional laser processing (left) vs. full-wafer processing and testing made possible by etching of the laser facets (right)

3. Etched facets in GaN

Early on in the development of GaN based blue lasers, CAIBE was applied to the fabrication etched facets for blue lasers on sapphire [10], however, the reflectivity obtained from such etched facets were smaller than cleaved facets.

The lower reflectivity was blamed primarily on roughness of the facet [11] as well as the deviation of the facet from vertical [12].

A key to obtaining high quality etched facets is high selectivity between the etch mask and the semiconductor material in the etching process. The etch facets formed in GaN were formed with a selectivity of better than 10:1 and the etch rate was higher than 0.25µm/min. Figure 2 shows a scanning electron microscope (SEM) image of an exemplary facet obtained using silicon dioxide as the etch mask.

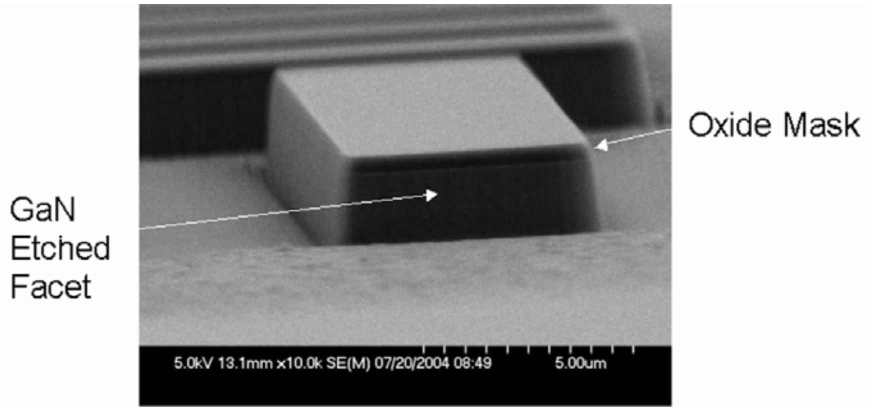

Figure 2. SEM of high quality etched facets in GaN using CAIBE

Formation of a cavity in the GaN system through cleaving does not easily allow a cavity length below 500µm. Since the material system has very high defect density (presently around 10^5 defects/cm^2 for the best available material), assuming a ridge width of 2µm, a cavity of such length will on average contain at least 1 defect. As such, the GaN system provides additional incentive for using etch facets since much shorter cavities can be formed with relative ease. Assuming a cavity length of 50µm with the same ridge width of 2µm, the probability of a cavity with a defect is a factor of 10 lower. This leads to significantly increased yield.

A ridge structure in GaN has been formed using CAIBE and the top view of this structure is shown in Figure 3. The EFT allows the integration of additional elements such as a Monitoring Photo-Detector (MPD) that can be seen on the lower part of the figure.

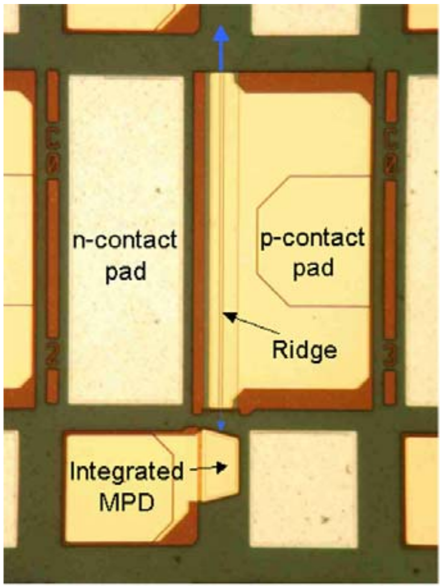

Figure 3. GaN ridge structure with etched facets and integrated MPD

4. HCSELs and Future of Photonic Integration on GaN

We recently presented a horizontal cavity surface-emitting laser (HCSEL) in the InP material system [13]. Figure 4 schematically shows a HCSEL with an integrated MPD and a Distributed Bragg Reflector (DBR). The DBR is incorporated to allow high reflectivity at the back facet without the need for FRM.

HCSELs offer advantages beyond surface emission in that they relax the requirements on singulation of the chips. They also allow the realization of two-dimensional arrays for high power applications as well as monolithic integration of additional functions. For example, the integration of a HCSEL with receive detectors enables the creation of a compact optical head.

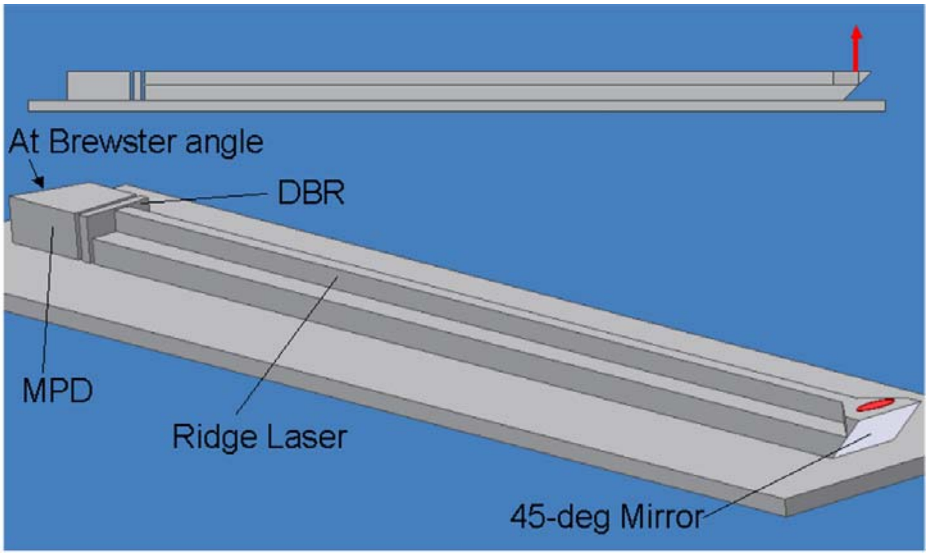

Figure 4. The HCSEL is a new kind of surface-emitting laser enabled by EFT

5. Conclusions

Etched facet technology is beginning to make inroads in GaAs and InP systems in the fabrication of integrable semiconductor lasers. The GaN material system is especially suitable for use of etched facets since cleaving is harder than GaAs or InP due to the hexagonal lattice structure. The ability to form short cavities with etch facets is especially desirable in view of the high defect density in GaN material system. The HCSEL structure provides a vehicle for monolithic integration with other photonic devices in GaN.

References

[1] Nakamura S, Fasol G, Pearton S J 2000 *The Blue Laser Diode: The Complete Story* (Heidelberg: Springer).

[2] Merz J L and Logan R A 1976 *J. Appl. Phys.* **47** 3503-9.

[3] Merz J L, Logan R A, and Sergent A M 1979 *IEEE J. Quantum Electron.* **QE-15** 72-82.

[4] Salzman J, Venkatesan T, Margalit S, and Yariv A 1985 *J. Appl. Phys.* **57** 2948-50.

[5] Behfar-Rad A, Wong S S, Ballantyne J M, Soltz B A, Harding C M 1989 *Appl. Phys. Lett.* **54** 439-495.

[6] Chinn J D, Fernandez A, Adesida I, Wolf E D 1983 *J. Vac. Sci. Technol.* **A1** 701-4.

[7] Behfar-Rad A, Wong S S, Davis R J, and Wolf E D 1989 *J. Electrochem. Soc.* **136** 779-82.

[8] Behfar A, Green M, Morrow A, Schremer A and Stagarescu C 2005 *Optical Fiber Conference* OTuM5.

[9] Vettiger P, Benedict M K, Bona G –L, Buchmann P, Cahoon E C, Datwyler K, Dietrich H –P, Moser A, Seitz H K, Voegeli O, Webb D J, Wolf P 1991 *IEEE J. Quantum Electron.* **27**, 1319–1331.

[10] Kneissl M, Bour D P, Johnson N M, Romano L T, Krusor B S, Donaldson R, Walker J, and Dunnrowicz C 1998 *Appl. Phys. Lett.* **72** 1539–41.

[11] Stocker D A, Schubert E F, Grieshaber W, Boutros K S, and Redwing J M 1998 *Appl. Phys. Lett.* **73** 1925-7.

[12] Adesida I, Ping A T, Youtsey C, Dow T, Asif Khan M, Olson D T, and Kuznia J N 1994 *Appl. Phys. Lett.* **65** 889-91.

[13] Behfar A, Schremer A, Green M, Stagarescu C, and Morrow A 2005 *Photonics West* 5737-08.