Etching of GaAs/AlGaAs VCSEL Mesa for High Volume Production

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Abstract

This paper presents a high uniformity, low footing etch of GaAs/AlGaAs mesa on 150 mm wafers for VCSELs. The high uniformity means the process is suitable for fully automated optical endpointing techniques. Extended marathon tests have been performed to demonstrate the reliability and repeatability of the process necessary for high volume production.

INTRODUCTION

The application and market share of Vertical Cavity Surface Emitting Lasers (VCSELs) is growing, with increasing demand for 'high tech' applications such as facial recognition in smart phones, LiDAR (Light Detection and Ranging) and data transfer [1].

VCSELs are simpler and therefore cheaper to manufacture than standard edge emitting lasers. Emitting light perpendicular to the plane of the wafer allows for in-line testing, the formation of 2D arrays and a high level of integration of the VCSEL with other optical components and even whole devices. VCSELs also have a lower threshold current and lower power consumption than comparable edge emitters, so they do not compromise battery life. There are also exciting possibilities for effective wavelength tuning [2].

There are multiple steps in the formation of a VCSEL, all of which must be precisely controlled to ensure consistent performance of the final device. A critical step is etching through the epitaxial layers and the active region to form the main structure of the laser - the mesa. Examples of plasma etched VCSEL mesa are shown in Fig. 1. The shape, height and pattern of the mesa must be carefully considered as their structure is critical to the final performance of the device. VCSEL patterns are becoming more complex with smaller features and mesa closer together; well-defined features with low footing and high uniformity are becoming increasingly important.

VCSEL MESA ETCH

A process has been developed by Oxford Instruments Plasma Technology for the etching of GaAs/AlGaAs mesa on a PlasmaPro 100 Cobra ICP plasma etcher using chlorine- and nitrogen-based chemistry which fit the stringent criteria for

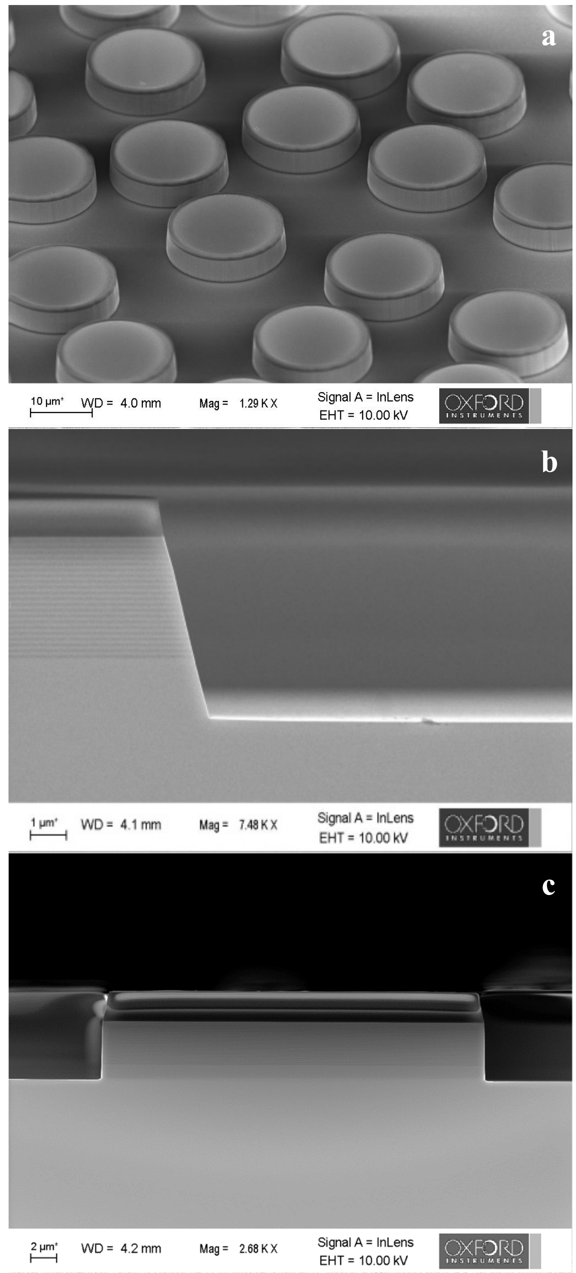

Fig. 1. SEM images of GaAs/AlGaAs mesa etched using a SiN_x mask. a) mesa pattern array, b) sloped profile, c) vertical profile.

etching VCSEL mesa [3]. A smooth surface and accurate repeatable profile are essential for the reliability of a finished device. In this process a careful balance of the chlorine containing etching gas and nitrogen, the passivation gas, is used to produce a profile between 60° and 90° with smooth, defect-free sidewalls. The etch rates of GaAs, AlGaAs and similar GaAs based materials are the same (1:1 selectivity) meaning there is no rippling of the Distributed Bragg Reflector (DBR) nor undercutting/notching at the active region, see Fig. 1. An undamaged active region means oxidation will always start at the same point on the mesa, ensuring accurate and repeatable aperture formation with high yield.

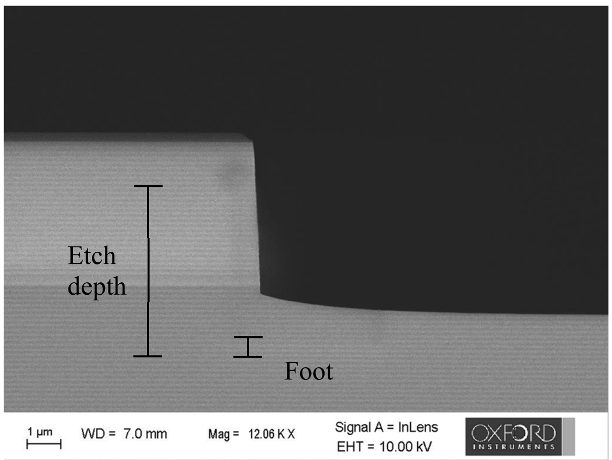

Fig. 2. SEM image of an imperfect mesa etch with large footing.

Photoresist (PR) or SiN_x hard masks both have their advantages: fewer process steps are required using a PR mask but it produces more chamber contamination when compared with a hard mask. Either mask can be used to produce the mesa results reported here allowing the appropriate choice to be made for the application. The process results for the sloped and vertical processes are shown in Table 1.

TABLE 1. ETCHING PARAMETERS FOR 150 MM WAFERS WITH A 5 MM EDGE EXCLUSION. UNIFORMITY IS DEFINED AS

$$\pm U\% = \frac{max-min}{2\times average} \times 100$$

Profile	Sloped	Vertical
Etch rate	>600 nm/min	>600 nm/min
Selectivity to PR	>1.5:1	>3:1
Selectivity to SiN_x	>5:1	>10:1
Within wafer uniformity	<±3%	<±3%
Run-to-run uniformity	<±3%	<±3%

Footing is the curve between the sidewall and the base of the etch (see Fig. 2). The optimal VCSEL mesa has as little footing as possible, because in widely spaced mesa designs a large foot can necessitate deeper etching than under ideal conditions, affecting the oxidation of the active region and the placement of contacts. For newer designs with smaller gaps, low footing means features can be placed closer together while still maintaining electrical isolation. The addition of nitrogen as the passivating gas is the key to achieving low footing. Both the sloped and vertical processes described here have very low footing. Footing of <3% of the etch depth is routinely achieved and in many cases, it is effectively non-existent, as shown in Fig. 1b/c. Footing also contributes to the uniformity of the process. A large foot means several epilayers are exposed at the base of each mesa, thereby increasing the non-uniformity across the wafer.

The other main driver of non-uniformity when etching GaAs based materials is "centre slow, edge fast" chemically-driven etching. This is due to the higher concentration of exposed GaAs at the centre of the wafer compared to the edge with a similar concentration of active species available. The effect on uniformity is more pronounced as production moves from 100 mm to 150 mm and eventually 200 mm wafers. Chamber furniture has been optimised to improve the uniformity, with hardware designed using simulation and practical experiment to increase the velocity of the molecules close to the wafer and change the distribution of the plasma in the chamber. This improves the achievable uniformity more than two-fold compared to process changes alone.

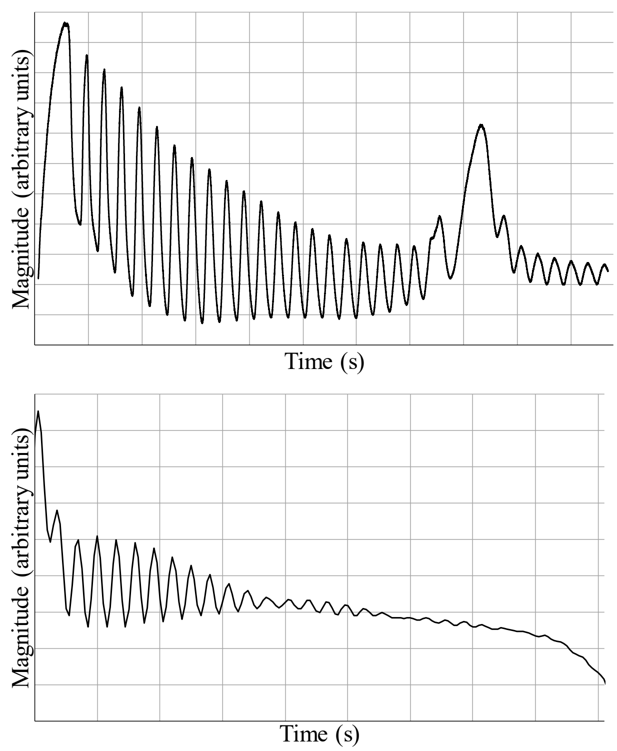

Fig. 3. OES trace of the ratio of gallium and aluminium signals during the etching of GaAs/AlGaAs mesas. Top: high uniformity process and Bottom: lower uniformity process.

Process Endpointing

The etching of the mesa aims to expose the aluminium-rich layer which is oxidized to form the aperture of the laser. The design of a VCSEL is carefully chosen to give the required electrical and optical properties, therefore, it is important for the mesa etching to stop repeatably on the required layer. Time dependent etching is sufficient for some applications but endpointing techniques allow tighter control of the etch depth. Optical Endpoint Spectroscopy (OES) reduces the wafer-to-wafer variation to <±1.5%.

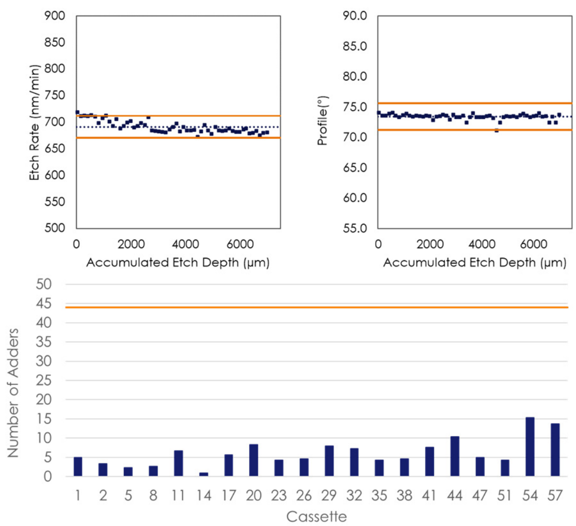

Fig. 4. Etch rate and profile repeatability for the VCSEL etching process during extended marathon running (top) and particle count data (bottom). Lines indicate the acceptable limits.

OES detects the spectrum being emitted by excited species in a plasma. The spectrum produced can be analysed to detect particular components and how the concentration of those components change during the etching process. For a typical VCSEL structure the ratio in the concentrations of gallium and aluminium in the plasma are used to 'count' down through the structure as the epilayers are etched. The high uniformity and low footing of this process means that the same epilayer is being etched across most of the wafer. The concentrations of species in the plasma are representative of the layer currently being etched, therefore the OES trace is well defined throughout the etch. Fig. 3 shows the OES spectra for a process with high uniformity showing a well-defined signal and a lower uniformity process where the signal intensity drops off as multiple layers are being etching across the wafer. A well-defined signal means a reliable automatic endpoint can be set up.

The advantage of OES is that it is a fully-automated production friendly technique which monitors the whole wafer. The main alternative is in situ Laser Interferometry (LI), which uses the change in the interference trace of a laser reflected off the sample to track the etch. However, LI only tracks etching in one location on the wafer, requiring an open area in of ~60 µm^2 in the centre of the wafer and manual locating of the laser spot for every run.

Production style marathons were run to demonstrate the repeatably and low particle production of this process. The process was run for over 300 hours, etching 7450 µm of material and showing an etch rate and profile repeatability of <±3% (shown in Fig. 4) and footing <±1% of the etch depth. Particle measurements on 150 mm wafers during the marathon were consistently below 15 adders/wafer.

Conclusions

A high uniformity mesa etching process using chlorine- and nitrogen-based gas chemistry has been shown to produce a reliable and repeatable VCSEL mesa. The high uniformity and low footing allow automated OES to be used to monitor the etching, and to endpoint when the required layer is reached. Marathon experiments have demonstrated the long-term reliability and low particle production of this process.

References

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Acronyms

VCSEL: Vertical Cavity Surface Emitting Laser
LiDAR: Light Detection And Ranging
DBR: Distributed Bragg Reflector
PR: Photoresist
OES: Optical Emission Spectroscopy
LI: Laser Interferometry