In-situ etch-layer monitoring of GaN based laser diode structures

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By monitoring the light emitted from the etched atoms in the plasma above the sample, we show that it is possible to reliably determine the etch-stop-time for conventional GaN-based laser structure processing. This determination is based on the reduction in etch rate for aluminum containing cladding layers.

Introduction

Dry etching is conventionally used to form the physical structure for GaN based current injection laser diodes grown on sapphire substrates. Typically, a "mesa" structure is etched in order to reach the n-type material and make electrical contact. Optionally a narrower structure may be etched away from the mesa to form a "ridge" for lateral optical confinement. Several layers of varied compositions must be etched in order to reach the buried n-type GaN contact layer, as shown in Fig. 1.

Due to its very low composition selectivity, dry etching must be applied during a precisely established interval of time in order to stop in the desired layer. To determine the etch time for a laser process, the exact thickness and composition of each layer as well as the composition-dependent etch rates must be known. Such information is rarely accessible when processing a new experimental structure. Furthermore, the changes in the plasma chamber conditions with time due to contamination from the etch gas or from the etched material affect the overall rates in an unpredictable fashion. These accumulated uncertainties usually result in the sacrifice of portions of the laser wafer for parameter determination.

This problem can be avoided in principle if the layer being etched is known in real-time, so that irrespective of the etch rates, the process can be stopped in the desired layer. Such methods are routinely used in other material systems to automate the dry etching step in a process lines.

With such a goal in mind we attempted to determine the etched layer composition in-situ by measuring the light emitted from the plasma just above the sample. Although the results obtained and described below are empirical in nature, we show that such a technique can be applied in the etch process of laser structures.

Experimental setup

In order to limit the light detection as much as possible to emission from etched atoms, a view port of the reactive ion etching (Anelva L-201D-L RIE) chamber directly above the sample was used. The captured light was brought via a quartz optical fiber to a spectrometer and CCD detector (Hamamatsu Photonics Plasma Process Monitor C6670). The spectrum was visualized on a computer with less than one second delay from the time of measurement. 2nm resolution spectra from 300nm to 800nm could be visualized in real-time. The plasma gas was boron tetrachloride, at a pressure of 5 Pascal and flow rate near 10 sccm. The 13.56MHz plasma was maintained at 250W with 0% reflection. The bias voltage was not a controllable parameter and could not be measured on this instrument. The samples were square, and about 1cm by 1cm in dimension.

Measurement

Fig. 3 shows part of the measured spectrum with and without a GaN sample in the plasma chamber. Two peaks are clearly visible in the latter, one at 403nm and the other at 417nm, from etched gallium electronic transitions. Because of the low signal to noise ratio for this measurement, the effect of the varying plasma spectrum with time were minimized by subtracting the intensity of the plasma at 410nm from the peak intensity. Thus the relative intensity of the 417nm peak was monitored as a function of time during the etch process.

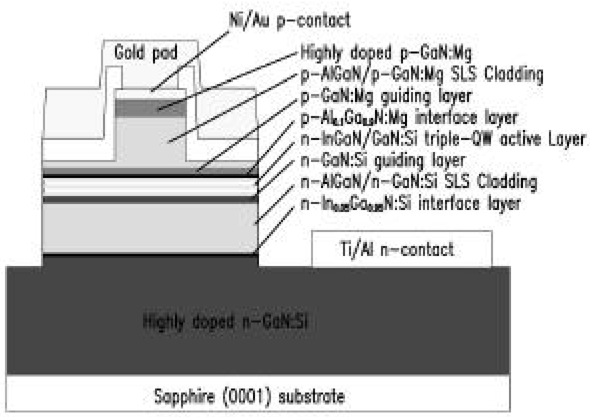

Fig. 1 Schematic cross-section of our laser diode showing the mesa and the narrower ridge structure. Also shown are the various alloys of varied thickness and etch rates, which must be controllably etched in order to reach the bottom n-type GaN for electrical contact.

Results and discussion

The trace obtained during etching of our laser diode mesa structure (Fig. 1) is shown in Fig. 2. The first obvious feature appeared when the metal contact layer had been completely removed and the top layer (p-type GaN) etch began. This could be confirmed visually. Next, a drop in intensity signaled the transition from GaN to the harder AlGaN p-cladding layer. Since the etch rate of aluminum containing layers is lower, so the amount of gallium in the plasma above the sample was reduced. The intensity increased again at the InGaN/GaN multi quantum well layer, but not to the initial level. This and the fact that the measured interface transitions were not as sharp as expected may be partially explained by a spatial non-uniformity in the etch rate. The etch process was stopped after the n-cladding layer was completely removed , after 35 minutes, signaling that we had reached the n-type GaN contact layer. Also the required time to etch the ridge structure could be readily obtained from the recorded data (in this case, 15 minutes).

Further applications of this monitoring were also implemented such as in-situ etch parameter optimization. For example by varying the plasma gas pressure to maximize the gallium peak intensity, while etching a sample of GaN, we could roughly maximize the etch rate in a single experiment.

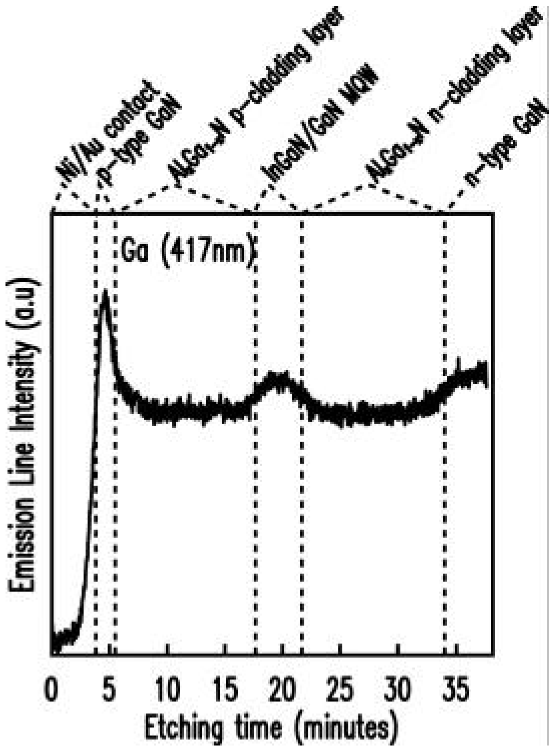

Fig. 2 Trace of the 417nm gallium emission line as a function of etch time for a laser structure.

Conclusions

A method for real-time control of dry etching of GaN based current injection laser structures grown on sapphire substrates has been demonstrated. From the drop in the etch rate of aluminum containing layers, resulting in a reduced intensity of the gallium light emissions in the plasma, we showed that the etch process could be reliably stopped in the n-type GaN contact layer. Furthermore, this process simultaneously provided the required etch times for further processing such as ridge structure formation. The applications of this technique are not limited to laser structures, as described briefly above. We are proceeding with other investigations that may result in further improvements and efficiency of the dry etching process.

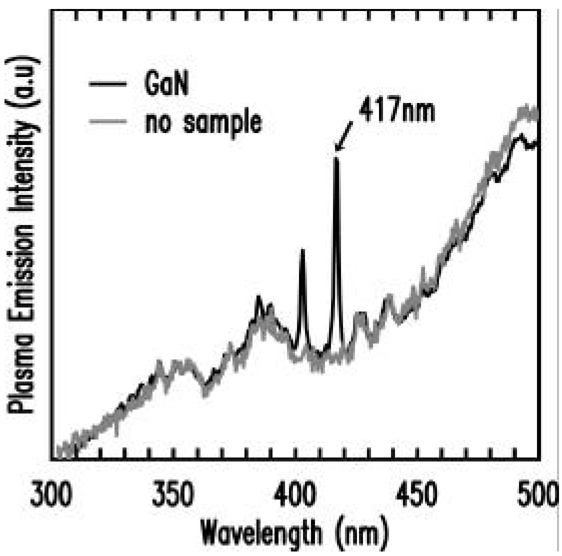

Fig. 3 The emission spectrum from the plasma above a sample of GaN during etching.

Acknowledgements

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