P-Type Contact Optimization in Nonpolar Gallium Nitride-Based Blue Lasers

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Abstract

Polar gallium nitride (GaN)-based blue lasers have been hindered by poor yields in their fabrication. Nonpolar GaN-based blue lasers, which are grown along a different crystal plane than polar GaN-based blue lasers, show great promise for increasing laser yields and lifetimes. They lack the polarized electric field inherent in c-plane GaN substrates. Continuous-wave (CW) operation of nonpolar lasers has been recently achieved, yet they are hindered by their low lifetimes relative to polar blue lasers. Initial measurements suggest that a large increase in lifetime can be realized by reducing the resistance across the p-type metal contacts of the laser. Contacts schemes were tested using a circular transfer length method (CTLM) structures. Significant improvements in the p-type contact resistance have been realized by optimizing metallization schemes, thermal annealing conditions, and doping levels.

Introduction

GaN and related materials have been around for over a decade and are extremely useful blue and near-UV light emitting diodes and lasers. Their uses include ultra high density optical storage, lighting sources, high resolution printing and advanced medical imaging applications [1].

Non-polar GaN substrates are inherently difficult to grow and appropriate metal contacts with work functions higher than p-GaN are difficult to find [2]. The metals are typically more difficult to deposit due to higher evaporation temperatures and consequently are less reliable. Experiments have shown that the majority of the resistance is across the p-type contact resistance, so they are the best candidate for optimization at this point. Typically contacts for polar p-GaN use some combination of platinum (Pt), palladium (Pd), and gold (Au) contacts. Research has also shown that the resistance can be significantly reduced by growing a highly doped, p^{++}, layer on top of the p-GaN just beneath the contacts [2].

Experiment

The p-GaN M-plane substrates were grown by Mitsubishi Chemical. The top 20 nm p^{++} layer was grown by metal-organic chemical vapor deposition techniques. The sample was then rapid thermally annealed at 750°C in nitric oxide (N_2O_2) for 15 minutes. Then 100 nm of silicon oxide (SiO_2) was deposited on top of the p-GaN as a protective layer during processing. The CTLM contacts were fabricated with standard photolithography techniques. The spacing varied between 5 μm to 100 μm. Then we used a 20 minute UV ozone de-scum followed by a 1 minute buffered hydroflouric acid (HF) wet etch and a 30 second hydrochloric acid (HCl) dip. The metal contacts were then put down with standard electron beam deposition techniques. The liftoff was preceded by a 30 second sonication in 70°C deionized water. Depending on what contacts we were making, we would repeat the process to make a set of 100-250 nm gold pads on top of the contacts to protect them during testing. Then I-V curves were obtained for three sets of CTLM's on each sample using a standard 2-probe arrangement. The data was aggregated and the contact resistances were determined at the 250 μA current level.

Results and Discussion

Figure 1 shows the specific contact resistivity as a function of the bis-cyclopentadienylmagnesium (CP_2Mg) flow rate (in standard cubic centimeters). The flow rate of the dopant gas during the metal-organic chemical vapor deposition (MOVCD) process

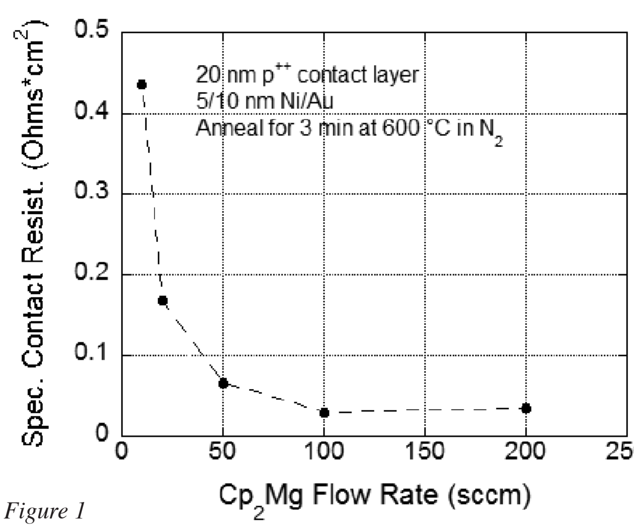

Figure 1

was varied for different samples. 100 sccm was found to be the ideal flow rate. More research is needed to optimize the specific contact resistivity between the 100 and 200 sccm flow rates. With the Ni/Au contacts in the first sample run the I-V curves were found to be considerably non-ohmic, and the resistances and several orders of magnitude higher than the literature on C-plane contacts suggested they should be.

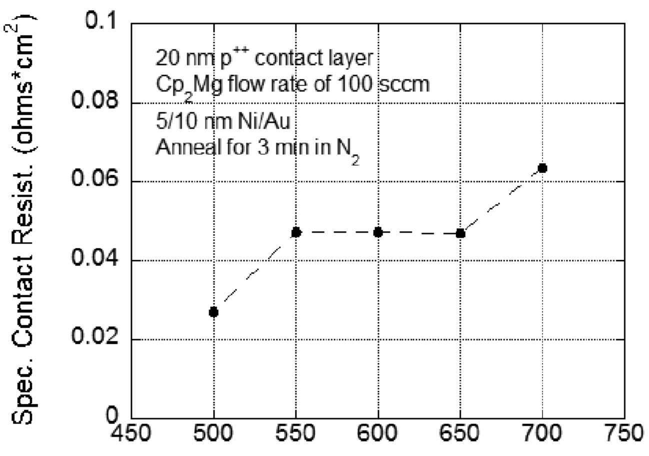

Figure 2

Then the anneal temperature of the Ni/Au contacts themselves was varied (Figure 2). We found considerable difference across the anneal temperatures. We still kept the original anneal temperature for the p-GaN the same for each sample. The overall numbers were around the same order of magnitude as the previous flow series. The I-V curves were slightly more linear, but still far from ohmic. However we determined that the nickel was perhaps not the best metal for the contacts and then varied the metallization scheme for the contacts.

The metallization scheme proved to be our most significant. We found that different metals provided an order of magnitude decrease in contact resistivity. We tried using metals with higher work functions since those seem to have lower contact resistance. The Pt/Pd/Au (7/7/100nm) proved to be the best scheme (Figure 3). Not only was the resistance lower, but most of the I-V curves were nearly perfectly ohmic. At higher spacing the curves were more linear, but at the lower spacing (5 to 10 μm) the curves looked slightly like a p-n junction I-V curve. We later tried several variations of the Pt/Pd/Au scheme and were able to optimize the thickness as well.

Contact Metals	Specific Contact Resistivity (Ω*cm^2)
Pt/Pd/Au	***0.0051***
Ni/Au Annealed in N_2 O_2	0.0106
Ni/Au Annealed in N_2	0.0115
Pd/Au	0.0497
Ti/Au	0.1306

Figure 3

Summary

We found an optimum metal scheme and thickness for the contacts. We also optimized the surface treatments and wet etching processes. Our best contacts were nearly ohmic and the calculated specific contact resistivities were on the order we hoped for. We still have some work to be done with optimizing the flow rate and doping levels of the top p^{++} layer of the p-GaN, but the improvements made so far should give an order of magnitude increase in the laser lifetime and efficiency of the next batch of fabricated lasers.

Acknowledgements

I would like to thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program for their funding and support, as well as everyone in the Nakamura research group at UCSB, especially Robert Farrell.

References

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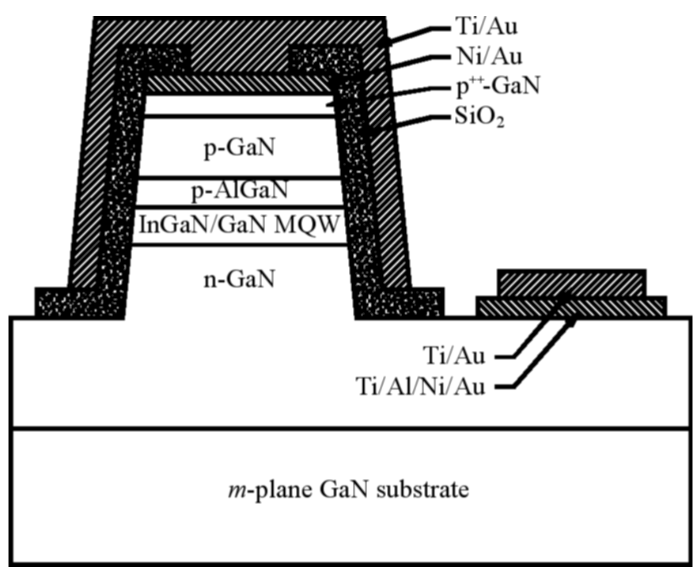

Figure 4: A cross sectional view of the laser [1].