Nanoscale Light Emitting Diodes with Tunable Emission Colors

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Abstract:

Indium gallium nitride/gallium nitride (InGaN/GaN) nanopillar arrays of different diameters were formed in a green multiple quantum well (MQW) light emitting diode (LED), Figure 1. Using a top-down approach, the fabricated nanoLED was able to achieve multiple color emissions using strain engineering from the same InGaN active region. During the etchback of the spin-on-glass (SOG), using $SF_6/C_4F_8/Ar$ gas, the tip of the nanopillar, made of p-type GaN, was exposed using inductively coupled plasma. Consequentially, the electrical properties of the p-GaN deteriorated, e.g. the turn-on voltage and contact resistance increased. In order to optimize the nanoLED, a recovery treatment is necessary to restore the damage induced. We report on damage recovery by means of wet chemical treatments and rapid thermal annealing (RTA) on planar p-GaN test samples. We measured the contact resistance using rectangular and circular transmission line methods (TLM) to determine which treatment can be used to optimize the fabrication of the nanoLED. The results demonstrated that for our sample boiling potassium hydroxide (KOH) yields the most improvement in resistance. However, KOH does not fully restore the sample. We concluded that the combination of chemical treatment and annealing is necessary or a different dry etching scheme has to be developed to minimize the plasma damage.

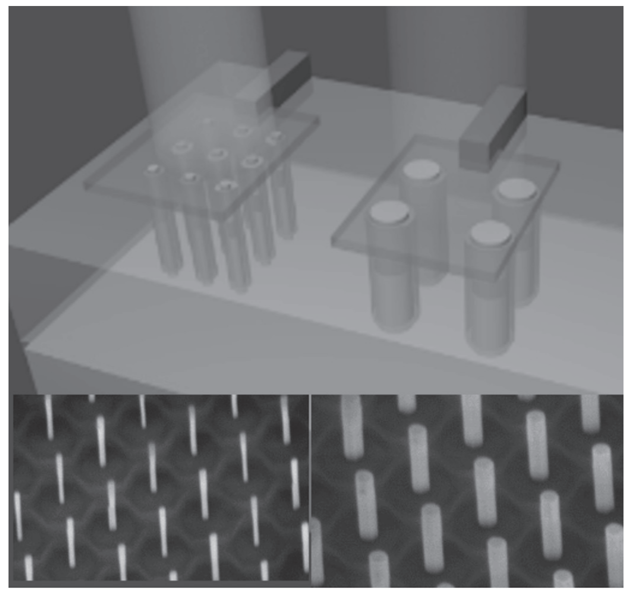

Figure 1: Top, nanoLED and bottom, SEM images of different nanopillar sizes.

Introduction:

InGaN/GaN nanopillars have been studied and used in the fabrication of multiple color pixels LEDs in a single chip [1]. This nanoLED is suitable for micro display applications, lighting and sensors. The InGaN nanopillar structure is used over planar structure because of its advantages: improved internal quantum efficiency and light extraction efficiency of photonic devices, enhancement in emission intensity and improvement in decay rate. To form p-GaN/metal contact on nanopillars, one common method is to planarize the sample surface by spin-on-glass or polymer materials, such as polyimide. After planarization, dry etching is required to expose the p-GaN, however, it induces damage on the GaN surface. Using hydrogen chloride (HCl), KOH, and molten KOH, the wet chemical treatment can etch the damaged layer formed by the dry-etch process. RTA provides thermal energy that results in dopant reactivation and repairs surface damage from ion bombardment. The TLM is a technique used to calculate the contact resistance used to compare the restoring methods [3]. For this experiment, we calculated the specific contact resistance instead because the contact resistance depends on the size of the contact, which provides a bad comparison.

The technique involved making a metal test structure deposited in the planar p-GaN sample. The pattern deposited was separated by various distances, Figure 2. A voltage was applied between the metal contacts and the total resistance of each separation was calculated.

As a result, one can plot a linear graph of total resistance vs. spacing, which then can be used to calculate the specific contact resistance, Figure 2. The purpose of having two

Optics & Opto-Electronics

patterns was that the current from the rectangular contact was not uniform [3].

TLM Pattern Fabrication/Experiment Procedure:

The nanoLED detailed top-down fabrication is clearly described elsewhere [1]. The TLM pattern fabrication procedure is as follows; first, the planar p-GaN sampled were intentionally damaged, followed by the restoring method. Then the samples were patterned via photolithography and a Ni/Au layer was deposited, 8 nm each. Then the sample was oxidized Ni/Au layer. The final thickness was 10/200 nm respectively.

For the first experiment, the samples were tested for the wet chemical treatment method. The samples were individually soaked; at room temperature HCl:H_2O (1:1), boiling HCl:H_2O (1:1), and boiling KOH:H_2O (1:1) solutions for ten min. From the current-voltage (IV) curve, KOH showed an improvement.

For the second experiment, a higher concentration of KOH was investigated, i.e., molten KOH. A sample was also tested for the RTA method at 600°C in nitrogen ambient.

Finally, the specific contact resistance was measured using Keithley 4200, a semiconductor characterization system.

Results and Conclusion:

Molten KOH, boiling KOH and annealing treatments on planar structure p-type GaN samples improved the specific contact resistance, Figure 3.

The calculated value of the circular and rectangular pattern of the intact sample were 0.042 and 0.788 Ω-cm^2, respectively. The calculated value of the boiling KOH circular and rectangular pattern were 0.640 and 7.53 Ω-cm^2, respectively. The difference between the rectangular and circular patterns' corresponded to the current not flowing uniformly. The calculated value of the damaged sample, although inaccurate, was 130,000 Ω-cm^2 and demonstrated that when the sample was damaged it was almost not conducting.

In other experiments, HCl has been used to effectively etch surface oxide, such as gallium oxide (Ga_2O_3) on a GaN layer formed by a dry etch process [4]. HCl showed no improvement, a possible reason being that the oxide layer was not formed with the plasma species used in these experiments.

Prior to these experiments, the nanoLED was annealed and it showed an improvement, Figure 4. Our results showed that none of these processes fully restored the sample. In future work, boiling KOH and annealing can be combined as a restoring method. Another alternative is to substitute SOG by polyimide. This polymer can be dry-etched using an oxygen gas species. The restoration from an oxygen based plasma can be easier than fluorine based plasma.

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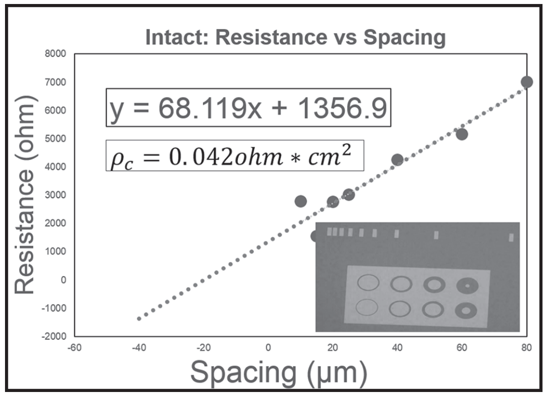

Figure 2: Total Resistance vs Spacing. TLM pattern.

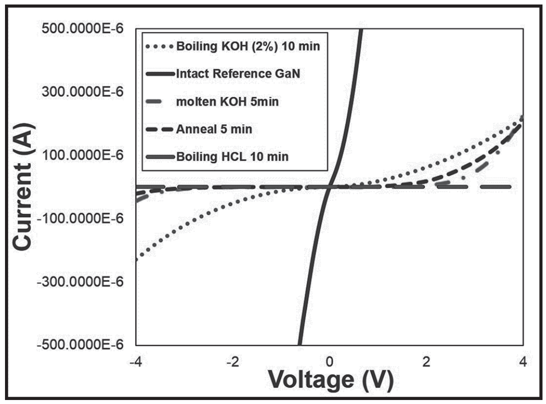

Figure 3: Recovering method.

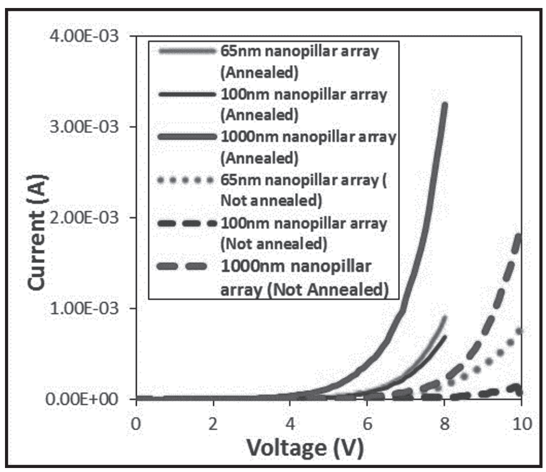

Figure 4: Annealed recovering method on nanoLED.

References:

[1] Teng, Chu-Hsiang, et al. In CLEO:Science and Innovations, pp. SF2G-4. Optical Soc. of America, 2015.

[2] Zhang, Lei, et al. Applied Physics Letters. 104, 5, 051116-1-051116-5, 2014.

[3] Klootwijk, et al. Proceedings of the 2004 International Conference on Microelectronic Test Structures, 2004.

[4] I. Shalish, et al. Appl. Phys., 89, 390, 2001.