Ohmic n-contacts to Gallium Nitride Light Emitting Diodes

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Abstract:

Efficient light emitting diodes (LEDs) seek to minimize input power while maximizing optical output power. To minimize input power, the total voltage drop across the LED should be reduced. Significant loss occurs at metal-semiconductor junctions where electrical contact is made to the diode. This experiment studied different methods of minimizing the voltage drop across the LED. The p-contact on our device is made of indium tin oxide (ITO), which cannot tolerate annealing temperatures of 650°C or more [1,2]. The titanium aluminum gold (Ti/Al/Au) triple layers we use have been demonstrated to be effective n-contacts, but require annealing temperatures upwards of 750°C [3]. Therefore, our Ti/Al/Au contacts have been left unannealed, resulting in Schottky diode-like behavior of the junction.

Experimental Procedure

To improve the quality of the contact behavior, two contact schemes and methods of treating the n-type gallium nitride (GaN) surface were tested. The Ti/Al/Au scheme was compared to a copper germanide (Cu_3Ge) scheme. Cu_3Ge contacts to n-GaN can be annealed at temperatures within the tolerance of ITO [4]. Hydrogen chloride (HCl)-based wet etches are effective at removing native gallium oxides (Ga_xO_y) [5]. Lastly, etching the n-GaN surface by reactive ion etching (RIE) has been demonstrated to both improve ohmic behavior of the contact and decrease contact resistance [6]. The effect of annealing temperature on the Cu_3Ge contact scheme was also examined, but is not presented here.

Ohmic behavior and contact resistance were determined using the transmission line method (TLM). We used quarters of 2-inch Al_2O_3 wafers with epitaxial LED layers grown by metal-organic chemical vapor deposition (MOCVD). Before processing, the n-type GaN layer was exposed using an inductively coupled plasma etch to simulate etch damage that occurs during regular LED processing.

Sample	n-GaN treatment	Contact Scheme	Annealing Conditions
A	HCl	Ti/Al/Au	Unannealed
B	HCl	Cu_3Ge	550°C
C	RIE, 110W	Cu_3Ge	550°C
D	RIE, 170W	Cu_3Ge	550°C

Table 1: Contact scheme and surface treatment combinations.

Contact Deposition

Contact schemes and surface treatments were distributed across samples according to Table 1. Contact metals were deposited by electron-beam evaporation. Ti/Al/Au layer thicknesses were 200/600/3000Å. The Cu_3Ge contact scheme was deposited as Ge/Cu/Ge:400/970/400Å. This 30 at.% Ge composition has been observed to yield the low-resistivity ε_1-Cu_3Ge phase after annealing [7]. Cu_3Ge annealing was performed in a rapid thermal annealer at 550°C for 10 minutes in N_2 with a flow rate of 5 sccm. Ti/Au (200/3000Å) contact pads were then deposited on top of all n-contacts. The final step was to isolate the TLM patterns by etching around them through the n-type GaN to the Al_2O_3 substrate. The width of the resulting structure was 100 μm and the depth was 3.6 μm. Contact dimensions were $94 \times 50\ \mu m^2$, and the TLM spacings varied from 5 μm to 40 μm.

Surface Treatment

n-GaN HCl immersion and RIE treatment were examined for their effect on ohmic behavior and contact resistance. Because these treatments affect only the n-GaN and not the contact, the resultant relative improvements in electrical performance are expected to be independent of the particular contact scheme. Therefore, these surface treatments were only tested on the Cu3Ge contact scheme. HCl treatment was performed by immersion in a HCl:DI 1:3 solution for 1 minute at room temperature. RIE dry etch was performed in $SiCl_4$ with a flow rate 10 sccm. Chamber pressure was 25 mTorr, and the etch depth was 50 nm into the n-type GaN. The samples were not temperature controlled during the RIE etch.

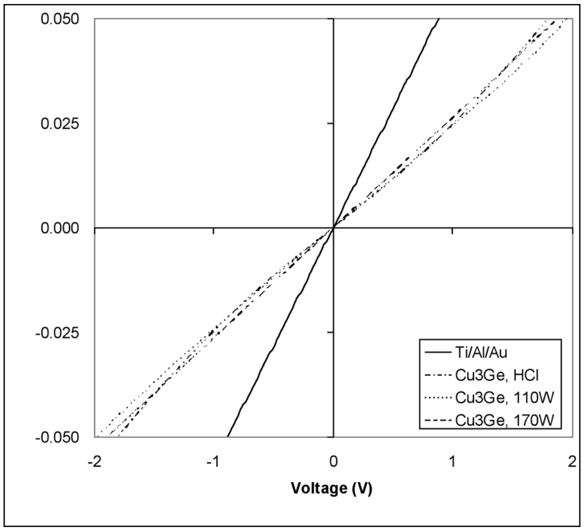

Figure 1: Current-voltage characteristics for different Cu_3Ge contacts on n-GaN.

Surface Treatment and Contact Scheme Results and Discussion

As can be seen in Figure 1, the behavior of Samples A and D were closest to ohmic. There are several possible explanations for ohmic behavior in samples. One is the removal of surface oxides and other types of surface scum that tend to accumulate during LED processing. In the case of the Sample A, the removal of gallium oxide by HCl etching is believed to be responsible for forming an ohmic contact. However, HCl immersion alone did not produce ohmic behavior in the Cu_3Ge-based samples. The emergence of ohmic behavior only after RIE treatment indicates other mechanisms besides oxide removal.

Schuette and Lu present evidence that RIE creates both Ga and N vacancies, but Ge preferentially diffuses into N vacancies and behaves as a donor, increasing the level of n-doping of the GaN [6]. $SiCl_4$ may also decrease the length of the electron depletion region [4]. Another possibility is that the RIE treatment helps remove etch damage caused by previous etching.

Figure 2 compares the contact resistances of the samples. The contact resistance of unannealed Ti/Al/Au was calculated to be ~ $1.8 \bullet 10^{-4}$, less than half that of Cu_3Ge when both samples are treated only with HCl. However, it can be seen that RIE treatment dramatically reduced the contact resistance of the Cu_3Ge contacts.

Conclusions

Schuette and Lu show that RIE treatment reduces the length of the depletion zone in n-GaN [4]. Thus, the relative improvement of the Cu_3Ge contact with RIE surface treatment should be true regardless of contact scheme. Ti/Al/Au contacts will be used for further experimentation with RIE because of their superior performance compared to Cu_3Ge in the HCl control test. Lastly, the data indicate that there is a need to optimize RIE etching power for ohmic behavior and low contact resistance.

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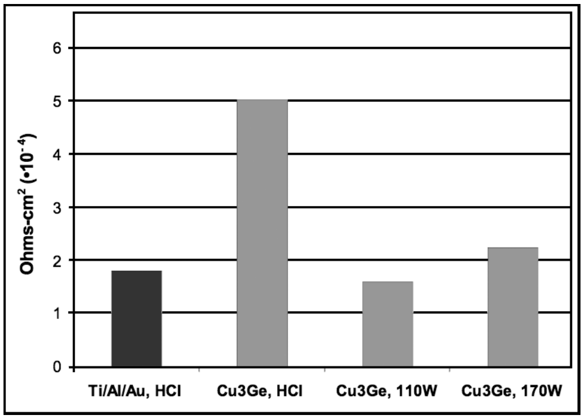

Figure 2: Specific contact resistance for different treatments.