

Ti/Al/Ni/Au Ohmic Contacts on AlGaIn/GaN HEMTs

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Abstract

Optimization of the ohmic contacts in an n-AlGaIn high electron mobility transistors (HEMT) structure is presented. The method used was similar to that reported in [1]. In this case four different metal stacks were present in a single wafer. The metal stacks were optimized for different vendors. The results from the optimization are presented.

INTRODUCTION

There is an emphasis being placed on the development of GaN-based Field Effect Transistors (FET) for power applications such as cellular base stations and military radar applications. This novel device technology is still far behind GaAs-based FET devices. In order for these devices to be used in MMIC manufacturing of power amplifiers, repeatable device parameters are required. Due to the immaturity and non-uniformity of the substrate and epitaxial material, individual measurements of device and process parameters are not sufficient in determining process conditions.

PROCESS

In order to accommodate 4 metal stacks, and be able to track how ohmic contacts varied with material uniformity a high-density mask was designed. The mask allowed for four different metal stacks per reticle. This technique can be used to determine which metal stack and alloy conditions would yield the best ohmic contacts on a single wafer. The process control structures measured in this experiment were traditional linear TLM, cross-bridge and Van der Pauw structures, for contact resistance, metal sheet resistance and active layer sheet resistance measurements, respectively. All processing included mesa isolation. Once the wafer was patterned with the four metal schemes, it was diced into quadrants and alloyed at different temperatures. This experiment was repeated with different epitaxial material suppliers.

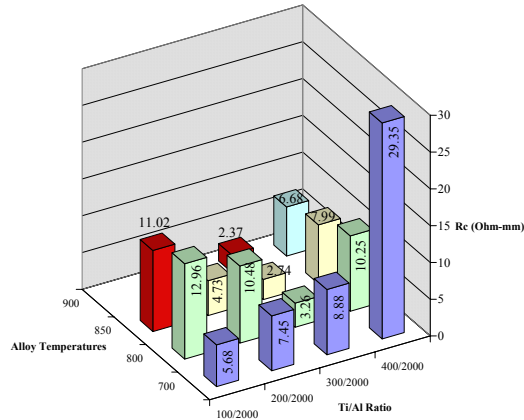
For comparison we used as a baseline our 4 layer metal stack, Ti/Al/Ni/Au with 100/2000/500/200 Å respectively, alloyed at 850 °C for 30 sec. Since the temperature at which the contact resistance reaches a minimum may vary, a full

curve (temp vs. contact resistance) for each metal variation is needed [1,2]. Four points will be used for the curve. The structures tested were regular HEMT structures consisting of a 2 μm thick semi-insulating GaN buffer, grown on sapphire by MOCVD. This layer was followed by an unintentionally doped AlGaIn layer. The structures were created by mesa isolation using a low damage RIE etch. The alloy was done in an N₂ atmosphere for 30 sec, unless otherwise noted.

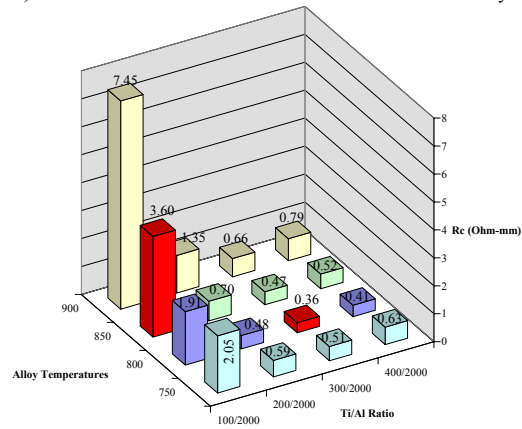
The optimization of the metal stack is divided into two portions. First will be the optimization of the Ti/Al ratio and thickness. This ratio is responsible for the formation of the ohmic contact by partially consuming the semiconductor [3, 4]. After this reaction a thin layer of AlN, TiN, or AlTi₂N has been shown to be present at the interface. This creates a high n-type region underneath the contacts, believed to be generated by nitrogen vacancies. The optimum ratio is obtained by starting from the baseline metal stack and incrementing the Ti thickness in 100 Å increments. Fixing the ratio, the Ti/Al thickness is varied for further optimization. The second portion of the experiment is the optimization of the Ni/Au ratio and thickness. The Au is used to prevent the oxidation of the Ti/Al, but it diffuses towards the semiconductor causing degradation of the ohmic contact. To prevent this, a Ni, Pt, or Ti metal layer is used as a barrier [3]. It has also been shown that this ratio affects the contact resistance [1]. To obtain the optimum ratio for this portion of the experiment, the Au thickness will be initially incremented until an optimum Ni/Au ratio is found. While maintaining the optimum Ni/Au ratio, the Au thickness will then be varied until an optimum thickness is found. While working with the Ti/Al portion of the experiment, the Ni/Au ratio and thickness will be maintained at the baseline level. However, when experimenting with the Ni/Au portion the Ti/Al portion will be maintained at the optimum conditions found above.

RESULTS

Once all four metals were deposited the wafer was quartered and alloyed. The TLM spacings were measured using a high-resolution microscope and tested on an automatic Keithley probe station. For analysis purposes the data in which the TLM method showed a correlation



a) Source A.1 wafer 1 with 20% Al and 250 Å AlGaIn layer



b) Source B.1 with 30% Al 230 Å AlGaIn layer

Figure 1. Contact resistance as a function of Ti/Al ratio.

coefficient of 0.999 or better were used. The statistical median was used to represent the filtered data. The results of the optimization of the Ti/Al ratio are presented in Figure 1. The optimum Ti/Al ratio was determined to be 300/2000 for both material vendors. Material coming from source A had a of 4.6 factor improvement while material from source B had a factor of 10 improvement over the baseline performance. The temperature at which the contact resistance reached a minimum was different for each material source. For source A.1 (the # is used to refer to the wafer sequence for the experiment) the optimum temperature was 900 °C while for source B.1 was 800 °C. A sample wafer map is shown in

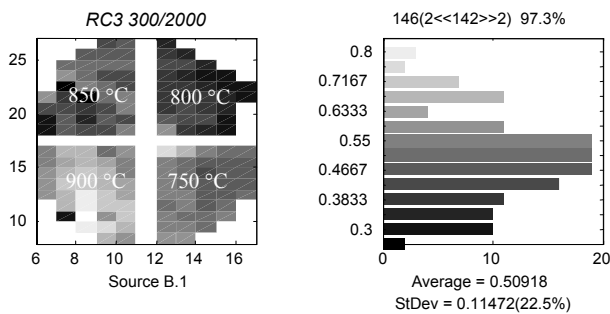
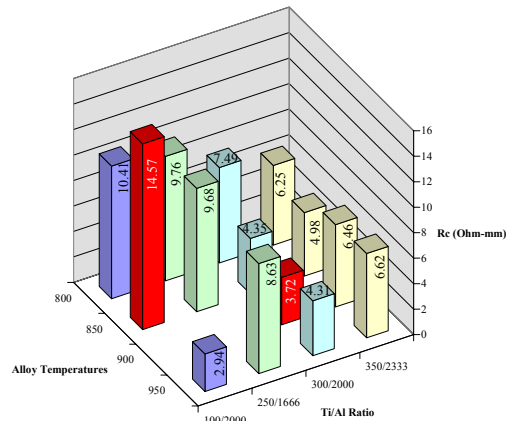


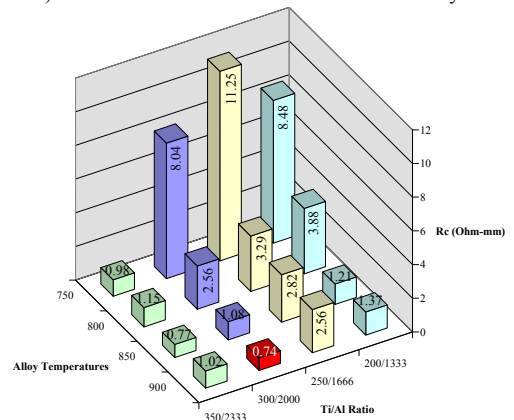
Figure 2. Wafer map for source B and Ti/Al ratio of 300/2000

Figure 2 for source B.1. The wafer map shows how the four wafer quarters were alloyed and the distribution of contact resistance across the wafer. The values in the map were unfiltered.

The results of the thickness variation with the optimized fixed ratio are shown in Figure 3. For material source A.2, the baseline metal stack resulted in better contacts at 950 °C. However, there was only one site that had a correlation coefficient of 0.999 or better, as shown in Figure 4, thus was discarded. Again the 300/2000 Ti/Al ratio alloyed at 900 °C displayed the minimum contact resistance. For material source B.2 the Ti/Al ratio of 300/2000 was also the best however, the temperature at which the minima occurred increased from 800 °C to 900 °C. There was a variation from wafer to wafer that affected the temperature where the minima occurred. The active layer sheet resistance showed the variations between wafers even from the same material source, see Figure 5. This variation is suspected to be responsible for the temperature difference in which 300/2000 obtained a contact resistance minimum in Figure 1 and Figure 3. Analyzing yield, the percentage of available sites with a TLM correlation coefficient of 0.999 or better, as a function of temperature and metal ratio and thickness

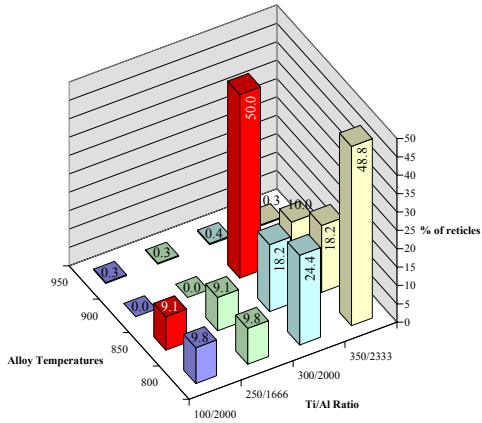


a) Source A.2 with 20% Al and 250 Å AlGaIn layer

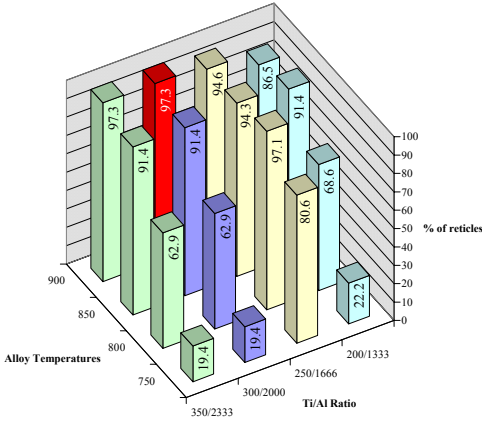


b) Source B.2 with 30% Al 230 Å AlGaIn layer

Figure 3. Contact resistance with Ti/Al ratio fixed and varying the thickness

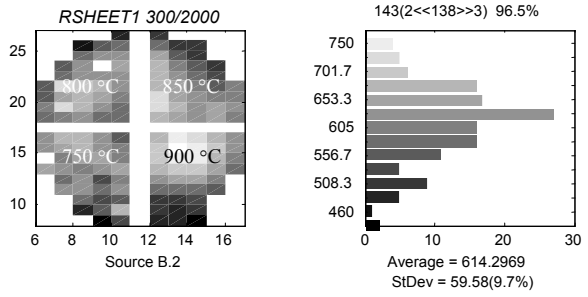


a) Source A.2

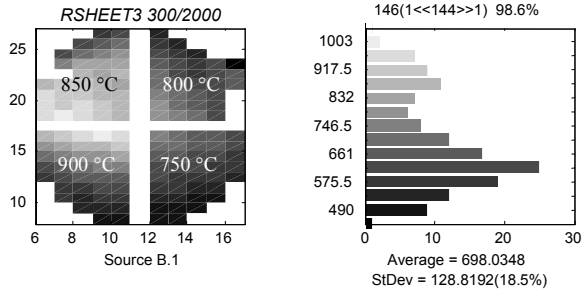


b) Source B.2

Figure 4. Percentage of sites with a TLM fit of 0.999 or better



a) Ti/Al thickness variation



b) Ti/Al ratio variation

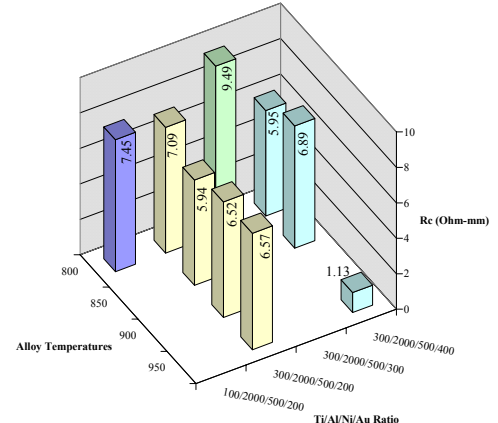
Figure 5. Active layer sheet resistance for wafers B.1 and B.2

we see a sweet spot in the temperature range from 800 °C to 900 °C. The baseline metal stack showed considerable increase of ohmic contact resistance at 900 °C.

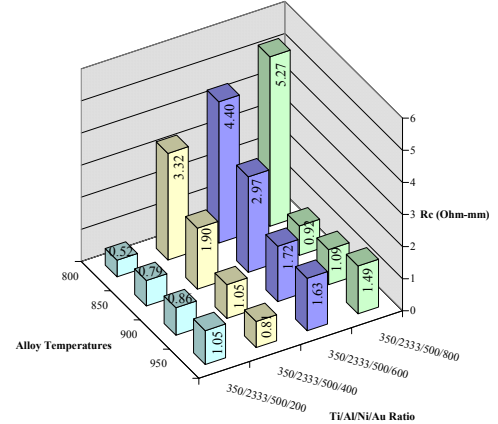
The variation in the Ni/Au ratio source A.3 was inconclusive due to the low yield, see Figure 6. For material source B.3 the Ti/Al ratio used was 350/2333, due to it's low contact resistance over a range of temperatures, see Figure 3 b). The minima appears to be around 850 °C. Increasing the Au thickness seemed to increase the contact resistance initially. But for Au thickness of 800 Å the contact resistance was reduced. Further experiments need to be done to see if the contact resistance can be reduced even further using thicker Au.

CONCLUSIONS

Through this study an improvement of contact resistance was obtained, independent of the material source. The amount of improvement obtained depends on the source of the material. Also, the optimum metal stack and alloying conditions varied depending on the source of the material. Even wafer-to-wafer variation from the same source would skew the optimum recipe. Possible variations that would



a) Source A.3



a) Source B.3

Figure 6. Contact resistance as a function of Ni/Au ratio

influence the contact resistance would be variations in the Al concentration and thickness of the AlGaN within the wafer and from wafer-to-wafer. Also, it is suspected that different HEMT structures would have their minima at different ohmic contact recipes. Even one particular HEMT structure could have multiple localized minima's with either one or multiple global minima. This is inferred by different ratios of Al/Ti reported in other papers such as in reference [5].

For the present study a minima was found in the ratio of Ti/Al of 0.15. For material source A the Ti thickness was chosen to be 300 Å. For material source B the Ti thickness was chosen to be 350 Å, although it didn't have the minimum contact resistance. A small increase in contact resistance was traded for a lower alloy temperature, 850 °C.

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ACRONYMS

HEMT: High Electron Mobility Transistors
MMIC: Monolithic Microwave Integrated Circuit
TLM: Transfer Length Method