DESIGN, TECHNOLOGY AND CHARACTERIZATION OF GALLIUM NITRIDE BASED HIGH POWER HETEROSTRUCTURE FET FOR MICROWAVES[1]

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ABSTRACT

The paper discusses the development of compound elements like AlGaN/GaN, power amplifiers. The paper is on the optimization of the Ti/Al/Ni/Au metallization scheme on a doped AlGaN/GaN FET structure. With systematic investigation the contact resistance was reduced to 0.2 mm ($7.3x10^{-7}$ cm^2) for Al/Ti thickness ratio of 6. For this thickness ratio, as per Al-Ti binary phase diagram, it does not result in excess Ti which should react with nitrogen in the AlGaN layer to render the surface heavily doped. If prior to metallization, RIE oxygen plasma in combination with a NH4OH dip is performed, it indicates an improvement in the reverse leakage current.

INTRODUCTION

Towards the development of high-power amplifiers, the utmost importance lies on discrete HEMTs, along with it the matching circuitry is also very important. Amplifiers can be realized either in a hybrid fashion, or in a monolithic fashion (MMIC) with all the elements on the same substrate. The aspects of CPW[6,7] and contacts are important issues in the development of compound elements like AlGaN/GaN, power amplifiers. The following section discusses about the aspects of contacts in the development of compound elements like AlGaN/GaN, power amplifiers.

METAL-SEMICONDUCTOR CONTACTS

Introduction

Till now the researchers present only the final results and not the optimization procedures on low contact resistances and Schottky contacts with low leakage current [1-5]. These two types of contacts are important aspects of AlGaN/GaN FET's influencing gain and thermal behavior. The paper talks on both procedures and results of Ti/Al/Ni/Au.

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Optimization Procedures and Results for Ohmic Contacts

Two identical HEMT wafers consisting of a sapphire substrate, a 40 nm AlN buffer layer, a 2 µm non- intentionally doped (n.i.d.) GaN layer, a 3 nm $Al_{0.25}Ga_{0.75}N$ separation layer, a 10 nm $Al_{0.25}Ga_{0.75}N$Si-doped donor layer ($1.0\times10^{19}cm^{-3}$) and a 5 nm n.i.d. $Al_{0.25}Ga_{0.75}N$ contact layer were used. The structure had a sheet resistance of 550 Ω/sq. For cleaning ultrasonic acetone agitation followed by an isopropanol rinse was used. Samples were loaded in the e- beam evaporator without any additional cleaning or acid treatments after the photolithography. The Ti/Al/Ni/Au metallization scheme with different metal thickness ratios and thicknesses were used. Contact parameters were measured using a circular Transmission line model geometry.

By systematically changing the metal composition of the metallization scheme the effect on contact resistance was seen. First the optimal Al/Ti thickness ratio was required to find out. In [1, 2] it was revealed that an excess of Ti can react with the nitrogen of the AlGaN layer rendering the surface highly doped facilitating a tunneling contact. For the Al/Ti thickness ratio of 2.82 for the alloy, the Al/Ti binary phase diagram predicts the formation of Al_3Ti for annealing temperatures above 300 ^{0}C [1]. Thus, below 2.82 results in excess Ti, the results are shown in fig.1. The fig.2 shows several different Al/Ti thickness ratios which was tested. The optimal Al/Ti thickness ratio of 6 was used and tried to find the optimal thickness of the Ti layer (figure 2).

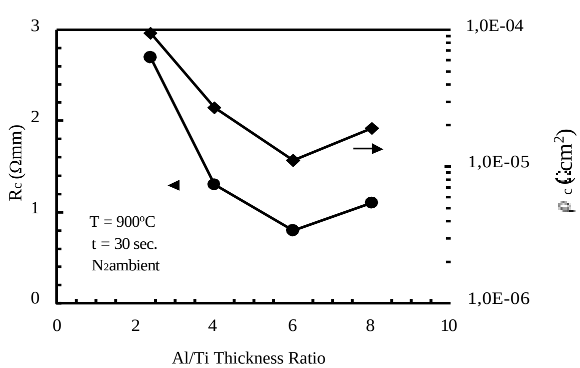

__Figure 1:__ Contact resistance vs. Al/Ti thickness ratio.

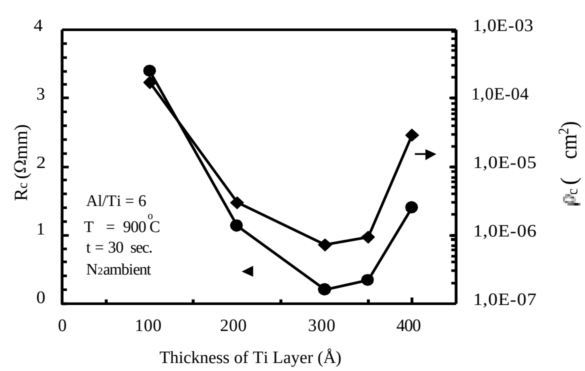

__Figure 2:__ Contact resistance vs. thickness of the Ti layer.

Finally, to optimize the Ni-Au combination was obtained, where the total thickness of the Ni-Au was kept constant at 1900 Å fig. 3. The conclusion was that by selecting the correct Ni thickness is important, although this layer only act as a diffusion barrier. In the above steps RTA step for30 seconds at 700, 800, 900 and 1000 ^{0}C for each sample (sample cleaved into 4 pieces) under N_2 ambient was used. The best annealing conditions for each sample were 30 seconds at 900 ^{0}C. All these optimization steps led to the following metallization scheme: Ti (300Å) Al (1800 Å) Ni(400 Å)Au(1500Å).A more detailed optimization of the annealing conditions is illustrated in fig.4, which showed the same result. The optimization detailed above resulted in a contact resistance of 0.2mm (7.3x10^{-7}cm^{2}).

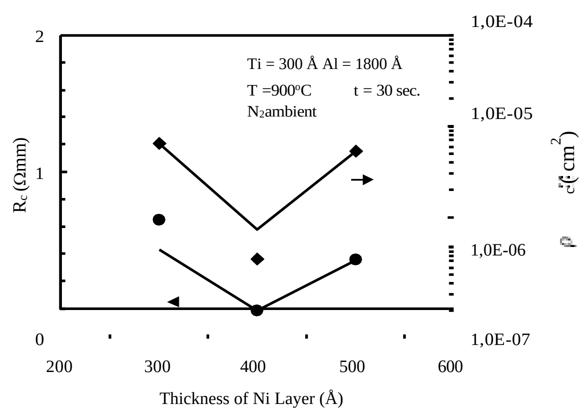

Figure 3: *Contact resistance vs. thickness of the Ni layer.*

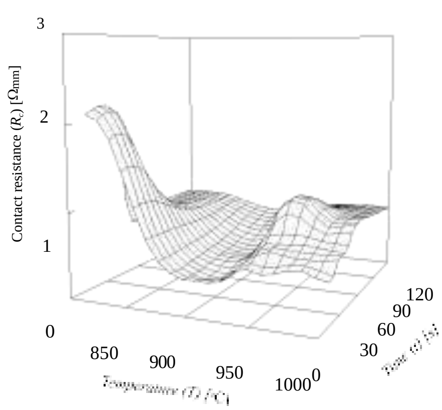

Figure 4: *Contact resistance for different RTA temperatures and times under N_2 ambient*

Schottky contacts

Circular Schottky diodes (area=1x10^{-4} cm^2) were made on the same wafers. The initial investigation was focused on optimizing the Ni/Au (200/2000 Å) contact in combination with the optimized Ti/Al/Ni/Au ohmic contact. The following pre-metallization treatments was done: as grown, diluted HCl dip, diluted NH4OH dip, RIE O2 plasma, RIE O2 plasma + diluted NH4OH dip, RIE O2 plasma + diluted HCl dip. The O2 plasma was done at 20 W giving a self-bias of –70 V. The (I-V) data for these experiments are depicted in figure 5. The O2 plasma followed by a diluted NH4OH dip showed the best results. The reverse current is relatively constant up to the breakdown voltage, which exceeds 100 V for a spacing of 5 m. The large reverse current is probably related to the doping used in the structure. (C-V) measurements conducted at 1 MHz showed a non-linear trend in the charge control region fig.6, which predicts a capacitance of 45 pF. This deviation may be related to the small area/edge ratio of the contacts.

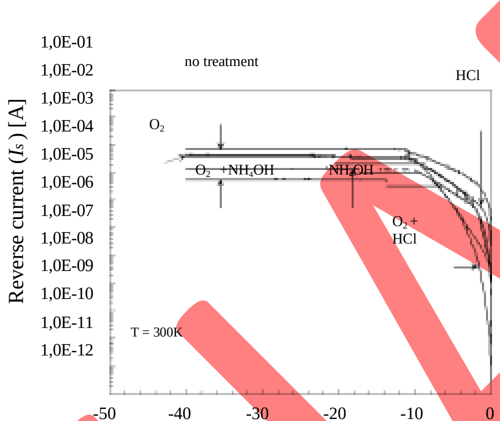

***Figure 5:** Reverse characteristics ofa Ni/Au diode fordifferentpre-treatments.*

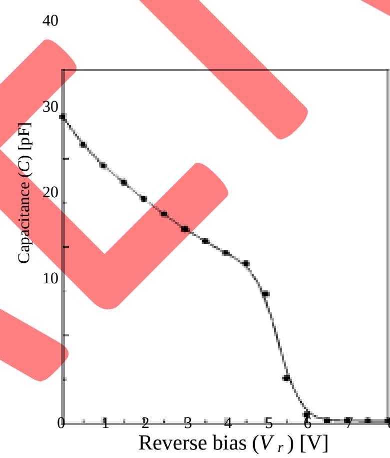

***Figure 6:** Reverse C-V characteristics fora Ni/ Au diode with O_2 plasma + NH_4OHdip.*

CONCLUSIONS

This paper presented the optimization procedure for reducing the contact resistance for a Ti/Al/Ni/Au metallization scheme on a doped AlGaN/GaN FET structure with a sheet resistance of 550 /sq. Ti(300 Å)Al(1800 Å)Ni(400 Å)Au(1500 Å) annealed for 30 seconds at 900 ^{0}C in a N2 ambient resulted in a contact resistance of 0.2 mm (7.3x10^{-7} cm^2). The Ni/Au Schottky contacts made on the same material showed high leakage currents probably related to the doping.

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