AlInN/GaN HEMTs on SiC and on Silicon with Regrown Ohmic Contacts by Selective Ammonia MBE

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ABSTRACT
Low-resistance Ohmic contacts are fundamental performance enablers in millimeter-wave wide bandgap GaN-based HEMTs. Whereas conventional AlGaN/GaN HEMTs already prove challenging, the higher Aluminum content and wider bandgaps associated with AlInN or AlN barriers pose an even greater manufacturing challenge to achieving repeatable low-resistance Ohmic contacts. We report the realization of AlInN/GaN HEMTs on semi-insulating SiC and high-resistivity Silicon (HR-Si). Both substrate types offer excellent maximum oscillation frequencies exceeding f_{MAX} and attractive large-signal properties in W-band (94 GHz).

1. INTRODUCTION

Low resistance Ohmic contacts are of primordial importance to the realization of short gate length HEMTs as shown by the classic work of Hughes and Tasker for AlGaAs/GaInAs HEMTs [1]. The important impact of Ohmic contacts in GaN HEMTs was first pointed out by DiSanto *et al*. [2,3] who pointed out for the first time that much faster GaN HEMTs could be achieved if Ohmic contacts could be improved. The ultimate demonstration of this line of thought was given in the work of Shinohara *et al.* who achieved cutoff frequencies f_T / f_{MAX} = 450 / 440 GHz in completely self-aligned AlN/GaN HEMTs with regrown Ohmic contacts [4]. In the present work we describe the realization of non-self-aligned regrown *n*+ Ohmic contacts in AlInN/GaN HEMTs grown on both SiC and HR-Si enabling maximum oscillation frequencies in excess of f_{MAX} = 300 and 230 GHz on each substrates, respectively. We report on both the small- and large-signal properties of the resulting transistors, including load-pull measurement data at W-band (94 GHz).

2. EXPERIMENTAL PROCEDURE

2.1. Regrown *n*+ GaN Ohmic Contact Preparation by Ammonia MBE

Fabrication began with mesa definition by Cl_2 based dry etching. Then, a SiO_2 mask was deposited by plasma enhanced chemical vapor deposition (PECVD), followed by the opening of the TLM pattern by optical lithography and SF_6-based dry etching. The heterostructure was finally recessed in the contact region by Cl_2-based dry etching. Before loading the samples in the MBE chamber for n^+-GaN regrowth, the etched surface was cleaned with a wet process discussed hereafter. After regrowth, the SiO_2 mask was removed with diluted HF and the TLM structure was completed with the evaporation of Ti/Au metal pads. The total contact resistivity, measured from a TLM structure, is 0.25 Ω·mm which is made up of three contributions (M/S contact, *n*+ GaN resistance, and 3D-2DEG contact resistance).

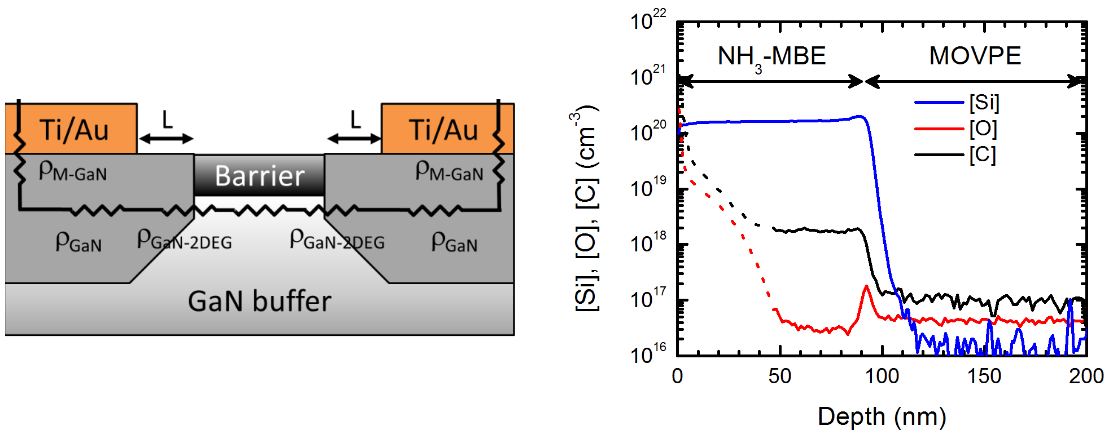

Fig. 1: Left: Regrowth of *n*+ GaN and resulting contact resistance contributions. Right: SIMS profile for Si, O and C impurities through the MBE regrown contact and the MOVPE original epitaxial HEMT layers. Details of the regrowth process will be presented in the extended abstract and at the conference.

2.2. Small- and Large-Signal Device Characterization

AlInN/GaN HEMTs with the improved Ohmic contacts based on the *n*+ GaN regrowth procedure were processed on both semi-insulating SiC and HR-Si substrates in a manner similar to [5]. Fig. 2 below shows the results of small-signal measurements on both substrate types for 50 nm gates: it is noteworthy that similar f_T values are obtained on both substrates, while the f_{MAX} = 300 and 232 GHz on SiC and HR-Si, respectively. Fig. 3 shows the results of load-pull characterization at W-band (94 GHz). The devices on SiC show a saturated output power of 1.51 W/mm and a peak PAE of 8.5% at 1 W/mm, while the device on HR-Si shows a slightly lower 1.35 W/mm saturated output power but a higher peak PAE of 12% at 1 W/mm.

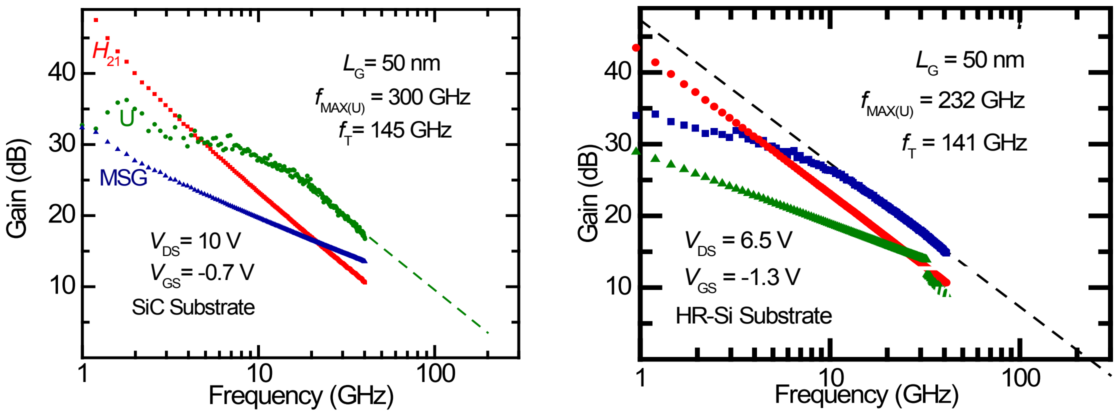

Fig. 2. Left: Peak small-signal performance for device on SiC. Right: Peak performance for device built on HR-Silicon. Both devices were implemented with 50 nm gate lengths.

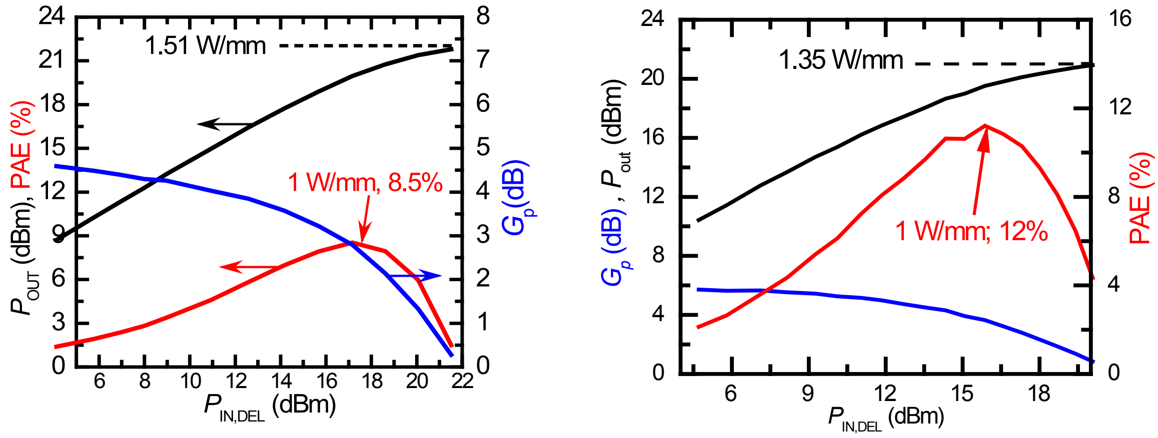

Fig. 3. Left: W-band load-pull characterization for device on SiC. Right: W-band load-pull for device built on HR-Silicon. Whereas the device on HR-Si shows a slightly lower saturated output power, it displays a higher peak PAE at 1 W/mm.

3. CONCLUSIONS

We demonstrate that excellent AlInN/GaN HEMT performances can be achieved when *n*+ GaN regrown Ohmic contacts are implemented on transistors grown on SiC or HR-Si substrates. Our presentation will describe the fabrication process as well as compare the performance gains achieved with regrown contacts in comparison to identical devices with standard annealed Ohmic contacts.

4. References

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