Influence of Dielectric Plasma Etch Source for PHEMT Device Performance

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Abstract

PHEMT device parametric performance was improved by transfer from a transformer coupled plasma source to an RF helicon wave high density plasma source for the oxide dielectric etch prior to ohmic metal deposition. Process stability and uniformity were enhanced leading a higher yielding product with a wider process window. Significant improvement was measured for device parameters such as contact resistance, on resistance, and transconductance. Evaluation of etch source differences were investigated by examining surface damage.

INTRODUCTION

AuGe eutectic alloyed ohmic contacts are routinely used in GaAs semiconductor device manufacturing. Parameters such as contact resistance (Rc), on-resistance (Ron), transconductance (Gm) and efficiency are impacted by the quality of the contact [1,2]. Device performance is therefore closely allied to the preparation of the exposed surfaces prior to metal deposition. Variation in microstructure through damage, contaminants or oxidation will affect the quality of the interface.

A critical component of the device fabrication process is opening the dielectric window to the ohmic contact area. The dry (plasma) etch process will impact CD control and ion damage. These dielectric etches are commonly implemented using low pressure, low damage sources, such as inductively coupled plasmas (ICP), which offer independent control of ion energy and ion density [3,4]. However, the impact of different high density, low damage sources may result in the formation of different radial species and ion distributions that could affect the quality of the metal-semiconductor contact.

EXPERIMENTAL

Two systems were used to investigate the impact of low damage plasmas on the GaAs surface from the dielectric etch of the ohmic contact window, a LAM TCP 9400 and PMT helicon wave source. The transformer coupled plasma (TCP) is produced by induction. An RF coil is separated from the plasma chamber by an insulating window [5]. The oscillating magnetic field produces an azimuthal RF electric field in the chamber. The plasma is generated by electron absorption and excitation from the electric field. The system has a separate applied substrate stage RF bias to exact independent control over ion energy. Helicon wave plasmas are also inductive in nature, although they can generate plasma densities significantly higher. They consists of an RF antenna separated from the chamber by an insulating wall or dome. Concentric magnetic coils are deployed to allow for generation of the helicon wave mode along the axis to be absorbed by electrons [6].

Devices used for the study were pHEMTs with an alloyed AuGeNiAu contact. The ohmic metal contacts a doped GaAs layer pHEMT.

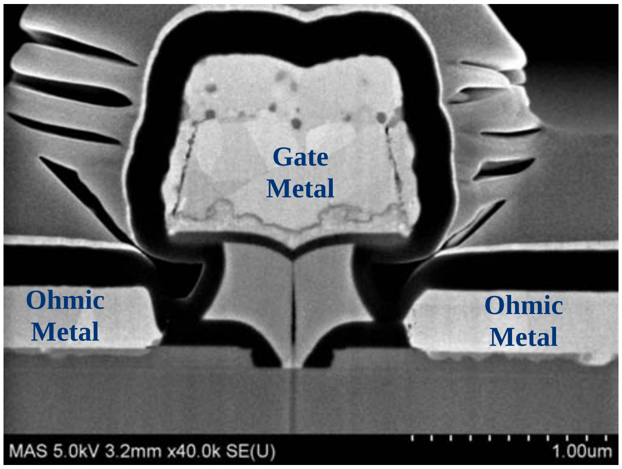

Figure 1. pHEMT device structure. The oxide was removed by LAM TCP and PMT helicon mode etching.

An oxide layer must be etched to open the ohmic contact, hence is a critical phase of the process. The dielectric etch for opening the ohmic contact must be low damage and highly uniform. The process window must be wide enough to adequately clear the contacts across the 150mm wafer without inflicting excessive ion damage to the GaAs. The choice of process gases and applied powers must be judicious to avoid compromising the device quality.

The LAM TCP process was a timed etch containing CF4 and He at a 20mTorr process pressure. Adequate endpoint capability could not be developed for this tool and the process window was only a few percent of the total process time. With moderate etch rate variations wafers could be underetched, not clearing the oxide or overetched causing excessive damage. Figure 2 is a wafer map illustrating the problem for the contact resistance, where the outer diameter with high contact resistance indicates uncleared oxide.

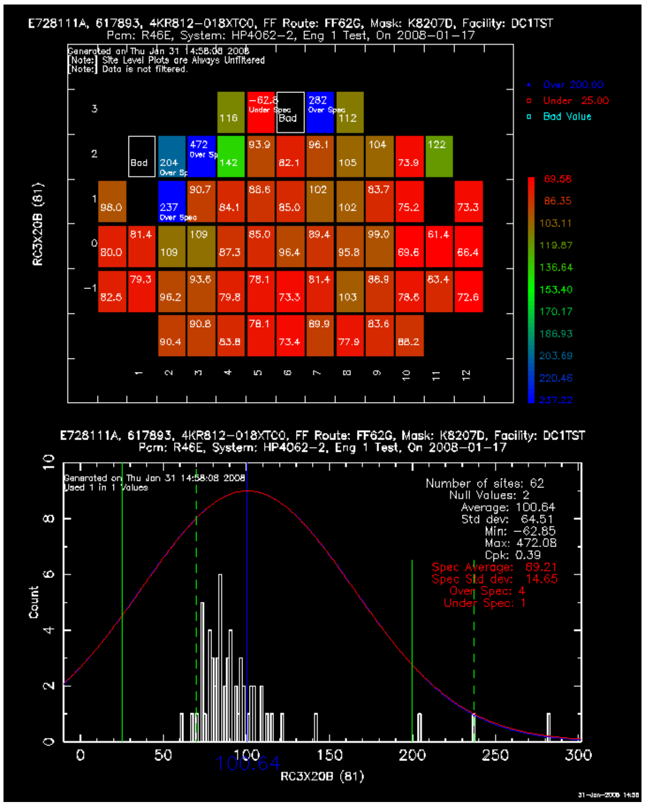

Figure 2. Wafer map of contact resistance Rc for LAM TCP dielectric etch.

The PMT was investigated as an alternative due to better endpoint capability, potentially lower damage and lower process pressures for improved CD control. A three factorial design of experiment was done to determine an optimal process regime. This resulted in a 5mTorr etch using CF4, O2 and Ar. The use of CF4 can sometimes result in carbon polymer formation on the exposed surface, so O2 was added for emphasis. The process was endpoint capable, enabling considerably more control over the etch. The process window was determined by evaluating minimum etch times to clear and maximum etch times for parametric evidence of suface damage or degradation. Even at 50% overetch the PMT helicon wave etch showed no evidence of ion damage and increased contact resistance, whereas the LAM process showed parametric failures for more than a 10% overetch. Thus the process window was expanded dramatically. A typical wafer map for the PMT process is given in Figure 3.

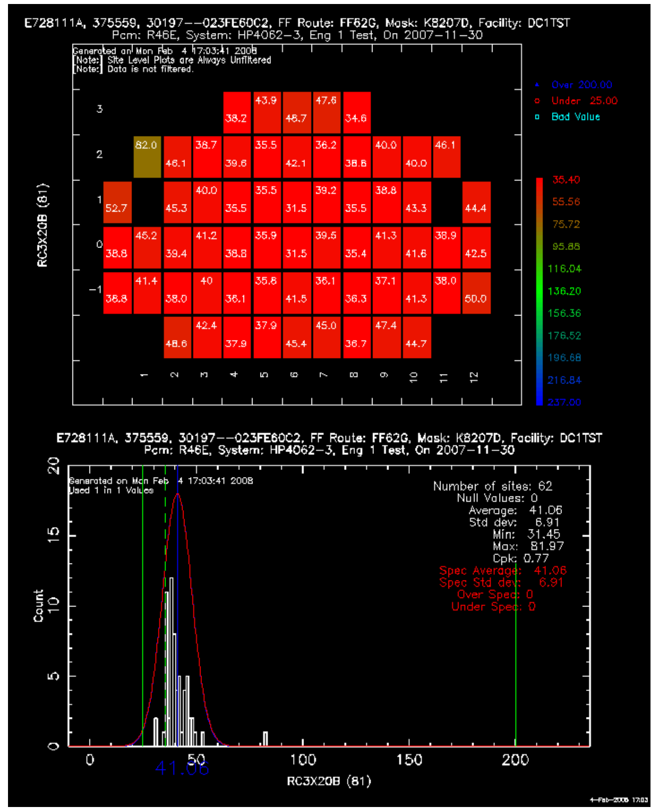

Figure 3. Wafer map of contact resistance Rc for PMT helicon wave plasma dielectric etch.

Figure 4 gives a summary of the statistical difference in the two etches for the contact resistance. The results were statistically significant using a student's t-test to p-value < 0.05. The mean Rc decreased by over 50% with a standard deviation 30% of the LAM TCP process. Table 1 gives a parametric summary for related parameters.

Table 1.

Parameter	TCP	TCP Std	PMT	PMT Std
Rc (Ω)	100	34	47	11
Gm	751	30	578	33
Ron(Ω-mm)	0.88	0.5	0.68	0.07

An investigation was made to determine the source of variation between the two etch systems. Surface damage was evaluated by reducing the RF bias power for the TCP from 50W to 35W. This did reduce the contact resistance consistent with surface damage by about 25%. As an alternative means of gauging damage Au sputter rates were compared between the two tools. The LAM TCP was found to have a rate 3 times the PMT, indicating much more energetic species impinging on the surface.

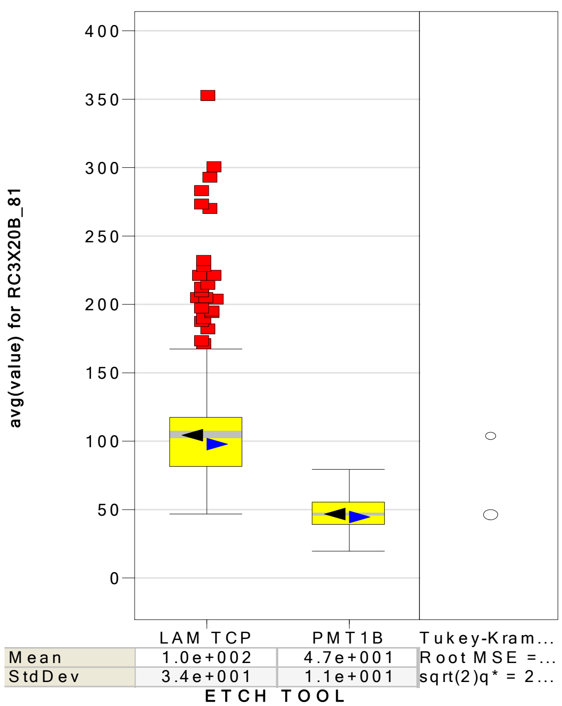

Figure 4. Contact resistance Rc differences between the LAM TCP and PMT ohmic oxide etch.

CONCLUSIONS

Etch capability is critical to optimum device performance. The variation between tools a helicon wave and transformer couple system were evaluated with regard to an oxide etch prior to ohmic metal contact. The helicon wave system was found to achieve a dramatically wider process window, endpoint capability and greater control of uniformity. Fundamental parameters such as contact resistance, on-resistance and transconductance were all markedly improved. The helicon system is believed to reduce ion damage to the substrate for an improved semiconductor-metal interface.

ACKNOWLEDGMENT

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ACRONYMS

pHEMT pseudomorphic high-electron mobility transistor
TCP: Depletion-mode field effect transistor
Rc: Ohmic contact resistance.