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# Low damage, high selectivity $Ar/Cl_2/CH_4/O_2$ gate recess etching for AlGaN/GaN HEMT fabrication

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## 1. Introduction

High performance AlGaN/GaN HEMTs on Sapphire or SiC substrates have been successfully applied to microwave power device applications. This is due to the excellent characteristics of GaN, namely a wide bandgap (3.4eV), a high breakdown filed ($2\times10^6$ V/cm), and a high saturation velocity ($2.2\times10^7$ cm/s). Additionally, the induced 2DEG in the interface of the AlGaN/GaN can reach about $1x10^{13}$ $cm^{-2}$ sheet concentration, which is almost 5 times larger than the case in AlGaAs/GaAs HEMTs [1]-[2]. Plasma dry etching is an important technique to realize the AlGaN/GaN HEMTs. In this study, we developed a low surface damage and high etching selectivity dry etching recipe for the gate recess process in the AlGaN/GaN HEMT fabrication [3].

## 2. Selective etching and surface damage

The traditional dry etching for GaN is using the $Ar/Cl_2$ mixture gas in the Reactive Ion Etching (RIE) system. In order to deduce the surface damage, the additional $CH_4$ gas is introduced. However this approach still has the problems of the residual surface damage and low etching selectivity between AlGaN and GaN materials. Therefore, the following RTA at 700°C is necessary to recover the surface properties [4]. In this study, we proposed the $Ar/Cl_2/CH_4/O_2$ (20:150:25:*x* sccm) mixture plasma, instead of the $Ar/Cl_2/CH_4$ (20:25:15 sccm) plasma for the gate recess etching. The etching rate of the AlGaN and GaN is shown in Fig.1 versus the flow rates of $O_2$, where the AlGaN etching rates decrease with the $O_2$ flow rates. The selectivity between AlGaN and GaN can be as high as 16 with a 10 sccm $O_2$ flow rate. We also measured the current level from the drain to source to evaluate the surface damage after the RIE etching. As to the results shown in Fig.3, the current level after the etching is almost 30% lower to the fully RTA recovered sample for the $Ar/Cl_2/CH_4$ plasma etching, and this value is less than 10% for the current recipe. The high selectivity and low surface plasma damage of the $Ar/Cl_2/CH_4/O_2$ plasma is due to the $O_2$ plasma forming an oxide layer on the AlGaN surface, which prevents the AlGaN being further etched away and reduces the surface damage. Therefore, we can deposit the gate metal on the recess area directly after RIE etching without doing the RTA surface recovery process.

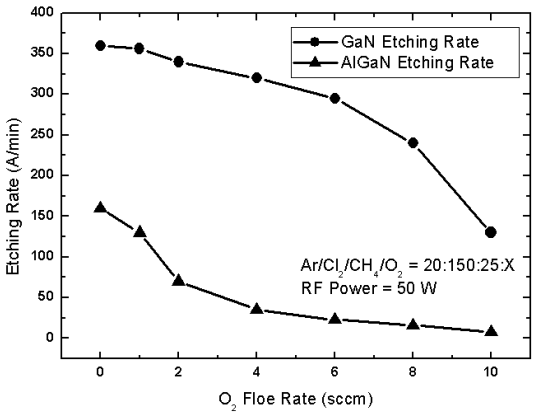


Fig. 1 AlGaN and GaN etching rates using the $Ar/Cl_2/CH_4/O_2$ mixture plasma

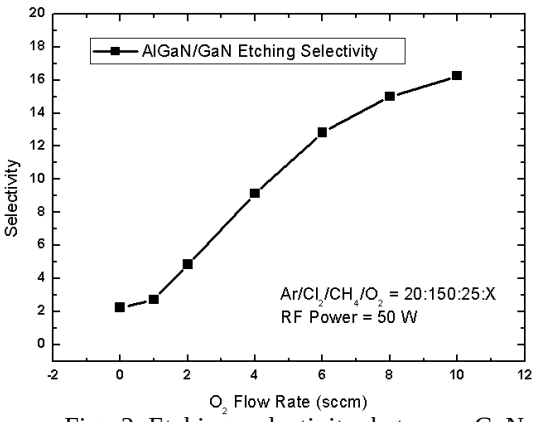


Fig. 2 Etching selectivity between GaN and AlGaN vs the $O_2$ flow rate.

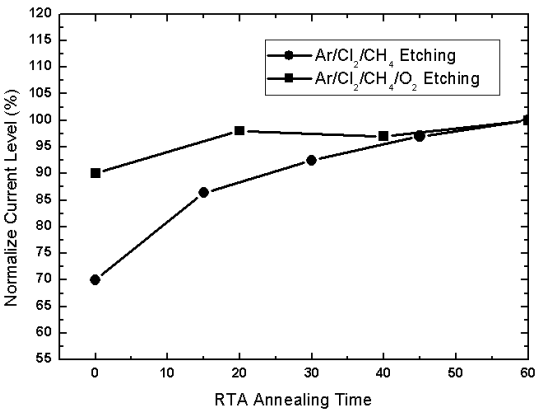


Fig. 3 Normalized recovered channel current vs RTA annealing time.

## 3. Device fabrication and DC performance

The MOCVD-grown AlGaN/GaN HEMT shown in Fig.4 consists of the sapphire substrate, a 2.7 μm undoped GaN buffer layer, a 200Å undoped $Al_{0.28}Ga_{0.72}N$ Schotty layer, and a 200Å GaN ($5\times10^{18}$ n-doping) cap layer. The electron sheet charge density and mobility of this structure were $9\times10^{12}$ $cm^{-2}$ and 1300 $cm^2/Vs$ respectively. Drain and Source ohmic contacts were formed by using the Ti/Al/Pt/Au and annealed at 780°C. The contact resistance is about 0.6O-mm. The mesa etching was done by using the $Ar/Cl_2$ plasma, and the gate recess etching was carried out by using the characterized $Ar/Cl_2/CH_4/O_2$ plasma. Finally, the gate metal Ni/Au was deposited on the recessed area without the post-etching annealing. This AlGaN/GaN HEMT with a 2μm gate-length shows that the current density is 370 mA/mm at $V_{gs}$= 1V, and the maximum $g_m$ is 130 mS/mm. The breakdown voltage is larger than 40V, and the gate turn on voltage is 1.7V.

## 4. Conclusions

The high selectivity and low damage etching technology was developed for the AlGaN/GaN HEMT gate recess process. By using this technology, the process variation and the device yield can be improved.

## References


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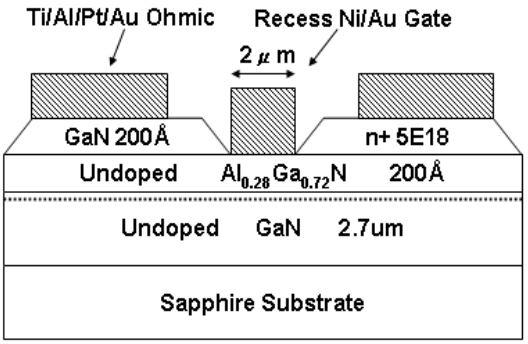


Fig. 4 AlGaN/GaN HEMT fabricated device cross-section.

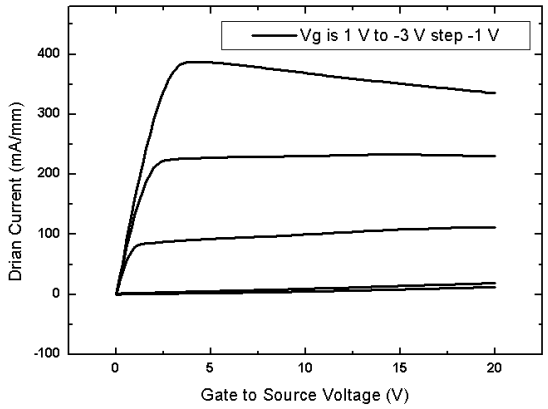


Fig. 5 DC I-V output characteristics of AlGaN/GaN HEMT with a 2 μm gate-length

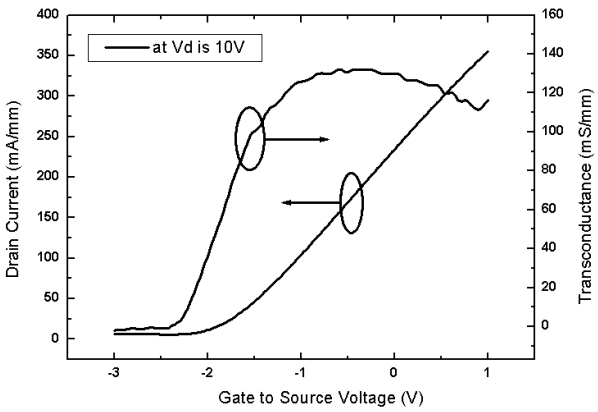


Fig. 6 DC I-V transfer characteristics of AlGaN/GaN HEMT with a 2 μm gate-length