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# Improved Ohmic-contact to AlGaN/GaN using Ohmic region recesses by self-terminating thermal oxidation assisted wet etching technique

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**Abstract**. Lower Ti/Al/Ni/Au Ohmic contact resistance on AlGaN/GaN with wider rapid thermal annealing (RTA) temperature window was achieved using recessed Ohmic contact structure based on self-terminating thermal oxidation assisted wet etching technique (STOAWET), in comparison with conventional Ohmic contacts. Even at lower temperature such as 650°C, recessed structure by STOAWET could still obtain Ohmic contact with contact resistance of 1.97Ω·mm, while conventional Ohmic structure mainly featured as Schottky contact. Actually, both Ohmic contact recess and mesa isolation processes could be accomplished by STOAWET in one process step and the process window of STOAWET is wide, simplifying AlGaN/GaN HEMT device process. Our experiment shows that the isolation leakage current by STOAWET is about one order of magnitude lower than that by inductivity coupled plasma (ICP) performed on the same wafer.

## 1. Introduction

Improvement of Ohmic contacts is essential to fully utilize the advantages of GaN heterostructure electron devices. Etching the Ohmic regions by plasma before deposition of metals is one of the most widely used ways to improve the performance of Ohmic contacts on AlGaN/GaN [1-5], which may result in serious damages, and the power of plasma and the etching time of Ohmic region recesses should be accurately controlled [2, 4, 5].

In this letter, self-terminating thermal oxidation assisted wet etching technique (STOAWET) with thermal oxidation of AlGaN layer followed by etching in KOH solution, which has been applied to gate recess etching [6], is proposed to be used in the fabrication of Ohmic region recess and mesa isolation at one process step, simplifying the device process. The experimental results show that lower Ti/Al/Ni/Au Ohmic contact resistance (Rc) and wider rapid thermal annealing (RTA) temperature window could be obtained by STOAWET in comparison with conventional Ohmic contacts structure, where all Ohmic contacts were fabricated on the same wafer. The isolation leakage current by STOAWET is about one order of magnitude lower than that by inductivity coupled plasma (ICP) performed on the same wafer, implying the practicability of STOAWET in the isolation on AlGaN/GaN heterostructure.

## 2. Experiments

AlGaN/GaN epi-wafer used in this work was grown on (0001) sapphire substrate by metal organic chemical vapour deposition (MOCVD). The wafer structure consists of a 2μm unintentionally doped

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GaN buffer layer, a 22nm unintentionally doped $Al_{0.23}Ga_{0.77}N$ barrier layer and a GaN cap layer with thickness of 2.8nm. Transfer length method (TLM) structures were fabricated. Firstly, 200nm plasma-enhanced chemical vapour deposition $SiO_2$ was deposited on top of the sample as mask layer. Then, Ohmic recess and isolation regions were defined by optical lithography followed by the removal of $SiO_2$ using $SF_6$-based plasma. The sample was subsequently treated by thermal oxidation for 45 min at 650°C followed by 45 min etching in KOH solution at 70°C. After $SiO_2$ was then removed by buffered oxide etching, Ti/Al/Ni/Au (20nm/160nm/50nm/100nm) metals for Ohmic contact were formed by electron beam evaporation followed by lift-off process. For comparison, TLM structures without Ohmic region recesses (conventional structures) were also fabricated on the same wafer with $SiO_2$ protecting the Ohmic contact regions during oxidation and wet etching. Then the wafer was diced into several samples, annealed in $N_2$ ambience at different temperatures to investigate the effect of RTA temperatures. Channel width of the TLM structures is 95μm and the contact resistance was derived by TLM patterns with separations of 5μm, 10μm, 15μm, 20μm, 25μm and 30μm. Partial cross-section of the recessed TLM structure is shown in Figure 1. As depicted in [6], the whole AlGaN layer in etched regions is etched away by STOAWET without affecting the underlying GaN layer. To compare the isolation efficiency of STOAWET and ICP, $Cl_2/BCl_3$ based plasma was used to etch the isolation regions with conventional Ohmic contact structure on another sample from the same wafer.

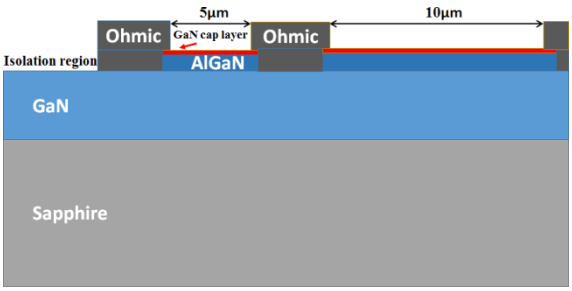
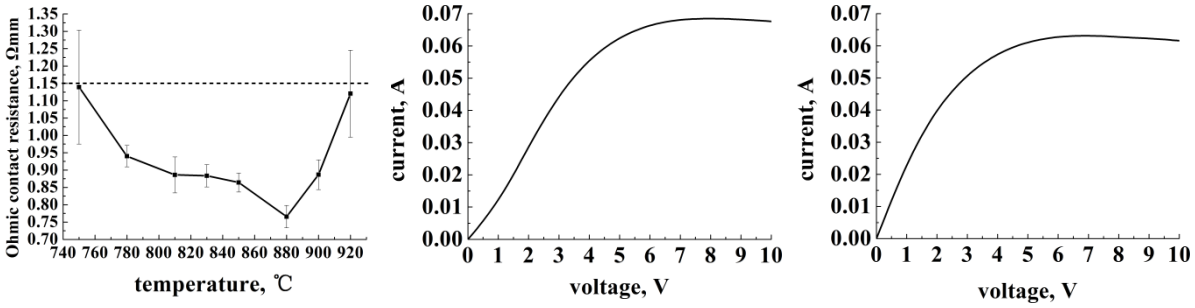



**Figure 1.** Partial cross-section of recessed TLM structure

## 3. Results and discussion

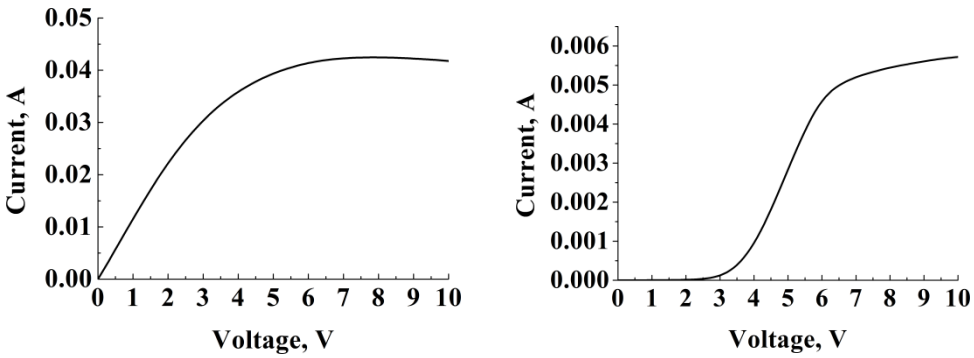
Figure 2(a) shows the lowest Rc of recessed Ohmic contact achieved at various RTA temperatures. It could be seen that Rc from 0.76Ω·mm to 0.94Ω·mm could be achieved annealed at the temperature from around 780°C to 900°C for recessed Ohmic contact. However, conventional Ohmic contact could only achieve the lowest Rc of about 1.15Ω·mm at 830°C for 35s, larger than those of recessed structure annealed from 750°C to 920°C. Conventional Ohmic contact became worse (not straight in linear regions of I-V curves) annealed at 810°C as shown in Figure 2(b) compared with recessed structure as shown in Figure 2(c) and after annealing at 850°C for 32s average Rc as large as 2.62Ω·mm was obtained, indicating a narrow RTA temperature window (<40°C, defined by Rc of ~1Ω·mm). Therefore, etching the Ohmic contact regions by STOAWET before metals deposition could effectively decrease Rc and expand RTA temperature window (>120°C, defined by Rc<1Ω·mm), making this technique easier to achieve lower Rc with a wider Ohmic annealing temperature window improving the tolerance of temperature fluctuation in practical production. It is mentioned that the best Ohmic performance is obtained when the two-dimensional electron gas (2DEG) channel is completely removed [2] and minimum contact resistance is obtained just before etching through the barrier [4], therefore recessed Ohmic structure by STOAWET just meets the condition for improving Ohmic contacts to GaN heterostructures.




(a) (b) (c)

**Figure 2.** (a) Lowest recessed Ohmic contact resistance achieved at various RTA temperatures derived by TLM patterns with separations of 5μm, 10μm, 15μm, 20μm, 25μm and 30μm. RTA time differs from 20s to 50s. Dotted line marks the lowest Rc of conventional Ohmic contact, which was achieved at 830 ℃ for 35s. (b) I-V curve of conventional Ohmic structure and (c) I-V curve of recessed Ohmic structure with separation of 5μm and width of 95μm annealed at 810°C for 40s.

Some samples were also annealed at 650°C for different time and achieved the best Rc of 1.97Ω·mm for recessed structure after 5min RTA. I-V curves of recessed and conventional Ohmic structures with separation of 10μm and width of 95μm annealed at 650°C are shown in Figure 3, indicating that conventional Ohmic structure could not achieve Ohmic contact at such low temperature at all.




(a) (b)

**Figure 3.** I-V curves of (a) recessed and (b) conventional Ohmic structures with separation of 10μm and width of 95μm annealed at 650°C for 5min

Samples by STOAWET and ICP isolation with conventional Ohmic contact structure were annealed at 830°C for 35s. The leakage current at a bias of 10V between two pads with separation of 40μm and width of 95μm isolated by STOAWET is measured as 4.8pA, which is about one order of magnitude lower than that between two mesas isolated by ICP (24pA). It is reported that low surface roughness of ~0.27nm could be achieved by STOAWET [6] and damages could be caused by ICP [7]. Therefore, it is speculated that smoother GaN surface by STOAWET with fewer surface damages results in lower isolation leakage current.

It should be noted that by using STOAWET recessed Ohmic structure and device isolation could be fabricated in one process step. Moreover, as reported in [6], the window of oxidation temperature, oxidation time and wet etching time of STOAWET is wide enough, making the condition of Ohmic

region recessing easy to control using STOAWET, improving the convenience and consistence of practical AlGaN/GaN device process, in comparison with dry etching method.

## 4. Conclusion

It is demonstrated that by using STOAWET Ohmic region recesses and mesa isolation could be fabricated in one process step. Lower Ohmic contact resistance and wider RTA temperature window of recessed Ohmic contact could be achieved by STOAWET in comparison with conventional Ohmic contact. According to our experimental results, the recessed contact resistance achieved by STOAWET in this work is obviously improved compared with the contact resistance of conventional Ohmic structure. At lower temperature such as 650°C where conventional Ohmic structure cannot form Ohmic contact, recessed structure by STOAWET could still obtain Ohmic performance with Rc of 1.97Ω·mm. About one order of magnitude lower leakage current between two mesas is achieved by STOAWET than by ICP, implying the practicability of STOAWET in AlGaN/GaN isolation. Due to the wider process widows of Ohmic region recessing and RTA and the integration of Ohmic region recess and device isolation processes, STOAWET could improve the convenience and consistence of practical AlGaN/GaN device process.

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