Modulation of Ohmic Contact Formation in GaN HEMTs by Process-Dependent Thermal Transport Mechanisms

Junhyung Kim
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
junhyung@etri.re.kr

Jong Yul Park
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
jongyulpark@etri.re.kr

Kyujun Cho
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
kjcho12@etri.re.kr

Gyejung Lee
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
lgj@etri.re.kr

Byoung-Gue Min
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
minbg@etri.re.kr

Junhyung Jeong
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
jjunh05@etri.re.kr

Hong-Gu Ji
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
hkji@etri.re.kr

Woojin Chang
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
wjchang@etri.re.kr

Jong-Min Lee
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
leejongmin@etri.re.kr

Dong-Min Kang
RF&Power Components Research Section, ETRI
Daejeon, Republic of Korea
kdm1597@etri.re.kr

***Abstract*— This study investigates the critical differences in ohmic contact formation between piece-scale and wafer-scale rapid thermal annealing (RTA) processes for AlGaN/GaN high electron mobility transistors (HEMTs). While small-scale samples readily form low-resistance ohmic contacts across a broad range of annealing conditions, full 4-inch wafers often fail to achieve consistent results due to poor thermal uniformity. We identify a difference in thermal mass as the primary factor affecting temperature profiles and contact quality. Furthermore, reducing nitrogen flow during RTA from 10 standard liters per minute (SLM) to 1 SLM significantly improves wafer-scale contact formation by minimizing convective heat losses. This adjustment enhances thermal uniformity, particularly at wafer centers, resulting in resistance values comparable to those obtained from piece-scale samples.**

Keywords—GaN HEMTs, Ohmic, annealing, rapid thermal process

I. Introduction

Ohmic contact formation in AlGaN/GaN HEMTs typically involves Ti/Al/Ni/Au metal stacks followed by rapid thermal annealing (RTA) at temperatures above 800°C. [1-2] This process enhances electron transport through the 2DEG by forming TiN protrusions and creating nitrogen vacancies. However, RTA conditions are often optimized using small-scale test pieces, which may not reflect the actual thermal behavior during full wafer processing. [3]

Temperature uniformity is essential for consistent contact performance, but achieving it across a full wafer is challenging due to edge effects and the significantly larger thermal mass. These factors can lead to non-uniform heating and inconsistent contact quality. [4] In this study, we investigate the differences between piece-scale and wafer-scale RTA processing for GaN HEMTs, focusing on the role of nitrogen flow rate in improving thermal uniformity and ohmic contact formation.

II. Methods

AlGaN/GaN heterostructures were epitaxially grown on 4-inch SiC substrates using metal-organic chemical vapor deposition (MOCVD). A wafer consisting of a 13nm $Al_{0.3}Ga_{0.7}N$ barrier layer, a 1 nm AlN insertion layer, a 250 nm GaN channel, and an AlN nucleation layer was used. Source/drain ohmic contacts were fabricated by depositing Ti/Al/Ni/Au metal stacks, followed by rapid thermal annealing at 880°C for 30 seconds.

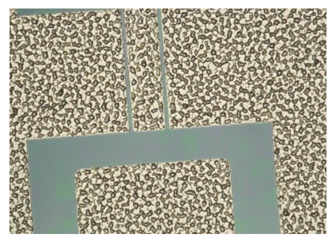

Fig. 1. Optical microscope image of Ohmic metal after RTA process

The annealing procedure was conducted using an RTP-3121SA (Premtek). A two-stage process was adopted to achieve annealing at 880˚C. Initially, samples underwent annealing at 550˚C for 20 seconds, followed by a second stage at 880˚C lasting 30 seconds. During the transition between stages, the temperature increased from 550˚C to 880˚C at a ramp-up rate of 30˚C/sec. The rapid thermal annealing (RTA) was carried out under atmospheric pressure conditions in a nitrogen-filled chamber. Two different nitrogen flow conditions were examined: a standard flow rate of 10 SLM and a reduced flow rate of 1 SLM. Susceptor temperature measurements were conducted via pyrometry. For each annealing condition, 1 cm × 1 cm piece samples and 4-inch wafer samples were used. In all cases, it was confirmed that the oxide concentration inside the chamber during annealing was below 1 ppm. After the RTA process, resistance measurements were carried out using a 5 µm of channel.

III. Results and Discussions

Figure 2 presents the resistance comparing 1cm×1cm pieces with 4-inch wafers under standard processing conditions (10 SLM nitrogen flow). The small pieces consistently achieved excellent ohmic contact formation with resistance of 19.9±0.4Ω at 880˚C. The temperature window for successful ohmic formation was remarkably wide, providing substantial process margin. In contrast, full 4-inch wafers showed poor ohmic contact formation under identical

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conditions. The resistance was measured of 24.6±1.23 Ω at 880˚C. Even at optimized temperatures that successfully formed ohmic contacts on pieces, wafer-scale processing failed to achieve reliable contact formation.

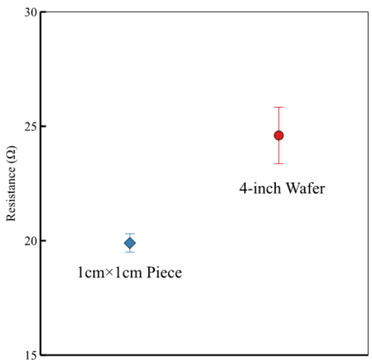

Fig. 2. Resistance measured between TLM patterns with a 5 μm spacing after annealing. Samples are 1 cm × 1 cm pieces and 4-inch wafers, respectively.

One notable observation was that relatively lower resistance was consistently measured near the wafer edges compared to the center region. This phenomenon is illustrated in Figure 3(a) and was repeatedly observed across multiple wafers. Moreover, the same trend persisted even when the annealing temperature was adjusted above or below 880˚C. The morphology observed at the wafer center, which exhibited higher resistance, was similar to that seen in piece samples annealed at lower temperatures where optimal formation did not occur. Conversely, the morphology at the wafer edges resembled that of samples exhibiting properly formed, low-resistance characteristics.

The observed differences between piece and wafer processing can be attributed to fundamental thermal capacity and heat transfer considerations. Small 1cm×1cm pieces have significantly lower thermal mass compared to full 4-inch wafers, resulting in faster and more uniform heating. The heat capacity difference of approximately 16× between pieces and wafers (scaling with area) creates substantial differences in thermal response during RTA processing. The susceptor-to-sample heat transfer mechanism plays a crucial role in determining temperature uniformity. For wafer-scale processing, the outer regions receive more efficient heat transfer due to edge effects and radiation from the chamber walls. The center region, being thermally isolated, experiences slower heating rates and potentially lower peak temperatures, explaining the poor ohmic contact formation in these areas.

The most significant breakthrough occurred when reducing nitrogen flow rate from 10 SLM to 1 SLM. Figure 3 shows the wafer-scale ohmic contact formation results under reduced nitrogen flow conditions. The overall region achieved successful ohmic contact formation comparable to piece-scale results (20.1±0.94Ω). The nitrogen flow rate significantly affects heat transfer within the RTA chamber through several mechanisms. At high flow rates (10 SLM), nitrogen acts as a heat sink, carrying away thermal energy from the wafer surface and creating additional thermal losses. The convective heat transfer coefficient increases with flow rate, leading to enhanced cooling effects that compete with the intended heating process.

Reducing nitrogen flow rate to 1 SLM decreases convective heat losses, allowing for more efficient heat transfer from the susceptor to the wafer. This improved thermal coupling results in better temperature uniformity, particularly benefiting the edge regions where the combination of radiation and conduction heating becomes more effective. Although it was plausible that reducing the nitrogen flow could lead to increased oxide levels and thus cause the observed changes, the oxide sensor in the equipment did not detect any significant variations sufficient to affect the process. Additionally, experiments performed on piece samples showed no noticeable changes.

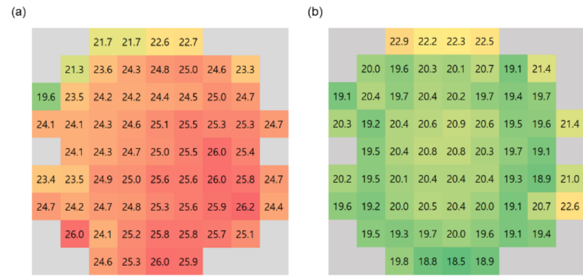

Fig. 3. Resistance between TLM patterns with a 5 μm spacing for wafers annealed under (a) N_2 flow of 10 SLM and (b) N_2 flow of 1 SLM.

IV. Conclusion

This study demonstrates significant differences in ohmic contact formation when comparing piece-scale and wafer-scale RTA processing of GaN HEMTs. While small piece samples consistently achieved excellent ohmic contacts across a broad temperature range, full wafer samples faced considerable challenges attributed primarily to limitations in thermal uniformity. These challenges stemmed from a substantial difference in thermal mass between pieces and wafers, leading to fundamentally different thermal behaviors during the annealing process. Moreover, reducing the nitrogen flow rate from 10 SLM to 1 SLM notably improved wafer-scale ohmic contact formation by minimizing convective heat losses. Spatially, successful ohmic contacts consistently formed preferentially at wafer edges, where heat transfer efficiency was greatest.

Acknowledgment

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