Enhanced Visual Performance in GaN HEMT Technology

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Abstract — Visual yield performance is enhanced in our GaN manufacturing line by revising the bottom metal for the substrate via etch stop and updating the clean solution for byproduct removal. By changing these processes, it is possible to increase the visual yield performance and thermal stability under high-temperature operation. This is effectively demonstrated by a 1 hour, 350 °C baking test showing no observed evidence of visual abnormity during 500-X microscopic inspection. We present models for the underlying mechanisms responsible for visual failures which are consistent with the measurement data. These yield performance improvements provide an excellent opportunity for AlGaN/GaN HEMTs to be used in harsh environments.

Keywords: AlGaN/GaN, visual, backside via,

I. INTRODUCTION

AlGaN/GaN heterostructures have been extensively studied for their applications in high-power, high-temperature microwave devices [1-3], in high-frequency field effect transistors, and in blue light-emitting and laser diodes [4]. Recently, there also has been a growing interest in hyperfine details about the manipulation of spin generation in AlGaN/GaN semiconductors [5-6]. However, the performance of these devices is governed by the robust foundry processes. Therefore, high process yield and thermal stability are always demanded by customers and studied by all GaN foundries in the world.

In this article, WIN Semiconductors examines detailed visual yield improvement. WIN increases the visual yield dramatically by changing the ohmic metal design and the clean solution after ICP etching. As shown later, our experimental results suggest that high visual yield is achievable with the right chemical and suitable metal design.

II. PROCESS OPTIMIZATION

Before enhancing the visual yield, one needs to know the dominant factors that cause yield loss. According to human visual inspection (HVI), there are two major failure symptoms called front-side (FS) nitride crack and back-side (BS) discoloration. These two visual abnormalities are experimentally demonstrated in (0001)-oriented AlGaN/GaN HEMT devices.

Figure 1 shows the typical optical microscope images of both failures. By changing thermal treatment temperature and duration, it is possible to manipulate the failure rate of the FS nitride crack and BS discoloration. In order to prevent the above defects and increase thermal stability, we made several key process changes in our GaN foundry.

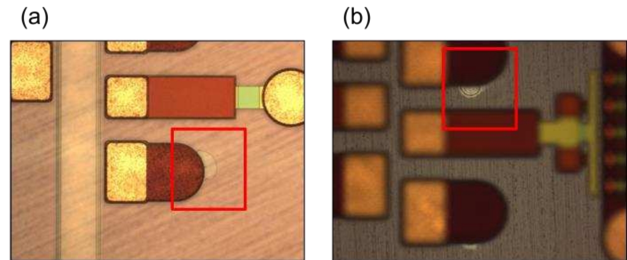

Fig. 1. Microscopic pictures of (a) front-side nitride crack and (b) back-side discoloration.

Figure 2 shows the SEM and FIB studies of the 1st failure mode called front-side nitride failure. Obviously, this nitride crack is because of metal erosion after back-side ICP etching followed by subsequent thermal processing. Figure 3 displays the possible failure mechanism caused by the back-side ICP process. Due to our hypothesis, we could reduce this anomaly effectively by changing to a more robust front-side bottom metal for the substrate via etch stop.

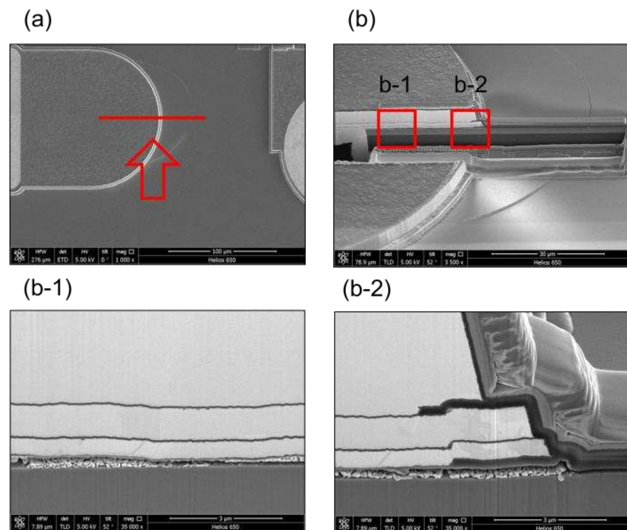

Fig. 2. (a) SEM image of front-side nitride crack failure. The red arrow indicates the FIB analysis direction. (b) FIB image of the front-side failure. The etched metal causes the nitride crack shown in zoomed-in (b-1) and (b-2) pictures.

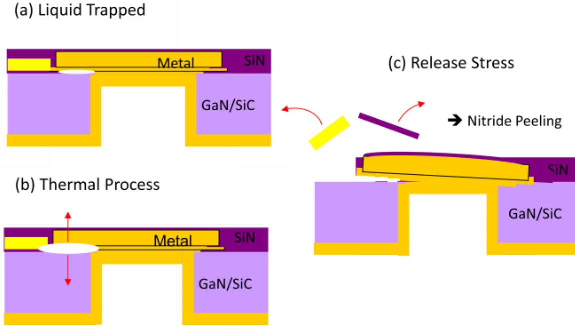

Fig. 3. The animated pictures describe the origin of the front-side nitride failure mechanism. (a) Liquid is trapped in the vacancy caused by the back-side ICP etch process. (b) Phase transition from liquid to gas occurs due to subsequent thermal processes. (c) A nitride crack forms to relieve stress.

According to statistical data listed in Table 1, the increased yield is enabled by a bottom metal change for the front-side contact to the back-side via. By changing the bottom metal layer as shown in Fig. 4, one can reduce the metal undercut and liquid trapped during back-side manufacturing. Consequently, front-side nitride thermal stability becomes better due to a more robust metal. The statistical data confirms our prediction of the underlying mechanism responsible for front-side nitride crack.

TABLE I. Statistical yield results of different front-side bottom metals used for back-side ICP etching. Visual yield increases from 40.30 % to 100 % based on HVI of 1000 chips from 4 wafers.

Table I

HVI on Fresh Chips		
	Previous Bottom Metal	**Revised Bottom Metal**
Yield (FS Nitride Crack)	**40.30%**	**100.00%**

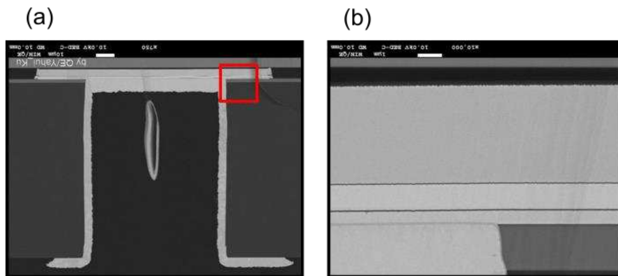

Fig. 4. (a) Cross-section image of the revised front-side bottom metal for back-side ICP etching. (b) Zoomed-in image showing the robust profile of back-side to front-side metal contact with no vacancy.

On the other hand, the observed 2nd failure mode called back-side discoloration anomaly is proven to be a back-side metal adhesion issue. As shown in Fig. 5, we need to focus very “deeply” to get clear images when inspecting the front-side of the wafer. This implies the discoloration symptom should NOT happen on the front-side surface. Therefore, we performed a cross-sectional polish (CP) of this odd discoloration. Based on the CP images shown in Fig. 6, the root cause of discoloration anomaly is due to the existence of a delaminated interface between the substrate and back-side seed layer. In addition, the failure rate of this 2nd failure mode increases with increasing operation temperature and the rainbow-like discoloration becomes much more pronounced after harsh thermal treatment. For GaN high-power and high-temperature application purposes, we need to provide sufficient back-side metal/substrate adhesion in our AlGaN/GaN device.

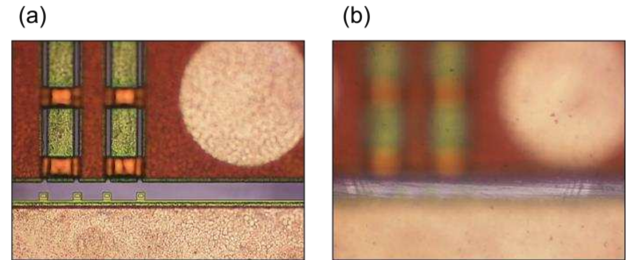

Fig. 5. Microscopic pictures of the back-side discoloration. The images are focused on (a) front-side surface and (b) back-side substrate.

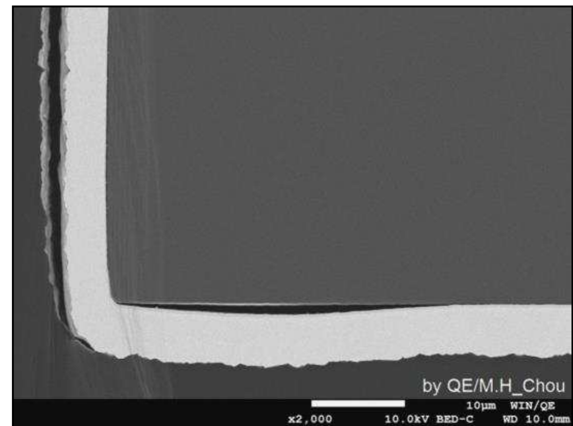

Fig. 6. CP image of the discoloration. The back-side discoloration is due to optical diffraction from the delaminated interface.

In order to understand the whole picture of the BS discoloration mechanism, we have come out with a back-side metal delamination theory as shown in Fig. 7. Theoretically, if the surface is not clean enough, the delaminated interface would occur not only on back-side substrate surface but also in the ICP-etched substrate via. With the 3D X-ray imaging study shown in Fig. 8, the back-side metal distortion in the via is verified to occur in the sample exhibiting discoloration. In addition, tilted X-ray images can even indicate the weak location. By comparing the CP and X-ray investigations, our model can explain the origin of the discoloration. Based on our study, the back-side surface cleanliness after via etch is the key for metal adhesion. Due to the remaining, stubborn byproduct after ICP etch, one cannot easily get a clean surface prior to BS metal deposition. As a result of this study, WIN implemented a suitable clean solution to remove the byproduct and the discoloration symptom can be suppressed significantly. Table 2 shows the apple-to-apple comparison of different clean solutions. It's obvious that "SO_4^{2-}-based chemical" has a higher visual yield after high-temperature bake.

Fig. 7. The back-side delamination model caused by residue on the back-side surface.

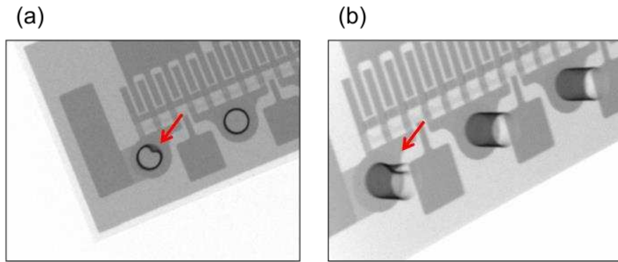

Fig. 8. (a) X-ray image of the distorted metal after 1 hour, 350 °C bake. (b) Tilted X-ray image showing the 3D geometry of the delaminated metal.

TABLE II. Yield performance with different clean conditions after back-end ICP process. Calculated results show SO_4^{2-}-based chemical gets zero HVI and X-ray failure over 1 hour, 350 °C bake. Tested results are based on 600 chips in 6 wafers.

Table II

HVI and X-ray Detection after 1 Hour, 350 °C Bake

	NH_4OH^--Based chemical	NO_3^--Based chemical	SO_4^{2-}-Based chemical
BS Discolor (HVI)	59.49%	94.55%	100.00%
BS Via Distortion (X-ray)	96.92%	97.27%	100.00%

III. CONCLUSIONS

In summary, by utilizing the revised front-side metal scheme and the new chemical clean, we are able to get zero visual failures after 1 hour, 350 °C thermal treatments. We list the calculated results which show pronounced yield improvement in our AlGaN/GaN technology. In addition, the distorted back-side via can also be greatly repressed with the new recipe in contrast to the old recipes. Our study provides an excellent opportunity for high power devices to be used at relatively high temperature.

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