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Room Temperature GaN Bonding by Surface Activated Bonding Method

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Abstract

GaN-Si bonding at room temperature was demonstrated by surface activated bonding method. The bondings using different GaN specimens were compared. In addition, the bonding interfaces between freestanding GaN and Si were investigated.

1. Introduction

Gallium nitride (GaN) is a very attractive material for high power and high frequency devices owing to its high electron saturation velocity and wide band gap [1]. Epitaxial GaN could be grown on hetero-substrate such as silicon, sapphire or silicon carbide [1-3] and on homo-substrate [4]. Recently, several epitaxial-lift-off methods with the reuse of expensive SiC substrate or even GaN substrate in the future have been developed [5-6]. By these epitaxial-lift-off methods, a high quality GaN epitaxial layer grown on SiC substrate or GaN substrate could be transferred to any desired target substrate after device fabrication at low cost. The bonding for transfer has to be accomplished at a low temperature, since not only the thin GaN epitaxial layer with a thickness of a few micrometers but also the adhesive or thermal release tape, usually employed for the handling, are very sensitive to high temperature [5-6]. Thus, a low temperature bonding process is desired to avoid the problems from high temperature process. Surface activated bonding (SAB), as a room temperature bonding method, should be a good candidate [7].

Therefore, in this study, the bonding of GaN to Si has been attempted by surface activated bonding method at room temperature.

2. Experimental and results

Materials and bonding process

Two kinds of GaN substrate were employed for bonding: Ga-face GaN template obtained by metal-organic chemical vapor deposition (MOCVD) and freestanding GaN substrate obtained by hydride vapour phase epitaxy (HVPE). Both of them are 2-in. and commercially bought. The GaN templates consist of 2 μm thick GaN epitaxial layer grown on 430 μm thick sapphire. Different from GaN template, freestanding GaN substrate has both Ga-face and N-face. For the freestanding GaN substrates as bought, chemical-mechanical polishing (CMP) was only done on Ga-face while N-face was not polished. To study the crystal-face dependence in bonding, CMP was also applied on the N-face of some freestanding GaN substrates. The average RMS roughness of as-grown Ga-face of GaN template is ~0.40 nm. The Ga-face after CMP is uniform across the wafer with an average RMS surface roughness of ~0.25 nm, while N-face after CMP is not uniform with some rough areas in the edge and center part. The smooth areas of N-face are similar as Ga-face after CMP. The average RMS surface roughness of the rough areas is ~0.69 nm. For bonding with GaN specimens, 6-in. (100) Si wafers with a thickness of ~500 μm were prepared. The bonding surfaces of Si were mirror polished (100) with a root-mean-square (RMS) roughness of ~0.15 nm.

The bonding was carried out in one UHV-bonding machine, which consists of a load-lock chamber and a processing-bonding chamber. The load-lock chamber was designed to maintain a high vacuum in the processing-bonding chamber. There are two ion beam sources in the processing-bonding chamber, which were used for surface activation prior to bonding. After surface preparation, two wafers would be pressed together for bonding at room temperature.

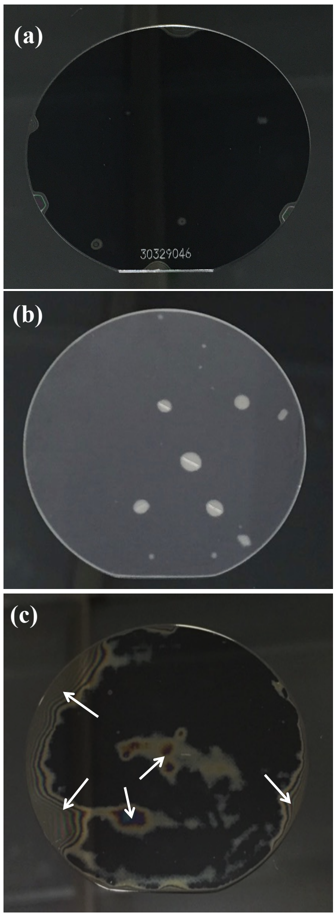

Fig. 1 The bonded wafer of GaN to Si: (a) GaN template to Si, (b) Ga-face of freestanding GaN wafer to Si and (c) N-face of freestanding GaN wafer to Si.

Results and discussion

Fig. 1 (a), (b) and (c) show the bonded wafers of GaN template to Si, Ga-face of freestanding GaN wafer to Si and (c) N-face of freestanding GaN wafer to Si, respectively. It can be seen that the GaN template and the Ga-face of the freestanding GaN were almost completely bonded except some bonding voids, while N-face of the freestanding GaN wafer can only be partly bonded to Si. Some un-bonded areas were found in the edge and center parts of the bonded wafer of N-face to Si, which should be caused by the un-uniform CMP of N-face. This reveals that the CMP process for N-face should be improved to get a uniform smooth surface for a complete bonding.

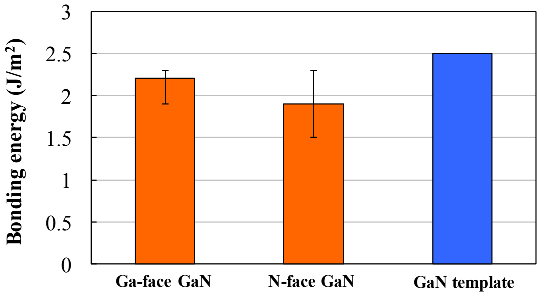

Fig. 2 Comparison of the bonding energies of the three kinds of bonded wafers.

The bonding energies of the bonded wafers were measured by Maszara crack-opening test and compared in Fig. 2. The bonding between GaN template and Si as strong as bulk Si. The bonding using both Ga-face and N-face of freestanding GaN are not as good as that using GaN template, which might be caused by larger sori of the freestanding GaN. The average bonding energy of Ga-face to Si reaches ~2.2 J/m^2, while the average bonding energy of N-face to Si is only ~1.9 J/m^2 with a larger deviation. The larger variation of the bonding energies of N-face to Si might be due to the un-uniform CMP of N-face. One should note that the maximum bonding energies of both Ga-face to Si bonding and N-face to Si bonding is the same, which is 2.3 J/m^2. It is expected that both the Ga-face to Si bonding and the N-face to Si bonding might be further improved after the improvement of CMP of N-face and the reduction of wafer sori.

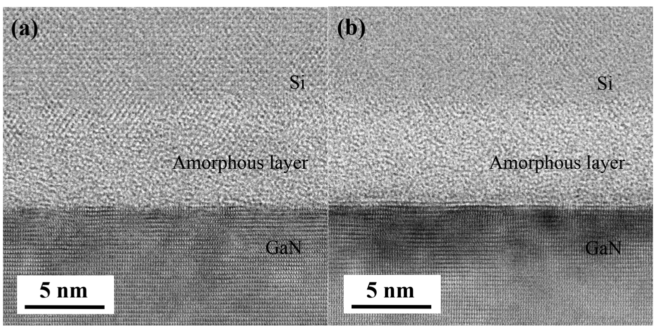

Fig. 3 High-resolution BF-STEM images of the bonding interfaces between freestanding GaN and Si: (a) Ga-face to Si and (b) N-face to Si.

Besides, the bonding interfaces have been investigated by TEM. Fig. 3 shows the high-resolution BF-STEM image of the bonding interfaces between freestanding GaN and Si. At the bonding interfaces, a ~5 nm thick amorphous interfacial layer without any cracks or nano-voids was found. By further composition analysis of the interfaces, the phenomenon of Ga-enrichment during surface activation and Ga-diffusion into Si at room temperature has been assumed.

3. Conclusions

In this study, the room temperature bonding of GaN to Si has been demonstrated by SAB method. It was found that the bonding using GaN template could be as strong as bulk Si. While, the bonding using both Ga-face and N-face of freestanding GaN are not as good as that using GaN template, which might be caused by larger sori of the freestanding GaN. The results of Ga-face to Si bonding are better than that of N-face to Si bonding due to the un-uniform CMP of N-face. The bonding interface have been analyzed. At the bonding interfaces, a ~5 nm thick amorphous interfacial layer without any cracks or nano-voids was found. According to the further composition analysis, the phenomenon of Ga-enrichment during surface activation and Ga-diffusion into Si at room temperature has been assumed.

References

[1] Han S-W, Noh Y, Jo M.-G, et al. IEEE Electron Dev. Lett. **37** (2016) 1613.

[2] Wośko M, Paszkiewicz B, Szymański T, et al. Superlattice Microst. **100** (2016) 619.

[3] Pengelly R S, Wood S M, Milligan J W, et al. IEEE Trans. Microw. Theory Tech. **60** (2012) 1764.

[4] Oka T, Ina T, Ueno Y, et al. Appl. Phys. Express **8** (2015) 054101.

[5] Kim J, Bayram C, Park H, et al. Nat. Commun. **5** (2014) 1.

[6] Meyer D J, Downey B P, Katzer D S, et al. IEEE Trans. Semicond. Manuf. **29** (2016) 384.

[7] Mu F, Iguchi K, Nakazawa H, et al. Appl. Phys. Express **9** (2016) 081302.

Appendix

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