Photoelectron Spectroscopy Investigation of Silicon Nitride and Gallium Nitride Surfaces

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The electronic structures of silicon nitride and gallium nitride surfaces have been studied by photoelectron spectroscopy (PES). Ultrathin β-Si_3N_4(0001) epitaxial films were grown by N_2-plasma nitridation of Si(111) substrates and were studied *in-situ* by photoelectron spectroscopy using synchrotron radiation. On the other hand, the GaN *p-n* junction can be directly visualized on cleavage surfaces in a cross-sectional geometry, where the focused synchrotron radiation images the different doping layers.

PES spectra of Si(111)-7×7, crystalline β-Si_3N_4, and RT-SiN_x were measured with 54° take-off angle and 150 eV photon energy. In Fig. 1, the Si 2$p_{3/2}$ and 2$p_{1/2}$ signals due to the spin-orbit splitting can be well resolved. The bulk (B) and surface states (S1-S5) of clean Si(111)-7×7 can be fitted consistently with the literature values besides different relative intensities resulting from different take-off angle, temperature, and system resolution. The Si 2*p* signal of silicon nitride has a higher binding energy relative to that of bulk silicon because of a different bonding environment. In these *in situ* measured spectra, there is no 2*p* signal resulting from silicon oxide. For the case of ultrathin crystalline β-Si_3N_4 (<1 nm) prepared by plasma nitridation at 900 °C, we find that the main chemical components of silicon nitride is the stoichiometric Si^{4+} valence state and we have only a small contribution from the Si^{+} valence state. The contribution from the Si^{3+} valence state is negligibly small. This is very different from previous studies.

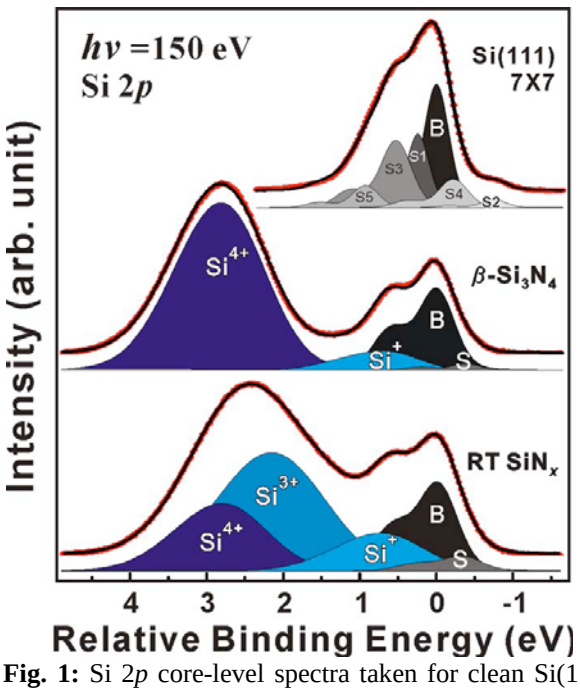

Fig. 1: Si 2*p* core-level spectra taken for clean Si(111)-7×7, β-Si_3N_4/Si(111), and RT-SiN_x / Si(111).[1]

On the other hand, we provide direct evidence for the unpinned nature of cleaved *a*-plane GaN surfaces. The surface cleavage quality was confirmed by *ex situ* scanning electron microscopy (SEM) (Fig. 2(a)) after the SPEM/S experiment. In Fig. 2(b), we show the SPEM images acquired from three selected photoelectron energy channels, corresponding to the binding energies of Ga 3*d* core levels in *p*-type GaN and *n*-type GaN, respectively, as well as Si 2*p* core level in Si substrate. These SPEM images are in good spatial agreement with the SEM image shown in Fig. 2(a). Figure 2(c) shows the μ-PES spectra taken from three different regions at the cross-sectional surface of GaN *p-n* junction. The Ga 3*d* core-level peak of *n*-type GaN region is at 20.5 eV, while that of *p*-type GaN region is at 18.4 eV. The binding energy difference of Ga 3*d* core levels for two doping types of GaN can be directly determined to be 2.1 eV by using the μ-PES spectrum of Ga 3*d* core-level emissions taken at the *p*-GaN/*n*-GaN interface, which shows the dramatic presence of two core-level peaks, which are in agreement with that from individual layers. This result clearly indicates that the built-in voltage at the bulk GaN *p-n* junction can indeed be observed at the cleaved surface.

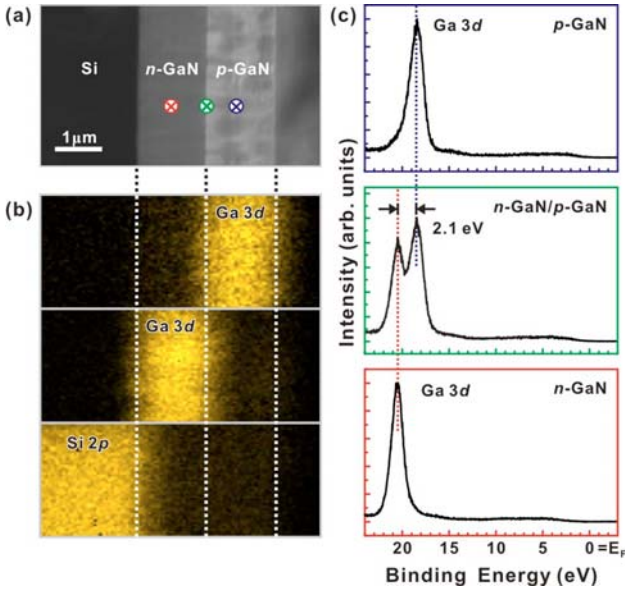

Fig. 2: XSPEM/S measurement on the *in situ* cleaved *a*-plane surface of GaN *p-n* junction.

References

[1] H.-M. Lee, C.-T. Kuo, H.-W. Shiu, C.-H. Chen, and S. Gwo, Appl. Phys. Lett. **94**, 122110 (2009).
[2] C.-T. Kuo, H.-M. Lee, H.-W. Shiu, C.-H. Chen, and S. Gwo, Appl. Phys. Lett. **94**, 122110 (2009).