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Band discontinuity at the interface of rutile $Ti_{1-x}Co_xO_{2-\delta}$/*p*-GaN heteroepitaxial structure studied by synchrotron-radiation photoelectron spectroscopy

Yasushi HIROSE*[1,2], Taro HITOSUGI[2,3], Akira CHIKAMATSU[1], Satoshi TOYODA[1], Hiroshi KUMIGASHIRA[1], Masaharu OSHIMA[1], Junpei KASAI[2], Toshihiro SHIMADA[1,2], Tetsuya HASEGAWA[1,2]
[1]Univ. of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0083, Japan
[2]KAST, Sakado, Takatsu-ku, Kawasaki 213-0012, Japan
[3]Tohoku Univ., Katahira, Aoba-ku, Sendai 980-8577, Japan

Introduction

In the field of spintronics, ferromagnetic diluted magnetic semiconductors (DMSs) are key materials. The rutile and anatase polymorphs of Co-doped TiO_2 ($Ti_{1-x}Co_xO_{2-\delta}$) are among the most extensively studied ferromagnetic DMSs because of their extremely high Curie temperature (> 400 K) and excellent transparency in the visible region.

When applying $Ti_{1-x}Co_xO_{2-\delta}$ to spintronic devices, such as the spin injection electrode and integrated optical isolator, the material has to be grown heteroepitaxially on group IV or group III-V semiconductors (Si, GaAs, etc.), which are widely used in conventional electronics. To date, however, $Ti_{1-x}Co_xO_{2-\delta}$ has been synthesized mostly on oxides, including $LaAlO_3$, $SrTiO_3$, and Al_2O_3, and heteroepitaxial growth of $Ti_{1-x}Co_xO_{2-\delta}$ on such semiconductors has scarcely been attempted.

Recently, we report the heteroepitaxial growth of room-temperature ferromagnetic rutile $Ti_{1-x}Co_xO_{2-\delta}$ films on wurtzite GaN by pulsed laser deposition (PLD) method [1]. The high-resolution cross-sectional transmission electron microscope images of the film showed atomically smooth interface without intermixing. Thus, $Ti_{1-x}Co_xO_{2-\delta}$ is a good candidate for a spin injector in GaN-based spin-electronic devices.

In this study, expecting an application for a spin-polarized LED, the band discontinuity in the interface of $Ti_{1-x}Co_xO_{2-\delta}$/*p*-GaN was evaluated with synchrotron-radiation x-ray photoelectron spectra (SRPES).

Experiment

$Ti_{0.97}Co_{0.03}O_{2-\delta}$ films were fabricated on Mg-doped *p*-type (n_{hole} = 4×10^{17} cm^{-3}) GaN(0001)/Al_2O_3(0001) templates by PLD[1]. In order to obtain clean surfaces, GaN templates were degreased by ultrasonication in ethanol and acetone, and subsequently etched in 36% HCl solution and rinsed with deionized water. In addition, the substrates placed into the deposition chamber were pre-heated at 700°C in vacuum. The substrate temperature and oxygen partial pressure were keep at 550°C and 1×10^{-5} Torr during the deposition. The film thicknesses were 3nm and 30nm. The SRPES of the samples were measured at the Photon Factory BL-2C of KEK. The photon energy of the synchrotron radiation was 800 eV.

Results

Figure 1(a) shows the valence band spectra of 3 nm $Ti_{0.97}Co_{0.03}O_{2-\delta}$ on *p*-GaN. The spectra of 30 nm $Ti_{0.97}Co_{0.03}O_{2-\delta}$ film and *p*-GaN substrate were also shown in fig. 1(b) with relative binding energies which were evaluated from O1*s* spectra of $Ti_{0.97}Co_{0.03}O_{2-\delta}$ and N1*s* spectra of *p*-GaN. Comparing these valence band spectra, the difference between valence band maximum of $Ti_{0.97}Co_{0.03}O_{2-\delta}$ and *p*-GaN (Δ_{VB}) was determined as ~1.0 eV. Because the band gap of rutile TiO_2 and GaN were 3.0 and 3.4 eV, respectively, the difference between conduction band minimum (Δ_{CB}) was ~1.4 eV.

In the application of $Ti_{1-x}Co_xO_{2-\delta}$/*p*-GaN for spin LED, injecting spin-polarized electrons of $Ti_{1-x}Co_xO_{2-\delta}$ to *p*-GaN is important. However, our results shows that the potential barrier for electron injection from $Ti_{1-x}Co_xO_{2-\delta}$ to *p*-GaN is higher than hole injection from *p*-GaN to $Ti_{1-x}Co_xO_{2-\delta}$. In order to clear this problem, a tri-layer structure with a hole blocking layer would be useful.

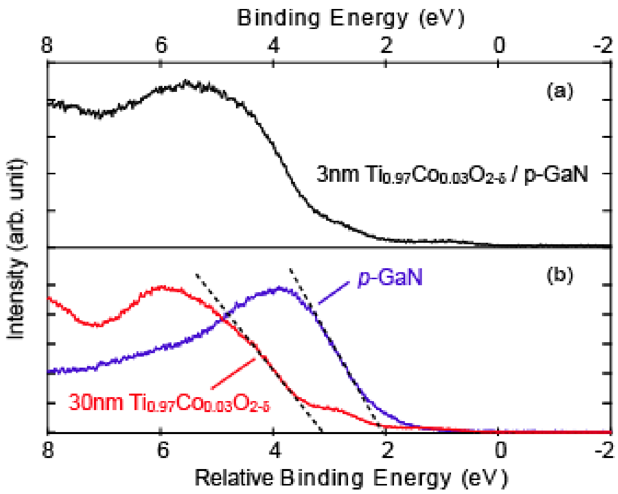

Figure 1 Valence band spectra of $Ti_{1-x}Co_xO_{2-\delta}$/*p*-GaN

References

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* hirose@chem.s.u-tokyo.ac.jp