

Characterization of GaAs Surface State by Hard X-ray Photoemission Spectroscopy

Yoshihiro Saito, Junji Iihara, Takumi Yonemura, Koji Yamaguchi, and Daisuke Tsurumi

Sumitomo Electric Industries, Ltd.
Analysis Technology Research Center
1-1-3, Shimaya, Konohana-ku, Osaka, 554-0024, Japan

Abstract

The surface states of GaAs have been characterized, by using the hard x-ray photoemission spectroscopy (HAXPES). To investigate the effect of the oxide on the surface state, two specimens with different quantities of surface oxide were prepared. The HAXPES measurements of Ga2p_{3/2} and As2p_{3/2} clarified that, in the specimen with more quantity of oxide, the binding energies of both orbitals shifted positively by approximately 0.2 eV. The binding energy shift demonstrates the existence of negative charge at the GaAs surface and the most probable origin of the electron traps is the oxide on GaAs surface.

1. Introduction

Gallium arsenide (GaAs) has some unique features as a semiconductor material when compared with silicon (Si). For instance, the electron mobility of GaAs is five times higher than that of Si. Also, it is possible only in GaAs to make semi-insulating substrates. These features are ideal for transistors that have a very high operation speed with a relatively low consumption power. Thus, GaAs high electron mobility transistors (HEMTs) have become indispensable devices in wireless communication systems.

In GaAs-HEMTs, the surface of the GaAs channels should be passivated with an insulating film. Usually, there are carrier traps at the interface between the film and channel, as shown in Figure 1. The traps capture electrons, which increase the GaAs surface potential and expand an undesired depletion layer in the channel. As the traps deviate the FET characteristics such as break down voltage and trans-conductance, it is important to control the traps from an engineering point of view. However, the detailed mechanism has not been clarified yet.

In this study, we have investigated the GaAs surface states processed by different conditions. Generally, GaAs surface can be oxidized in atmosphere at room temperature. We have focused on the effect of these “native oxides”, since they have been thought to be one of the origins of electron traps [1]. We have employed the hard x-ray photoemission spectroscopy (HAXPES) technique, which enables us to analyze nondestructively the interface chemical states [2]-[5].

2. Experiments

We have fabricated two specimens, (a) and (b), as listed in Table 1. As a starting material, we prepared n-type GaAs substrates, in which the carrier concentration was 5E16/cm³.

In specimen (a), we evaporated 6 nm thick Au-Pd alloy on the GaAs substrate. The native oxides were expected to remain at the interface between the Au-Pd and GaAs. The metal alloy, whose composition was confirmed to be Au_{0.6}Pd_{0.4}, was necessary to reduce the charge-up phenomenon during the HAXPES measurements, as described later.

In the case of specimen (b), the GaAs substrate was initially dipped in an acid solution. After that, 11 nm thick silicon nitride (SiN_x) insulating film was deposited on the GaAs substrate, using the plasma enhanced chemical vapor deposition (PECVD) technique. These two steps were introduced to minimize the quantity of the remaining native oxide. Finally, the Au-Pd alloy was evaporated on the SiN_x film in the same way as specimen (a).

The HAXPES measurements were performed at Beam Line No.46 in SPring-8. Both the back and front sides of the specimens were connected to ground level via carbon tapes. The employed x-ray energy was 7.94 keV and photoelectrons from Ga2p_{3/2}, As2p_{3/2} and Au4f_{7/2} orbitals were detected by using a hemispherical electron analyzer with an energy step of 50 meV, at take-off angles (TOAs) of 80 and 30 degrees.

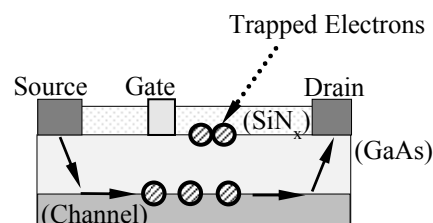


Figure 1 Electron traps in GaAs-HEMT.

Table I Specimens for HAXPES Analysis

	(a)	(b)
Structure	GaAs/AuPd	GaAs/SiN _x /AuPd
Dipping in Acid Solution	No	Yes

3. Results

We found that the Au4f_{7/2} peak positions of the two specimens were slightly different from each other. This was due to the charge-up that could not completely be eliminated by the Au-Pd coating. To correct for the peak shifts, we additionally performed soft x-ray photoelectron spec-

troscopy (XPS) measurements for an $\text{Au}_{0.6}\text{Pd}_{0.4}$ standard sample whose thickness was 1 μm . As a result, the $\text{Au}4f_{7/2}$ peak position was confirmed to be 83.606 eV. Then, all the spectra obtained in the HAXPES were corrected so that the $\text{Au}4f_{7/2}$ peak position would be the same as that of the $\text{Au}_{0.6}\text{Pd}_{0.4}$ standard sample.

Figure 2 shows $\text{Ga}2p_{3/2}$ and $\text{As}2p_{3/2}$ spectra from the two specimens. In the $\text{Ga}2p_{3/2}$ spectrum of specimen (a), we found that a sub peak existed at higher binding energy than the main peak of GaAs crystal and that the sub peak became larger as the TOA got smaller. The sub peak is considered to be due to the native oxide that remained at the Au-Pd/GaAs interface. While in the case of specimen (b), we found no such sub peaks at either TOAs. Exactly the same trends were confirmed in the $\text{As}2p_{3/2}$ spectra. These results demonstrate that the quantity of the remaining native oxide in specimen (b) is negligible.

We have also found that the binding energies of the $\text{Ga}2p_{3/2}$ and $\text{As}2p_{3/2}$ main peaks in specimen (a) are smaller than those in specimen (b) by approximately 0.2 eV. The positive shift of the main peaks indicates that the GaAs surface potential in specimen (a) is higher than that in specimen (b), since more electrons are trapped near the GaAs surface. The most probable origin of the traps is the native oxide that remained only in specimen (a).

Figure 3 shows the schematic interface structures and band diagrams that are considered from the HAXPES results. As the carrier concentration in GaAs was very small, so-called band bending was hardly expected to occur in the near-surface region of GaAs. This is thought to correspond to the fact that the TOA caused no difference in the main peak positions in each specimen.

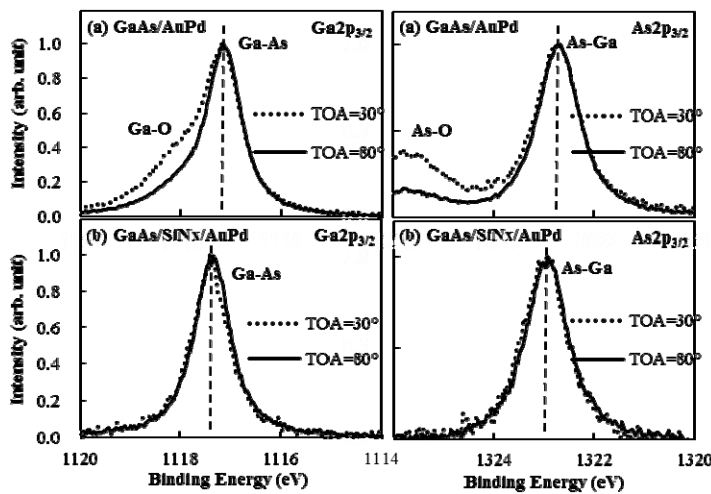


Figure 2 $\text{Ga}2p_{3/2}$ and $\text{As}2p_{3/2}$ spectra from specimens (a) and (b).

4. Conclusions

In summary, we have investigated the GaAs interface state using the HAXPES analyses. In case that the native oxide remained at the interface between the GaAs and Au-Pd, we found a positive shift of the $\text{Ga}2p_{3/2}$ and $\text{As}2p_{3/2}$ peaks, which indicated that the oxides are the origin of the electron traps. It is expected that the increase of the oxide should result in the higher GaAs surface potential and the superior break down voltage of GaAs HEMTs.

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References

- [1] G. P. Schwartz, B. Schwartz, J. E. Griffiths and T. Sugano: J. Electrochem. Soc. Solid-State Science and Technology, **Oct.** (1980) 2269
- [2] K. Kobayashi: Butsuri (Physics), **60(8)** (2005) 624 [in Japanese]
- [3] M. Yoshiki: SPring-8 Research Frontier. 142 (2008)
- [4] L. Walsh, G. Hughes, J. Lin, P. Hurley, T. O'Regan, E. Cockayne, and Joseph C. Woicik: Phy. Rev. B 88, 045322 (2013)
- [5] M. Shibuta, T. Eguchi, Y. Watanabe, J. Son, H. Oji, and A. Nakajima: Appl. Phys. Lett. 101, 221603 (2012)

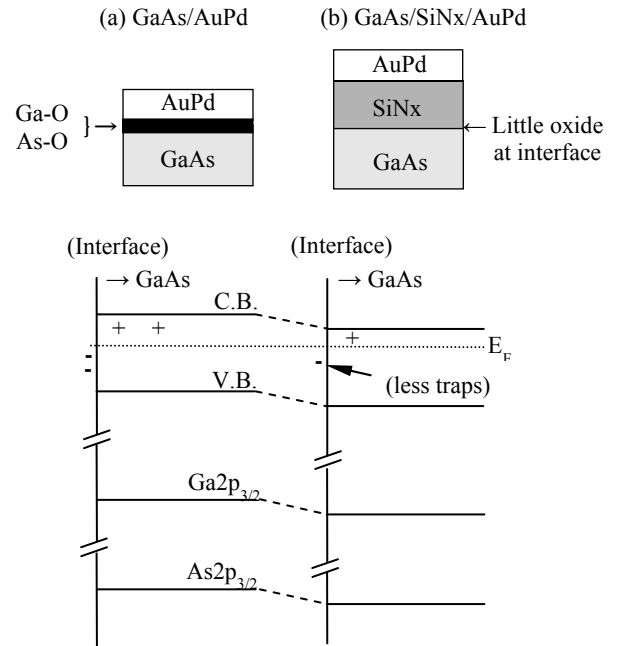


Figure 3 Schematic interface structures and band diagrams.