Direct Observation of Interfacial Charge Transfer in Graphene Device Structures by 3D-nanoESCA

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Recently, Graphene has attracted growing interest for its fascinating electronic properties such as giant carrier mobility (>10^5 cm^2/Vs), superior mechanical properties, and conical dispersions with massless Dirac fermions. Graphene-based devices have been actively studied for post-silicon electronics especially in the field of radiofrequency electronics. However, graphene-based devices based on the conventional field effect transistor (FET) principle suffer from some fundamental problems. For example, one of the reasons for the response deterioration in graphene FET is a charge transfer at the graphene/electrode interface [1].

In order to investigate the local electronic properties at such interfaces in device structures, spectromicroscopic techniques are truly powerful tools. Recently, we have developed a new scanning photoelectron microscope (SPEM) system with a depth profiling analysis capability for three-dimensional (3D) spatially resolved electron spectroscopy for chemical analysis (ESCA), called “3D-nanoESCA” [2]. This system has been installed at the University-of-Tokyo Materials Science Outstation beamline, BL07LSU, at SPring-8.

In the present study, we have employed nondestructive 3D highly spatial distribution analysis using our 3D-nanoESCA for the definite observation of the interfaces in the graphene device structure.

In the sample preparation, exfoliated monolayer graphene was transferred to SiO_2/p^+-Si(100) wafer and Ni electrodes were fabricated by vacuum deposition.

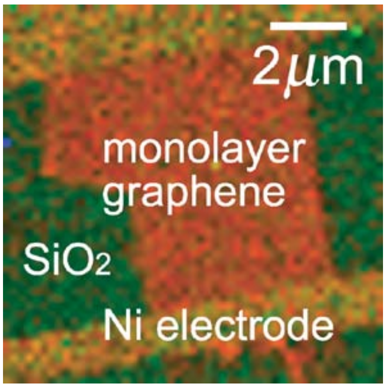

Figure 1. Photoelectron intensity map of a graphene device structure taken by the 3D-nanoESCA.

Fig. 1 shows an elemental mapping image of the graphene sheet sample on a SiO_2 thin film on a p^+-Si(100) substrate. The SPEM contrast reflects the X-ray photoelectron spectroscopy (XPS) intensity of C 1*s* peak (red in Fig. 1) distinguished from surface contamination in a way described below and Si 2*p* peak (green in Fig. 1). The monolayer graphene sheet is clearly distinguished.

A pinpoint analysis of the C 1*s* core level spectrum taken on the graphene is presented in Fig. 2a. The C 1s peak is decomposed into the graphene sp^2 (I) and surface contaminants (II). This identification of each component is confirmed by the depth profiling analysis. As shown in Figs. 2b and 2c, the intensity of the peak II increases compared to that of the peak I as the emission angle becomes larger, suggesting that the component of peak II originates from surface contaminants on the graphene which yield the peak I, that is the graphene sp^2 component.

We have succeeded in precisely determining the binding energy (BE) and the peak shape of the component purely from the graphene sp^2 by excluding the contaminant component.

In order to investigate the spatial variation of the electronic states of monolayer graphene in the vicinity of the graphene/metal electrode boundary, the line-profile for the BE of the graphene is taken across the graphene/electrode contact interface. The energy shift of ~70 meV is clearly detected over the width of 500 nm as shown in Fig. 3. This result is the direct observation of the charge transfer region.

Moreover, the theoretical calculation of the charge transfer region in terms of charge screening within the framework of Thomas-Fermi approximation and the depth profiling for O 1*s* spectra suggests that the bonding state at the graphene/substrate interface can affect the charge transfer region at the graphene/electrode interface.

Our results can serve a wealth of information of electronic and chemical states of the graphene device interfaces which are essential for the device performance [3].

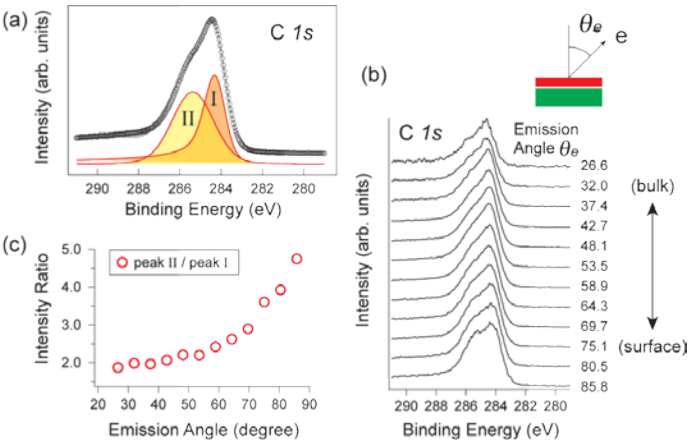

Figure 2. (a) C 1s core-level photoemission spectrum measured on a monolayer graphene sheet. (b) ARPES spectra of C 1s taken at various emission angles. (c) Emission angle dependence of the relative intensity ratio between two components: peak II/peak I.

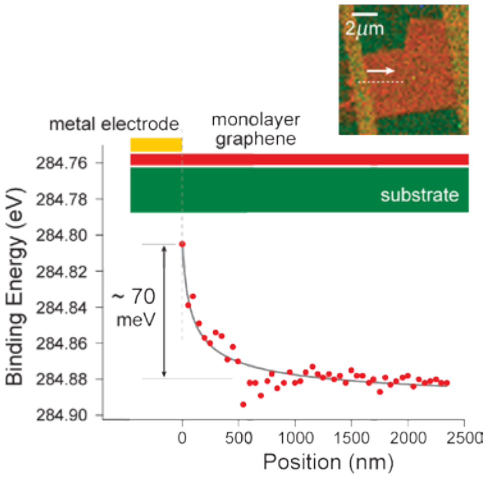

Figure 3. Line profile for the binding energy peak position of the graphene component (peak I in Fig. 2) taken along the dashed white line shown in the inset mapping image. The energy shift of ~70 meV occurs at the graphene/electrode interface. Red circles indicate the results of peak fitting. A gray curve represents the results of theoretical calculations.

References

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