Research Group for Molecular Spintronics

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Spintronics is an emerging technology taking advantage of the dual property of electrons; the charge and spin degrees of freedom. Recent studies have started to shed light on the spintronics applications of molecular materials including organic molecules and nanocarbons. In the molecular spintronics, the effective controls of spin and electronic information via the magnetic heterostructures and interfaces are important for achieving the spintronic applications. Our group aimed at elucidating the interface-related properties of the magnetic heterostructures composed of graphene and its related materials as the fundamental component of the graphene-based spintronic devices.

Contact-induced Spin Polarization in Monolayer Hexagonal Boron Nitride/Ferromagnetic Metal Heterostructure

Hexagonal boron nitride (h-BN), an isomorph of graphene, is becoming the focus of attention as an insulating material for graphene spintronics. It was recently demonstrated that electrical spins can be injected into graphene by using monolayer h-BN as an ultra-thin tunneling barrier between graphene and a ferromagnetic metal electrode [1]. We successfully clarified the spin-dependent electronic structures of the monolayer h-BN contacted with a ferromagnetic Ni(111) by employing spin-polarized metastable-atom deexcitation spectroscopy (SPMDS) with spin-polarized metastable helium atom (He*) as a surface spin detector [2].

A monolayer h-BN/Ni(111) heterostrucuture was synthesized by chemically depositing h-BN on the Ni(111) surface using borazine as precursor. The evolution of the surface electronic structure with the growth of h-BN was *in-situ* observed in the range of the h-BN coverage (θ) from θ = 0 to 1 by measuring the kinetic energy distribution of ejected electrons in the spin-dependent He* deexcitation process on the sample surface.

Figure 1 shows the spin asymmetry spectra representing the spin-dependent change of the kinetic energy distribution of the ejected electrons. For the Ni(111) surface (θ = 0), the spin asymmetry of 9% was observed around the Fermi level (~14 eV). According to the principle of SPMDS, a positive (negative) spin asymmetry indicates a negative (positive) spin polarization of the surface electrons. Therefore, the positive spin asymmetry at θ = 0 shows negative spin polarization of the Ni(111) surface.

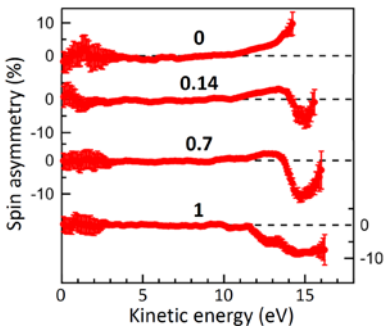

Fig. 1 Spin asymmetry obtained from the monolayer h-BN/Ni(111) heterostructure at different h-BN coverages (θ= 0, 0.14, 0.7 and 1).

The h-BN growth resulted in a significant change in the spin asymmetry in the region around the Fermi level (~16 eV). New states with the negative asymmetry appeared and increased with increasing the h-BN coverage-fraction. Under the full coverage (θ = 1), the asymmetry became as large as − 8%, suggesting large positive spin polarization of h-BN. The positively spin-polarized states are attributed to the metallic-like in-gap states of h-BN generated by the π-d hybridization.

The present result clarified that, in the h-BN/Ni(111) heterostructure, insulating h-BN turns to be metallic-like and positively spin-polarized in contrast to the negative spin polarization of Ni(111). The present study demonstrated that the application of h-BN in combination with graphene could offer a promising way to optimize the operation of graphene-based spintronic devices.

Strong Physical Interface Interactions in Graphene/Sapphire Heterostructure

The large area growth of graphene on insulating substrate is one of the central issues to be addressed for the development of electronic and spintronic applications. In graphene/insulator heterostructures, the charge and spin transport properties of graphene could be affected by the interactions between graphene and insulators at the interface. In this study, the interface interaction in the monolayer graphene/sapphire(0001) heterostructure was assessed by using the normal-incidence X-ray standing wave (NIXSW) spectroscopy [3].

We demonstrated that unusually strong physical interaction exists between graphene and sapphire from the small interlayer distance between the graphene and the sapphire surface (Fig. 2). The interfacial interaction is shown to be dominated by the electrostatic forces involved in the graphene π-system and the unsaturated electrons of the topmost O layer of sapphire rather than the van der Waals interaction. Such interaction causes graphene the p-type doping and enables the graphene to easily slide on the sapphire surface despite the small interlayer distance with the energetic stability.

The present study provides a basis for manufacturing high performance electronic and spintronic devices.

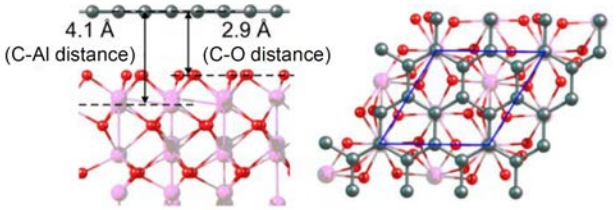

Fig. 2 Atomic structure of the monolayer graphene/sapphire(0001) heteorstructure elucidated with NIXSW spectroscopy. The cross-sectional view at the left and the top view at the right. C, O and Al atoms are marked by black, red and pink colors, respectively.

References

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[2] M. Ohtomo *et al.*, Appl. Phys. Lett. **104**, 051604 (2014).
[3] S. Entani *et al.*, Nano Research **8**, 1535 (2015).