Evaluating a Crystallographically Heterogeneous Graphene/$L1_0$-FePd Interface with a Perpendicular Orbital Moment by Depth-Resolved X-Ray Magnetic Circular Dichroism

A heterogeneous interface was fabricated by growing graphene (Gr) using chemical vapor deposition on an $L1_0$-FePd epitaxial film grown by sputtering. The depth-resolved X-ray magnetic circular dichroism (XMCD) analyses revealed that the perpendicular magnetized orbital magnetic moment was excited at the Gr/$L1_0$-FePd interface. The perpendicular orbital moment is owing to the shortening of the interatomic distance between Gr and $L1_0$-FePd, which produces a robust high electron density at the interface, resulting in a chemisorption-type vdW force having strong orbital hybridization.

Van der Waals (vdW) force is a type of intramolecular force that acts between atoms, ions, and molecules, and has a weaker bond force than covalent bonds, ionic bonds, and metal bonds; so-called vdW is the flexible bonding. Graphene (Gr) is a carbon consisting of a single layer of atoms arranged in a two-dimensional honeycomb lattice (hexagonal crystal symmetry). An $L1_0$-FePd has tetragonal crystal symmetry, which possesses a high uniaxial magnetocrystalline anisotropy (UMA) constant together with a low magnetic damping constant [1], which are attractive magnetic properties for the recording layer in a high-density nonvolatile magnetic random-access memory (MRAM). The hexagonal Gr and the tetragonal $L1_0$-FePd are crystallographically heterogeneous. However, the first-principles calculations predicted that the Gr/$L1_0$-FePd heterogeneous crystal interface exists with an energetically stable crystal orientation that is Gr armchair axis was parallel to FePd $[100]_{L10}$, then it is possible to experimentally fabricate the Gr/$L1_0$-FePd heterointerface. (Fig. 1) We are interested in exploring a new heterointerface to find new interfacial physics. This study aims to explore new interfacial physics in a crystallographical heterointerface of Gr/$L1_0$-FePd bilayer. To understand the crystallographically heterogeneous interface at the atomic resolution level for explaining the novel physical properties, a cross-sectional scanning transmission electron microscope (STEM) observation was carried. Furthermore, in order to investigate spin magnetic moments and orbital magnetic moments individually, and also to investigate these depth profiles, the depth-resolved X-ray magnetic circular dichroism (XMCD) measurement was carried out [2].

The heterogeneous interface was fabricated by growing Gr using chemical vapor deposition on the $L1_0$-FePd epitaxial film grown by sputtering [3]. The Gr/$L1_0$-FePd was fabricated by a chemical vapor deposition (CVD) method for the hexagonal Gr on the $L1_0$-FePd epitaxial film, which was grown by r.f. magnetron sputtering. The $L1_0$-FePd surface was cleaned by heating and pressurized under a reducing hydrogen atmosphere before growing the Gr by the CVD [3].

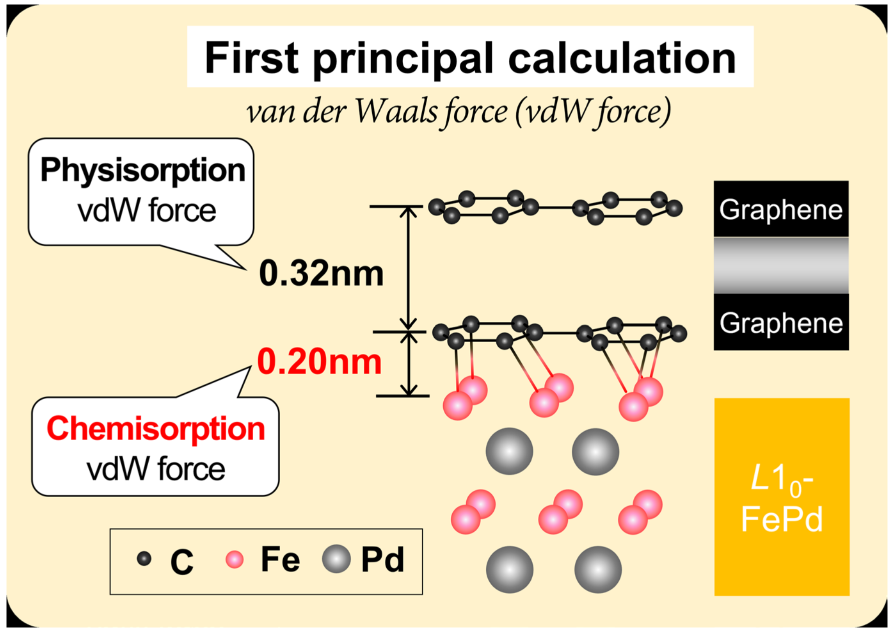

Figure 1: Calculated crystal structure of graphene/$L1_0$-FePd heterointerface. The interlayer distance between graphene was 0.32 nm which is physisorption vdW force, and the shorter interlayer distance between graphene and $L1_0$-FePd was chemisorption vdW force [2].

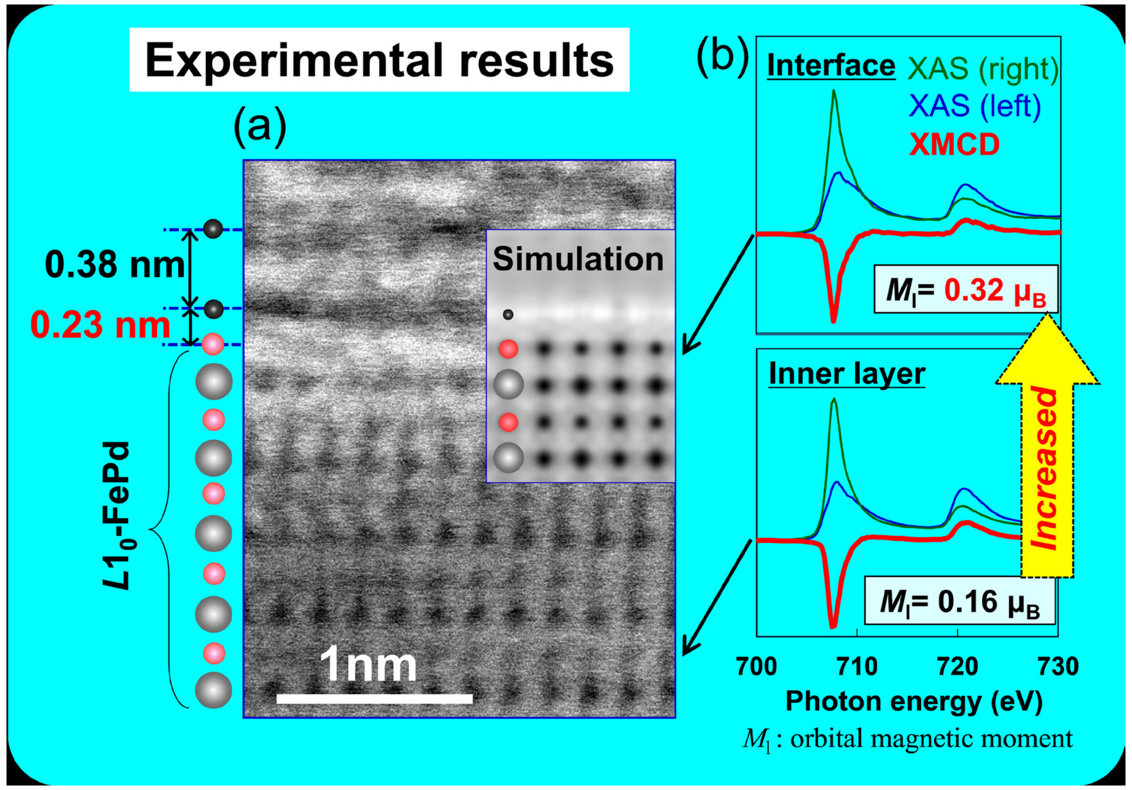

Figure 2: (a) cross-sectional STEM image and (b) depth-resolved XAS and XMCD spectrum by BL-16 [2].

Figure 2(a) shows the cross-sectional STEM image for the Gr/$L1_0$-FePd interface [2]. The inset shows the simulated image by the first-principles calculation considering minimum energy orientation. It was revealed that the Gr/$L1_0$-FePd interface was successfully bonded with the minimum energy orientation owing to a flexible vdW force. By STEM image, the interlayer distance of Gr was 0.38 nm, [Fig. 2(a)] which is roughly consistent with the 0.32 nm predicted by the first-principles calculation. (Fig. 1) The interlayer distance between the Gr and the $L1_0$-FePd was 0.23 nm, which was shorter than the interlayer distance between Gr layers (0.38 nm). This shortening of the interlayer distance can be explained by chemisorption-type vdW force. Generally, the chemisorption-type has a higher electron density than that of physisorption-type vdW force. Figure 2(b) shows the depth-resolved X-ray absorption spectrum (XAS) and XMCD spectrum at the interface and inner layers. The spin magnetic moment (M_s) and orbital magnetic moment (M_l) were calculated by the SUM rule. Noted that the M_l was drastically increased at the interface (M_l: 0.16 μ_B/Fe @inner $\Rightarrow$ 0.32 μ_B/Fe @interface). The enhanced M_l at the interface has anisotropy in the perpendicular direction, so-called interfacial perpendicular magnetic anisotropy (IPMA). From these multifaceted analyses, it can be considered that shortening of the interatomic distance produces a high electron density of chemisorption-type vdW force and that eventually, the IPMA emerges at the Gr/$L1_0$-FePd interface. The chemisorption-type vdW induces strong interfacial perpendicular magnetic anisotropy.

The IPMA induced at the Gr/$L1_0$-FePd is added to the bulk UMA of $L1_0$-FePd. This means the total perpendicular magnetic anisotropy increased, *i.e.* summation of the IPMA and the UMA. The micromagnetic simulation predicted that the Gr/$L1_0$-FePd can overcome thermal fluctuations even at a few nanometer-sized dots owing to large total perpendicular magnetic anisotropy (PMA). The large PMA found in the Gr/$L1_0$-FePd is practically useful for the next X-nm generation ultra-high-density MRAM.

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