Contribution ID : **112** Type : **Oral Presentation**

Iron spin-reorientation transition by dynamic interface alloy formation with Mn

Tuesday, 14 August 2018 10:30 (15)

Magnetic thin film heterostructures have been widely studied for fundamental interests in the emergence of novel magnetic phenomena as well as their promising practical applications. The heterointerface interaction plays a dominant role in the development of interesting electronic and magnetic properties. The coupling at the heterointerface strongly relies on the interfacial structure on the atomic scale such as atomic roughness, steps and intermixing, which could degrade electronic and magnetic interactions considerably compared to the theoretically predicted ideally-abrupt interface. However, little comprehensive study that takes overall interfacial factors including electronic hybridization on the atomic scale into account and identifies their individual roles has been conducted so far.
We use scanning tunneling microscopy (STM) and x-ray absorption spectroscopy/x-ray magnetic circular dichroism (XAS/XMCD) as complementary tools to study the correlation between the microscopic interface properties and macroscopic magnetic properties of Mn overlayers on an fcc Fe thin film. Successive atomically-resolved in situ STM characterizations of the surface structural and electronic properties during the growth of the Mn overlayer in ultra high vacuum (UHV) give crucial information on the dynamical process of the heterointerface formation. Element-specific and quantitative observations of electronic and magnetic properties by in situ XAS/XMCD measurements can be linked with microscopic origins of the heterointerface characteristics.
Our fcc Fe thin films are grown on Cu(001) with Mn overlayers in UHV. Magnetic properties of the ferromagnetically-coupled top two layers in the fcc Fe film on Cu (001) are quite sensitive to the local lattice strain even on the atomic scale. Thus, the fcc Fe thin film could highlight the role of atomic-scale interfacial factors with the Mn overlayers.
We find in the XMCD measurements that the Fe layer in Mn/Fe thin film heterostructure exhibits a two-step SRT from out-of-plane to in-plane magnetization with increasing the Mn coverage. The origin of the observed two-step SRT is identified by separately evaluating the roles of entangled interfacial factors using STM with atomic-resolution imaging and spectroscopic capabilities. At low Mn coverages (< 1 ML), a considerably rough heterointerface due to the formation of the disordered alloy drastically weakens the out-of-plane magnetization of the Fe layer, accordingly triggering the first step of the SRT. In the second-step SRT, the in-plane magnetic anisotropy of Mn/Fe thin film heterostructures is gradually enhanced up to ~ 3 ML Mn coverage. At the same time, an ordered FeMn alloy is formed with the increase of the Mn coverage. With the help of our first-principles calculations, we attribute the stabilization of the in-plane magnetization dominantly to the electronic hybridization of the Fe layer with the ordered alloy at the heterointerface.
The present results demonstrate that microscopic characterizations by STM can be effectively integrated into macroscopic ones by XAS/XMCD to achieve a comprehensive understanding the relation between the magnetic properties and the dynamic heterointerface formation. Furthermore, a considerable enhancement of the magnetic anisotropy of the Fe layer across the second-step SRT will provide a new perspective on the materials design using the interfacial alloy to reinforce magnetic thin film heterostructures.

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Session Classification : Speaker Sessions and Seminars

Track Classification : Magnetic Surfaces, Interfaces and Nanostructures