論文の内容の要旨

論文題目 **Interface electronic and magnetic structures in atomic-scale Mn/Fe heterostructures**
（原子スケール Mn/Fe ヘテロ構造における界面電子磁気構造）

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In modern society, applications of magnetic materials can be found almost everywhere. Magnetic thin films and multilayers have been intensively studied in various aspects for their importance in both fundamental physics and application. The most outstanding impact of magnetism occurs via spintronic devices, which consist of artificially structured magnetic materials. Detailed understanding of spin structure at the interfaces and surfaces on the local scale is important issue in understanding the coupling of various magnetic materials, which is related to the phenomena of interlayer exchange coupling, giant magnetoresistance, and exchange bias. One of the main goals of the research on such low-dimensional magnetism is to find correlations between the structure and the magnetic properties of ultrathin epitaxial films on the atomic scale. Since the local environment at surface and interface could have drastic influence to overall properties, a detailed understanding of such a relationship is not only of basic interest but would allow us to tailor magnetic materials with desired properties.

As highly interesting model system to study the correlation of structural, electronic and magnetic properties in the vicinity of the anti-ferromagnetic/ferromagnetic (AFM/FM) interface, we adopted Mn/Fe thin film heterostructures as a probe multilayer. Fe is known to be the prototypical ferromagnet with body-centered-cubic (bcc) phase at room temperature, but between about 1185 K and 1667 K it is face-centered-cubic (fcc). However, due to a small lattice mismatch between fcc-Cu (a_{Cu} = 3.61 Å) and fcc-Fe (a_{Fe} = fcc 3.59 Å), epitaxial growth of the Fe thin film grown on Cu(001) offers an unique opportunity to stabilize in a metastable structure. Since the magnetic phases of the Fe are energetically close, the Fe films are sensitive to the slight structural changes. Therefore, Fe/Cu(001) has become an important prototype system for studying the relation between structure and magnetism. And Mn film is grown on top of that as the AFM layer. Mn displays diverse phases on different crystalline and also accounts for the various magnetic properties in Mn-based alloys which are widely used in spin valve devices. Thus, in the Mn/Fe thin film heterostructures interfacial structure changes due to a formation of alloy can be expected and an epitaxy-stabilized metastable structure presents unique magnetic properties.

Spin-polarized scanning tunneling microscopy/spectroscopy (SP-STM/STS) and X-ray absorption spectroscopy (XAS) as well as the X-ray magnetic circular dichroism (XMCD) are the tools applied to study the structural, electronic and magnetic properties. The element sensitivity of XAS/XMCD can resolve the magnetic anisotropy of different magnetic layers, even to buried layers at the interface. SP-STM/STS is magnetically sensitive and has a high spatial resolution which allows not only the investigation of the very local environment but also the electronic origin which determines the magnetic properties in real space at the atomic level.

We first identify the growth of the Mn thin films grown on fcc-Fe/Cu(001) surface studied by STM/STS. Thickness dependent STM/STS measurements reveal the changes of the structural and electronic properties due to the intermixing between Mn and Fe thin films at the interface. The formation of a surface alloy was observed when the Mn layer was thinner than three monolayer (ML). From the four ML, Fe segregation is suppressed, and a pure Mn surface appears. Accordingly, spectroscopic measurements reveals the electronic difference between the surface alloy and Mn layers. Mn films thicker than five ML reveal that reconstructed pure Mn layer starts to grow with the same electronic structure and geometrically equivalent interlayer spacings. Second, we show for Mn/Fe thin film heterostructures that a dominant interfacial factor characterizing electronic and magnetic properties of the entire system dynamically changes with the amount of the Mn overlayer combining XAS/XMCD with STM/STS. Element specific magnetization curves of the Fe layer exhibit a two-step spin reorientation transition from out-of-plane to in-plane direction with increasing Mn thickness. Corresponding atomic-scale characterizations of structural and electronic properties successfully unravel the roles of entangled interfacial factors, and clarify the driving force at each transition. The results reveal that the first transition at low Mn coverages is dominantly due to the roughness or distortion induced by disordered MnFe interfacial alloy, while the electronic hybridization with ordered MnFe interfacial alloy dominates as the origin of the second transition at high Mn coverages. Finally, the surface magnetic ordering in Mn/Fe thin films heterostructure is studied by SP-STM/STS with magnetic coated tip. Spin-averaged and spin-polarized STS reveal a spin-polarized state around the Fermi level E_F. Spin resolved differential conductance exhibits magnetic contrasts due to the magnetic exchange interaction between Mn and Fe thin film, which has strong in-plane anisotropy revealed by element specific XMCD. Analysis of the intensity of the differential conductance signal reveals four different magnetic domains with respect to the tip magnetization reflecting the fourfold symmetry of the surface and uncompensated layerwise spin structure.

In summary, the present work in this thesis presents the structural, electronic and magnetic properties of the Mn/Fe thin film heterostructures. The above STM studies have revealed the growth of Mn thin film on fcc-Fe thin film. The observation of the interfacial alloy clarified the impact of the overlayer electronic and magnetic properties on the entire system. The spin-resolved STM observation shows a unique spin structure on the Mn surface unlike previous SP-STM studies about Mn films. These findings in the present study described above are expected to improve understanding of the origin of electronic and magnetic properties in artificially structured magnetic materials and provide a platform for the development of magnetic materials with desired properties. Our results also suggest that combining XMCD with SP-STM is an ideal choice for unraveling future magnetic materials.