論文内容の要旨

Structures and Electronic Transport of Two-Dimensional Phases on Ag-terminated Si Surface

銀終端シリコン表面上に形成される
二次元相の構造及び電子輸送

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One of the Ag-terminated Si surfaces, the Si(111)-$\sqrt{3} \times \sqrt{3}$-Ag superstructure ($\sqrt{3}$-Ag in short), has been studied with a vast variety of experimental and theoretical techniques in the field of surface science ever since its discovery nearly 40 years ago. Nowadays, both its atomic and electronic structures have been well known, and it itself has become a widely used template for fabricating new superstructures and self-assembled nanostructures by adsorptions of metal atoms or organic molecules thereon. This is because of two reasons mainly: the $\sqrt{3}$-Ag surface has a surface electronic state of an ideal two-dimensional electron gas (2DEG), and provides an atomically flat and intact substrate. This PhD thesis concerns a class of two-dimensional (2D) surface phases formed by adsorptions of submonolayer monovalent metal atoms (Au, Cs, K) on $\sqrt{3}$-Ag, especially a newly formed $\sqrt{21} \times \sqrt{21}$ superstructure and a disordered 2D phase. The atomic and electronic structures of these 2D surface phases as well as the electronic transport are investigated with a series of experimental methods and discussed in three parts.

The first part describes the structural transformations in the adatom overlayer on the $\sqrt{3}$-Ag surface as the adatom coverage increases. We reveal that the Au-induced $\sqrt{21} \times \sqrt{21}$ structure ($\sqrt{21}$-Au in short) is a self-assembly of Au nanoclusters forming at lower coverage and dispersing randomly on the $\sqrt{3}$-Ag substrate. A new structural model of the $\sqrt{21}$-Au surface is proposed to replace all the old ones. As a contrast, during the formation of the Cs- and K-induced $\sqrt{21} \times \sqrt{21}$ structures ($\sqrt{21}$-Cs and $\sqrt{21}$-K, in short, respectively), a first atomic-scale observations of 2D gas-liquid-solid phase transition is realized.

The second part reports the evolutions of electronic structures of the 2D surface phases on $\sqrt{3}$-Ag as the adatom coverage increases and as the sample temperature changes. At very low adatom coverages, the nearly-free electron (NFE) band is shifted downwards to higher banding energy due to electron donation from the adatoms, and deviated from the NFE model owning to interactions with other two surface bands beneath. On the other side, by cooling the Au adsorbed surface sample so that the Au adatoms transfer from a 2D adatom gas (2DAG) phase to the Au nanocluster phase, the NFE band split in two because of hybridizations with localized states. In addition, the Si $2p$ core level spectra of Au adsorbed $\sqrt{3}$-Ag surface strongly support the newly proposed atomic model of the $\sqrt{21}$-Au surface.

The last part discusses the surface-state electronic transport of Au adsorbed $\sqrt{3}$-Ag surface as well as the pristine $\sqrt{3}$-Ag surface itself. Before Au deposition, the $\sqrt{3}$-Ag surface shows a typical metallic behavior in the temperature dependence of surface-state sheet conductance, in consistent with its metallic electronic structure. At the Au nanocluster phase, electrons are weakly localized due to enhancement of back scattering by the Au nanocluster. As a result, the sheet conductance decreases logarithmically with temperature. In the $\sqrt{21}$-Au surface, the intrinsic deficiency of the surface prevent from measuring the inherent sheet conductance through the metallic surface-state band.

In this thesis, it is directly revealed by surface-science techniques that atomic defects/impurities play crucial roles in structural, electronic, and transport properties of 2 surface.