Title	走査型トンネル顕微鏡の真空ギャップ中に励起された電子定在波の研究とその表面解析への応用
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Abstract

This thesis presents the fundamental properties of the electron standing waves (ESWs) excited in a vacuum gap of scanning tunneling microscopy (STM), and their application to surface characterization.

The tunneling conductance change due to the ESWs excited between a tip and a sample can be found in a field emission (FE) regime of STM, where electrons field-emitted from a tip or sample can have a positive kinetic energy near the sample or tip surface at an applied voltage higher than a work function. In the region, the incident electrons can interfere in a vacuum gap with backscattered electrons, resulting in an ESW under proper boundary conditions of the sample or tip surface and a tunneling barrier. The tunneling probability increases when the Fermi energy of the tip coincides with the energy of the ESW, hence, changes in the excitation energies can be detected through changes in the differential conductance of a tunneling current. Up to now, a systematically comprehensive work on ESW phenomena has not been carried out yet. The major difficulty in studying the ESW probably lies in the principle of STM in itself, which has two objects of a tip and a sample: in previous studies it was difficult to separate the sample characteristics from the mixed information of the tip and the sample. To overcome this awkward situation, this study introduced the thermal field desorption (TFD) method to obtain clean tips with a shape under control: it is a well-defined tip. By using TFD treated tips, reproducible ESW spectra can be obtained. The means of the investigation were experiments and simulations. Obtained results are summarized as follows.

[Tip shape effect] Tip radius dependence was measured on Au(111) for electron tunneling form a sample to a tip. The peak interval in obtained ESW spectra decreased as the tip became sharp. In numerical simulations, a tip apex was assumed to be a sphere with a radius r. By introducing the electric potential from such the shape effect into a vacuum potential, experimental results were reproduced qualitatively. This result has revealed that the following three conditions are required to compare ESW spectra obtained on different sample surfaces: 1) bias voltages within the FE regime, 2) a constant tunneling current, and 3) regulating tips with a similar radius.

[Electron source properties] Electron emission from the sample surface of n-type Si(001) showed the unique feature in an ESW excitation. ESW peaks were clearly found for Au(111) and p-type Si(001) at the applied bias voltages near the work function, whereas n-type Si(001) had no apparent peaks around those voltages. This was attributed to the coherence deterioration caused by electrons emitted from surface states with a wide energy range on a semiconductor surface.

[Image potential effect] To investigate an image potential effect, both a tip and a sample were assumed to be flat metal surfaces, and a multiple image potential was introduced in a simulation. By fitting parameters of a tip radius and a tunneling area, the peak intervals of ESW spectra in the simulational results coincide with those in experimental results. In this case, however, simulated tip-displacement curves were not agreed well with experimental results. These results indicate that the other attractive potential exists near the sample surfaces.

[Band bending effect] A band bending effect on ESW spectra was evaluated by light irradiation on a Si(001) surface. Changes in the band bending inside the sample appeared as a parallel shift of ESW peaks. Then, introducing a band bending effect into a sample potential, simulational results showed that the amount of the shift corresponds to that of the band bending at the sample surface. This result have demonstrated that the amount of the band bending can be measured quantitatively through the shift of ESW peaks. Furthermore, by measuring the transient response of tip displacement, the electric field intensity originated from a bias voltage of STM can be evaluated. The obtained intensity was reasonable in comparison with the threshold intensity measured in field emission microscopy (FEM).

[Evaluation of surface electric field] This study have succeeded in obtaining the sample-specific electric field over the sample surface. The field intensities over sample surfaces have been evaluated from peak intervals of ESW spectra. The tips with similar radius must provide a similar potential over sample surfaces of any material, which should become the same intervals of ESW spectra. However, we have obtained the different peak intervals by changing samples of Au(111), Si(111), Si(001) or Ge(001). Therefore, these differences can originate from sample characteristics, not from tip ones. The peak intervals were analyzed with an asymmetric triangle well potential: the analysis indicates that the electric field intensities are different on these surfaces. The electric field strength depends on the element strongly, and on the surface structure weakly: Au(111) > Ge(001) > Si(001) > Si(111).

[Summary] Electron scattering studies with low energies as those in this study have not been conducted so much. In this thesis, the author has succeeded to measure the elemental difference in electric field intensity near the surface by utilizing the ESW excitation in a vacuum gap of STM. Combining the results in this study with the STM advantage of a high spatial resolution, the author has proposed the method for the atomic species discrimination on surfaces observed by STM.