Title	チャージアンプを組み込んだ非接触原子間力顕微鏡による固体表面の電子状態解析
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Analysis of the surface electronic states using a charge amplifier powered by non-contact atomic force microscopy

In this thesis, we demonstrate the novel measurement method using a charge amplifier installed in the non-contact atomic force microscopy (nc-AFM). A Si(111) clean surface and a silicene, a 2-dimensional material, on ZrB_2(0001)/Si(111) was investigated using the charge amplifier. In Chapter 2, the basic measurement method of the scanning probe microscopy (SPM) were introduced. That is, the scanning tunneling microscopy (STM), the atomic force microscopy (AFM), the nc-AFM, and the Kelvin probe force microscopy (KPFM). These SPM techniques use a sharp tip as a probe to detect the interaction between the tip apex and the sample surface. Physical quantities obtained using sharp tip are shown using formula and the schematic diagrams of them. The basic measurement systems are also shown in detail to promote understanding of the data. The force sensor named qPlus sensor used in this study is made of a quartz tuning fork. The characteristic of the quartz tuning fork is explained.

In Chapter 3, a principle of the charge amplifier is shown. The behavior of the charge amplifier is calculated by constructing the circuit model using LTSpice software. The charge amplifier, produced by FEMT GmbH, is also modeled and formulated using the capacitance C_{TS} and contact potential difference (V_{CPD}) between the tip- sample with the schematic diagram of the tip and the sample in this thesis to analyze the charge amplifier output. Additionally, the equipment composition is explained in this chapter.

In Chapter 4, the samples, Si(111) and ZrB_2(0001)/Si(111) the preparation methods for samples are introduced. The structure of Si(111)-7×7 reconstructed surface using dimer-adatom-stacking fault model, and $\sqrt{3}\times\sqrt{3}$ structure of the epitaxial silicene on ZrB_2(0001) are also shown by using schematic models.

In Chapter 5, the obtained results were shown to describe the formula of the charge amplifier output using Si(111) clean surface. A unique contrast is also obtained using the charge amplifier, that is the polarity inversion on Si adatoms during scanning with 0 V. This contrast on the charge amplifier output image is explained by the local V_{CPD} using the charge amplifier output model in chapter 3. Moreover, the contrast change on the charge amplifier output images during scanning are shown without no contact between the tip and the sample surface. And application of this measurement method is suggested from the charge amplifier output obtained on the Silicene.

In Chapter 6, the C_{TS} is calculated using an atomically resolved charge amplifier output image and the charge amplifier model with considering the CPD on Si(111). It is suggested that this measurement method can be a detector for C_{TS} and the variation ΔC_{TS}. The C_{TS} is approximately calculated using the plate-plate model, and the tip shape and size are estimated. And it is proposed that the charge amplifier has a potential to detect the charge transfer phenomena between two materials.

As a summary, it is suggested that this measurement method can be applicable for fast scanning to obtain the CPD instead of the KPFM. The wide bandwidth of the charge amplifier requires fast scan to obtain the contrast on the charge amplifier output image. The evaluation of the capacitance between the tip and the sample is also possible. And the charge amplifier has a potential to detect the charge transfer phenomenon just before the collision between two materials.

Keywords; charge amplifier, C_{TS}, CPD, nc-AFM, charge transfer