Heterodyne Kelvin Probe Force Microscopy with High Potential Sensitivity

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Surface potential distributions have been measured using Kelvin probe force microscopy (KPFM) combined with NC-AFM. Two types of KPFM have been widely used; the frequency-modulation (FM) method [1], and the amplitude-modulation (AM) method [2] In FM-KPFM, the electrostatic force is modulated after applying an ac bias voltage with frequency ω_m. The resultant ω_m component of the cantilever frequency shift (Δf_m) is detected and used for bias feedback regulation. In AM-KPFM, the electrostatic force is modulated after applying an ac bias voltage with the second resonance frequency (ω_2) of the cantilever. The resultant ω_2 component of the cantilever deflection (A_2) is detected and used for bias feedback regulation. FM-KPFM has the advantage of being sensitive to short range interactions, and therefore, high spatial resolution is achievable. However, FM-KPFM has the disadvantage of low potential sensitivity. Therefore high ac bias voltages are necessary, which contribute to topographic artifacts and result in a tip induced band bending at the semiconductor surface [3]. By contrast, AM-KPFM has the advantage of high potential sensitivity, therefore, use of low ac bias voltages is possible. However, AM-KPFM is sensitive to long-range interactions, and the strong averaging effect of the cantilever decreases the spatial resolution of this method [3].

In this paper, we propose a novel surface potential measurement method. This method is based on the heterodyne (i.e., frequency conversion) and AM techniques for the first and second cantilever oscillation resonances. The effect of the stray capacitance between a cantilever and a sample in KPFM is almost completely removed, because the distance (z) dependence of the modulated electrostatic force increases from $1/z$ to$1/z^2$. This method improves the sensitivity of short range forces and reduces the surface potential measurement crosstalk that is induced by topographic feedback. This method has the advantage of high potential sensitivity due to the high cantilever Q value under vacuum. Quantitative surface potential measurements are demonstrated (Fig. 1). In addition, atomic resolution imaging of surface topography and surface potential is successfully demonstrated on a Ge(001) surface. Notably, the heterodyne method proposed here is applicable not only to KPFM, but also to other scanning force microscopy methods using a modulation technique.

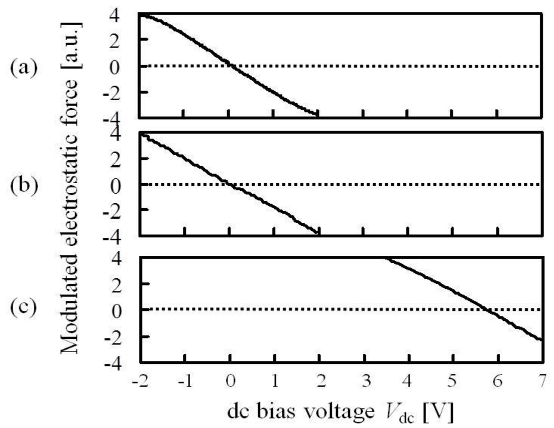

Fig. 1. Modulated electrostatic forces as a function of dc bias voltage between a W-coated cantilever and a Ge(001) surface measured in (a) FM-, (b) heterodyne AM-, and (c) AM-KPFMs. The stray capacitance due to the cantilever strongly influences the surface potential measurements in AM-KPFM, whereas the effect of the stray capacitance on the surface potential measurements is almost removed in heterodyne AM-KPFM.

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