Chapter 6　Conclusion

In this thesis, the electrostatic force was discussed and calculated precisely. The electrostatic force involved with many relative physical value, e.g., A, f_0, R, U, and D etc... On the samples consisting of domains of the different materials, the topography height measurement in AFM is typically incorrect if the electrostatic force due to difference contact potentials is not actively compensated. Our study shows that the difference between the NC-AFM measurement and the actual height of two materials depends strongly not only on the bias between the tip and the sample, but also on the size of the tip.

According to Amplitude modulation AFM (AM-AFM), the topography height measurement also varies with the effect of electrostatic force in a sample with different contact potential domains, and to obtain the correct height difference we need to compensate for the surface contact potential, this is the same as in NC-AFM. Our group has done experiments on relevant researches, but we will not show in this thesis.

6.1　Apparent Topographic Height Variations as Measured by Atomic Force Microscopy over a Flat, Differentially Doped Silicon Surface

A flat Si(100) surface is prepared with neighboring n- and p-doped regions. Measurements with a frequency-modulated non-contact atomic force microscope show large apparent topographic height variations across the differently doped regions. The height differences depend on the bias polarity, bias voltage, radius, and conducting state of the tip. The functional relationships are analyzed in terms of the electrostatic and van der Waals interactions between the tip structure and sample. The experimental results are well explained by model calculations.

Our conclusions are summarized in the following:

1. We made a calculation for the electrostatic force and vdW force, and have a good fitting with our experimental data.
2. We can get the contact potential difference from $\Delta f(V_t)$, and $D(V_t)$ from the turning point on the different material. The contact potential difference (CPD) between p- and n- type is about 0.2 V, and the AFM images have relatively different height because of the CPD effect.
3. The radius of the tip apex is the main cause due to the different height from electrostatic force. When there are two kinds of material on the sample, and different contact potential will cause the height errors.
4. We demonstrated a good method to get the real different height of the sample at the compensated bias and we found the tip radius more exact using the calculations of the $D(V_t)$.
5. We discussed the contribution of F_{apex}, F_{tr_cone}, and F_{vdW}, and fit the $D(V_t)$ of the experiment datum by three kinds of force gradient. The different height of the two materials is dependent of the tip radius, and there is a more exactly height range by different tip bias.
6. For using Si cantilever as probe, there is a very thin SiO_2 layer on the tip apex, therefore it will cause a different tip and sample distance between the electrostatic force and vdW force.
7. The height errors were reduced by using SiO_2 capping tip, even the contact potential was not compensated.

6.2 SiO_2/Si(111) Height Error by Atomic Force Microscopy

The bias voltage between the cantilever and the sample gives rise to a long-range force and changes the imaging conditions in atomic force microscopy operating in the FM demodulation mode. We found that the thickness measurement of SiO_2 films on the silicon substrate depends strongly on the bias voltage. Both the frequency shift vs. bias curves on the silicon area and the SiO_2 areas are recorded first. By applying the specific bias where the two $D(V_t)$ curves cross, we are able to obtain a precise thickness of the SiO_2 films. This result suggests that the suitable compensatory potential is common needed in taking a more realistic topographic image on a substrate with more-than-one composition domains.

Our conclusions are summarized in the following:

1. The ultrathin SiO_2 layer is 0.7 nm that can be obtained from the AFM image. The measurement value is equal to the theory calculation.
2. The contact potential difference between Si(111) and SiO_2 layer is about 0.5 V which obtained from $\Delta f(V_t)$, and $D(V_t)$.
3. The void size of the SiO(g) desorption is about 100×100 nm^2. The AFM image cannot have a good resolution cause of the blunt tip and large electrostatic force.
4. The tip radius can be obtained from the calculation of the $D(V_t)$. The best fitting range is from -1 V to 1 V because of the limit of the void size and tip radius.
5. In the relative step heights versus effective potential difference, the calculations of the simulation have a good fitting with the data between -1 V and 1 V.