Precise measurement of electrostatic tip-sample interaction using 3D-SFM mode

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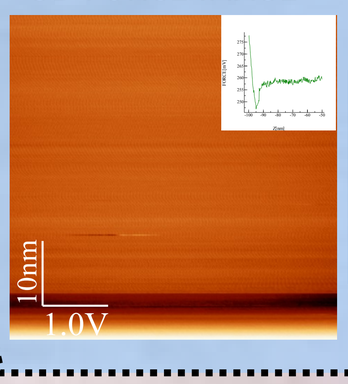
MOTIVATION

Interpretation of data obtained by ESFM or KPM is not an easy task. One of the main problems in this context is a precise knowledge not only of the state of the sample, but also of the precise behaviour of the tip. The latter is specially difficult, since, in contrast to the sample, the tip cannot be "seen" directly, that is, the tip cannot be imaged in order to study and infer its fundamental properties. In order to fully characterize with high precision the tip-sample system, in the present work we propose advanced spectroscopy methods based on multidimensional acquisition of "interaction images". As will be shown, careful processing of the force and, more importantly, the frequency shifts measured while tip sample voltage and tip-sample distance allow a precise and consistent evaluation of the tip behaviour.

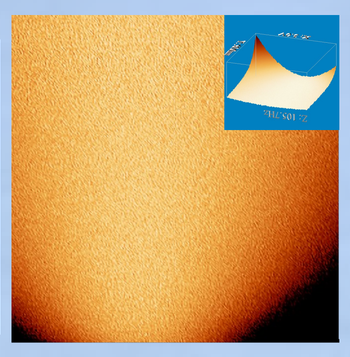
A variety of models have been proposed to describe electrostatic tip-sample interaction. Using appropriate models is a fundamental requisite for quantitative interpretation of data acquired by ESFM or KPM. Models and the experimental data obtained with the method described here are compared and give good agreement. In ESFM bias voltages of the order of 1 or 2 volts are usually applied over distances of just a few nm.. Such voltages are small, but imply huge electric field that may cause dielectric rupture in air and even destroy tip and sample, in particular if tip-sample contact occurs. Therefore, an important goal of our experiments has been to determine electrostatic interaction between tip and sample without needing to establish (mechanical) tip-sample contact.

3D FORCE IMAGE



FORCE KELVIN CAPACITY

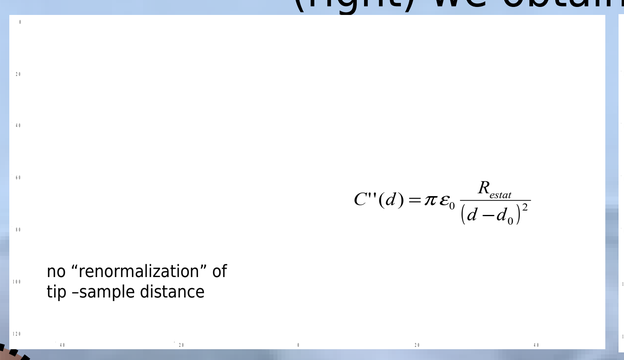
3D FREQUENCY IMAGE



FREQUENCY KELVIN CAPACITY

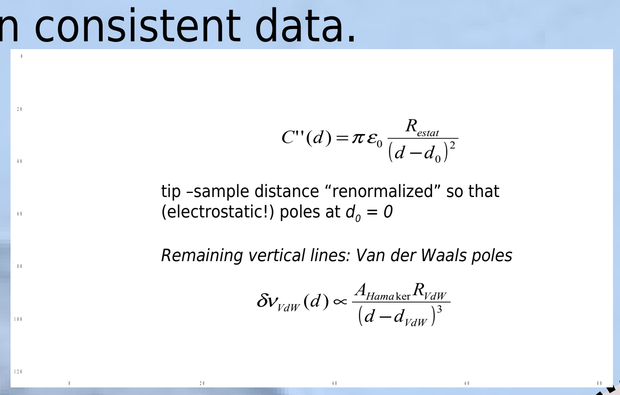
PLATINUM LEVER AND SAMPLE

Placing curves with their Electrostatic pole as reference (right) we obtain consistent data.



$$C''(d) = \pi \varepsilon_0 \frac{R_{estat}}{(d - d_0)^2}$$

no “renormalization” of tip –sample distance



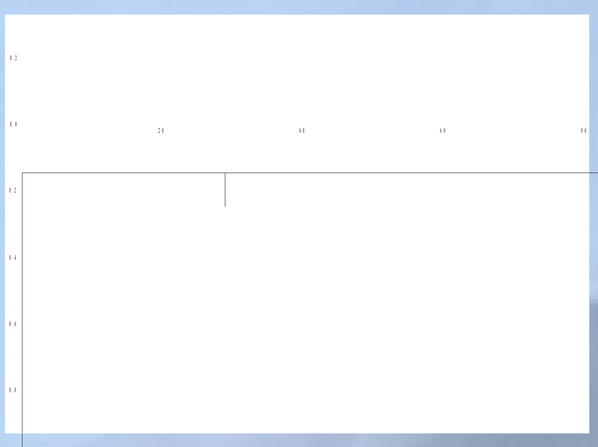
$$C''(d) = \pi \varepsilon_0 \frac{R_{estat}}{(d - d_0)^2}$$

tip –sample distance “renormalized” so that (electrostatic!) poles at $d_0 = 0$

Remaining vertical lines: Van der Waals poles

$$\delta\nu_{VdW}(d) \propto \frac{A_{Hamaker} R_{VdW}}{(d - d_{VdW})^3}$$

SURFACE CONTACT CAN AFFECT TIP AND SAMPLE



ORANGE: Initial contact potential (before tip-sample contact).

RED: Contact potential after mechanical “touch-down”.

We are able to detect changes of contact potential around 50 mV.

3D MODES ON Pt AT DIFFERENT VOLTAGE

Curves with different voltage fit together. Our model for metal interaction fits good. If tip and sample do not change we have very good reproducibility.

As theory predicts, capacity doesn’t change with voltage.

3D MODES ON Si TIP AND SAMPLE

Radius [nm]	Before	After
Van der Waals	0.9±0.3	5.4±0.4
Electrostatics	10±2	2.8±0.4

On Si we find more defined Van der Waals interaction and we can fit the curves to find a Van der Waals pole. We observe that electrostatic (“normalised” to *d=0*) and Van der Waals pole are very different before “touch-down” (yellow, green) and after. Moreover, after touch-down we have a perfect fit of both poles for a large number of curves. Not only the poles, also the Radii of the obtained from the fits to the data changes strongly (see the table).

CONCLUSIONS

Our advanced spectroscopy method allows to precisely characterise Van der Waals and Electrostatic tip-sample interaction as well as contact potentials in a SFM-setup. For the case of metal-metal electrostatic interaction a very good agreement between data and theoretic models is obtained. For the case of semiconductors (Si) we can accurately measure Van der Waals and electrostatic interaction. A very high level of control and precise information about tip sample interaction is obtained in a wide range before surface contact. So we can know electrostatic properties of the sample, without changing their condition, and without change our tip. Our method is highly reproducible and allow us to study a wide range of properties that are important in the present and future AFM techniques in a non-invasive way.

REFERENCES

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