特集 6
研究速報

Some Problems Related to Detection of Displacement of an Object by a Tunneling Current

トンネル電流を用いた変位検出の問題点

Hideki KAWAKATSU*
川勝英樹

Abstract

Due to its very high sensitivity to tunneling distance, the tunneling current has the potential of being used for detecting small displacements. Moreover, the target with which the displacement is to be measured need only be a few nanometers or less in size, which makes the detection technique a strong candidate for application to displacement measurement of nano to micrometric objects. In this paper, I will report on an experiment carried out to measure the displacement of a conventional scanning force microscopy cantilever, with an aim of applying the technique to vibration excitation and detection of a nanometric oscillator.

1. Introduction

We are looking for a technique to measure and/or excite the vibration of a nanometric mechanical oscillator. We have selected both optic and electronic techniques. As for the latter, application of the tunneling current for displacement detection seems to be one feasible solution. This is because the tunneling current has such properties and merits as: (i) the tunneling current is very sensitive to change of gap between two conducting electrodes; (ii) the target may be of nanometric size or smaller; (iii) unlike some optical techniques, there is no problem of low intensity of optical reflection even if the target is small; (iv) the non linear characteristics of the tunneling gap may be exploited for frequency mixing and thus used for mix-down of very high frequencies to lower frequencies.

An example of application of the tunneling current to displacement detection can be found in sensing in accelerometers[1]. Frequency mix-down[2–3] using the tunneling junction was carried out by various research groups working on detection of surface acoustic waves with the scanning tunneling microscope (STM).[4]

There are, however, some foreseeable problems related to displacement detection by the tunneling current. Such problems are: (i) possible ambiguity of the force acting between the tip and the target, (ii) difficulty in characterizing for each experiment, the shape and configuration of the tip and the target; (iii) susceptibility of the tunneling junction to the surface conditions and tip configuration not totally known at the moment. Measurement of the force acting between a tunneling tip and a sample is carried out by U. Dürig et al. using a so called Nanoguitar[5–6] and conventional conductive scanning force microscope[7] (SFM) cantilevers.

2. Instrumental

A commercial scanning tunneling microscope (STM) was put in a vacuum chamber of around 10^{-5} Torr. A commercial SFM silicon cantilever coated with gold or platinum was used as the vibrating sample. Prior to the experiment in vacuum, the cantilever was put in an SFM in air to measure its natural frequency. A cantilever with a relatively high spring constant was chosen to prevent snap-in of the cantilever to the STM tip. Figure 1 depicts the schematic of the experiment.

3. Experimental

The natural frequency of the cantilever was approximately 320 kHz, and the catalogue value of its spring constant 30 N/m. After approaching the tip to the cantilever to obtain tunneling, the tip was raster scanned to obtain the image of the metal coated side of the cantilever. Images of the gold corrugations or the relatively flat surface of the platinum coating could readily be observed. However, no peak was seen in the spectrum of the

*2 rd Department, Institute of Industrial Science, Univerity of Tokyo

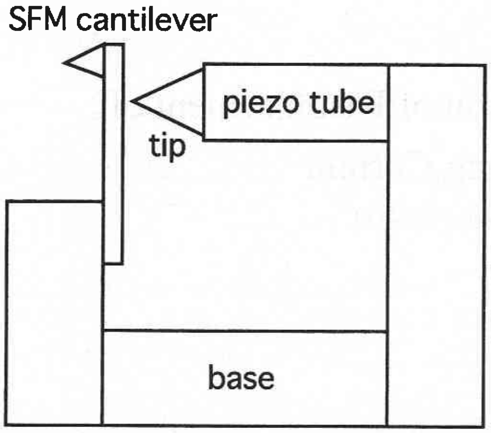

Fig. 1 Schematic of the experiment. An STM tip is positioned against the metal coated surface of a silicon SFM cantilever. Images of the metal coating could readily be observed in the STM mode, but free vibration of the cantilever was prevented by the tip sample interaction.

tunneling current at the natural frequency of the cantilever, which implies that the free vibration of the cantilever easily detectable with an optical deflection method was prevented by the tip sample interaction. The phenomena did not change even when relatively high tunneling bias in the order of a few 100 mV and a low set value of the tunneling current below 100 pA was chosen with an aim to increase tunneling distance, and hence lessen the effect of quasi contact of the tip to the sample.

The tunneling bias was modulated sinusoidally and swept in frequency to see if the modulated electrostatic force would excite the natural frequency of the cantilever. The level of vacuum at 10^{-5} Torr was sufficient to diminish the effect of damping by air. However, no change in the tunneling current was observed when the frequency was modulated around the natural frequency of the cantilever.

4. Conclusions

The fact that the natural frequency of the tunneling head could be observed as a peak in the tunneling current spectrum, as well as the application of the tunneling current for accelerometers made me expect that the tunneling current could be used to measure displacements of small compliant targets. However, contrary to the expectations, the tip to sample interaction was large enough to prevent free movement of the cantilever sample. Although the experiment results did not turn out as expected, detection and excitation with the tunneling current and tunneling bias, as well as frequency mixing using the non-linearity of the tunneling junction still rest a very attractive tool to be exploited in measurement and control of nanometric objects. We intend to retry the experiment in UHV using a clean tip with a known geometry.

5. Aknowledgments

The work was carried out during the author's sabbatical stay at the University of Basel, Switzerland. The author would like to thank Professor H.-J. Güntherodt, Dr. H.-J. Hug, and the low temperature MFM group for their support in the project.

(Manuscript received, September 26, 1997)

Reference

1) A. A. Baski, T.R. Albrecht, and C. F. Quate, J. Microscopy, Pt 1, 73, 1988.
2) W. Rohrbeck, E. Chilla, H. -J. Fröhlich, and J. Riedel, Appl. Phys. A. 52. 344 (1991).
3) J. Heil, J. Wesner, W. Grill, J. Appl.Phys. 64, 4 (1988).
4) G. Binnig and H. Roher, Ch. Gerber, and E. Weibel, Phys. Rev. Lett., 49, 57. (1982).
5) A. Stalder and U. Dürig, in proceeings of the NATO/ASI Foces in scanning probe methods, Kluwer achademic publishers, Series E Applied Sciences Vol. 286. 69, (1995).
6) U. Dürig et al., presented at STM '97, Hamburg.
7) G. Binnig, C. Quate, Ch. Gerber, Phys. Rev. Lett., 56, 930 (1986).