Development of a Scanning Tunneling Microscope for the Carrier Profiling of Semiconductors by Scanning Frequency Comb Microscopy

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We are developing a scanning tunneling microscope that is portable and optimized for scanning frequency comb microscopy (SFCM) as one part of our effort to complete a prototype for the carrier profiling of semiconductors by SFCM [1].

Conventional integral or integral plus proportion feedback control of the tunneling current in a scanning tunneling microscope (STM) is satisfactory once tunneling has been established but may cause tip-crash by integral windup during coarse approach. In tip-sample contact images with atomic-resolution may be obtained but the microwave frequency comb ceases because there is no optical rectification and scanning tunneling spectroscopy also fails.

Our new control algorithm requires three parameters; ΔV_1, ΔV_2, and I_T. First a simulation determines the approximate tip-sample distance at which the tunneling current is just perceptible above the noise. This distance is divided by the gain of the piezo actuator to determine the voltage increment that would move the tip from that point to tip-crash. Then ΔV_1, the voltage step-size used in coarse approach is set equal to a fraction, say one-fifth, of that increment. The voltage step-size when tunneling, ΔV_2, is set to 2 or 3 times the resolution in the voltage. The transition from ΔV_1 to ΔV_2 is made when the measured current exceeds I_T, which is chosen to be between the set point current and the noise in measuring the tunneling current.

We are studying a new control algorithm based on approximating the tunneling current as a polynomial in the bias voltage where the coefficients in this polynomial are not required. For example, if the voltage $V_1\cos(\omega t)$ is superimposed on the DC bias V_0, the DC tunneling current may be approximated by I_1V_0/V_1 where I_1 is the peak value of the tunneling current at the frequency ω. Simulations suggest that using an active narrow bandpass filter to measure the peak current at the frequency ω has faster response and greater accuracy than the conventional use of simple averaging or integration to estimate the DC tunneling current. Higher-order polynomials with measurements at two or more harmonics of ω may provide greater accuracy.

Changes in the apparatus, as well as the algorithms used for feedback control in the STM, are required to optimize this instrument for measuring the microwave frequency comb. For example, we couple the microwave harmonics from the tunneling junction by using a stationary section of miniature semi-rigid coaxial cable where the microwave circuit is completed by a fine wire connecting the cable shield to the sample. The STM head shown in Fig. 1 requires a slightly lower scan rate because the piezo actuator is mechanically loaded by the sample, but enables quantitative coupling of the microwave harmonics to a spectrum analyzer.

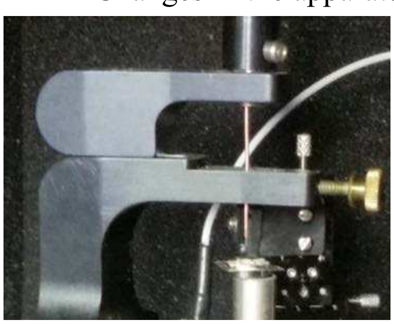

Fig. 1. SFCM-STM head with semi-rigid coaxial cable attached to the tunneling junction.

References:

1. C. Rhoades, J. Rasmussen, P.H. Bowles, M.J. Hagmann and D.A. Yarotski, “First measurements of a microwave frequency comb with a semiconductor sample in a scanning tunneling microscope,” 2016 IEEE Workshop on Microelectronics and Electron Devices, DOI: 10.109/WMED.2016.7458278.

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