Scanning Frequency Comb Microscopy—A new method in Scanning Probe Microscopy (Manuscript for post-deadline poster at the conference M&M-2018, Microscopy &Microanalysis, Aug. 5-9, 2018, Baltimore, MD.

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Background

When a mode-locked laser is focused on the tunneling junction of a Scanning Tunneling Microscope (STM) with a metal sample, hundreds of microwave harmonics are generated at integer multiples of the laser pulse repetition frequency. Each harmonic sets the present state-of-the-art for a narrow-linewidth microwave source to enable a signal-to-noise ratio greater than 20 dB even at attowatt power levels [1]. We are pursuing applications to the nondestructive profiling of semiconductors with true sub-nm resolution [2]. However, with semiconductor samples the microwave power has been measured with a surface probe within 200 μm of the tip [3] because of the dispersion during carrier transport [4]. Furthermore, the spreading resistance in a semiconductor sample promotes tip-crash in an STM [3].

Discovery—The DC tunneling current is not necessary!

1. For each value of the sample resistivity there is a corresponding tip-sample distance for maximum microwave power, and this power varies inversely with the square of the sample resistivity.
2. The measured attenuation of the microwave power at each harmonic is caused by the spreading resistance of the semiconductor which decreases the tip-enhanced quasi-static near-field of the laser.
3. The microwave power is generated by optical rectification and the sole function of the DC tunneling current and the DC applied bias is to adjust the tip-sample distance to maximize the microwave power.
4. Finer resolution in controlling the tip-sample distance at sub-nm values is possible by using the microwave power as the basis for feedback control instead of a setpoint value for the tunneling current.

Discussion

Figures 1, 2, and 3 are block diagrams showing the apparatus for measurements in an STM with metal samples and semiconductors, as well as in Scanning Frequency Comb Microscopy (SFCM) where there is no applied DC bias or tunneling current. Figures 4 and 5 suggest that greater accuracy and precision is possible by controlling the tip-sample distance based on the microwave power instead of the DC tunneling current. The additional stress on the tip from the DC current is eliminated.

Possible Applications

1. Surface topography with high resistivity samples where feedback based on the current would fail.
2. Non-destructive carrier profiling of semiconductors with true sub-nm resolution, even in operating devices, which is required by the semiconductor industry at the new sub-10 nm lithography nodes.

References:

[1] M.J. Hagmann, A.J. Taylor and D.A. Yarotski, Appl. Phys. Lett. **101** (2012) 241102.
[2] M.J. Hagmann, M.S. Mousa and D.A. Yarotski, Appl. Microsc. **47** (2017) 95-100.
[3] C. Rhoades *et al*, IEEE Workshop on Microelectronics and Electron Devices (2016) 1176324.
[4] C. Zhu *et al*, IEEE Workshop on Microelectronics and Electron Devices (2017) 8916934.
[5] This material is based upon work supported by the National Science Foundation under Grant No. 648811.

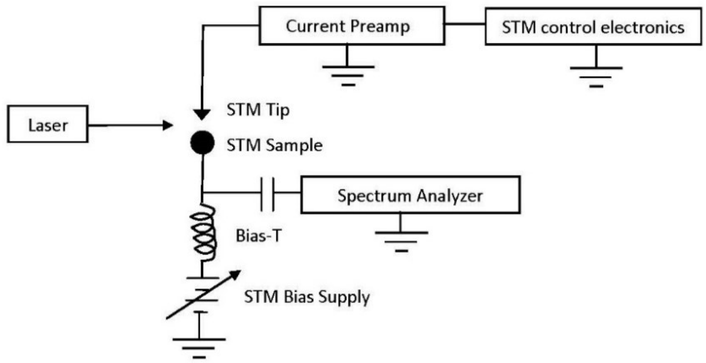

Figure 1. Block diagram with a metal sample in a scanning tunneling microscope.

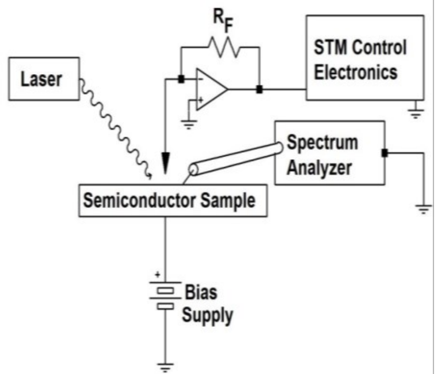

Figure 2. Block diagram with a semiconductor sample in a scanning tunneling microscope.

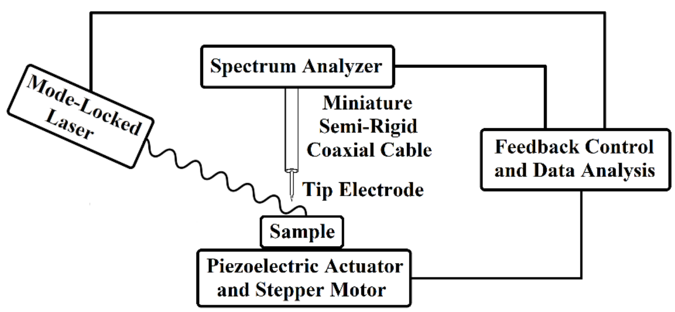

Figure 3. Block diagram for Scanning Microwave Frequency Comb Microscopy.

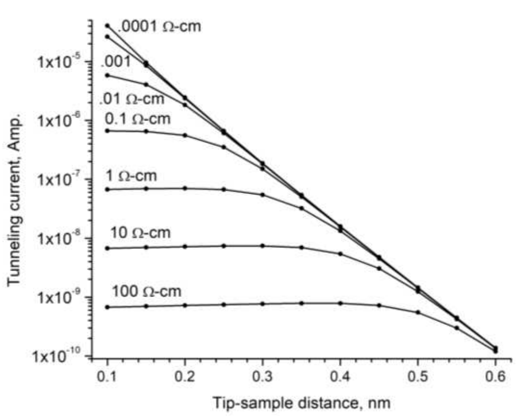

Figure 4. Simulated current vs. tip-sample distance for different sample resistivities with an STM.

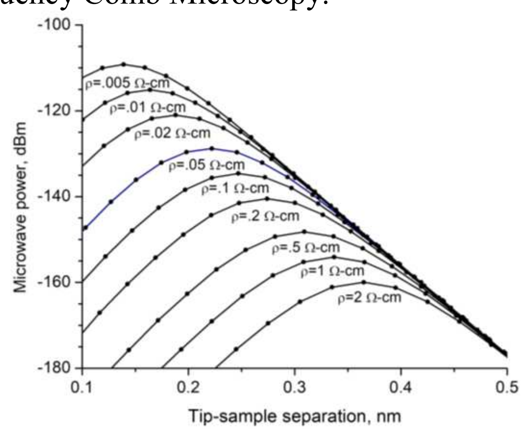

Figure 5. Simulated power vs. tip-sample distance for different sample resistivities with SFCM.