



Non-Contact Atomic Force Microscopy Fabrication of Gold Nanowire Electrodes



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Problem Statement & Goals

Problem Statement

Creation of sub-10 nm electrodes is crucial for conductance measurements of small molecules, such as pentacene. This conductance analysis is impossible with larger-scale electrodes, since many small molecules can simultaneously bridge a larger electrode gap. The result is collection of bulk data, which has been shown to be the theoretical equivalent of having nothing between the electrodes at all [1].

Image from: <http://en.wikipedia.org/wiki/Pentacene>

Goals

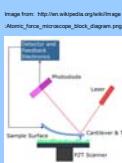
- Replication of results published by another group in 2005: consistent production of ~40nm wide gold nanowires, up to 55 μ m in length [2]
- Minimization of wire size by:
 - improvement of FM-AFM techniques
 - use of a unique cantilever with a sharp gold tip [3]



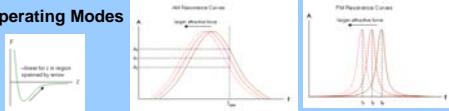
AFM Background

Basic Characterization

- Scanning probe microscope capable of atomic resolution
- Change in cantilever oscillation, due to tip-sample interaction, results in a topographical surface map
- Advantages over other microscopes:
 - unlike electron microscopes, can image samples in air and under liquids
 - unlike STM, can image non-conductive samples
- Mode of operation depends on quality factor, $Q = f_0 / \Gamma$, where f_0 = resonance frequency and Γ = bandwidth of resonance curve



Operating Modes



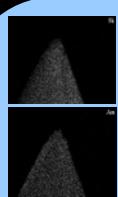
Both modes maintain tip-sample force (F , and hence tip-sample distance, z) and cantilever oscillation amplitude (A) and frequency (f) constant, but do so by different means.

Mode	Amplitude modulation (AM)	Frequency modulation (FM)
Because the AFM is operated in _____, quality factor (Q) is _____, making it easier to detect change in _____ when resonance curve shifts in response to F change. Therefore, feedback maintains F constant (by adjusting z) based on the calculation _____.	Air Low Amplitude	Vacuum High Frequency

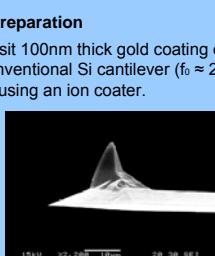
$$F = |A_0 - A_1|$$

$$F = |f_0 - f_1|$$

Lithography Methods



SEM-EDS images showing Si and Au content areas on tip; complete overlap indicates complete coating

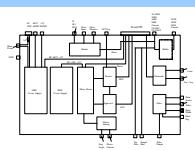
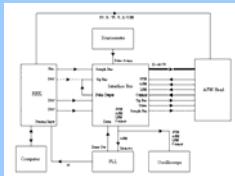
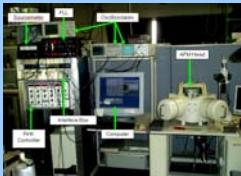


SEM image of gold-coated tip

Tip Preparation

Deposit 100nm thick gold coating on tip of conventional Si cantilever ($f_0 \approx 250$ kHz) using an ion coater.

AFM System Configuration

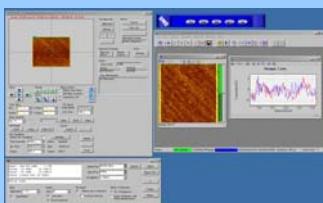


Operation Conditions

- FM mode—provides most precise tip-sample force-distance control
- Room-temperature and medium vacuum (3 Pa, necessary for maintaining high $Q \approx 20,000$)—minimizes setup time and complexity compared to conventional ultra-high vacuum (UHV) FM-AFM systems

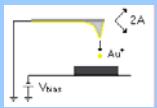
Imaging

- Search for a clean, flat surface
- Calculate nm-to-amplitude-setpoint relation by comparing the z of images taken at two different setpoints



Gold Deposition

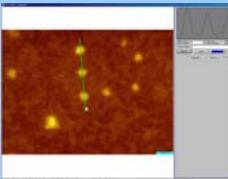
- Re-adjust setpoints for cantilever oscillation amplitude and tip-sample distance
- Turn off tip-sample distance feedback
- Pulse sample with a negative bias to deposit Au dot
- Turn feedback on again, retract and move tip to next deposition location, then turn feedback off again
- To create a wire, apply repeated pulses such that dots overlap



Results

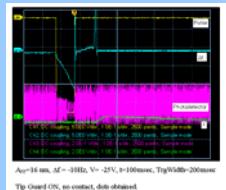
So Far

- Successfully deposited dots of diameter ~40nm
- Begun pulse parameter manipulation, examining effects on:
 - Various AFM signals (Δf , photodetector, z)
 - Success/failure of dot deposition
 - Size of dots deposited



Next Steps

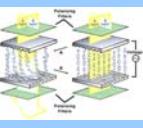
- Pulse optimization by parameter adjustment
 - A_{opp} = operating amplitude
 - Δf = tip-sample force setpoint
 - V = pulse voltage strength
 - t = pulse duration
 - D = dissipation (always set to minimum)



- Interfacing with LithoEdit programs to speed and abstract the drawing procedure—sample LithoEdit program for drawing a dot at position (15, 10)

Conclusions

A FM-AFM system provides greater force-distance control than an AM system, but FM-AFM is a newer field whose capabilities outside of UHV conditions have not been extensively investigated. This work is concerned with developing a FM-AFM system for use in less controlled atmospheric conditions, which may yield a valuable tool for many applications beyond lithography.



LCD mechanism
Image from: <http://www.santron.com/newsletter/C0504LCDTechnology.htm>

Within the scope of this particular experiment, FM-AFM improvement coupled with use of a unique, sharp gold tip could provide a precise enough system for sub-10 nm wire fabrication.



TFT
Image from: http://www.india-tft.com/techinfo/images/tft_04_img_04.jpg

Possible application of these wires: conductance measurements for molecules such as pentacene, a promising material for use in organic thin-film transistors (TFTs) of liquid crystal displays (LCDs).

Sources

- [1] Dadosh T, Gordin Y, Kitahine R, Khivrich I, Mahalu D, Frydman V, Sperling J, Yacobi A, and Bar-Joseph I, *Nature* **436**, 667 (2005).
- [2] M. E. Pumarol, Y. Miyahara, R. Gagnon, and P. Gruter, *Nanotechnology* **16**, 1083-1088 (2005).
- [3] Kotone Akiyama, T. Eguchi, T. An, Y. Fujikawa, Y. Yamada-Takamura, T. Sakurai, and Y. Hasegawa, *Review of Scientific Instruments* **76**, 033705 (2005).