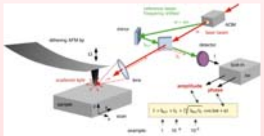
Forming nanoscale metal objects using Evaporative Vapor Deposition on a Focused Ion Beam milled substrate

M. Carlson, Y. Saito, T. Ichimura, S. Yasugi, Y. Inouye, S. Kawata
Laboratory for Scientific Instrumentation and Engineering, Osaka University, Osaka, Japan

Differential deposition has been observed that could be used to pattern small structures.

Purpose

Near-field Scanning Optical Microscopy



http://wwwex.biochem.mpg.de/baumeister/personal/Rainer/s-SNOM.html

Operating Principles:
1. AFM tip is held a fixed distance from the sample
2. The sample is irradiated with a laser
3. The scattered light is locally enhanced by the tip
4. The light is collected for different types of imaging
- *Down to 10 nm resolution*

The current **Aperture less metallic probe** used in NSOM allows:
- High optical throughput
- high field enhancement
- two-photon fluorescent imaging
- tip-enhanced Raman Spectroscopy
- high-resolution fabrication

But has some **problems**, such as:
- Full metal coating creates extra signal
- Resolution limited by size of the "green sphere" shown,

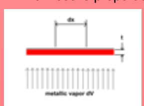
Apertureless probe (used with permission) [1]
- Orange ball represents a small structure being imaged
- Green area are evanescent photons for probe-sample interactions

A new **Split metallic probe** made with this technique could:
- Enable higher resolution by creating one point between the tips of highest field enhancement
- Enhances field in line with the tips
- Better tip-enhancement for Raman Spectroscopy

What is vapor deposition?

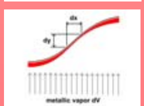
Evaporative Vapor Deposition (EVD)

1. **A small cup of metal is heated in vacuum**
2. **The heat and vacuum cause the metal to evaporate up towards the stage**
3. **Metallic vapor differentially coats the surface**
- Thickness is proportional to 1 over the area



A uniform metal coat deposits on a flat surface

$$t \propto \frac{1}{A} = \frac{1}{dx * dz}$$



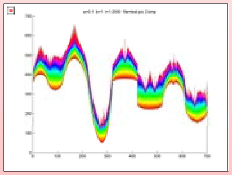
A non-uniform coat deposits on an angled surface

$$t \propto \frac{1}{A} = \frac{1}{dz * \sqrt{dx^2 + dy^2}}$$

I first modeled, and then tested the nature of the observed differential deposition

Computer Modeling

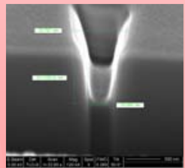
Modeling in Matlab:
- Initial surface shape is given by a **two color picture**
- Accepted model for vapor deposition is used to **estimate new layers**
- Program runs over and over to **build layers** up based on the previous layer
- Final surface is output on a graph with a **color gradient** to emphasize the **layering** by drawing each layer as a different color



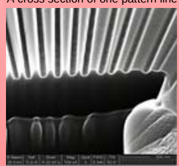
A test picture exploring differently sized cuts

Interesting Features:
1. **Dual peak** from a rounded peak and trough
   - Would halve feature size for making two peaks
2. **Bifurcation** and possible trifurcation of a slightly rounded peak
   - interesting for NSOM tip fabrication
3. Possible **trifurcation** from a small defect
   - May be modeling error or interesting feature

Milling

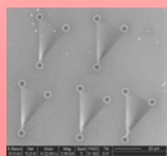


A cross section of one pattern line

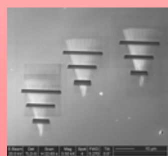


A cross-section of on line pattern

Sensu makes sense:
- Promising 2d shapes are milled as **patterns** of lines
- I adjusted the patterns to the capabilities of the FIB
- The best pattern was a **fan-shaped array** of lines to reduce the number of patterns necessary
- Final patterns are milled on different silicon samples to test different **deposition thickness**

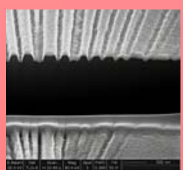


A full array of fan patterns

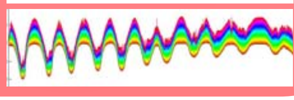


A full array of cross-sectioned fan patterns

Deposition

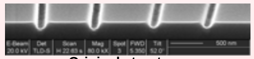


Gold Vapor Deposition:
- Test patterns are **cross-sectioned** for modeling
- Optimal **final layer thickness** is determined in Matlab
- Gold vapor is **deposited** to desired thickness
- The pattern area is **cross-sectioned** again to **compare** actual deposition with the **model**



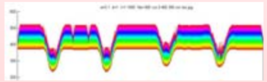
Many interesting deposition effects were observed in the trials

Results

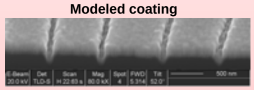


Original structure

Image of shape



Modeled coating



Gold coated to 150 nm

Summary

Summary of trials:
- **Piling** was not seen at these coating levels
- A **squaring effect** was seen on thickly coated samples rather than forming sloped sides like in the model
- Narrow cuts showed little coating as predicted, and continued piling could produce **two close peaks**
- **Rounded peaks** form **square** peaks and troughs when coated and could be good for **diffraction**

Future Work

More things to try:
- More tests could be done at **vapor-droplet scales**:
  - -repeat process at 50 nm per pixel
  - -test structures larger than 200 nm across
  - -test with a metal with smaller vapor droplets
  - -test at slower deposition rates to reduce droplet size
- Use **nanoparticles** to test the **bifurcation** caused by small particles placed in peaks or troughs
- Try annealing coated sample to produce different structures (e.g. **stalactites**)

Presenter Information:
Matt Carlson
University of Wisconsin, Madison
mcarlson2@wisc.edu

Sources:
[1] **Near-Field Microscope Probes Utilizing Surface Plasmon Polaritons, Satoshi Kawata**
[2] **http://wwwex.biochem.mpg.de/baumeister/personal/Rainer/s-SNOM.html**

Research conducted at Osaka University as a participant in the Rice University and NSF-PIRE sponsored NanoJapan 2007 program.