Reference Materials to Enable Precise and Accurate Imaging with Electrical Scanning Probe Microscopes

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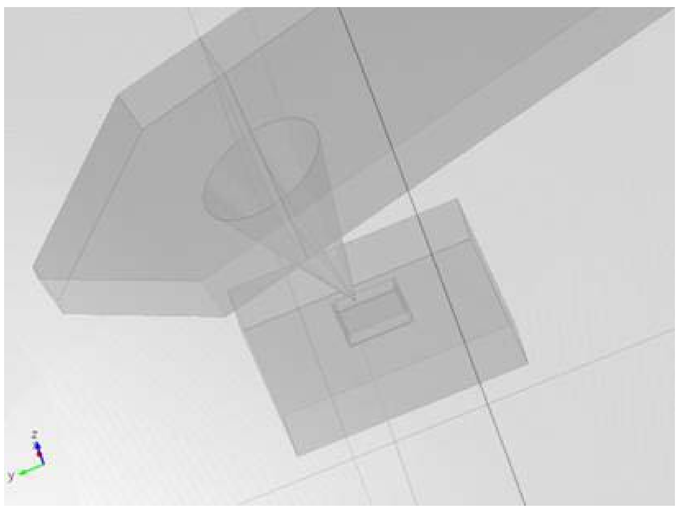
PROBLEM

Measurements of Electric Field or Magnetic Field are critically dependent on the measurement probe shape. When using a nanoscale scanning probe technique, such as scanning Kelvin force microscopy (SKFM) or scanning microwave microscopy (SMM), and measuring fields varying on the same scale, the problem is compounded. To make accurate spatial resolved measurements of field, or to extract accurate electrical properties (dielectric constant, ε, magnetic susceptibility, μ, or resistivity, ρ) from measurements, the electrically active tip shape most be known.

This work describes simulation, design and preliminary measurements of reference materials with precisely known geometries that will allow precisely calculable electric field gradients at a sub-micrometer scale to be generated. These structures have two intended uses: 1) as reference materials to determine the actual spatial resolution and accuracy of various eSPM techniques sensitive to electric field with different conductive tip technologies; and 2) as an electrical tip shape profiler. Electrical tip shape may vary significantly from physical tip shape. Knowledge of the electrical tip shape can then be fed back into image analysis software to improve the spatial resolution and accuracy of electric field measurements.

COMSOL SIMULATIONS



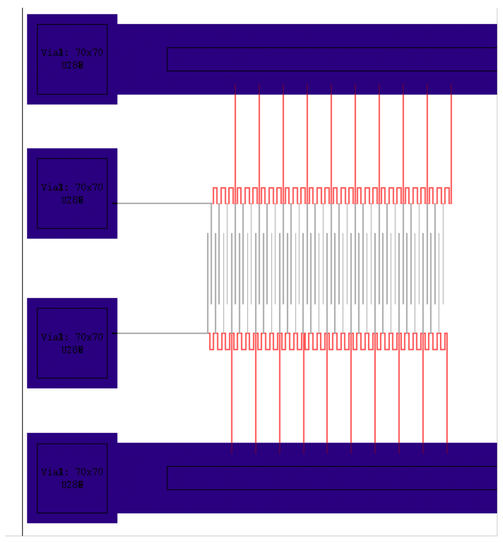
Simulation must include all active parts of tip, shank and cantilever.

Tip Parameters	
terminal tip radius	r_{tip}
tip cone angle	Θ
tip height	h
top cone radius	r_{top}

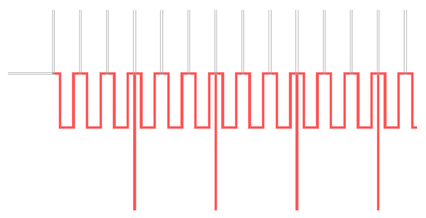
$r_{top} = h \tan(\Theta)$

COMSOL simulated potential measurement as a function of cone angle across a structure consisting of 1-μm wide lines separated by a 1-μm space, with the left line biased at -1V and the right line biased at +1V. Magnitude of the response is inversely proportional to the cone angle and the width of the response is proportional to r_{top}.

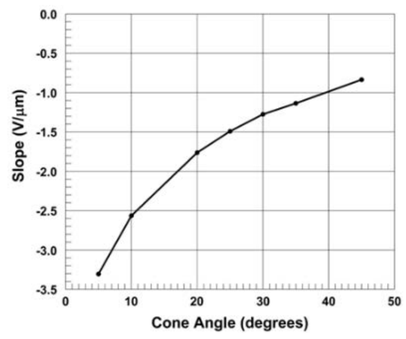
ELECTRIC FIELD GRADIENT REFERENCE

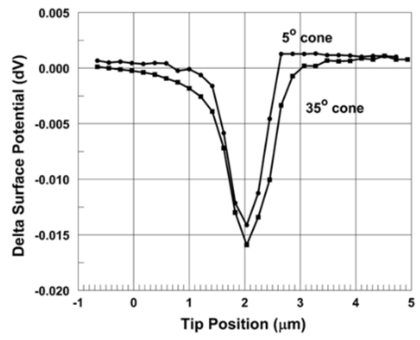


Potential applied across voltage divider allowing for periodic reduction of field over several orders of magnitude with a counter electrode between levels. Structures with various line widths are being fabricated.

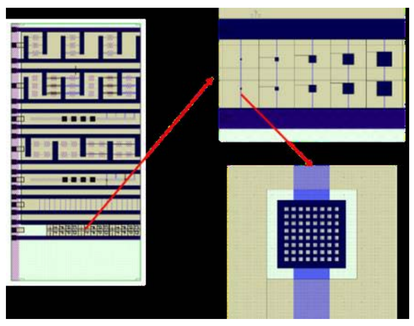


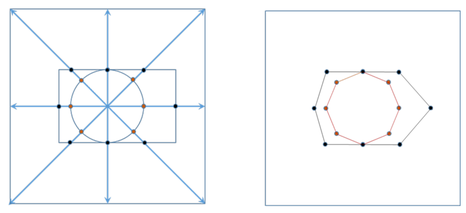
ELECTRIC TIP SHAPE PROFILER





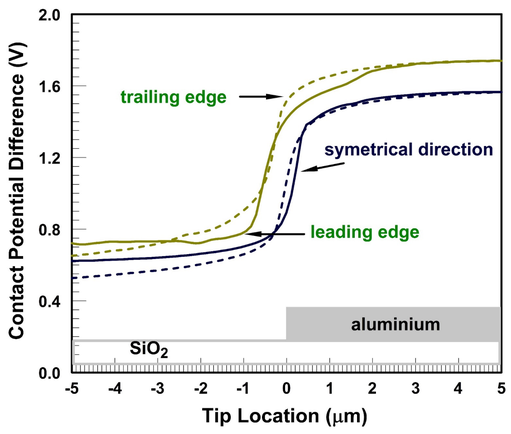
COMSOL simulations show that the tip shape influences the response of an electric field measurement across an abrupt boundary. Left: Dependence of the slope of electric field gradient at the boundary as a function of cone angle. Right: Width of response across a potential line varies with r_{top}.



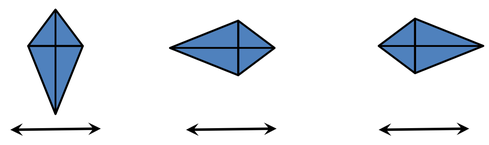


Left: Test structures for extracting the electrical tip shape from electric field dependent SPM measurements. Right: By processing the images from the test structures the tip parameters can be extracted.

ELECTRIC FIELD MEASUREMENTS



SKFM measured CPD with an asymmetrical conducting AFM tip. Scanning with the symmetrical direction normal to the boundary, the CPD profile is symmetrical. In the asymmetrical orientation, the CPD is determined by the tip orientation.



CONCLUSIONS

Will these reference materials be useful to you? We are seeking beta testers. We want to hear your ideas about what kind of Electric Field and Magnetic Field reference materials will help you make more accurate and precise measurements.

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