Profiling the Shape of Electrostatic Force Microscopy Probes Using Finite Element Simulations

Karthik Rao, Texas A&M University

Advisors: Joseph Kopanski & Dr. Yaw Obeng

Advanced Electronics Group, NIST

Summer 2021

Electrostatic Force Microscopy

- Scanning Probe Microscopy (SPM) is a technique that forms images of surfaces using a physical probe to scan specimen
- Atomic Force Microscopy (AFM) is a very high-resolution type of SPM that generates images by scanning a small cantilever over the surface of a sample
- Electrostatic Force Microscopy (EFM) is a non-contact atomic force microscopy technique which gives access to electrostatic and electronic surface properties of samples with high precision

COMSOL

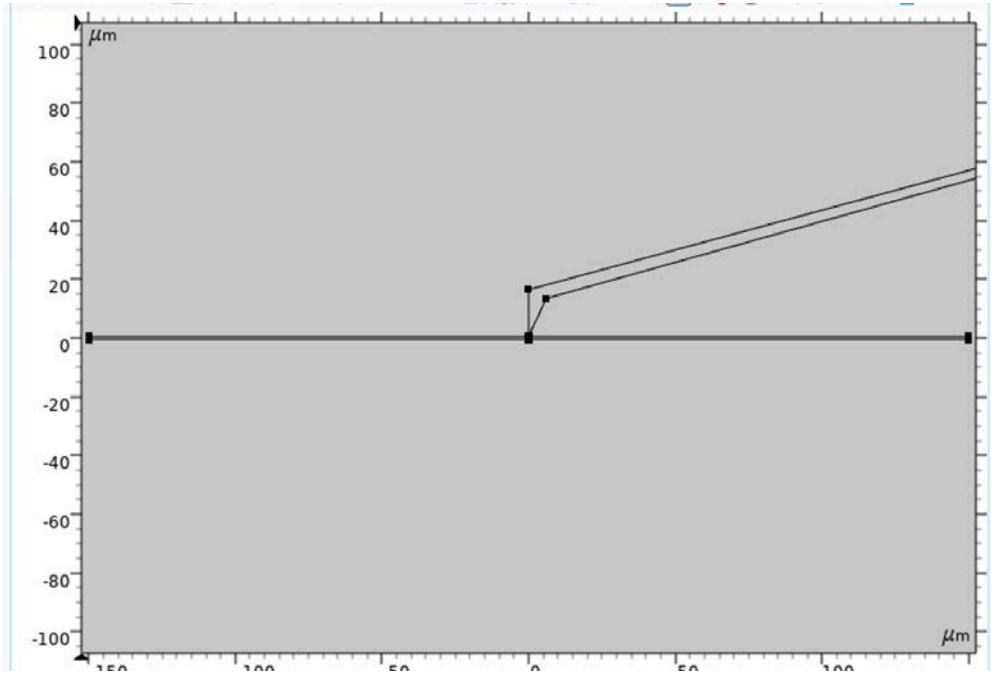
General-purpose simulation software based on finite element method involving partial differential equations

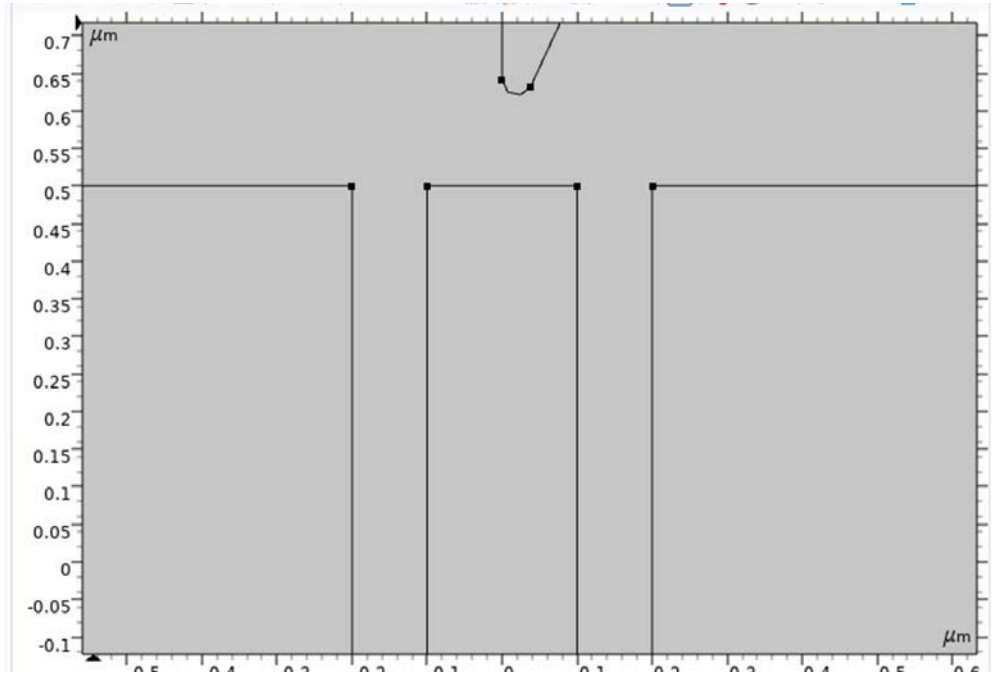
Fully coupled multiphysics and single-physics modeling capabilities

Set up environment and define studies where results can be calculated by solving Maxwell's Equations, boundary conditions and other physical attributes for electrical, mechanical, fluid, acoustics, and chemical applications

2D Simulations

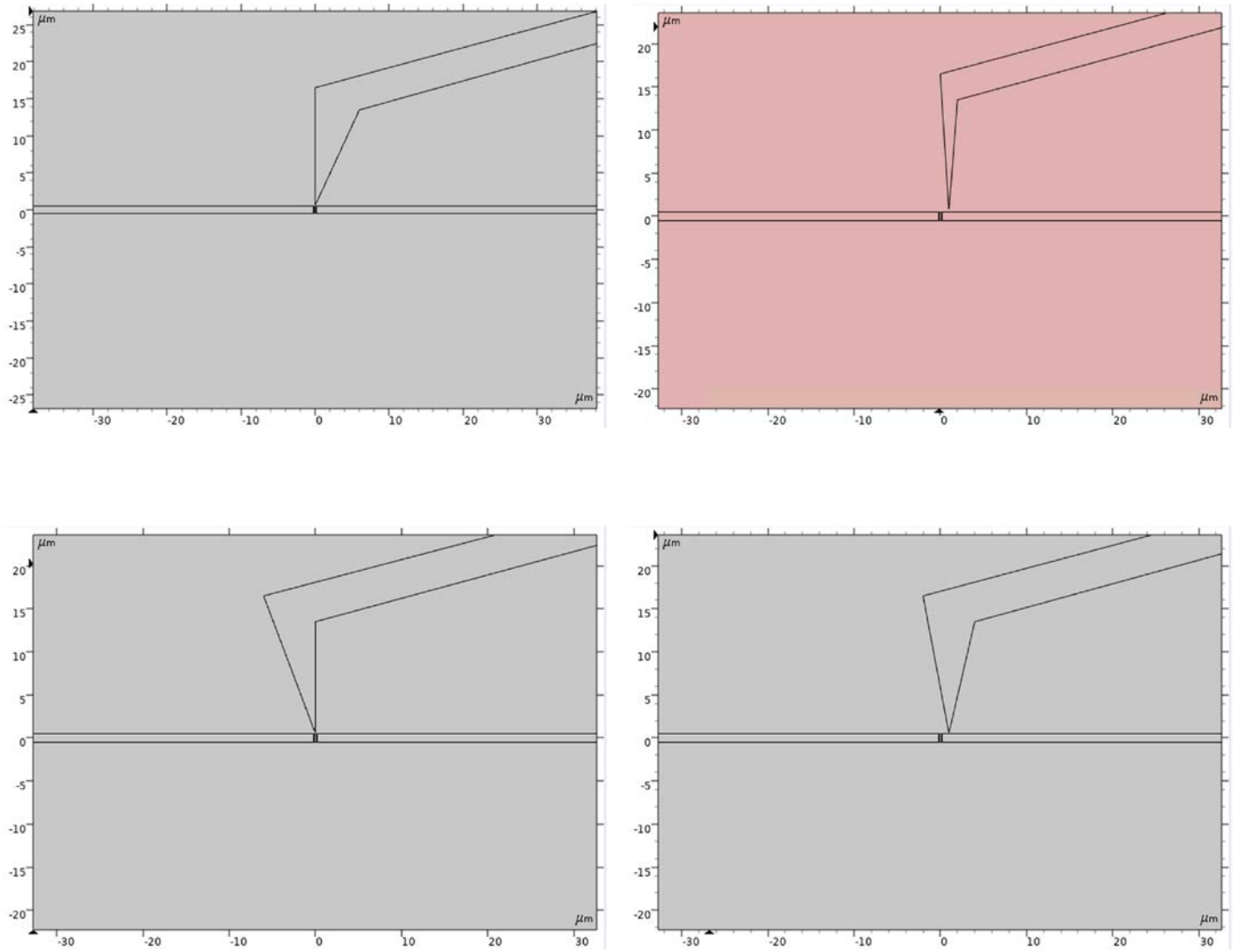
- Three aluminum strips
- Platinum probe and cantilever
- Strips surrounded by Silica
- Distance between strips is 0.1 µm
- Middle strip is 0.2 µm and is biased with 1 V
- The remaining strips are grounded
- Probe is at 0 V initially
- Distance between tip of probe and strips is 0.1 µm
- Tip of probe is curved with a radius of 20 nm
- Cantilever is at an angle of 15°





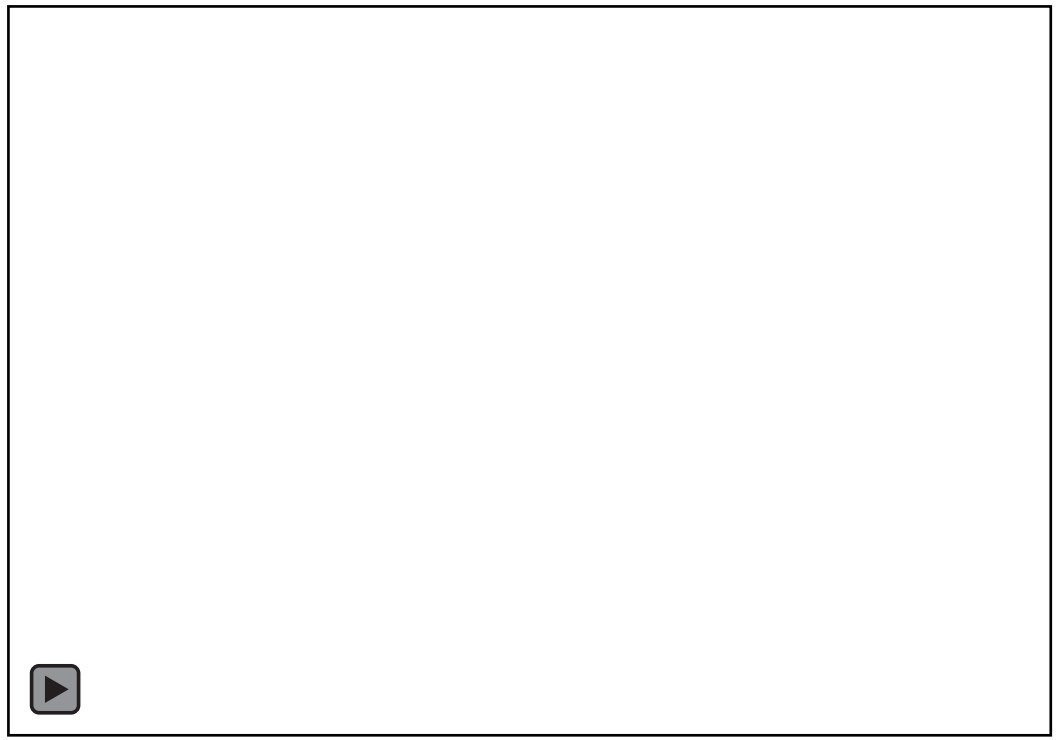
2D Probe Shapes

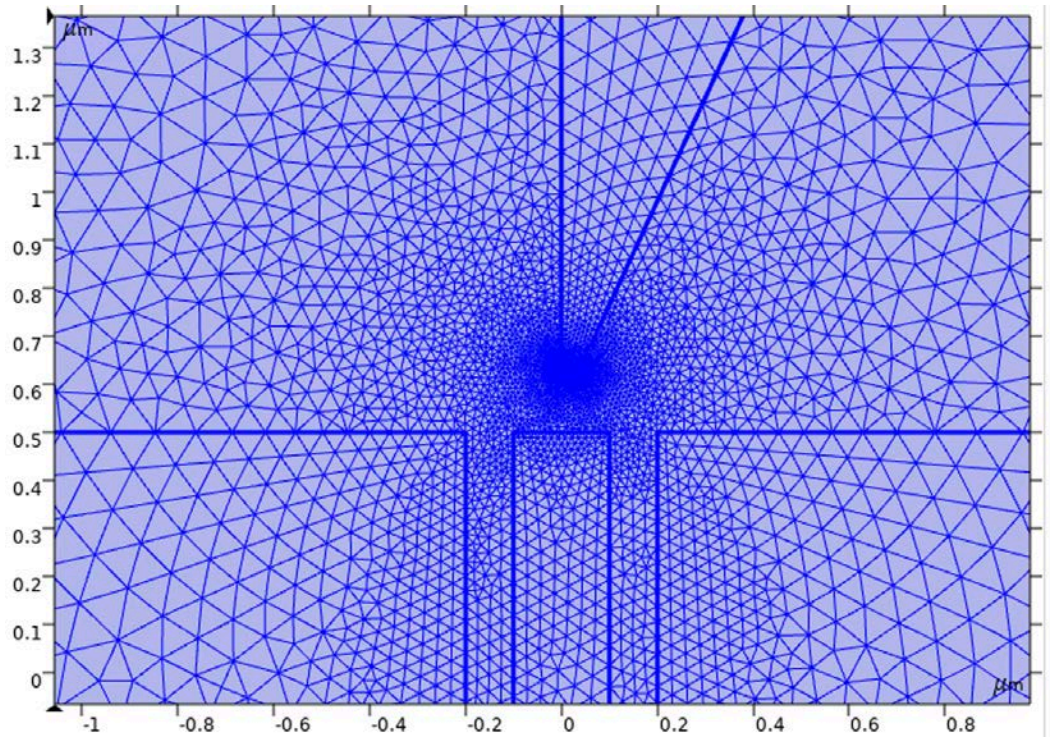
- Four probe shapes
  - Leading edge at 90
  - Trailing edge at 90
  - Symmetric
  - Small angle



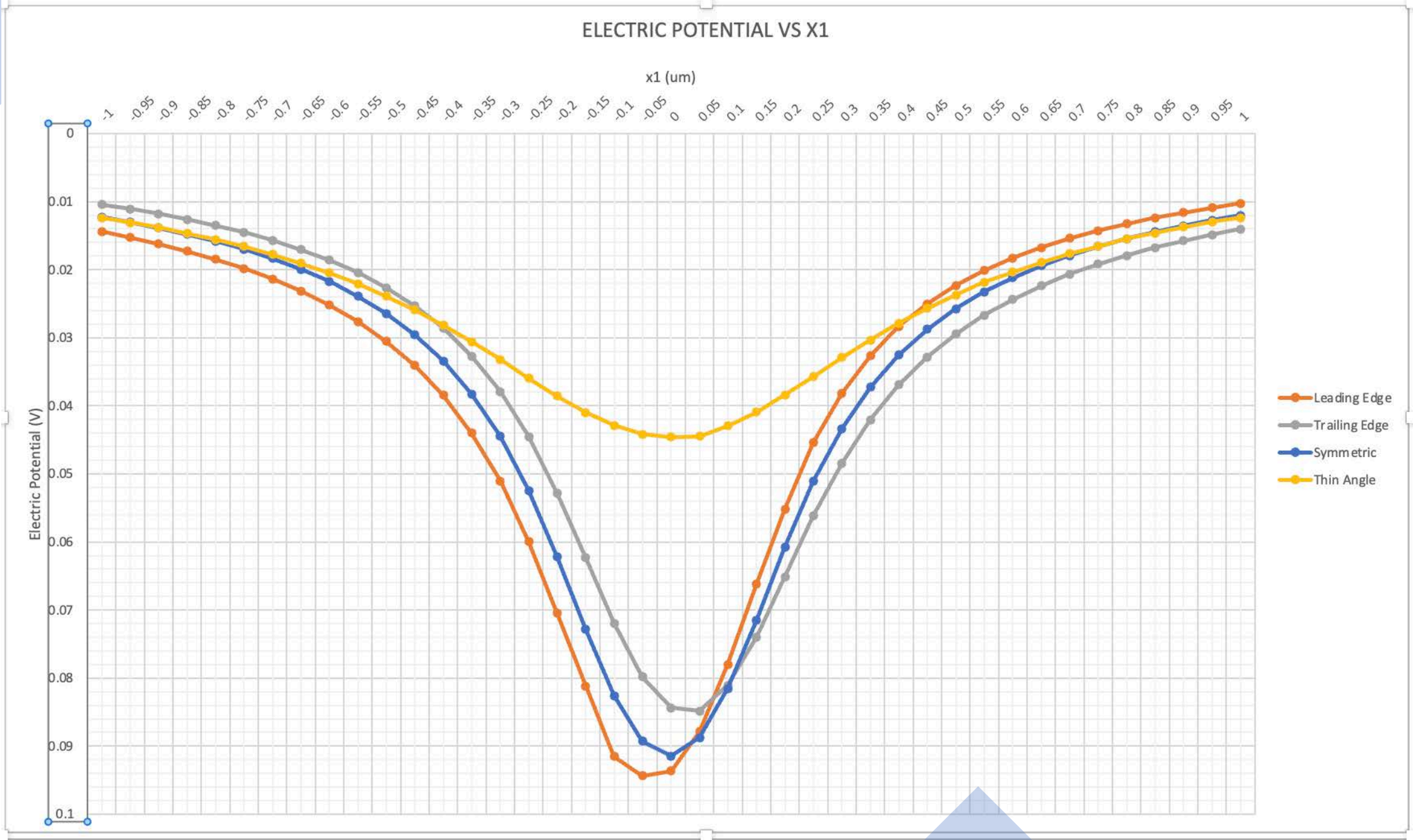
2D Study

- Simulations were done by scanning the probe from -1 µm to 1 µm in the x-axis and taking data every 0.05 µm
- The potential at the tip of the probe was calculated and recorded

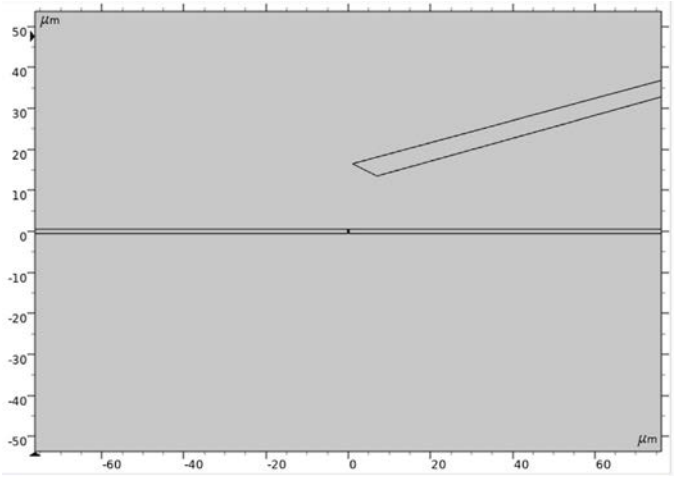


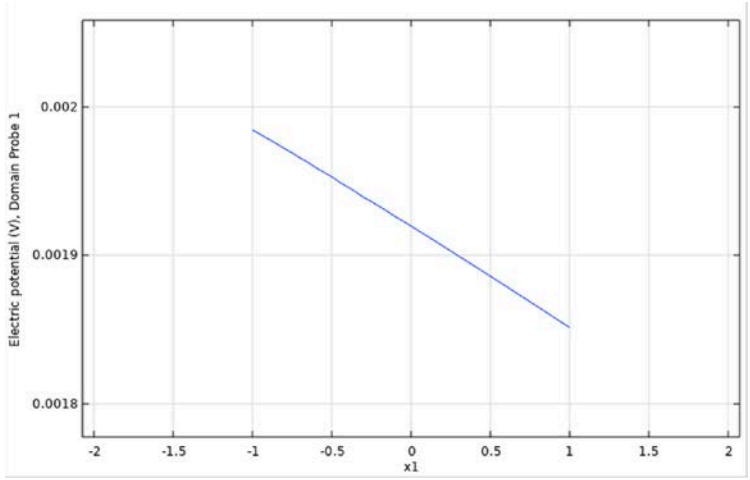


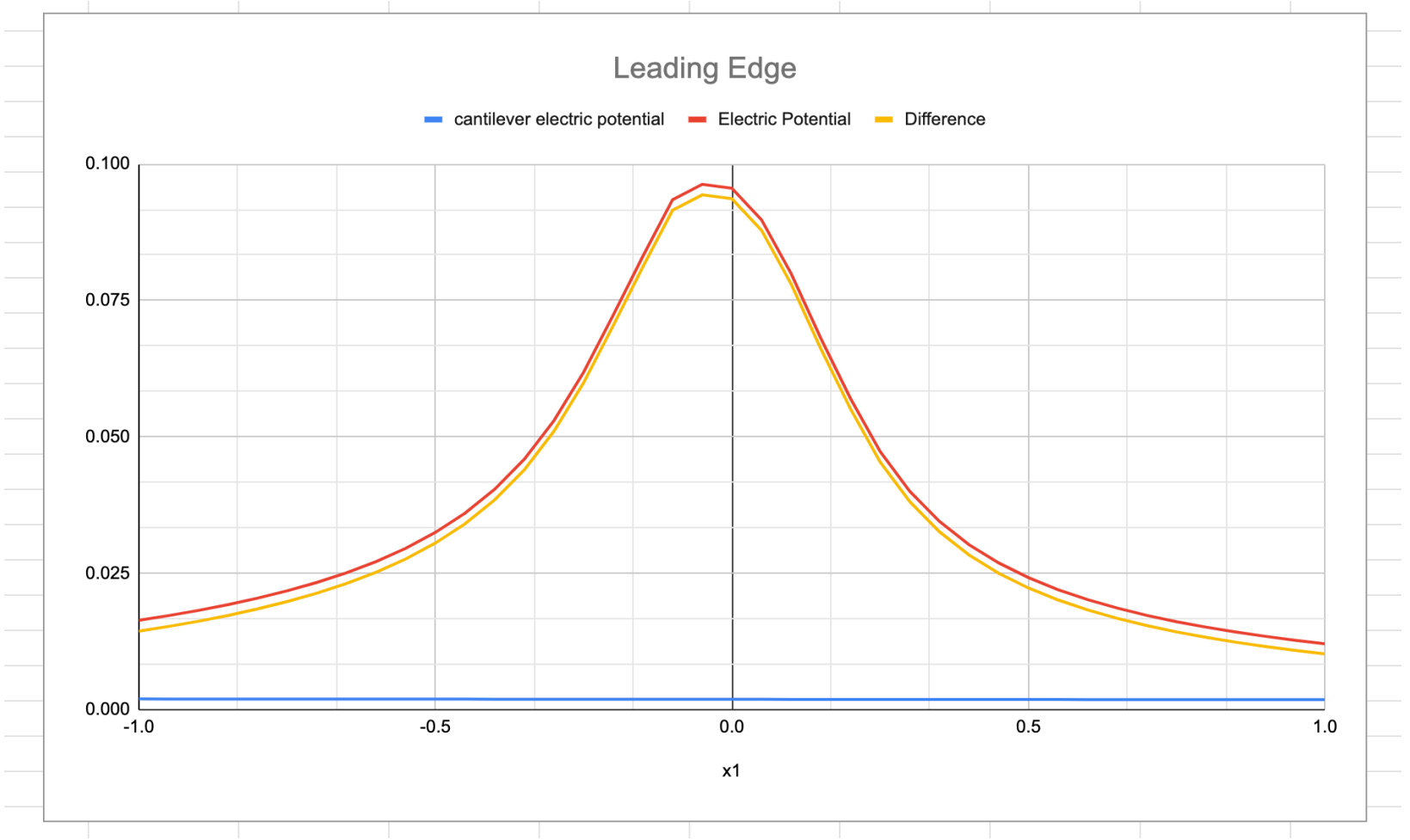
2D Results


ELECTRIC POTENTIAL VS X1
x1 (um)
-1 -0.95 -0.9 -0.85 -0.8 -0.75 -0.7 -0.65 -0.6 -0.55 -0.5 -0.45 -0.4 -0.35 -0.3 -0.25 -0.2 -0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
Electric Potential (V)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
Leading Edge
Trailing Edge
Symmetric
Thin Angle

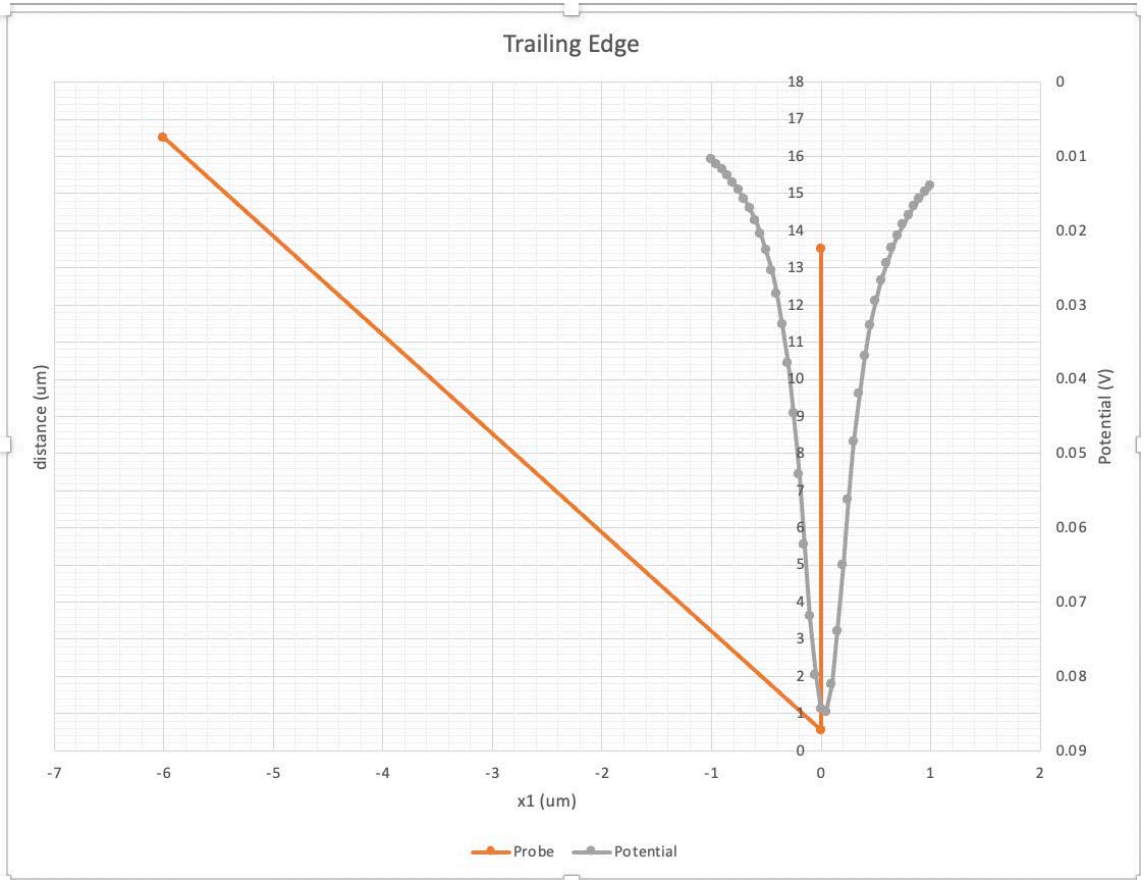
Analysis – Background Estimation

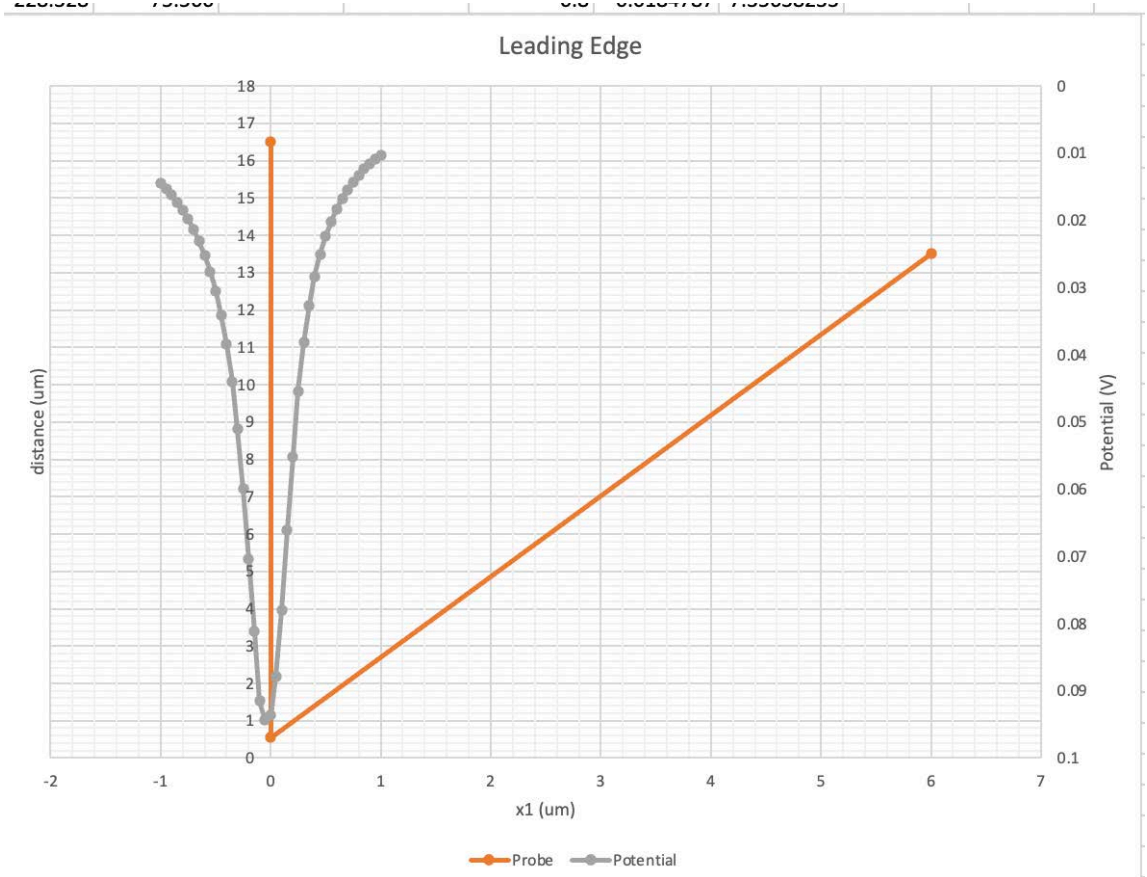




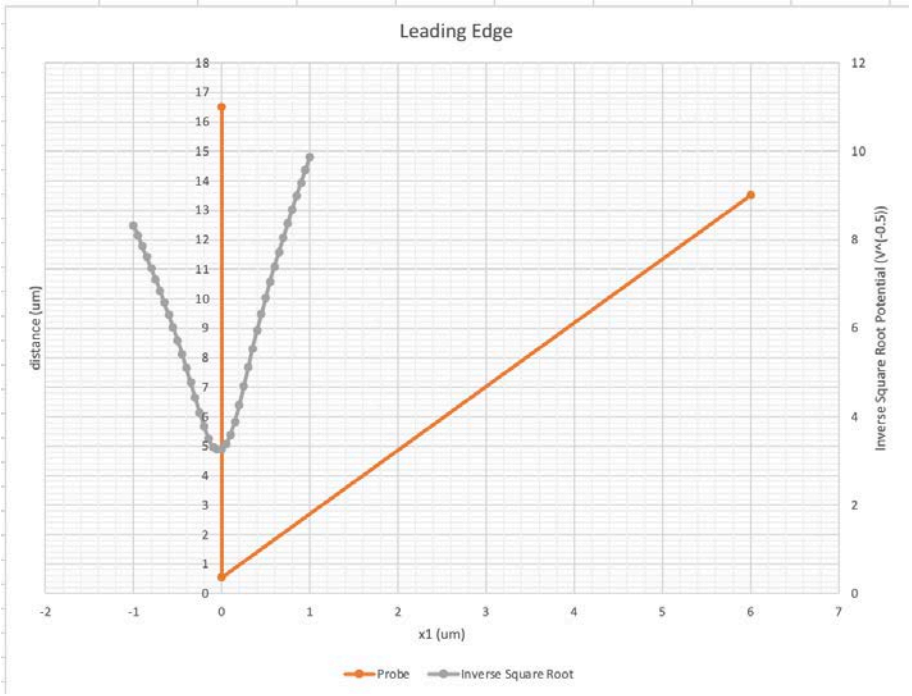


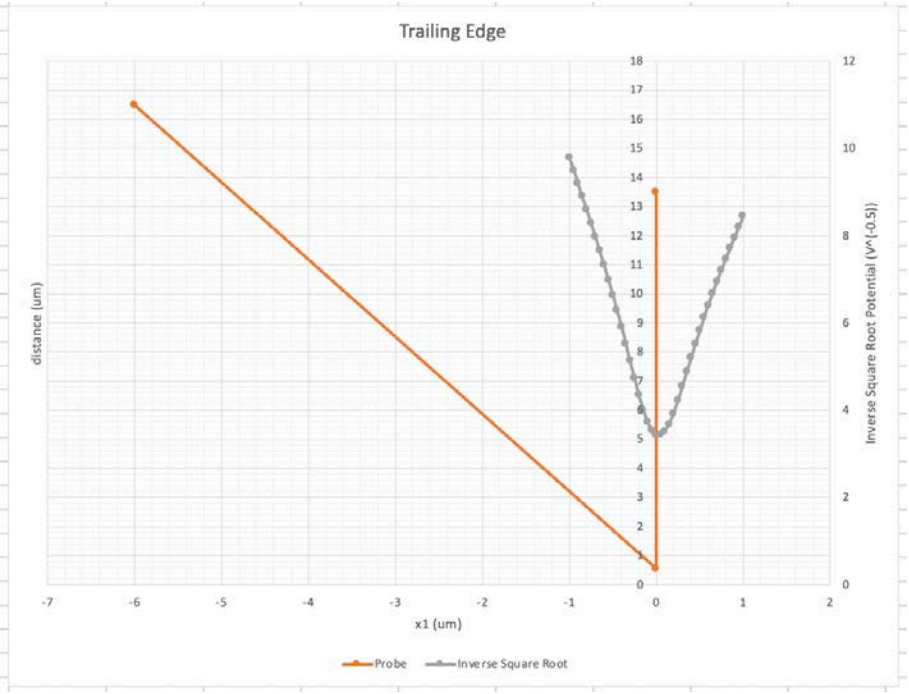
Analysis

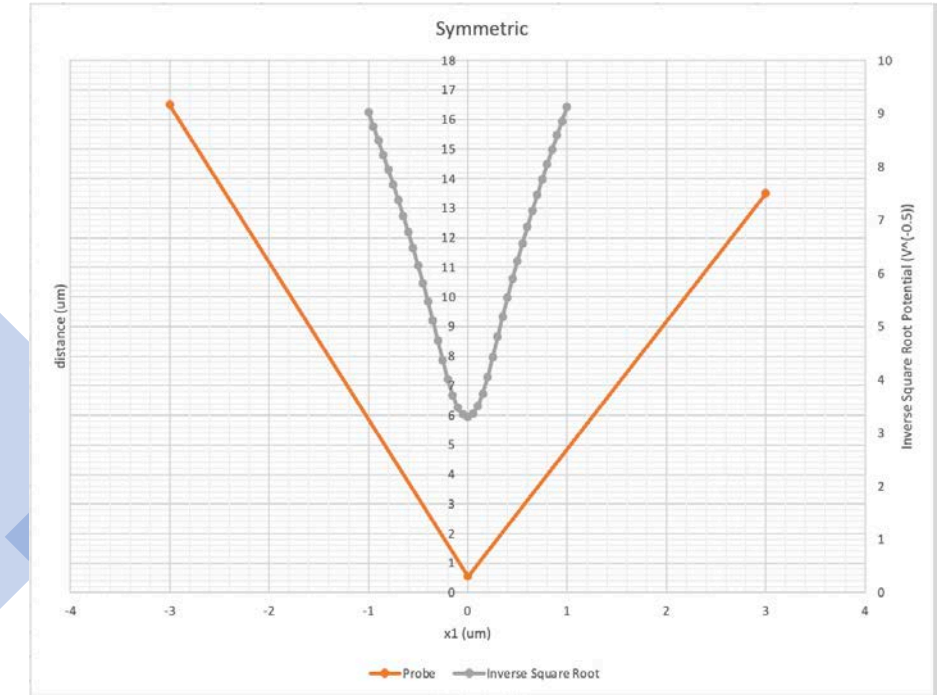

Trailing Edge
distance (um)
Potential (V)
x1 (um)
Probe
Potential

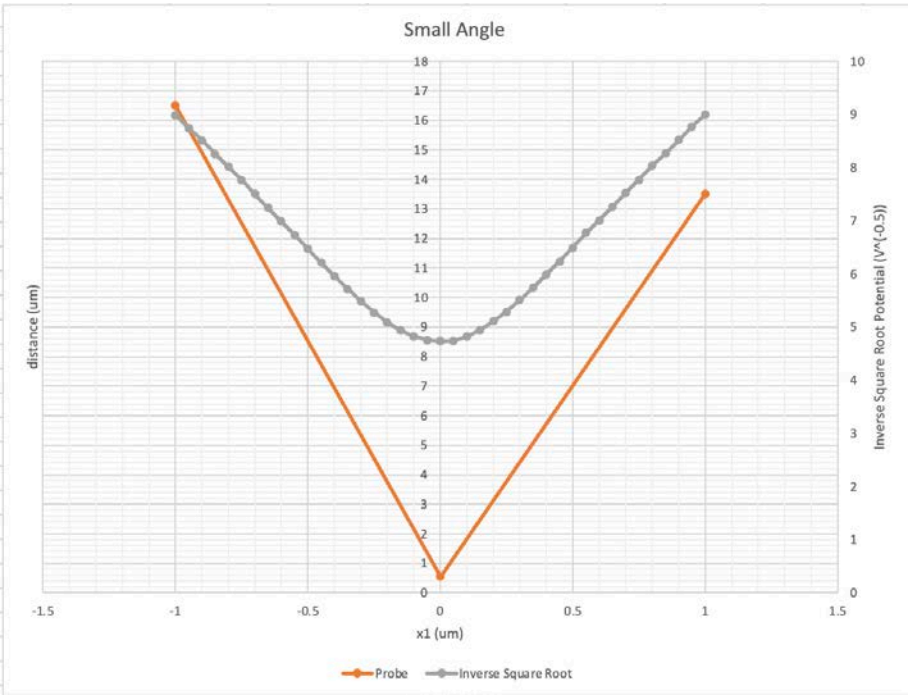

Leading Edge
distance (um)
Potential (V)
x1 (um)
Probe
Potential

Analysis


Leading Edge
distance (um)
Inverse Square Root Potential (V^(-0.5))
x1 (um)
Probe
Inverse Square Root


Trailing Edge
distance (um)
Inverse Square Root Potential (V^(-0.5))
x1 (um)
Probe
Inverse Square Root


Symmetric
distance (um)
Inverse Square Root Potential (V^(-0.5))
x1 (um)
Probe
Inverse Square Root


Small Angle
distance (um)
Inverse Square Root Potential (V^(-0.5))
x1 (um)
Probe
Inverse Square Root

Results and Future Work

- Tip shape appears to corelate with the potential being measured
- The relation is distance (which defines tip shape) is proportional to the product of a constant and the inverse square root of the potential being measured
- Use this data to create an algorithm that can give details about tip shape based on experimental scanning results
- Perform simulations in 3D to obtain a more realistic relation between probe tip shapes and resulting voltage distribution

Acknowledgements

Advisors: Joseph Kopanski & Yaw Obeng

NIST

Fellow Interns

SPS

AIP

Questions?