Exploration of Pinhole and Defect Density in Insulating Layer of Magnetic Tunnel Junctions

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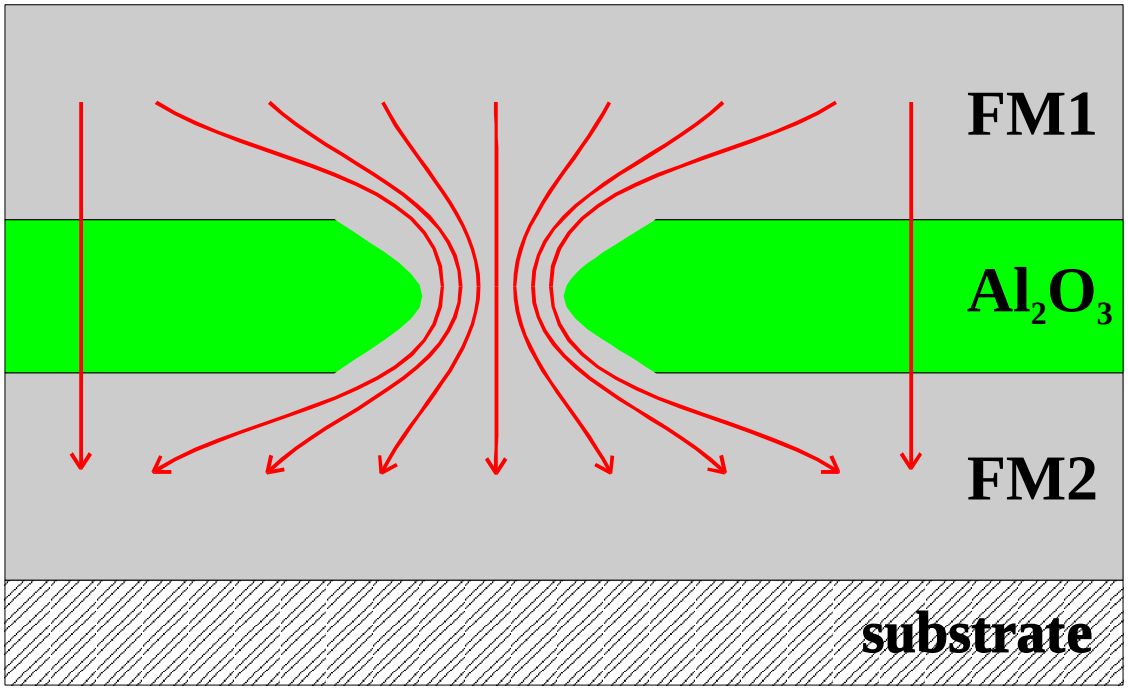
Problem:
pinhole formation in the tunnel barrier

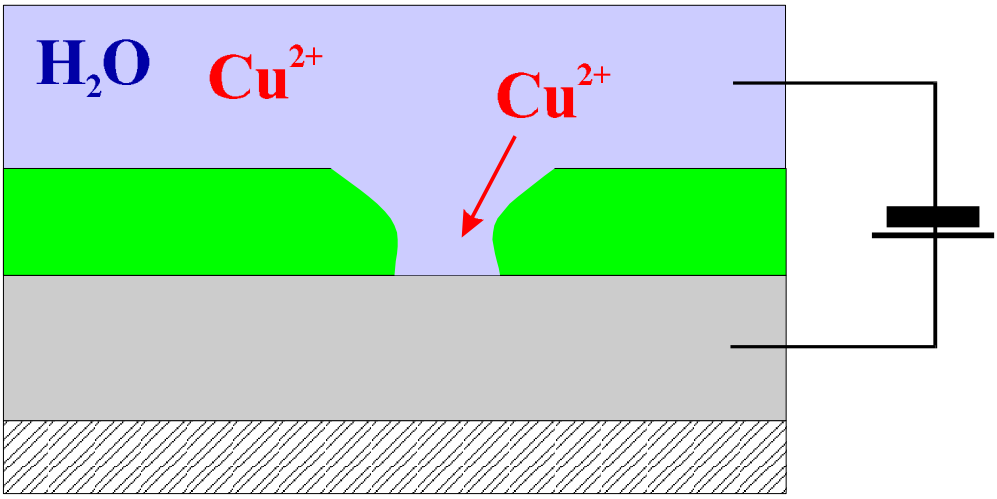


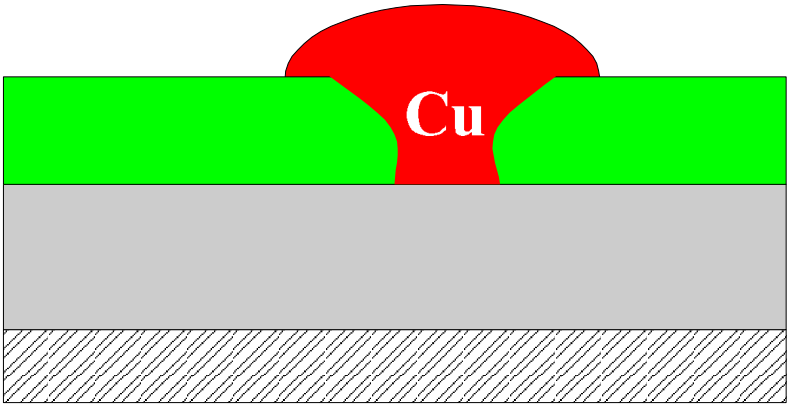
local electric and magnetic shortcuts

diameter: down to a few Å

how to make them visible ?

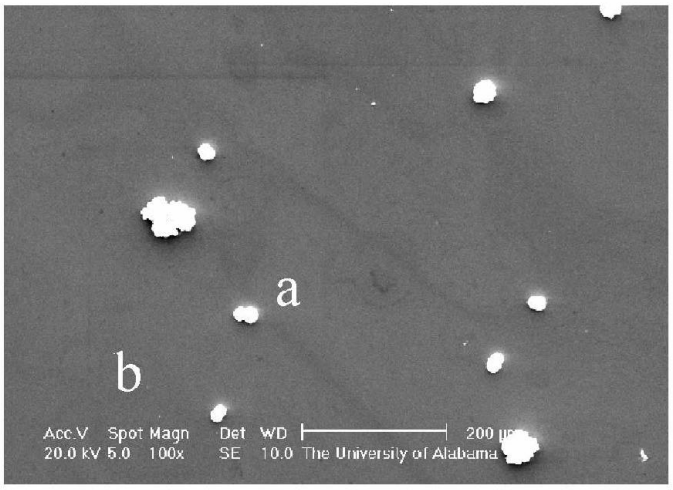
Solution:
decoration by electroplating - idea



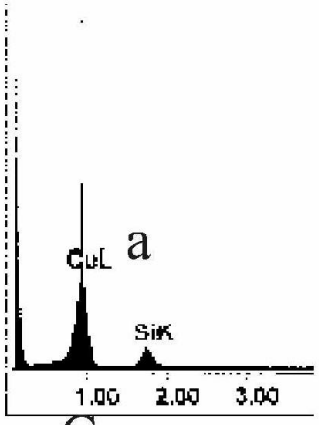


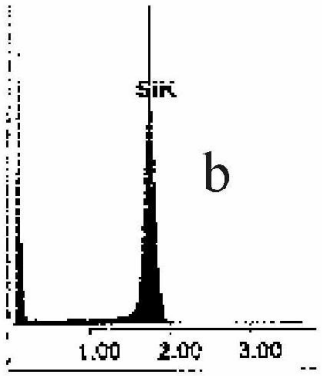
detection by SEM

Solution:
decoration by electroplating - result



This figure shows am SEM picture of the decoration of the pinholes along with a chemical analysis of the structures showing that they are indeed copper deposited through the electrodeposition.

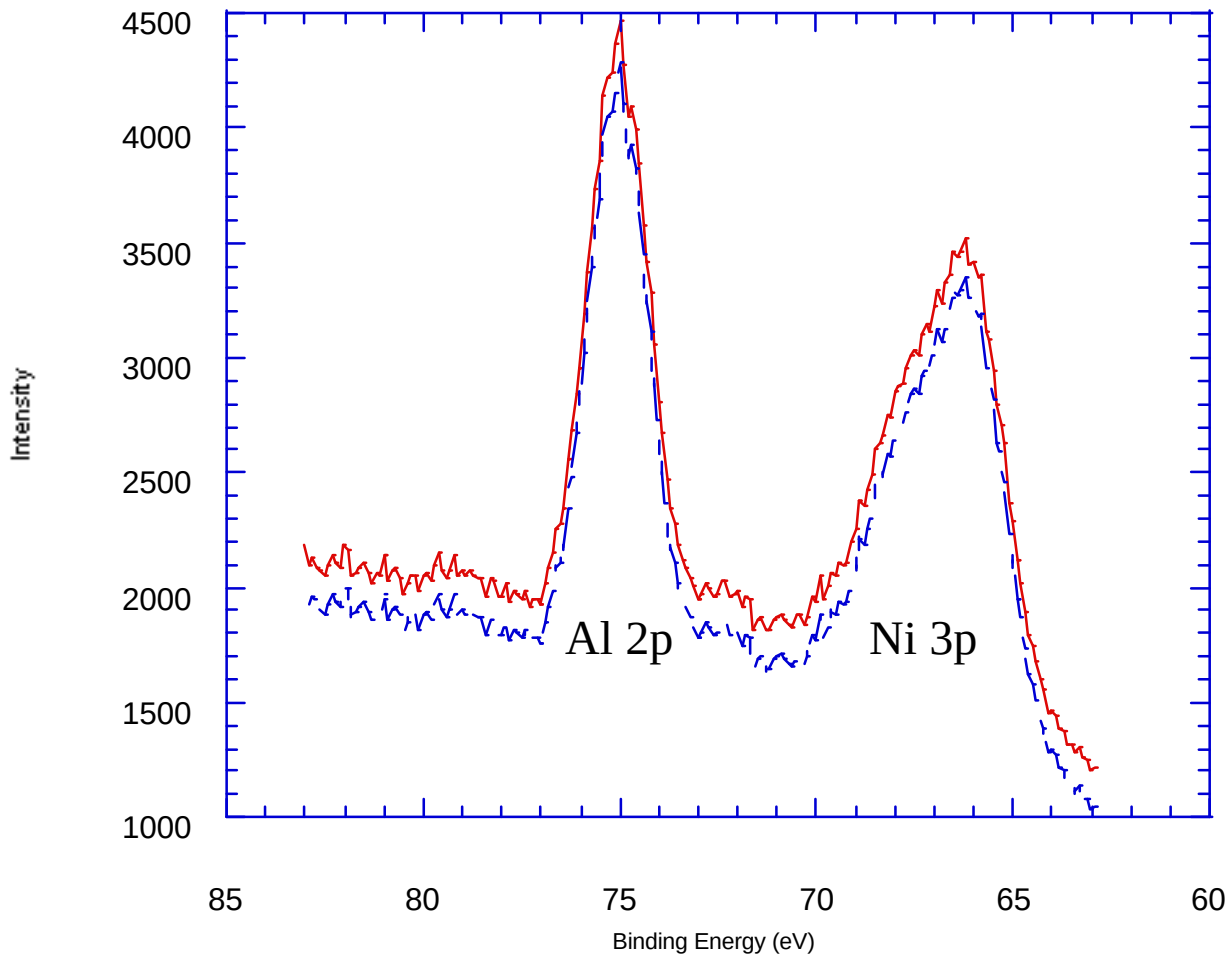




Concerns

The idea of using electrodeposition to allow the imaging of pinholes led to several concerns. First is the chemical stability of the aluminum oxide insulator layer in the chemical bath used for the deposition process. The second major concern was the possibility of dielectric breakdown of the insulator layer. With large enough electric fields (~10^9 V/m), an aluminum oxide layer which is not of uniform thickness could experience the breaking down of points of reduced thickness.

Chemical Stability: XPS Spectrum



The XPS data shows a comparison of an untreated sample and a sample subjected to the chemical solution used for deposition, without applying the potential.
This data shows that the samples are not changed by the chemistry of the electrodeposition.

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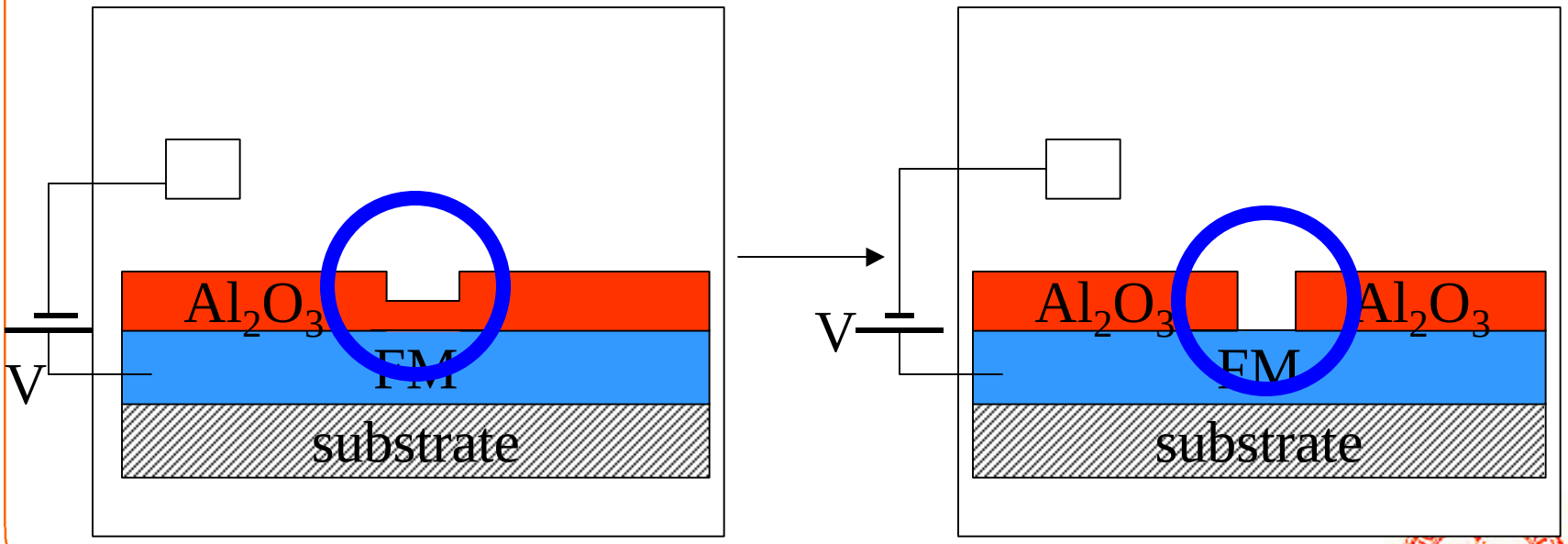
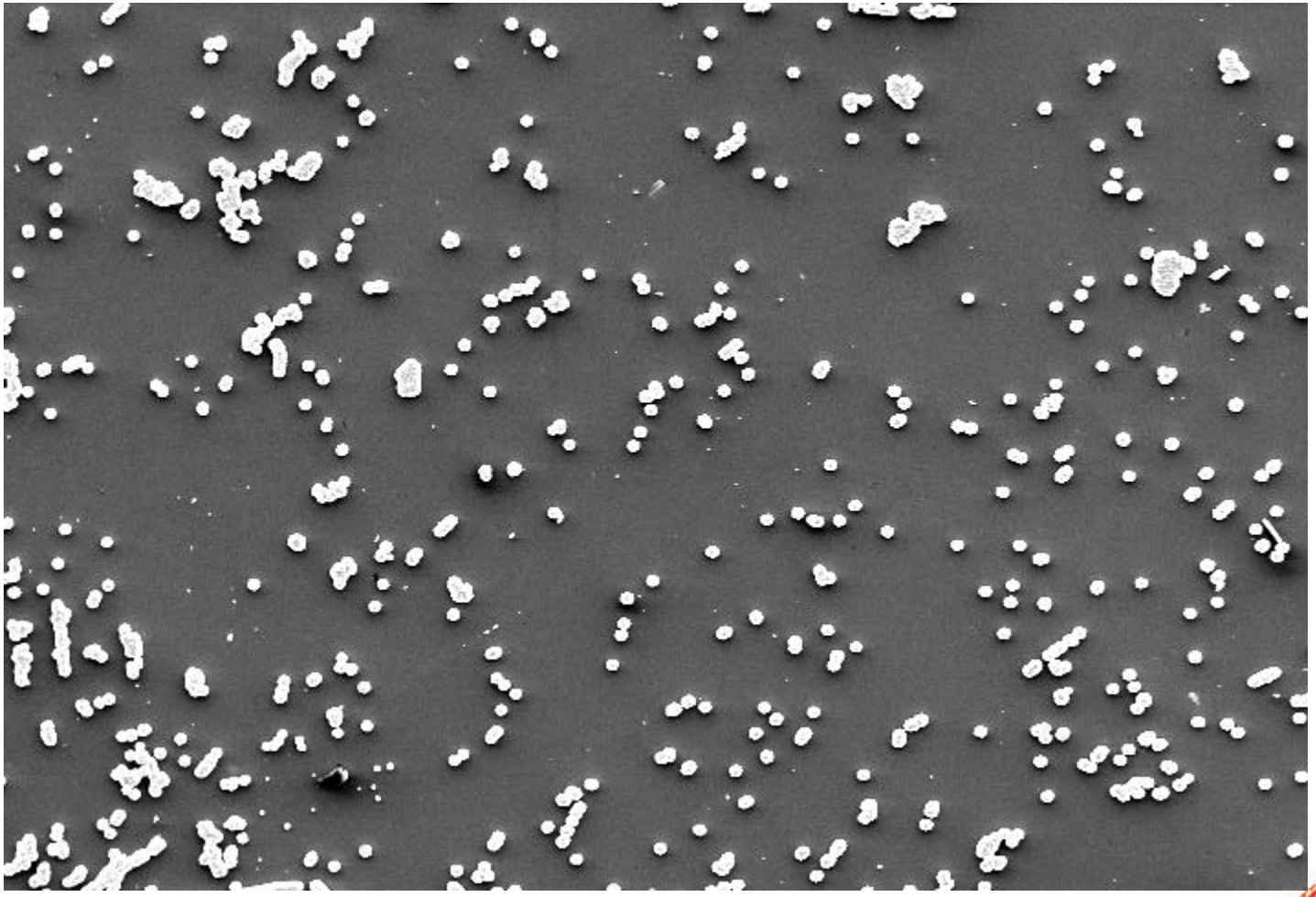
Electrical Stability

Points of reduced thickness may experience dielectric breakdown with large enough applied voltage (~1 V/nm) and become pinholes

Our method will allow us to find how likely it is for devices to fail during operation by applying different potentials during deposition.





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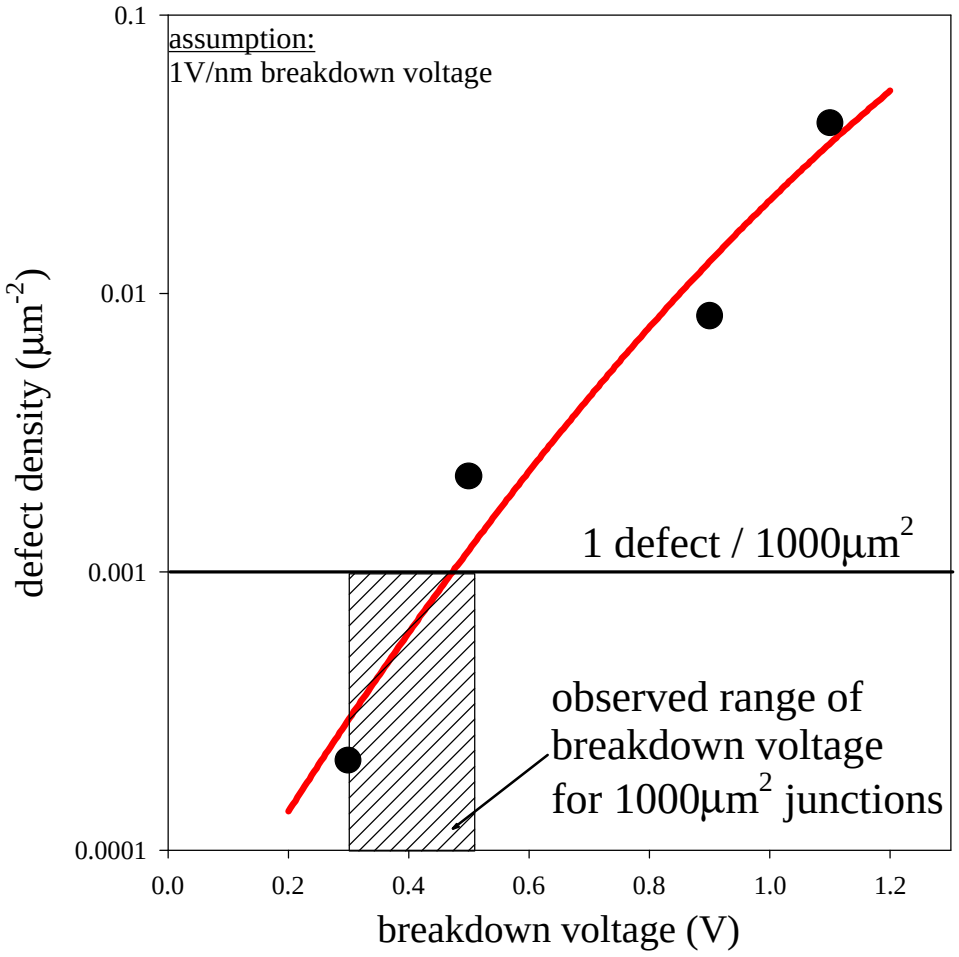
Areal Defect Density as a Function of Applied Voltage



As the potential used for electrodeposition is increased, the number of copper structures also increases. This is evidence of the dielectric breakdown of the insulating layer.
It also predicts at which potential tunnel junctions may fail. These results are very similar to those found by NonVolatile Electronics when applying a voltage to a tunnel junction.
Our method is very fast, these quality control measurements can be done in about 10 minutes.

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Conclusions

Our technique for decoration of pinholes by electrodeposition works

Electrodeposition for longer times does not increases the areal density of structures, indicating that the nucleation is preferential and is only at pinholes and not on the insulator

Larger applied voltages cause an increase in the areal density of structures, caused by dielectric breakdown. This allows the mapping of weak links as a function of the breakdown voltage. It also allows quality control measurements of produced tunnel junctions within a few minutes.

Future Developments

Relation of pinhole diameter to copper structure size

Reduction of applied voltages (Cu→Ag) will allow detection of pinholes and pinhole precursors at lower applied voltages

To study thinner Al_2O_3 layers, a protective layer with selective etching properties will be required (collaboration with J.S. Moodera, MIT)

Study of other insulator materials with lower a tunnel barrier than Al_2O_3 would allow fabrication of thicker, low-resistivity barriers.

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