14TH VIENNA CONFERENCE ON INSTRUMENTATION

MICRON SEMICONDUCTOR ltd

CVD Diamond Detector Metallization and Characterization

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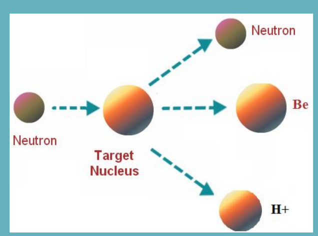
Introduction

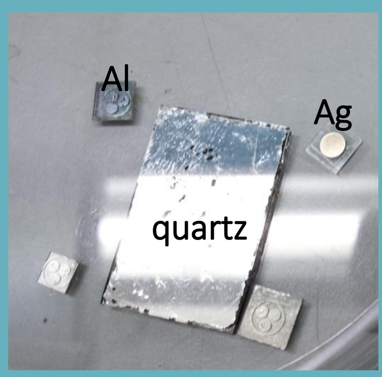
The diamond crystals have several attractive properties for detector applications. The choice of contact material, pre-treatment, and sputtering process details can alter significantly the detector performance. The very wide bandgap enables high temperature operation with low leakage currents; the high carrier mobilities should enable fast and efficient charge collection; the material can be used for a combined conversion-detection of fast neutron (through $^{12}C(n,\alpha_0)^{9}Be$ reaction creating a recoil atom and alpha particle); and the atomic number of diamond is similar to that of human body providing simple dose monitoring in medical applications.

Micron Semiconductor kindly provided us with 8 samples of different crystallinity and grades for our study.

CVD Diamonds with aluminum contacts on oven tray before anneal at vacuum



Fast neutron detection



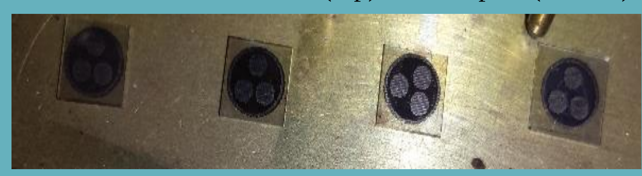
Printed Ag contact compared to evaporated Ti/Al contacts

Activation Energy

We have conducted the temperature dependent I-V measurements over the range of 50°C-300°C using Keithley 237 SMU's for measurement and oven with brass table and brass thermal mass for heat retention during the measurement cycles. The conductivity was shown to increase with temperature, which indicates trap(s) occupancy redistribution.

Keithley Triaxial connectors

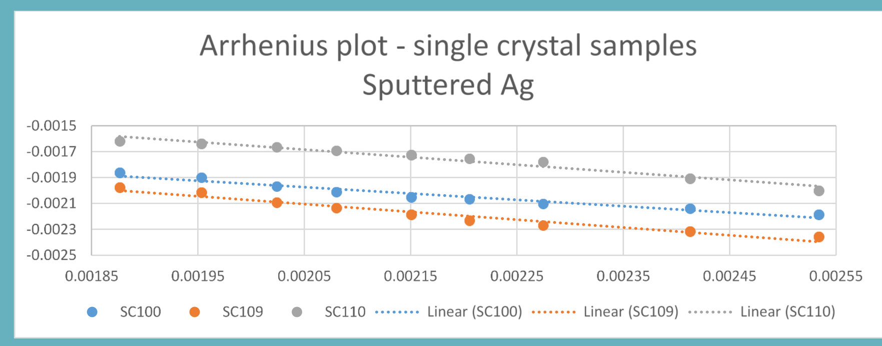
Brass measurement table (top) and samples (bottom)

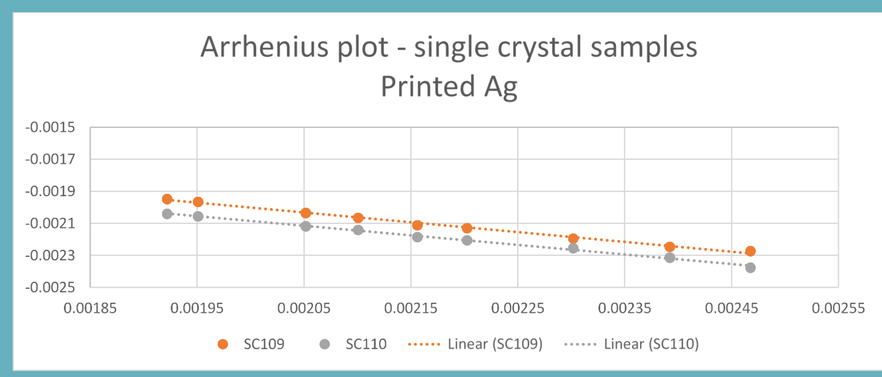


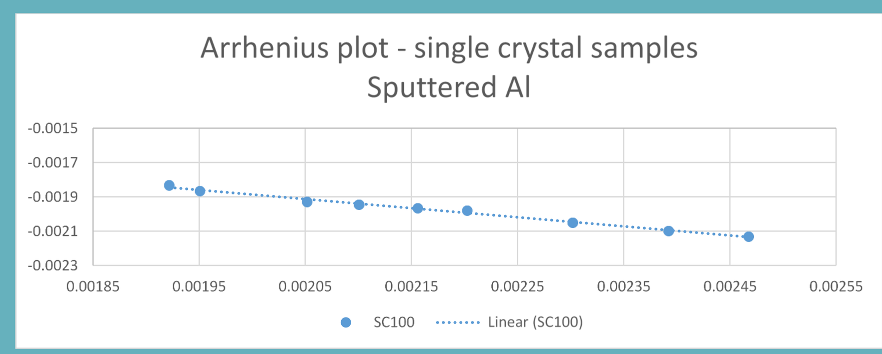
4 SMUs on GPIB bus

Samples in the sputtering machine under shadow mask

By applying Arrhenius plot regression, it became evident that the activation energy is 0.6±0.01eV (possibly related to the bulk induced isolated vacancy in +/0 state). Such vacancies are expected in intrinsic diamonds.





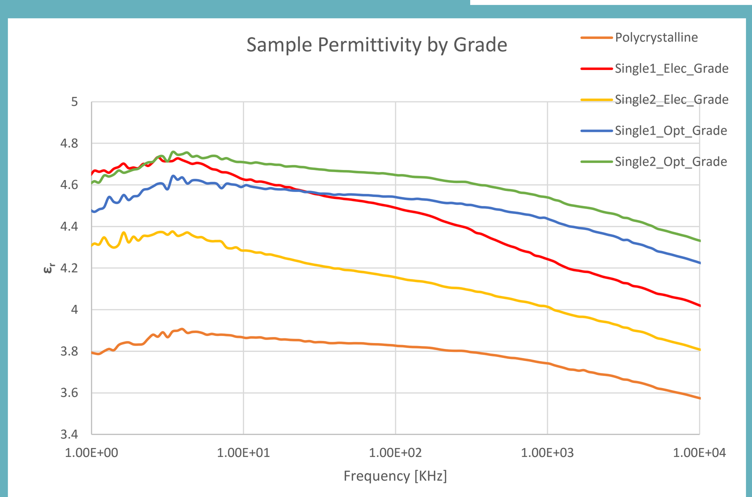


The activation energy is not dependent on three different metallization techniques we have applied, so traps related to the metal-semiconductor interface would not be the main trapping mechanism in the 50°C-300°C range.

Permittivity Measurement

We have conducted relativity permittivity and electric loss tangent measurements on poly and single crystal CVD diamond bare crystals and metallized devices. The measurement fixture was calibrated mechanically using fine torque adjustment (to make planes parallel) and compensated electrically with impedance analyzer (Agilent 4294A). The measurements were conducted in the vertical mode using two flat electrodes. The reference sample of known permittivity and geometry (Soda Lime Glass) was introduced in order to validate the results. The formula used to calculate the relative permittivity, is provided below:

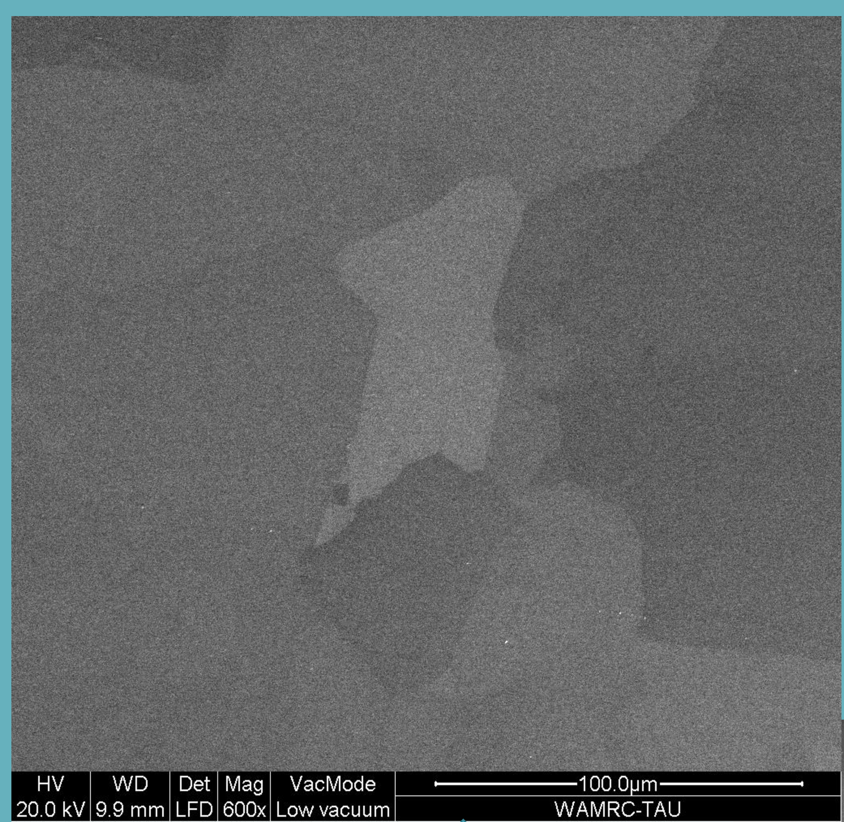
$$\varepsilon_r = \frac{(C_{meas} - C_{ext\_air}) \cdot d}{\varepsilon_0 \cdot A}$$

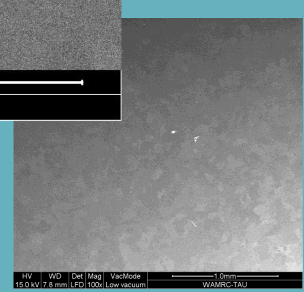


The permittivity measurements indicate that polycrystalline CVD diamonds have lower permittivity compared to single crystal CVD diamonds (both, optical and electronic grades). All measured CVD diamond samples show lower permittivity compared to the reported permittivity values of natural diamonds (~5.5)

E-SEM Analysis - Polycrystalline Sample

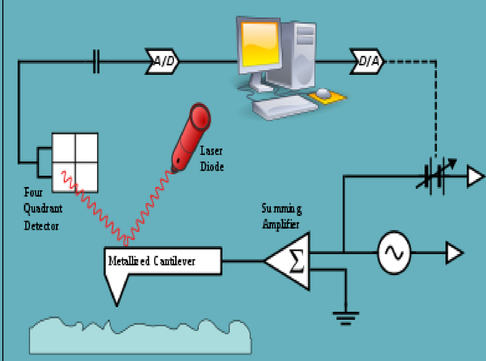
Zoom in (polycrystalline domains):





Typical domain size is of the order of 10um

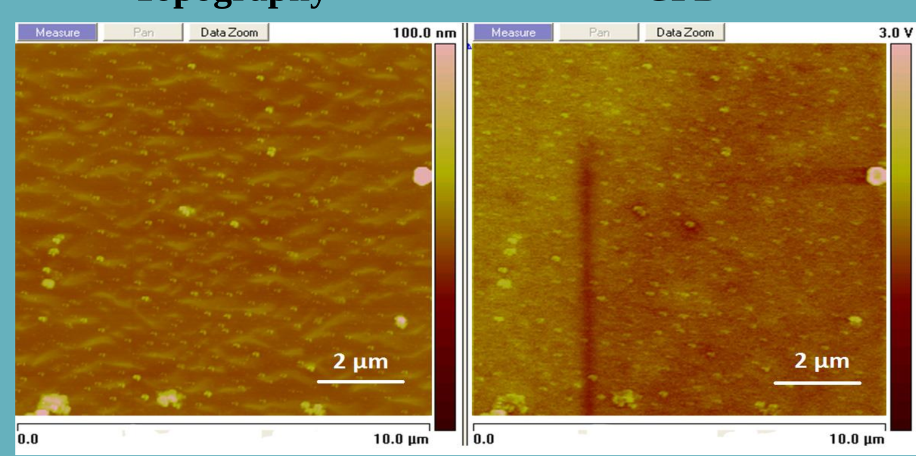
AFM – Topography and CPD mode



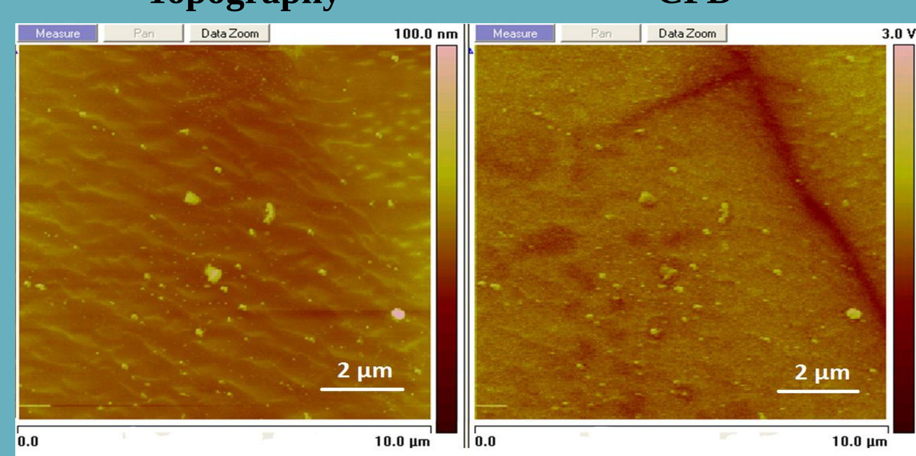
Four passes are made over each line: two in taping mode, and two in lift mode. During the taping scans the topography data is recorded. During the Lift Mode scans, the tip is lifted by typically 25-50 nm above the sample (using topography information). AC potential (at frequency ω_0) is applied between the tip and the sample. DC bias is added by feedback circuit to the ac potential to eliminate the cantilever vibrations at ω_0.

More "linear" defects (positively and negatively charged) in polycrystalline samples:

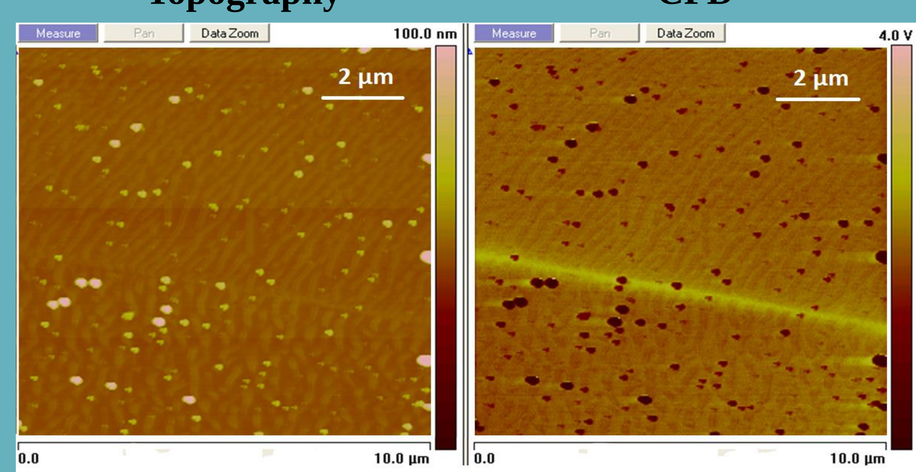
Topography | CPD



Topography | CPD

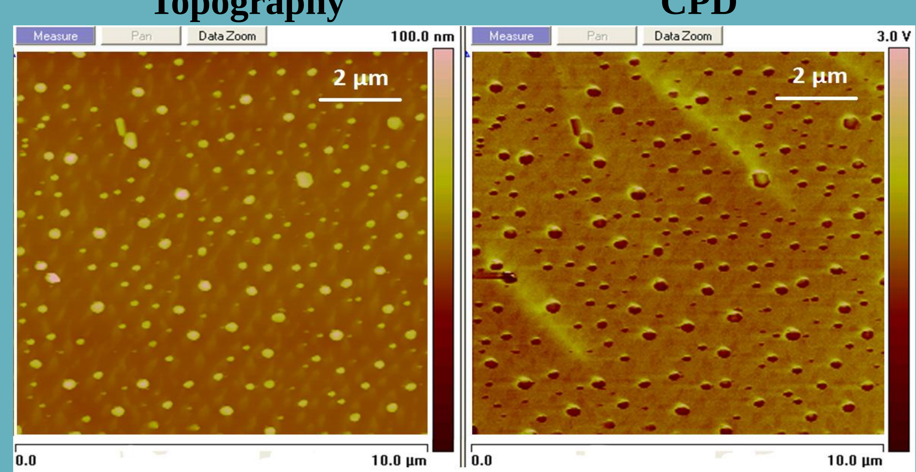


Topography | CPD

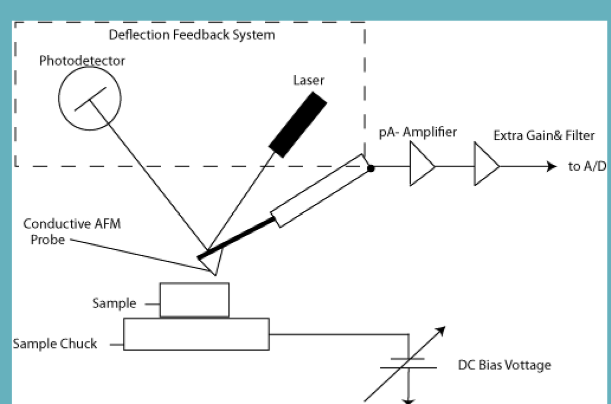


"Pyramid" shaped surface structures

Topography | CPD



AFM - TUNA mode

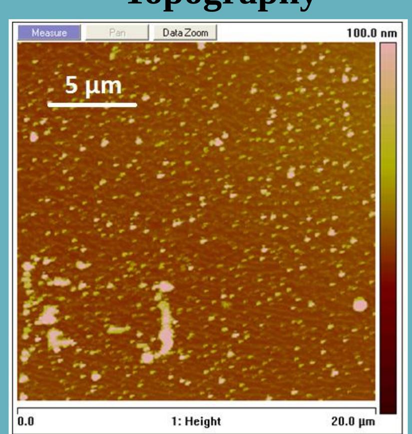


While scanning in contact mode, DC bias is applied between the tip and the sample. A current amplifier senses the resulting current passing through the sample as the topography image is obtained simultaneously.

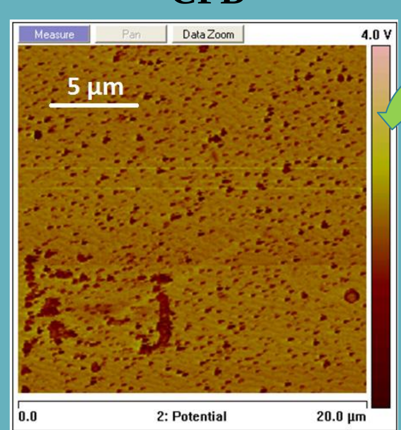
AFM Analysis – CPD and TUNA mode

Area 1

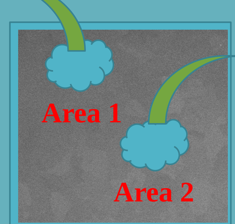
Topography



CPD

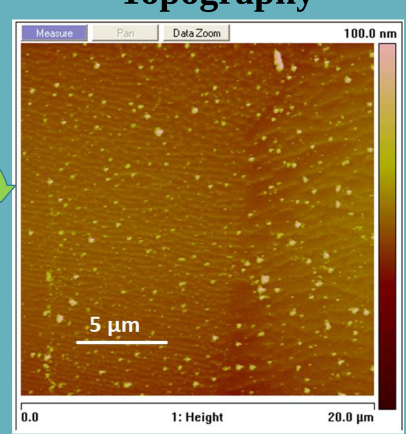


PC-CVD

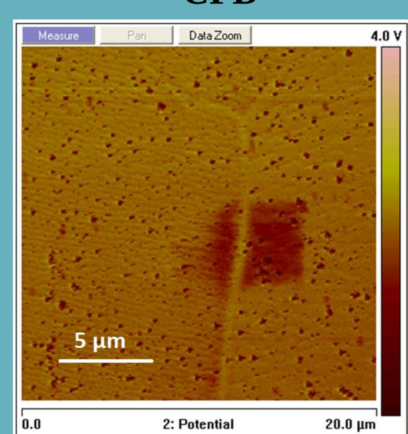


Area 2

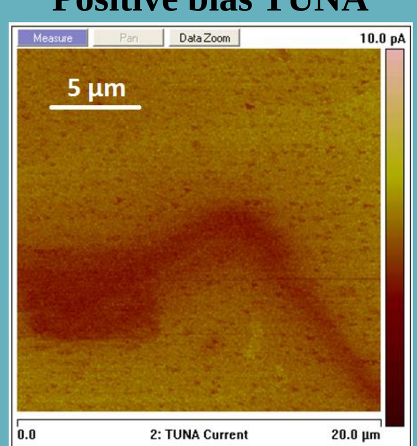
Topography



CPD

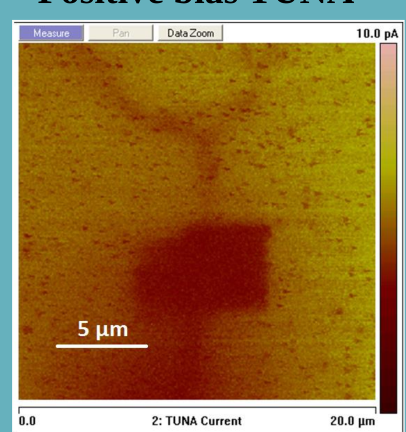


Positive bias TUNA

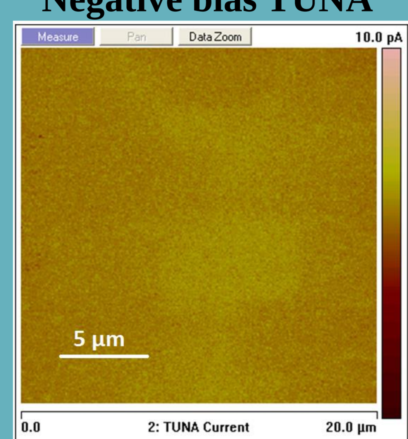


Linear lattice defects show depletion regions (rectangular shaped) on TUNA due to different carrier concentration on domain walls.
The behavior is very dynamic probably due to surface oxidation or charging by TUNA currents.

Positive bias TUNA

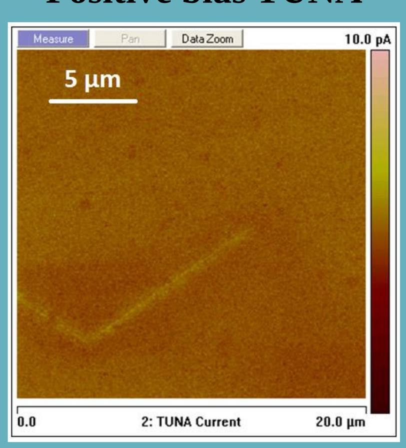


Negative bias TUNA

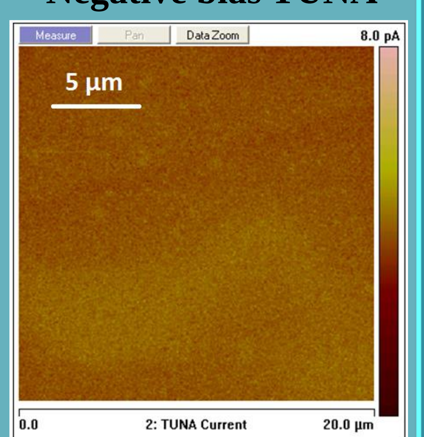


Repeated TUNA measurement – week delay:

Positive bias TUNA

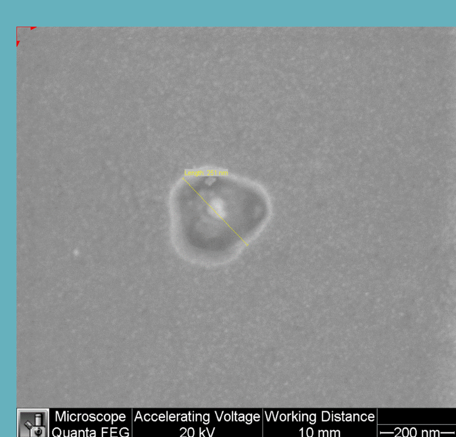


Negative bias TUNA

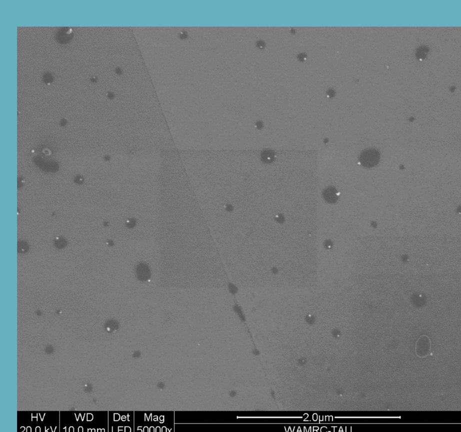


Summary

The Semiconductor-metal interface properties do not seem to affect the activation energies in the 50°C-300°C range. A significant difference in permittivity due to crystallinity types was observed. There were no electrically active features found by atomic force microscope in CPD or TUNA modes for single crystal samples. In polycrystalline samples both methods clearly show various (corresponding) electrically active features. Such local electrical activity might be attributed to trapping centers along crystalline defects (e.g., grain boundaries). Such trapping mechanisms make polycrystalline CVD diamond less viable for detector applications



"Pyramid" on ESEM



Linear defect on ESEM