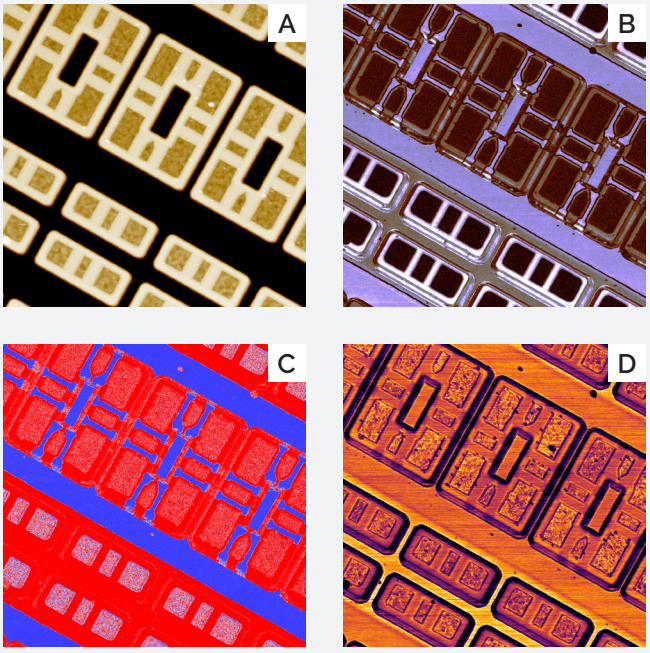
Scanning Capacitance Microscopy (SCM) for Cypher and Jupiter XR AFMs

OXFORD INSTRUMENTS

ASYLUM RESEARCH

Scanning Capacitance Microscopy (SCM) is a nanoelectrical atomic force microscopy (AFM) imaging technique that uses a microwave radio frequency (RF) signal to map electric charge carrier locations, dopant levels, and types (p-type versus n-type) in semiconductors and other samples. It is available on Asylum Research Cypher and Jupiter XR AFM platforms.

The Asylum Research SCM module is unique in that it measures **not just differential capacitance (dC/dV), but also capacitance** with resolution down to 1 aF. In addition to directly measuring capacitance, it offers both **higher resolution and faster scanning** compared to conventional SCM. Improved sensitivity allows the probing of metals and insulators, along with non-linear materials outside the class of traditional semiconductor devices—including those that do not form a native oxide layer.



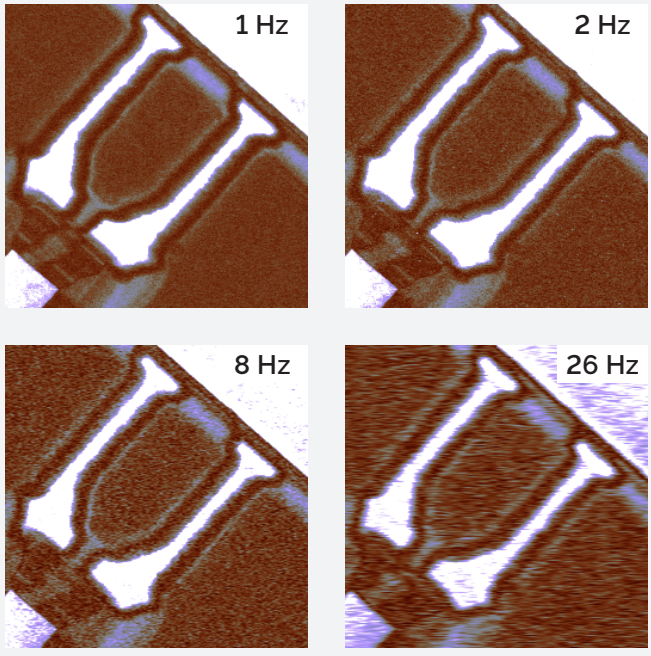
Static random-access memory sample (SRAM). All channels shown were acquired simultaneously over a 29 µm scan area, with **a)** Topography, **b)** dC/dV amplitude, which is inversely proportional to dopant levels, **c)** dC/dV phase, where blue indicates p-type doping and red indicates n-type doping, and **d)** Capacitance, which has a linear correlation with dopant levels.

Capacitance, Not Just dC/dV

Other SCM modules can only provide differential capacitance (dC/dV) data, which limits what users can conclude from measurements. Asylum's newly designed SCM module has the unique capability to provide both dC/dV and capacitance data for more complete materials characterization. With the capacitance channel offering a linear response to dopant level and detecting changes in capacitance with a resolution down to 1 aF, the new SCM module is a powerful tool for nanoelectrical characterization.

Faster Imaging

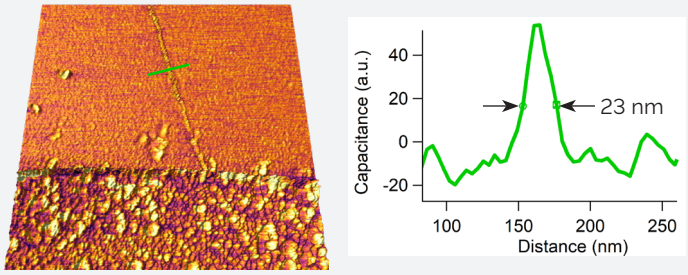
The new high-bandwidth SCM circuit allows acquisition of high-quality dC/dV and capacitance data at lines scan rates up to 26 Hz. Other SCM modules have much lower bandwidth and show significant data degradation at scan rates >1 Hz. Here, there is little to no loss of information at scan rates up to 26 Hz. This faster imaging improves the user experience and increases productivity.



Scan speed comparison on the SRAM sample. Differential capacitance (dC/dV) amplitude images of the same 5 µm area are shown at scan rates from 1 Hz to 26 Hz. Data quality remains almost the same at the fastest rate but the image was acquired in only 10 seconds versus 5-10 minutes for conventional SCM.

Higher Resolution

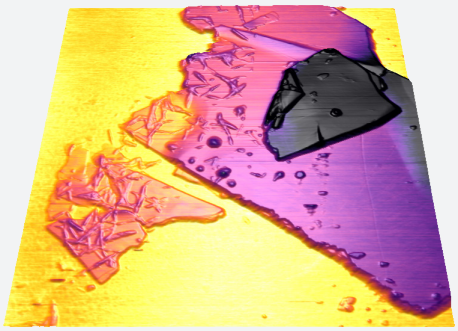
The newly designed SCM module exhibits higher sensitivity, which results in higher resolution images. Samples previously thought to be difficult to image using SCM mode due to low signal can now be routinely visualized. On the right, a single-walled carbon nanotube (CNT) was imaged with SCM mode with a lateral resolution of about 25 nm.



CNT on insulating substrate. Capacitance data overlaid on 3D topography. Image size 2 µm. Sample is courtesy of B. Wilson and J. Tresback, Harvard Center for Nanoscale Systems.

2D Materials Research

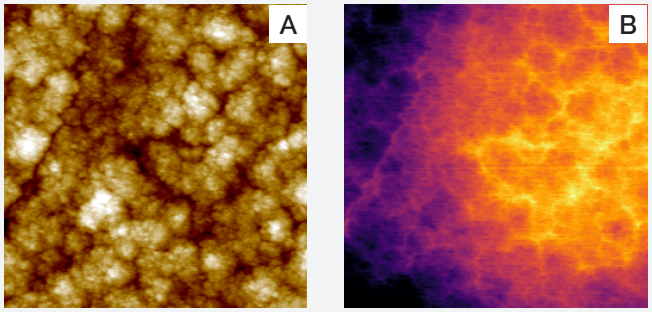
SCM is a useful technique for characterization of 2D materials, which exhibit unique physical and electronic properties. The image on the right shows copper indium disulfide ($CuInS_2$) deposited on silicon. The correlation of the capacitance signal with the thickness of the exfoliated material shows excellent potential for the use of SCM to confidently distinguish the thickness of 2D material layers.



$CuInS_2$ deposited on silicon. Here, the capacitance data is overlaid on 3D topography for a 20 µm scan area. Sample is courtesy of M. Cheng and Prof. V. Dravid at Northwestern University.

Battery Materials Research

Energy storage is another field of research where SCM can provide useful information. On the right, a test electrode from a battery is shown, where distinct contrast in the capacitance channel can be observed. The capacitance signal variation on both individual grains and at the grain boundaries provides insight into electron conduction. Such data could be correlated with conductive AFM and electrochemical strain microscopy to further understand structural and functional properties.



Test electrode of a battery. A 30 µm area was imaged with SCM, showing, a) Topography, b) Capacitance

Specifications

AC bias amplitude 0.1 V-5 V
AC frequency 10-150 kHz
DC bias range +/- 10 V (total incl. AC bias)
Lock-in bandwidth 300 Hz – 25 kHz
RF tunable frequency range 1.6 GHz – 2.2 GHz
RF center frequency ~1.8 GHz
RF resolution < 50 kHz (selectable by software)
RF power at tip -15 dBm
Channels dC/dV amplitude, dC/dV phase, Capacitance, Height, Deflection
Spatial resolution (electrical) <20 nm
Maximum Imaging speed 26 lines/s
Sensitivity (detectable dopant level) 1×10^{15} – 1×10^{20} atoms/cm^3
Sensitivity (detectable capacitance) < 1 aF (1×10^{-18} F)
Recommended probes Rocky Mountain (25PtIr300B), ASYMFMHM-R2
System compatibility Jupiter XR and Cypher platforms

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AFM.oxinst.com
AFM.info@oxinst.com
+1-805-696-6466