Scanning Microwave Microscopy (SMM) Mode

Highly Sensitive Imaging Mode for Complex, Calibrated Electrical and Spatial Measurements

Data Sheet

VNA (left), Universal Nose Cone on Scanner, 5500 AFM (right).

Features and Benefits

- Provides exceptionally high spatial and electrical resolution
- Offers highest sensitivity and dynamic range in the industry
- Enables complex impedance (resistance and reactance), calibrated capacitance, calibrated dopant density, and topography measurements
- Works on all semiconductors: Si, Ge, III-V (e.g., GaAs, InAs, GaN), and II-VI (e.g., CdTe, ZnSe)
- Operates at multiple frequencies (variable up to 20 GHz)
- Does not require an oxide layer
- Supported on the 5000 series AFMs

Applications

- Semiconductors, glasses, polymers, ceramics, and metals
- Ferroelectric, dielectric, and PZT materials
- Organic films, membranes, and biological samples
- Characterization of interfacial properties and contrast from molecular vibrational modes

Overview

Agilent Technologies' unique scanning microwave microscopy (SMM) Mode combines the comprehensive electrical measurement capabilities of a vector network analyzer (VNA) with the outstanding spatial resolution of an atomic force microscope (AFM). SMM Mode outperforms traditional AFM-based scanning capacitance microscopy techniques, offering far greater application versatility, the ability to acquire quantitative results, and the highest sensitivity and dynamic range in the industry.

In SMM Mode, the performance network analyzer sends an incident microwave signal through a diplexer to the sub-7 nm conductive tip of a platinum-iridium cantilever. The signal is reflected from the tip and measured by the VNA. The magnitude and phase of the ratio between the incident and reflected signals are calculated and a model is then applied in order to calculate the electrical properties of the sample. The AFM scans the sample and moves the tip to specific locations to perform point probing. Operation frequencies up to 20 GHz are supported.

SMM Mode includes a state-of-the-art VNA, a diplexer, and the necessary hardware for simple, quick AFM connectivity.

Agilent's SMM Mode offers unprecedented utility for a diverse set of applications. SMM Mode's ability to provide calibrated, high-sensitivity, complex electrical and spatial measurements is particularly useful for semiconductor test and characterization. In addition to enabling complex impedance (resistance and reactance) measurements, SMM Mode can be used to acquire calibrated capacitance and dopant density measurements when studying sidewall diffusion. SMM Mode works on all semiconductors: Si, Ge, III-V (e.g., GaAs, InAs, GaN), and II-VI (e.g., CdTe, ZnSe). Unlike scanning-probe capacitive techniques, SMM Mode does not require an oxide layer.

SMM Mode's exceptionally high electrical and spatial resolutions also make it a superb choice for a wide range of biological and materials science applications. Beyond its ability to measure semiconductors, glasses, polymers, ceramics, and metals, the technique allows Agilent AFM users to perform

high-sensitivity investigations of ferroelectric, dielectric, and piezoelectric materials. In the biological realm, studies of organic films, membranes, and other biological samples, SMM can provide unique insight into fundamental characteristics. For example, SMM's high sensitivity (1.2 aF) is ideal for looking at ion channels.

Agilent's second generation nosecone for the SMM mode greatly improves the user experience for the SMM measurements. Simplified setup of the scanner and nosecone reduce the number of steps required to start collecting data, as well as improve the probe exchange. Now compatible across all the Agilent 5000 series AFMs*, there are unique benefits that the Agilent 5500 AFM with the SMM option brings, including easy environmental control and related experiments with temperature and humidity control.

The wide range of excitation frequencies (2GHz up to 20GHz)** ensures that you can select the optimal frequency to maximize the signal to noise ratio for the best sensitivity. By adding the dopant profile measurement module (DPMM) the capabilities of SMM are extended to provide calibrated, absolute measurement of dopant densities, critical for advanced device physics studies.

VNA Reflection Mode Measurement of Impedance

The VNA provides three different methods for measuring complex impedance, depending on the frequencies and magnitudes involved. A DUT's (device under test) impedance is measured by comparing the reflected return from the incident signal on the DUT (hence 'reflectance' mode), and extracting the device's impedance. This method works best at microwave frequencies, and at impedances that are near the characteristics of transmission lines (50Ω or 75Ω). To ensure the best performance, the DUT is placed in parallel to a load to match the 50Ω ideal load and hence optimize the responsiveness of the VNA's measurements.

The SMM couples the high resolution complex impedance measurement capability of the VNA with the very small metallic AFM probe to provide high special resolution to the reflectance measurements of impedance. This simple, yet effective probe for the DUT yields the very small changes in impedance; that of the metallic AFM probe in contact with the semiconductor sample (thus a MOS capacitor).

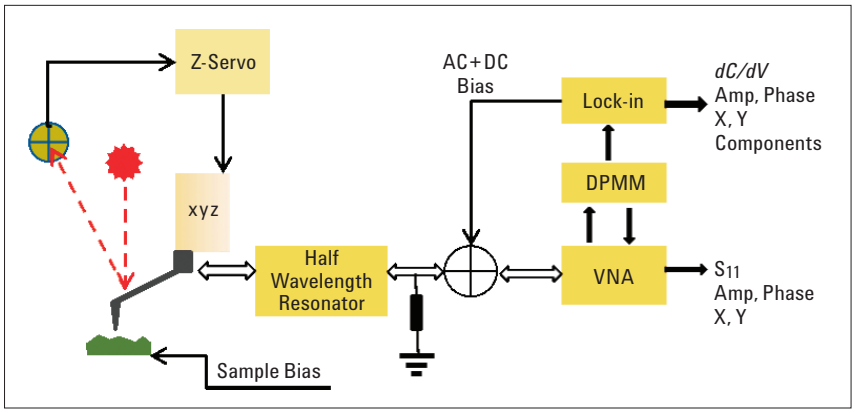

Figure 1. A simple block diagram of the SMM configuration for capacitance and dopant measurement.

Agilent 5000 Series AFMs

SMM Mode is compatible across the Agilent 5000 series and offers a solution that matches all needs. Available with:
Agilent 5420 — An approachable, open access system for basic AFM needs, the 5420 provides a cost effective path to SMM without sacrificing performance.

Agilent 5500 — The premier performance system in the Agilent AFM product portfolio combines world class imaging performance, outstanding applications flexibility, and unparalleled environment control options to drive your research. Match the scanner size with the application for the ultimate in performance and resolution.
Agilent 5600LS — All the performance of the Agilent 5500 but in a platform with a large travel, programmable stage that when coupled with SMM and one of our wafer chucks provides ample options to improve navigation, automation, and repeatable measurements. The choice for semiconductor research, and failure analysis labs, the Agilent 5600LS with the SMM option provides a powerful suite of tools for process development, performance modeling, and failure analysis.

Whatever your applications needs might be, Agilent has an AFM and SMM combination that will match your requirements and budget.

* Agilent 5100 AFM not supported.
** VNA selection can be tailored to your needs, from a budget friendly 2 GHz – 6 GHz model to a 2 GHz – 20 GHz PNA all interface and work with the SMM option.

Agilent AFM Modularity

SMM Mode uses Agilent's multi-purpose large scanner, which is capable of scanning areas up to 90 µm x 90 µm. An open-loop or a closed-loop large scanner can be selected. Each of these unique top-down scanners utilizes interchangeable nose cones that enable AFM users to switch imaging modes quickly and conveniently. An open-top design allows an unobstructed optical view of the cantilever and sample without sacrificing sample handling. A variety of robust, easy-to-use sample plates are offered to facilitate experiments.

Agilent's industry-leading temperature control options are also available. A patented thermal insulation and compensation design enables precise temperature control with excellent stability (±0.1° C or ±0.025° C; from 4° C to 250° C*) for high-resolution AFM imaging.

Software

SMM Mode requires the use of Agilent's PicoView version 1.12, or later, imaging and analysis software package for AFM-VNA integration and control.

For additional interactive post-processing capabilities, Agilent's easy-to-use Pico Image imaging and analysis software package includes all of the features and functions required to build a basic surface analysis report on multi-channel measurement data that is input from the AFM. The document consists of a set of frames containing surfaces, profiles extracted from surfaces, the results of applying filters and other operators, analytical studies, and 2D and 3D parameters. A measurement identity card, screen notes, and illustrations can be added to each document.

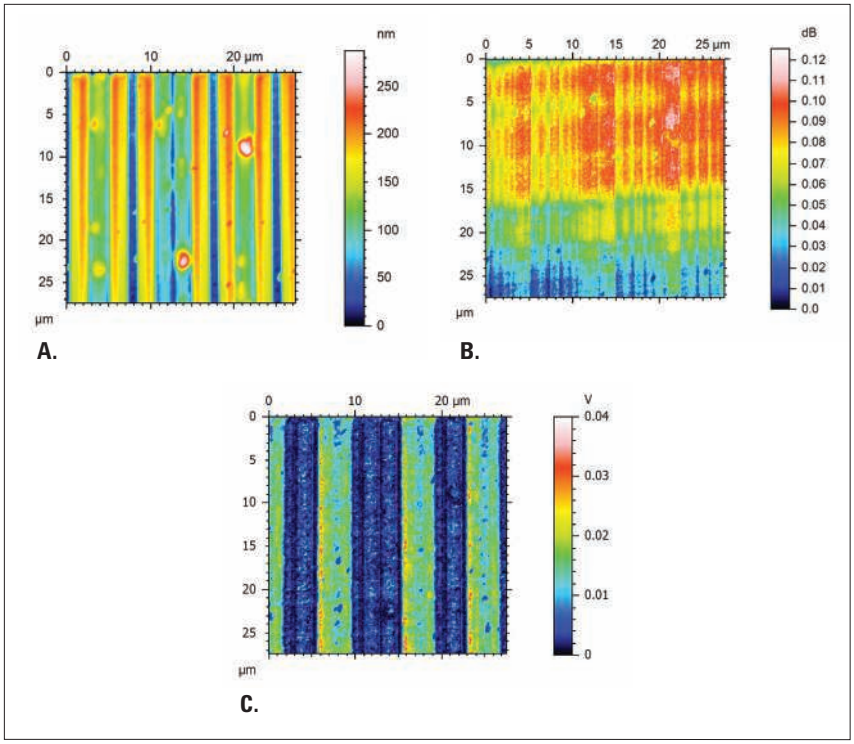

Figure 2. SMM images of SiGe: (A) topography, (B) capacitance, and (C) dC/dV amplitude.

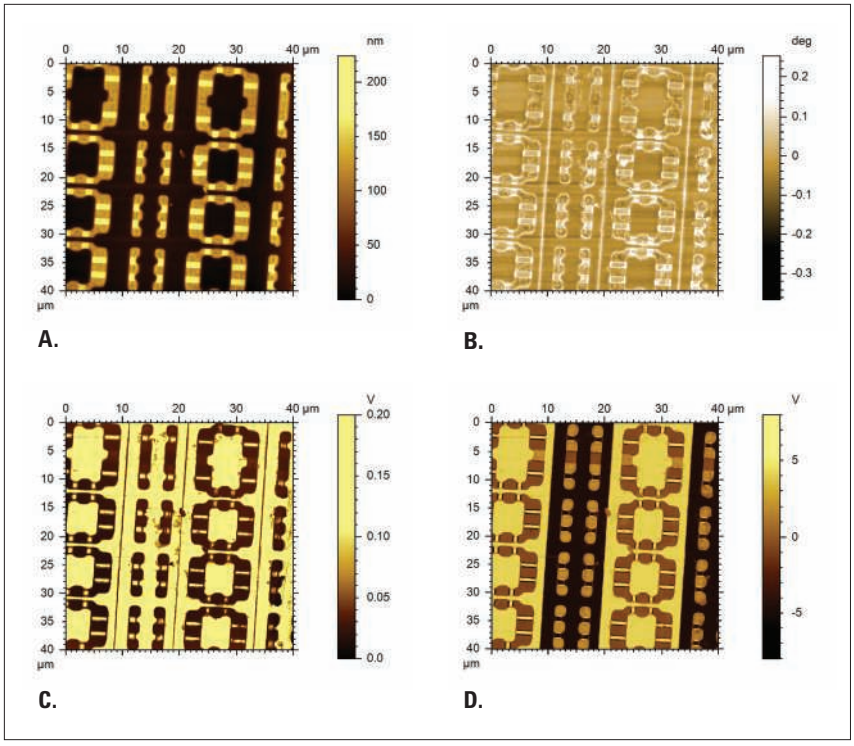

Figure 3. SMM images of SRAM: (A) topography, (B) PNA phase (capacitance), (C) dC/dV amplitude, and (D) dC/dV phase.

* Do not heat higher than 180°C while imaging with the SMM nosecone.

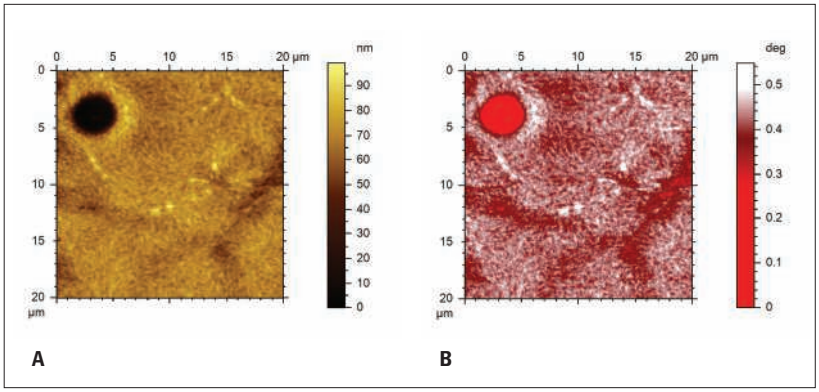

Figure 4. SMM images of *E. coli*: (A) topography, (B) PNA phase (capacitance).

Specifications

Scanning Microwave Microscopy Mode	
Measurements	S_{11}, dC/dV, and dopant densities
Frequency	2 GHz to 20 GHz
Dynamic range	10^{15} atoms/cm^3 to 10^{20} atoms/cm^3
Cantilever	Pt/Ir metal probe
Scanner	
Scanning range	90 µm x 90 µm
Z range	8 µm
Noise level	0.5 Å RMS

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AFM Instrumentation from Agilent Technologies

Agilent Technologies offers high-precision, modular AFM solutions for research, industry, and education. Exceptional worldwide support is provided by experienced application scientists and technical service personnel. Agilent's leading-edge R&D laboratories are dedicated to the timely introduction and optimization of innovative and easy-to-use AFM technologies.

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