

# Keysight Scanning Microwave Microscopy (SMM) Mode

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

Data Sheet



## Overview

Scanning microwave microscopy (SMM) mode from Keysight Technologies, Inc. combines the exceptional electrical measurement capabilities of a vector network analyzer (VNA) with the outstanding spatial resolution of an atomic force microscope (AFM). This unique 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, a VNA 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.

Keysight's SMM mode offers unprecedented utility for a diverse set of applications. SMM mode's ability to provide calibrated, high-sensitivity, compound electrical and spatial measurements is particularly useful for semiconductor test and characterization. In addition to enabling complex impedance (resistance and reactance) measurements, SMM 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 Keysight AFM users to perform high-sensitivity investigations of ferroelectric, dielectric, and piezoelectric materials. In the biological realm, which includes 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.

Keysight's second-generation nose cone for SMM mode greatly improves the overall user experience for SMM measurements. Simplified setup of both the scanner and the nose cone reduces the number of steps required to start collecting data, as well as improves the probe exchange

The wide range of excitation frequencies (2 GHz up to 20 GHz)\* ensures that users can select the optimal frequency to maximize signal-to-noise ratio and achieve 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, which are critical for advanced device physics studies.

## 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 20GHz)
- Does not require an oxide layer

## Primary 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

\* VNA selection can be tailored to your needs, from a budget friendly 2GHz – 6GHz model to a 2GHz – 20GHz PNA all interface and work with the SMM option.

## Keysight AFMs

SMM mode is compatible with Keysight 5000 and 7000 series AFMs, offering solutions to meet all experimental and budgetary needs. This innovative mode is available as an option with the following AFMs:

**Keysight 7500** – The new gold standard in small-sample AFMs from Keysight. Utilizing an entirely new scanner design, it provides outstanding closed-loop imaging to make imaging easier and more repeatable. Like the 5500, it provides unparalleled environmental experiment options, as well as new monitoring capabilities.

**Keysight 5500** – The Keysight 5500 provides world-class performance in an economical, convenient form factor. Unmatched modularity and industry-leading environmental control options mean you can tailor the system to your requirements. The 5500 is ideal for the cost-conscious lab.

**Keysight 5600LS** – All the performance of the Keysight 5500 but in a platform with a large-travel, programmable stage that when coupled with SMM and one of our wafer chucks affords ample options to improve navigation, automation, and repeatable measurements. The perfect choice for semiconductor research and failure analysis labs, the 5600LS with SMM option provides a powerful suite of tools for process development, performance modeling, and failure analysis.

## Keysight AFM Modularity

SMM mode uses a dedicated nose cone that interfaces the VNA to the Keysight atomic force microscope. For both the 5000 series and the new 7500 AFM, the convenience of tip scanning is combined with a top-down video view to facilitate accurate and rapid sample navigation, freeing researchers from complicated sample preparation and time-consuming setup.

Keysight's industry-leading temperature control options are also available. A patented thermal insulation and compensation design enables precise temperature control with excellent stability ( $\pm 0.1^\circ\text{C}$  or  $\pm 0.025^\circ\text{C}$ ; from  $4^\circ\text{C}$  to  $250^\circ\text{C}^{**}$ ) for high-resolution AFM imaging.

## Keysight Software

SMM mode requires the use of Keysight's PicoView version 1.12 (or later) imaging and analysis software package for AFM-VNA integration and control.

For additional interactive post-processing capabilities, Keysight'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.

## 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 ( $50\Omega$  or  $75\Omega$ ). To ensure the best performance, the DUT is placed in parallel to a load to match the  $50\Omega$  ideal load and hence optimize the responsiveness of the VNA's measurements.

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

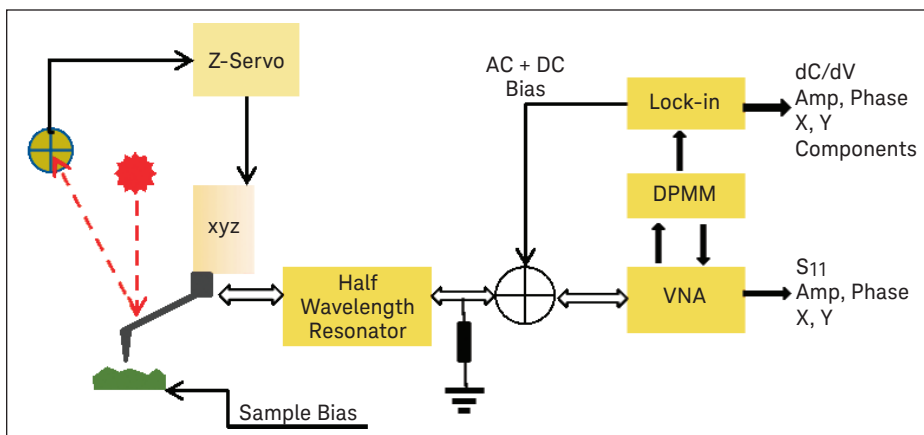


Figure 1. A simple block diagram of the SMM configuration for capacitance and dopant measurement.

\*\* Do not heat higher than  $180^\circ\text{C}$  while imaging with the SMM nose cone.

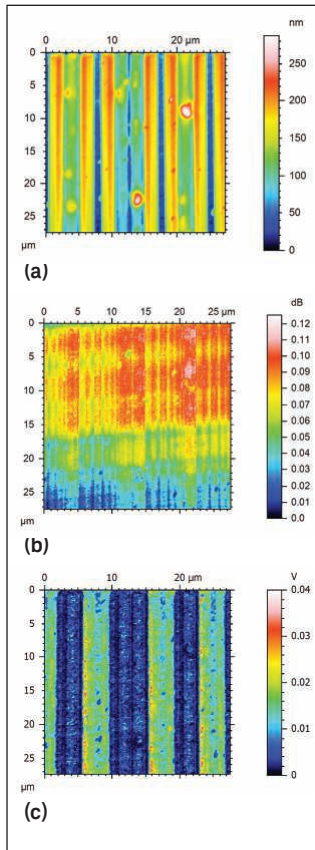


Figure 2. SMM images of SiGe: (a) topography, (b) capacitance, and (c) dC/dV amplitude.

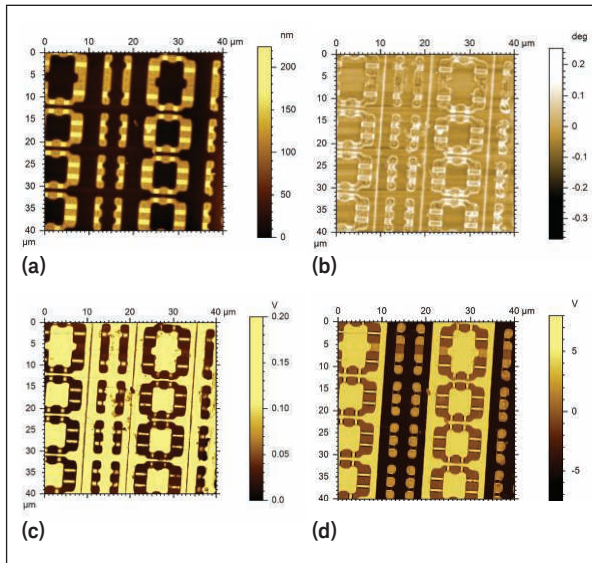


Figure 3. SMM images of SRAM: (a) topography, (b) PNA phase (capacitance), (c) dC/dV amplitude, and (d) dC/dV phase.

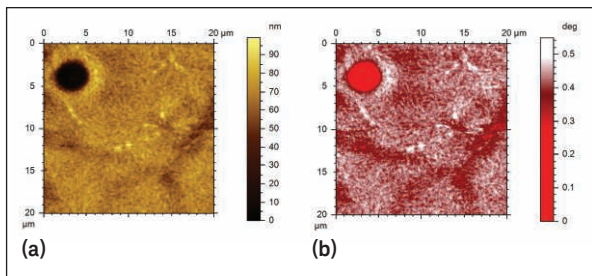


Figure 4. SMM images of E. coli: (a) topography, (b) PNA phase (capacitance).

## Specifications

### Scanning Microwave Microscopy Mode

Measurements:	S <sub>11</sub> , dC/dV, and dopant densities
Frequency:	2GHz to 20GHz
Dynamic range:	10 <sup>15</sup> atoms/cm <sup>3</sup> to 10 <sup>20</sup> atoms/cm <sup>3</sup>
Cantilever:	Pt/Ir metal probe

### 5500 Scanner

Scanning range:	90 μm in XY, 7 μm in Z
Noise level:	<5 Å in XY, <0.5 Å in Z

### 7500 Scanner

Scanning range:	90 μm in XY, >12 μm in Z
Noise level:	<0.3 nm in Z

## AFM Instrumentation from Keysight Technologies

Keysight 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. Keysight's leading-edge R&D laboratories are dedicated to the timely introduction and optimization of innovative, easy-to-use AFM technologies.

[www.keysight.com/find/afm](http://www.keysight.com/find/afm)

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: [www.keysight.com/find/contactus](http://www.keysight.com/find/contactus)

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