Scanning Microwave Microscopy (SMM) Mode

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

Data Sheet

VNA (left), and AFM scanner and 5420 (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 6 GHz)
- Does not require an oxide layer

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 6 GHz are supported.

Agilent Technologies

SMM Mode includes a state-of-the-art VNA, a diplexer, and the necessary cables 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 calibrated 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 resolution also make it a superb choice for a wide range of biological and materials science applications, including the characterization of interfacial properties and contrast from molecular vibrational modes. As well as its ability to work on semiconductors, glasses, polymers, ceramics, and metals, the technique lets Agilent AFM users perform high-sensitivity investigations of ferroelectric, dielectric, and PZT materials. Studies of organic films, membranes, and biological samples can also benefit from the use of SMM Mode. Its very high sensitivity (1.2aF) is ideal for looking at ion channels.

VNA Reflection Mode Measurement of Impedance

Impedance may be measured in three different ways, according to the frequency and the magnitudes involved. A VNA measures a DUT's (device under test) impedance by comparing the reflected signal to the incident signal (the reflection method). This method of measuring impedance is the one that works best at the microwave frequencies and for impedance values at or near the characteristic impedance of transmission lines (50 or 75). The accuracy of a VNA impedance measurement reduces however as the impedance values move away from these characteristic values.

At the heart of SMM's VNA-based impedance measurement technique is a simple yet effective scheme that brings the instrument's reflection-mode measurement capabilities to bear upon solving the problem of measuring with a very high resolution the small changes of a very small impedance (capacitance): that of the (AFM tip/semiconductor) MOS capacitor to the microwave ground.

Topography (left) capacitance (middle) and dC/dV (right) images of a doped SiGe device acquired with a scanning microwave microscope. Both capacitance and dC/dV images showed some dopant structure not seen in the topography. (W. Han)

Agilent 5400 and 5600LS AFM

SMM Mode is compatible with Agilent 5400 and Agilent 5600LS atomic force microscopes. The Agilent 5400 is a high-precision AFM optimized for research, whereas the Agilent 5600LS utilizes a fully addressable 200 mm x 200 mm stage and a new, low-noise AFM design. The programmable, motorized stage enables fast, accurate probe positioning for imaging and mapping large specimens at atomic-scale resolution using a state-of-the-art Agilent AFM. Investigators can precisely locate and identify an area of interest and, with the coordinates stored, automatically reposition the sample quickly and accurately for further study. Multiple locations can be programmed into the system.

The 5600LS is ideal for imaging large samples in air or smaller samples in air, liquid, and under temperature control. It provides researchers a perfect tool for many nanotechnology applications, including semiconductor, materials science, and life science studies. Samples up to 8" in diameter and 30 mm tall are easily accepted by the 200 mm vacuum chuck. The stage can accommodate a 300 mm wafer with repositioning.

Topography (left), capacitance (middle) and dC/dV (right) images of a SRAM chip acquired with a scanning microwave microscope. The underneath n-type (bright) and p-type doped structure are clearly identified in both capacitance and dC/dV images. (W. Han)

Agilent AFM Modularity

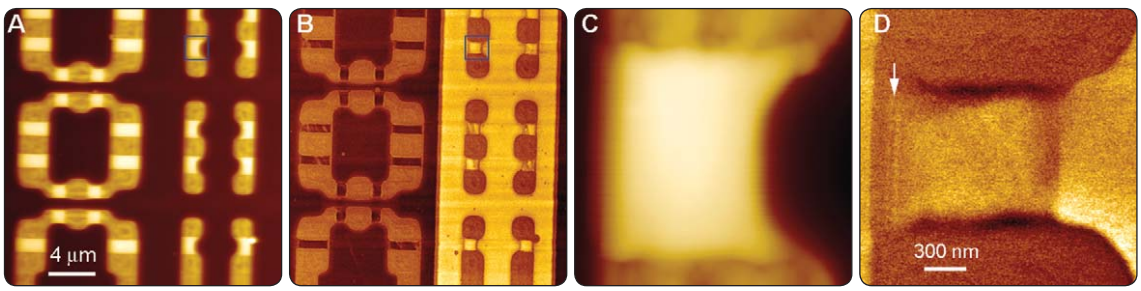
SMM Mode uses Agilent's multi-purpose large scanner, which is capable of scanning areas up to 90 µm x 90 µm. An open-loop or a closed-loop large scanner can be selected. Each of these unique top-down scanners utilizes interchangeable nose cones that enable AFM users to switch imaging modes quickly and 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 SMM Mode and non-SMM Mode 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.

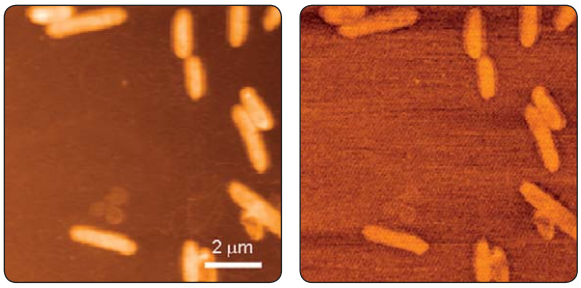
Software

SMM Mode requires the use of Agilent's PicoView 1.5 imaging and analysis software package for AFM-VNA integration and control.

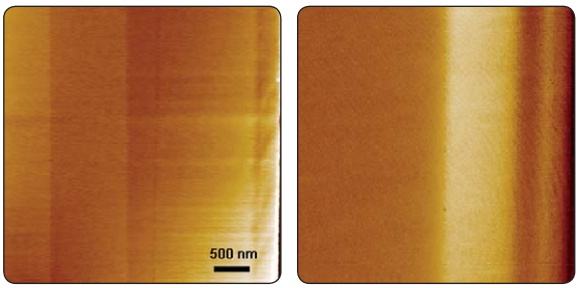
For additional interactive post-processing capabilities, Agilent's easy-to-use Pico Image Basic imaging and analysis software package includes all of the features and functions required to build a basic surface analysis report on multi-layer measurement data that is input from the AFM. The document consists 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.



Topography (A and C) and dC/dV (B and D) images of SRAM. C and D are zoomed scans on one of the transistors in the n well marked in the blue square in A/B. A very fine line feature of 10 to 20 nm in width can be seen in the dC/dV image, as pointed in D, indicating high resolution capability of the scanning microwave microscope.



Topography (left) and impedance (right) images of dried bacteria cells. (W. Han, sample courtesy of N. Hansmeier, T. Chau, R. Ros, and S. Lindsay at Arizona State University)



Topography (left) and impedance (right) images of the cross section of a InGaP/GaAs heterojunction bipolar transistor sample. Different regions from the emitter to the subcollector with different doping levels were clearly resolved in the impedance image. (W. Han, sample courtesy of T. Low)

Specifications

SMM Mode	
Measurements	S_{11} dC/dV
Frequency	2 GHz to 6 GHz
Capacitance	1.2 aF
Dynamic range	10^{14} atoms/cm^3 to 10^{20} atoms/cm^3
Spatial resolution (Tip dependent)	To 2 nm
Cantilever	Custom solid metal probe
Scanner	
Scanning range	90 µm x 90 µm
Z range	8 µm
Vertical range	0.5 Å RMS

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