Keysight Technologies
Current Sensing AFM Measurements Using 7500 AFM

Application Brief

Metroscanner (top) and preamp board (bottom).

Introduction

Current Sensing Atomic Force Microscopy (CSAFM) is an extended SPM mode for simultaneously probing the conductivity and topography of a sample. It takes the combined advantage of scanning tunneling microscopy and force microscopy, making it capable of studying localized electric properties of resistive samples. CSAFM utilizes electrically conductive AFM cantilevers and operates in standard contact mode. By applying a voltage bias between the substrate and the conducting cantilever, a current is generated. This current can be used to construct a spatially resolved conductivity image. It also allows for local current vs. voltage measurements (I/V) with purely topographic feedback. It is a measurement useful in a wide variety of material characterization applications, including thin dielectric films, ferroelectric films, nanotubes, conducting polymers, semiconductor devices, etc. CSAFM has also been applied in the study of electron transfer process in single molecules and transport process in ion conducting membranes.

Instrumentation

The Keysight Technologies, Inc. 7500 AFM/SPM microscope is a high-performance instrument that delivers high resolution imaging with integrated environmental control functions.
The standard Keysight 7500 includes contact mode, acoustic AC mode, and phase imaging that comes with one universal scanner operating in both Open-loop and Closed-loop mode. Switching imaging modes with the Keysight 7500 AFM/SPM microscope is quick and convenient, a result from the scanner's interchangeable, easy-to-load nose cones. All 7500 AFM's come with the lowest noise closed loop position detectors to provide the ultimate convenience and performance in imaging, without sacrificing resolution and image quality.

The Keysight 7500 microscope with the addition of a preamp, and the standard nosecone enables CSAFM mode. Preamps are available in three different sensitivity settings of 0.1 nA/V, 1 nA/V, and 10 nA/V, yielding current ranges of ±1 nA, ±10 nA, and ±100 nA respectively. Each of the preamp modules comes as a plug-and-play board that inserts into the interface slot on the scanner. Change of current sensitivity is simply done by switching between different plug-and-play boards, greatly increasing the flexibility of the microscope, and reducing the complexity of use.

Examples of CSAFM Measurement

Resistivity Mapping of Titanium-tungsten (TiW) Films

TiW is a common material used for multilevel metallization in VLSI technologies. It provides a good barrier to prevent Si diffusion into Al, the commonly used metal for interconnects

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in semiconductor devices. It adheres strongly to both SiO_2 and Si_3N_4 films and provides a clean and uniform nucleating surface for Al. TiW is an alloy of Titanium and Tungsten usually contains 10 wt.% of Ti and 90 wt.% of W in the film. The TiW film usually consists of columnar grains of W, while the Ti forms a solid solution with some W atoms at the grain boundaries. The distribution of Ti is an important factor for the behavior of the TiW film. The resistivity of the TiW film is reported to be in the range of 50–80 μΩ·cm. Figure 1 shows the topography and current images obtained simultaneously on a TiW film deposited on Si. The topography image reveals that TiW film shows a surface roughness of about 6 nm RMS. The current image shows higher conductivity at the areas between the granular domains, corresponding to the Ti/W liquid solution formed at the grain boundaries between columnar W phases. Change in polarity between current images (B) and (C) is a result of the opposite DC bias applied to the sample during imaging.

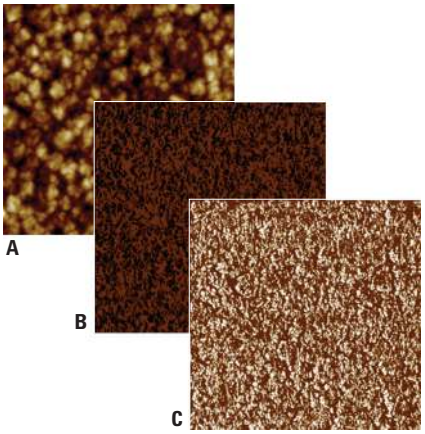

Figure 1. CSAFM imaging of TiW thin film: (A) Topography, (B) Current at -0.05 V, and (C) current at +0.10 V. Scan size: 1.5 μm x 1.5 μm .

Conductivity Measurement on Semiconductor Devices

An important CSAFM application is in the study of physical failure analysis of integrated semiconductor devices. CSAFM has been successfully utilized to localize the failure site on marginally failing devices and to obtain full electrical data on single bit failures. It is also a viable alternative tool to both voltage contrast imaging and in-FIB pico-probing. CSAFM provides simultaneously topography information with nanometer scale resolution as well as electrical characteristics of the surface. It can perform current mapping of large areas and provide current-voltage (I-V) characteristics of specific contacts, vias and even foreign particles in a non-destructive manner. The current image of the region of interest gives an easy to interpret map of the possible defective contacts or vias. CSAFM is more sensitive than PVC (passive-voltage-contrast) as the contrast mechanism is the direct current measurement of the surface. CSAFM technique for bulk silicon devices is easily performed by biasing the silicon substrate while scanning with the conductive tip to measure the current passing through each point of contact.

As an example, a CSAFM image of a piece of SRAM de-processed to the bare silicon level, exposing the PMOS and NMOS structures. The current images clearly reveal the different conductivity of differently doped regions.

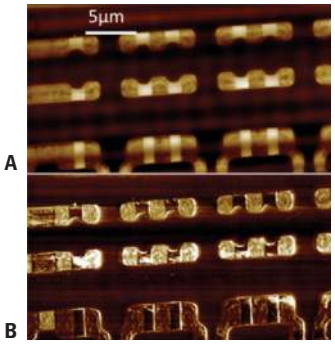

Figure 2. CSAFM topography (A) and current (B) images of of SRAM.

Summary

Current sensing AFM delivers nanometer scale current measurement with the help of constant force feedback control, offers high resolution, spatially resolved conductivity imaging for a wide variety of material characterization applications, including thin dielectric films, ferroelectric films, nanotubes, conductive polymers, IC devices, and many more. CSAFM also is a technique in the study of electron transfer process in single molecules and transport process in ion conducting membranes.

AFM Instrumentation from Keysight

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 and easy-to-use AFM technologies.
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