Atom Probe Tomography of a 3D FinFET

Sample Preparation and 3D analysis of a 14 nm device

Application Note #APT-11

Atom probe tomography (APT) of entire FinFET structures is easier than ever with high precision dual-beam FIBs that can reliably image and target small devices, along with CAMECA's LEAP 5000™ atom probe that enables atomic scale analysis of full device structures. Information about dopant distribution, layer thicknesses, and elemental composition on the nanoscale can now be obtained, all of which can be related to critical device performance. The three-dimensional atom probe data, identifying up to 80% of the ions in the region of interest, is unique among characterization techniques and central to providing a complete picture of FinFET structures.

Specimens can be prepared in a variety of different orientations with a dual-beam focused-ion-beam/scanning-electron-microscope (FIB-SEM) to improve data yield and to access specific regions of interest within the device structure. Figure 1 shows SEM images along with schematics of the device orientation of three tip preparation methods: (a) standard top-down; (b) backside or upside down; and (c) cross section. Changing the orientation of the device with respect to how it is mounted for sharpening can make sample preparation easier by avoiding difficult-to-mill materials or regions that are not important to device performance. CAMECA developed sample preparation stages for the FIB-SEM enable sample preparation in any orientation by allowing for rotation of the liftout. CAMECA technical notes are also available to provide step by step instructions on each different preparation method*.

Atomic scale compositional information can be obtained in the LEAP 5000 from devices prepared in any orientation by the FIB-SEM. Figure 2 shows atom probe data from one specimen containing a modern microprocessor. The Si fin is visible in the center, surrounded by the metal gate containing HfO, TiN, and TiAlC. Concentration profiles, bulk concentra- tions of each layer, and dopant analysis can be performed with the collected data. CAMECA's LEAP 5000 provides unprecedented 3D data, which has traditionally been very challenging to obtain with other techniques.

**Available on request. Please email cameca.leap@ametek.com.*

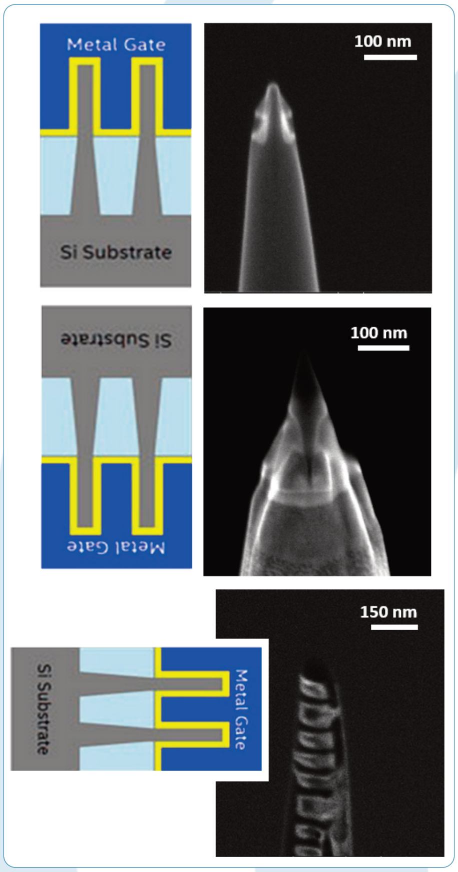


Figure 1: Different FIB preparation orientations, orienting the fin structure in the specimen tip (a) top-down; (b) backside; (c) cross section.

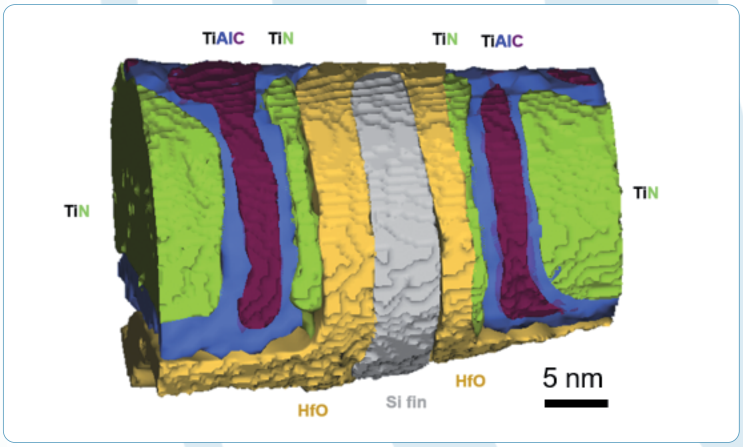


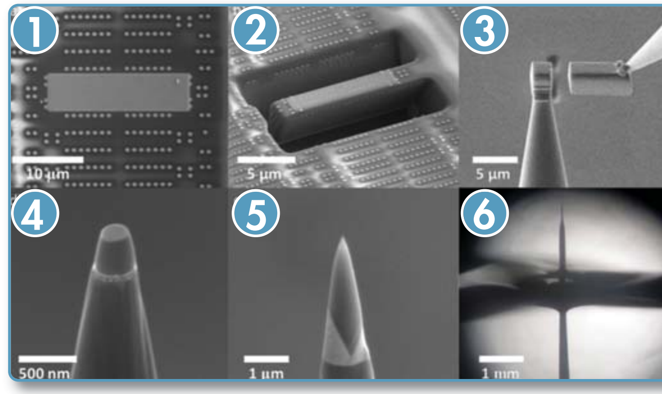
Figure 2: 3D volume showing the pure Si Fin surrounded by the metal gate structure.

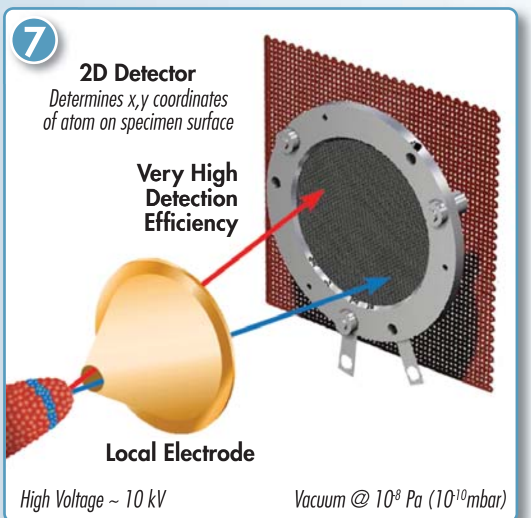
Adapted from I. Martin et al., Atomic Scale Analysis of Dopants in CMOS Structures by Atom Probe Tomography, Microsc. Microanal., 22 (S3), 1534 (2016)

Three Steps to 3D Nanoscale Analysis
An Introduction to Atom Probe Tomography

Step 1: Specimen Preparation

An atom probe specimen usually has a nanoscale region of interest (ROI) requiring both 3D compositional imaging and analysis. The sample is formed into a needle shape containing the ROI. Common APT specimen preparation methods using electropolishing or a Focused Ion Beam system (FIB) are very similar to TEM methods except instead of forming a thin sheet, a needle shaped sample is desired. At the right, standard FIB liftout and mounting of a specimen (figures 1 through 3) and then sharpening the sample with the ROI left at the very apex (4 and 5). In 6, a wire geometry sample is being electropolished.





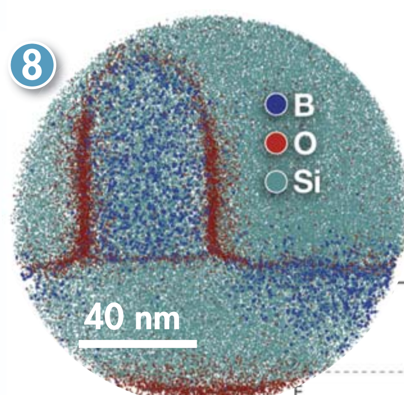
Step 2: Data Collection

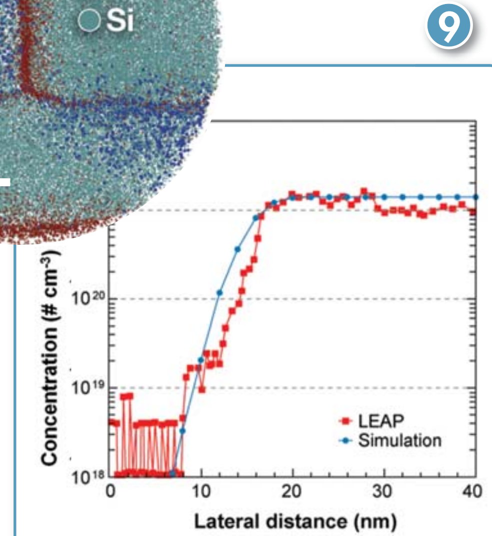
An atom probe produces images by field evaporating atoms from a needle-shaped specimen and projecting the resultant ions onto a detector 7.

A high magnification results from the ~ 80nm tip being projected onto an 80mm detector resulting in a magnification of approximately 10^6.

An atom probe identifies atoms by their mass-to-charge-state ratio *(m/n)* using time-of-flight mass spectrometry. Charge state, *n*, is typically 1 to 3.

The specimen is held at approximately 50K to reduce surface diffusion during the experiment. The high electric field results in 100% ionization and the high speed detector is capable of measuring up to 80% of the collected ions, independent of ion mass.





Step 3: Data Visualization and Analysis

Examples of data output are illustrated by a slice of a 3D atom map of a transistor† 8, and a dopant composition profile‡ 9. The image shows the positions of individual atoms (oxygen is red and boron is blue) in the transistor with subnanometer resolution. From the reconstructed data set many types of useful analyses are possible. These include 3D visualization, 2D atom mapping 8, 1D depth profiling and line scanning 9, as well as mass spectra and compositional analysis from user-selected volumes.

† *Lauhon, L. J. et al, MRS Bulletin "Atom Probe Tomography of Semiconductor Materials and Device Structures" 34(10) (2009) 738.*

‡ *Moore, J. S.; Jones, K. S.; Kennel, H.; Corcoran, S., Ultramicroscopy "3-D Analysis of Semiconductor Dopant Distributions in a Patterned Structure using LEAP" (2008), 108, 536–539.*

CAMECA SCIENCE & METROLOGY SOLUTIONS
nu
AMETEK MATERIALS ANALYSIS DIVISION

CAMECA International Headquarters
29 quai des Grésillons
92622 Gennevilliers, France
cameca.info@ametek.com
www.cameca.com

Atom Probe Technology Center
5500 Nobel Drive
WI-53711 Madison, USA
cameca.leap@ametek.com
www.atomprobe.com