Atom Probe Tomography of Semiconductor Devices

3D Analysis of a 28nm Node S/D Region

Application Note #APT-06

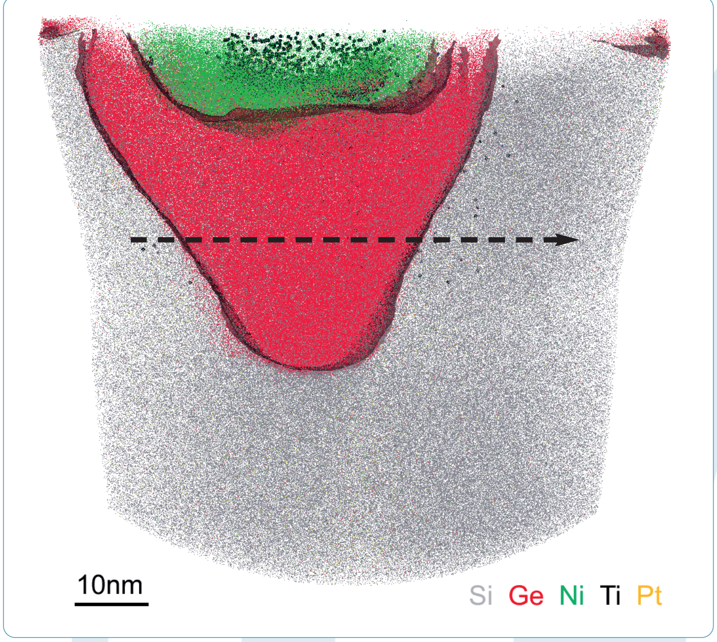
Atom Probe Tomography (APT) has seen recent expanding interest and use in the area of semiconductor device analysis. Ever smaller device technology nodes and increasing yield/performance requirements have resulted in growing demand for the type of data that the atom probe can provide: 3D distribution of isotopic species at the atomic scale with high detector efficiency (>75% of atoms identified in 3D) and high sensitivity. The LEAP is uniquely capable of providing isotopically sensitive information about buried interfaces - a capability that has been demonstrated with low ppm sensitivity. APT analyses of particular interest include dopant distribution in the source/drain, extension, and interfacial and channel regions of actual devices where other common analysis techniques lack sufficient spatial or compositional resolution.

APT has been used for semiconductor materials research for almost 10 years, but for much of that time it primarily served research and development of blanket wafers, test structures, or model devices. More recently, successes on fully processed devices has led to quick adoption, such that now seven of the top 10 semiconductor manufacturers have a LEAP system*.

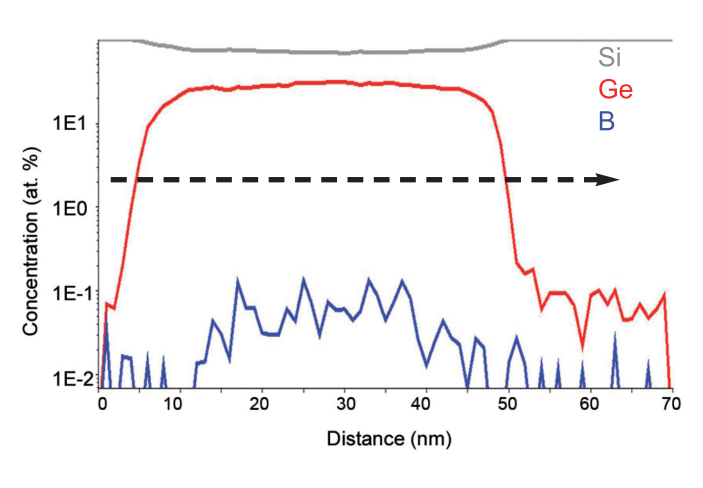
Analysis of a single, targeted device, such as failure analysis of a transistor with APT had rarely been performed due to the complicated sample preparation required and the relatively low data collection success rate on complex 3D structures with many interfaces. Continuing advances in APT and FIB/SEM techniques have rendered the previously slow and low quality efforts more routine, particularly for device specific analyses.

With these new sample preparation techniques, and the latest hardware and software in the new LEAP 5000 atom probe model, it has been demonstrated that true failure analysis work with a LEAP system is possible.

Other semiconductor applications include:
- High-k dielectrics
- Channel engineering
- Silicides
- Advanced metallization
- Compound semiconductors
- 3D device structures
- Optoelectronics



10nm slice of 3D data from a AMD Radeon R7 GPU. FIB/SEM was used to select individual devices for liftout and LEAP analysis. The 3D analysis of the source-drain region reveals Titanium and Platinum doping in the Nickel Silicide to SiGe contact. The arrow denotes a region of quantitative analysis through the S/D region, into the channel (see below)



One-dimensional concentration profile from the source drain region into the channel.

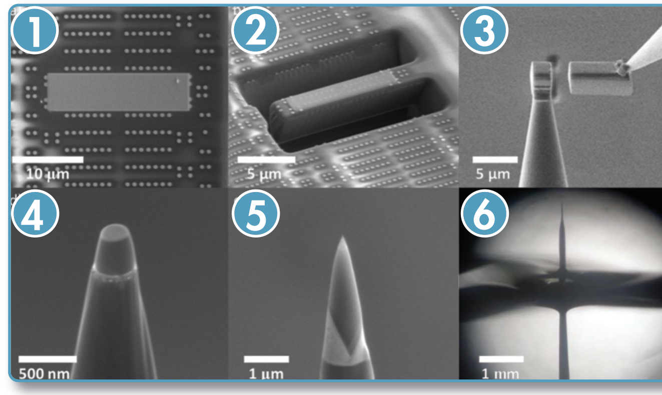
**McClean Report, IC insights 17 (2013).*
Adapted from D.F. Lawrence et al., Routine Device-Level Atom Probe Analysis, Proceedings of the 40th ISTFA 2014, Houston.

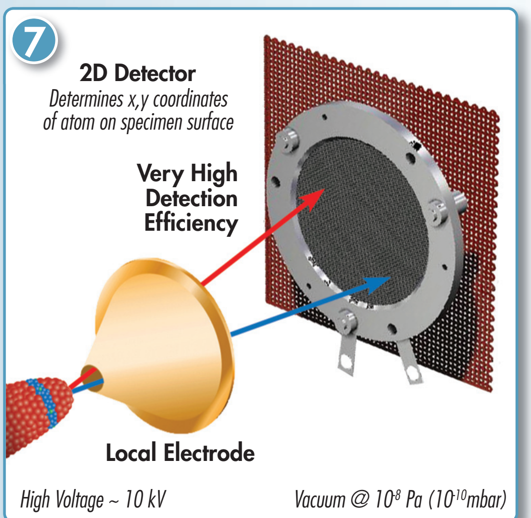
AN#APT-06 - Semi-28nm node - Jan 15

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.

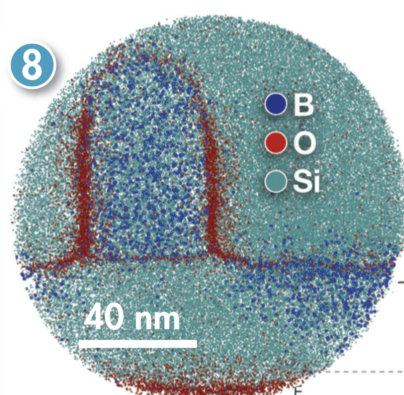
A high magnification results from the ~ 80nm tip being projected onto an 80mm detector resulting in a magnification of approximately 10^6.

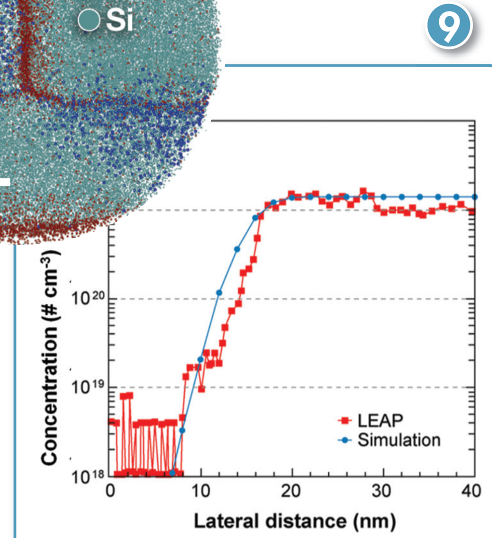
An atom probe identifies atoms by their mass-to-charge-state ratio *(m/n)* using time-of-flight mass spectrometry. Charge state, *n*, is typically 1 to 3.

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.*