Off-the-Shelf finFET Device Characterization by APT

Revealing nanoscale dopant non-uniformity and clustering

Precise nanoscale characterization is essential in the research and development of next generation semiconductors as the industry continues its trend of smaller devices. One such device is the Snapdragon X70, a 5G modem-RF system designed by Qualcomm that utilizes a unique 5G AI processor for performance optimizations. The basis of this modem relies on SRAM finFET architectures. With three-dimensional structures with critical device dimensions below 10 nm, advanced characterization techniques are becoming required to characterize the material composition, dopant distributions, and potentially detect failure mechanisms from the manufacturing or operation process. Atom probe tomography provides three-dimensional compositional information which can accurately address semiconductor manufacturing concerns. In this off-the-shelf device, we have prepared samples from the deprocessed fin structure as shown in Figure 1.

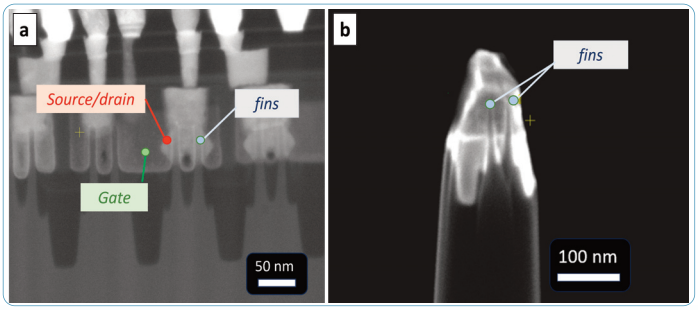


Figure 1:
(a) HAADF STEM image of fin structure in a Snapdragon x70 chip;
(b) APT tip prepared from the fin region.

The source/drain structures of n-type devices are typically heavily doped with boron; the distribution and concentration of these heavily doped regions have a strong influence on device performance. Figure 2 shows an atom probe dataset of a Snapdragon SRAM region containing two fin structures. The SiGe source drain region was extracted (dashed red box in Figure 2a). Significant non-uniformity was seen in the dopant distribution in the SiGe region, with inset in Fig 2b. Boron clusters were isolated by a 3% B isosurface as shown in Figure 2c. A proxigram was computed and the results are shown in Figure 2d. The boron content reached up to 10% in the cluster center. The significant clustering can affect the ability of dopants to efficiently contribute charge carriers, thus impacting device performance by creating opportunities for leakage current or inefficient carrier mobility.

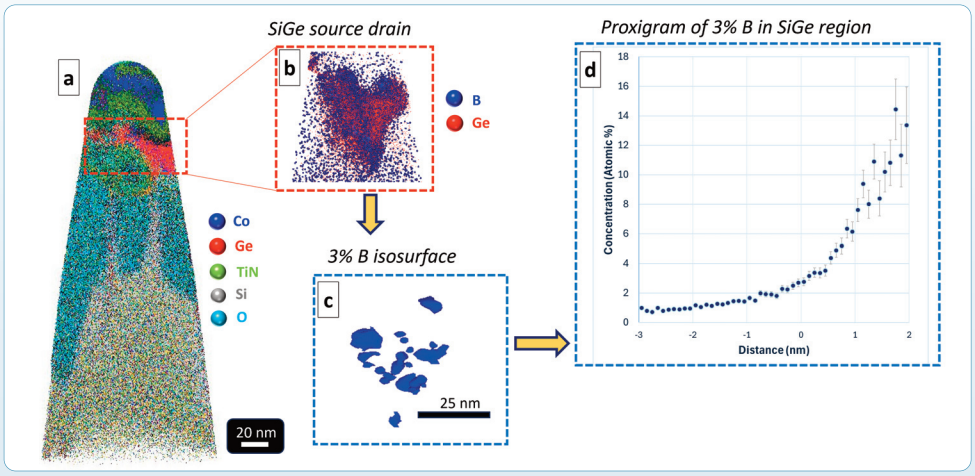


Figure 2:
(a) Ion map from an APT dataset of a Snapdragon finFET device,
(b) Region of interest showing heavily boron-doped SiGe,
(c) 3% Boron isoconcentration surface from the region of interest,
(d) Proxigram from isosurfaces showing increased boron concentration at the center of clusters.

Atom probe tomography is a characterization technique that can effectively analyze complex device architectures such as finFET, nanosheet, and nanowire structures and provide compositional information at the nanoscale that can reveal process changes.

Analysis conducted on an APT at the CAMECA Atom Probe Technology Center, Madison, WI, USA.

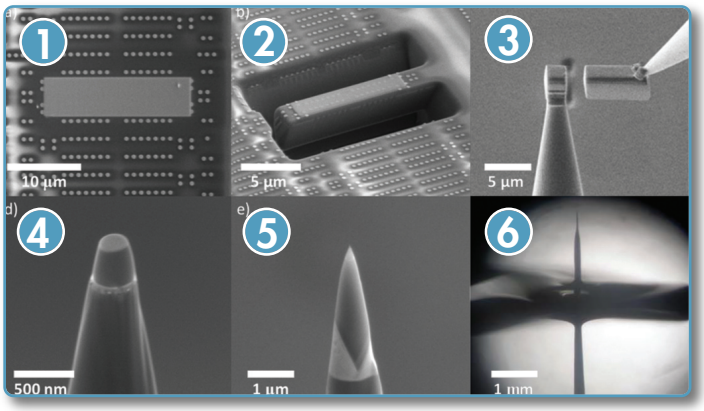
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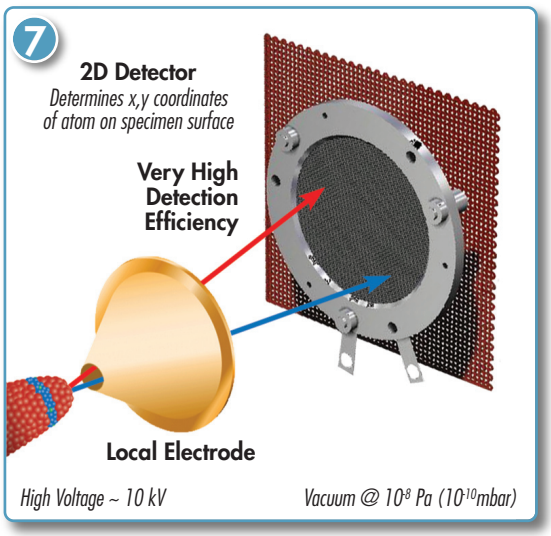
Three Steps to 3D Nanoscale Analysis

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.

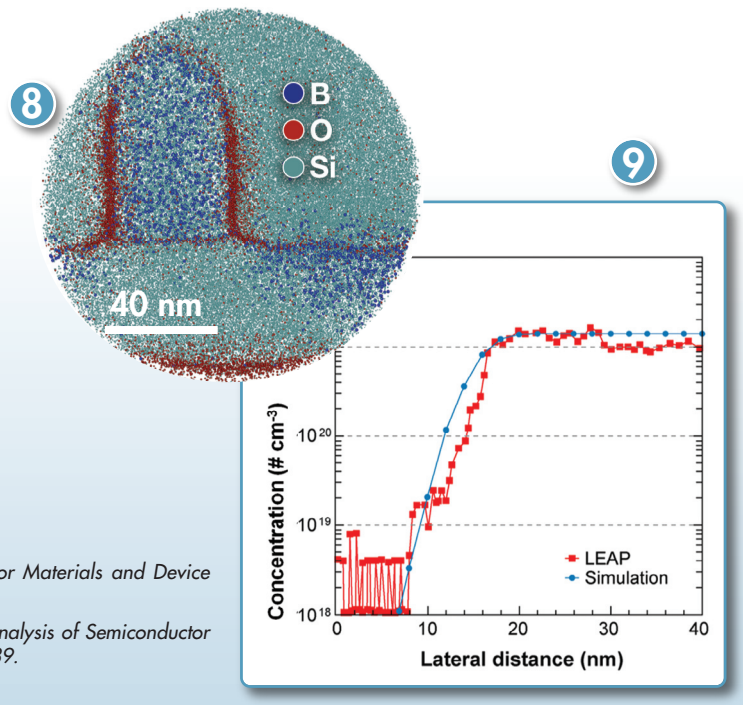
A high magnification results from the ~ 80nm tip being projected onto an 80mm detector resulting in a magnification of approximately 10^6.

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.*

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