Wavelength-Dependent Field Ion Emission in Atom Probe Tomography

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Laser-pulsed atom probe tomography (APT) is a powerful tool for materials characterization due to its desirable combination of high spatial resolution and analytical sensitivity. In current state-of-the-art commercial APT instruments, near ultraviolet (NUV; E ≈ 3.5 eV; $\lambda \approx 355$ nm) or deep ultraviolet (DUV; (E ≈ 4.8 eV; $\lambda \approx 257$ nm) laser pulses are used to provide the energy necessary to overcome the activation barrier for field ion evaporation. APT has been used successfully to characterize a wide range of materials including metals, semiconductors, insulators, biological materials, and even liquids. However, APT data quality and specimen survivability can be degraded due to non-uniform absorption, ionization, or heating of constituent elements or phases in complex heterostructured materials and devices.

Over the last decade, NIST Boulder Laboratories has engaged in a program aimed at exploring the effect of varying laser wavelengths on APT data quality and specimen survivability. Our initial efforts focused on integrating a fs-pulsed extreme ultraviolet (EUV; E ≈ 10 eV to ≈ 100 eV; $\lambda \approx 124$ nm to ≈ 12 nm) coherent radiation source into a commercial atom probe instrument [1]. We were able to successfully analyze a variety of material types including semiconductors, insulators, multilayer thin films, organic molecules, frozen water ice, 2D materials, and patterned 3D devices.

In this talk, I will present our newest results using pulsed EUV radiation in a variety of material specimen types, focusing specifically on “yield” or survivability-type samples [2], state-of-the-art 3D commercial gate-all-around (GAA) 3D nanosheet transistors (Figures 1, 2) [3], and an insulating bulk 2D material. In some cases, we have direct comparison with NUV and/or DUV pulsed laser sources. Lastly, I will discuss our current efforts aimed at building a 6 eV ($\lambda \approx 207$ nm) DUV laser pulsed APT instrument as well as our future plans to explore 8.4 eV ($\lambda \approx$148 nm) vacuum ultraviolet radiation sources.

References:

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[3] Gate-All-Around (GAA): The Ultimate Solution to Reduce Leakage. MSS Corps. Co., Ltd. *EE Times*, October 25, 2024. https://www.eetimes.com/gate-all-around-gaa-the-ultimate-solution-to-reduce-leakage/

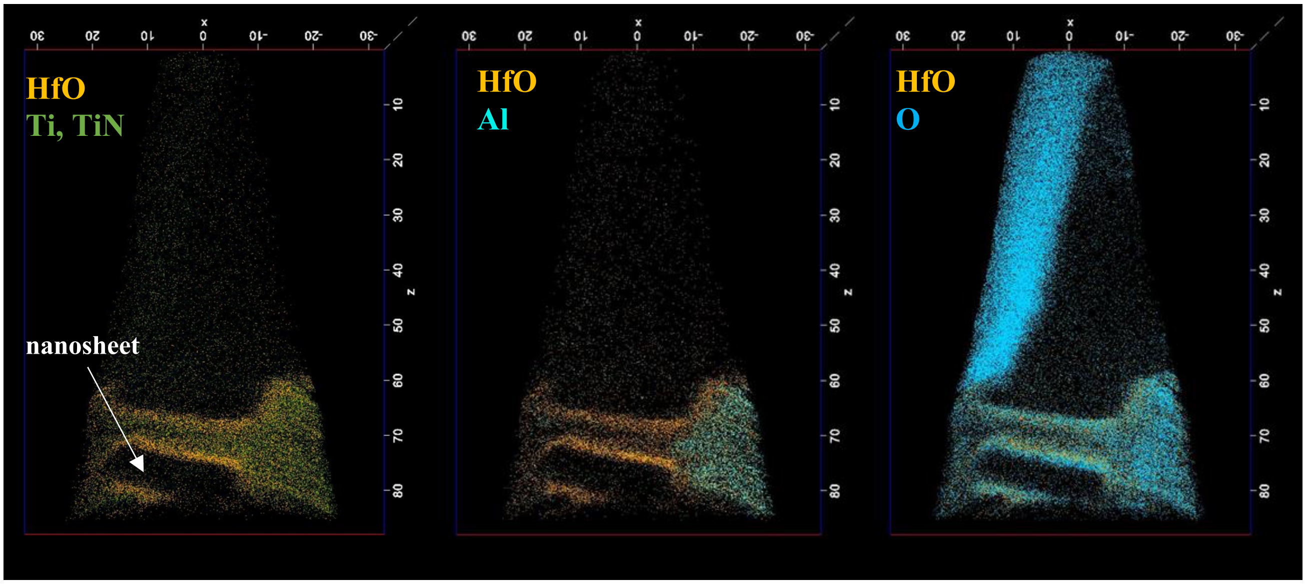

Figure 1: 3D EUV APT reconstruction of a commercial GAA nanosheet transistor showing a single Si nanosheet (Si atoms not shown for clarity) wrapped in the gate dielectric and surrounded by the gate metal. This data was collected on an inverted or "backside" specimen (i.e. the Si substrate wafer is toward the top and the metallization layers are toward the bottom). The size and shape of the nanosheet are captured with high fidelity. (Left) Atom map showing HfO (orange) and Ti, TiN (green). (Center) Atom map showing HfO (orange) and Al (cyan). (Right) Atom map showing HfO (orange) and O (blue). Bounding box scale markers are in nm.

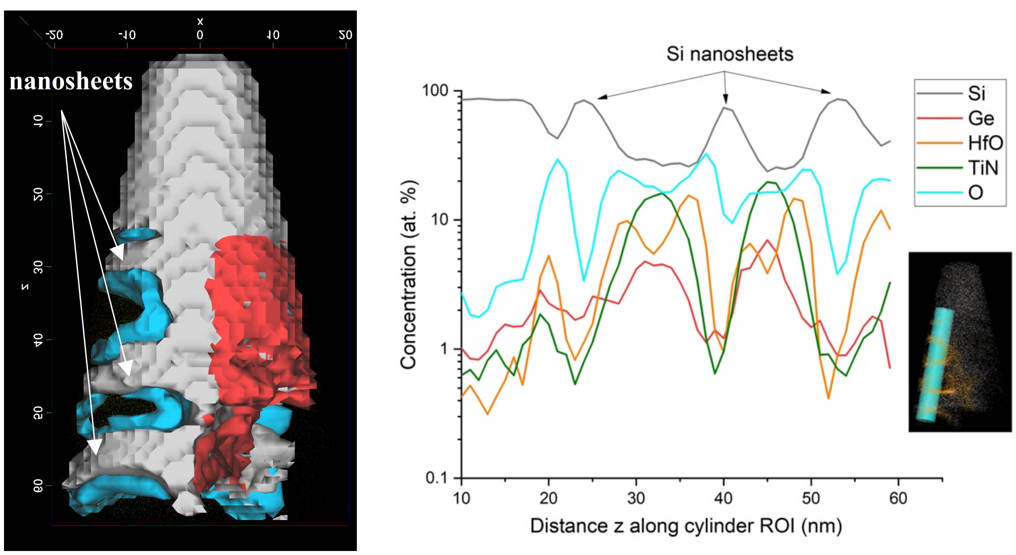

Figure 2: (Left) 3D EUV APT reconstruction of a commercial 3D GAA nanosheet transistor using isoconcentration surfaces to delineate various regions/phases. Gray shows Si (nanosheets, epi layers), blue denotes O (here representing the gate dielectric stack), and red represents Ge (source/drain contact). Three Si nanosheets are visible on the left side, surrounded by the gate dielectric stack. Bounding box scale markers are in nm. (Right) 1D concentration profile calculated from a 10 nm diameter cylindrical region of interest (ROI, inset) centered on the three Si nanosheets and analyzed along the z-direction. The three Si nanosheets, the gate dielectric stack, and the metal gate are all resolved.