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New applications in Atom Probe Tomography

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Recent innovations in atom probe tomography (APT), including laser-pulsed field evaporation and focused ion beam-based specimen preparation, have enabled a wide range of new applications [1]. This presentation provides a survey of those advances, including analysis of metal-oxide-semiconductor (MOS) transistor dopant distribution, geological dating of individual zircon crystals, quantum dot (QD) self-assembly in III-V multi-layer device structures, analysis of biological materials and nano-scale phase behavior of metallic glasses.

The structural variability in MOS transistors has substantially increased due to the reduction in lithographic feature size which occurs with each device generation. APT provides elemental mapping to correlate electrical performance with dopant concentration. For example in 65 nm-node n-MOS transistors, the channel dopant concentration, as imaged in Figure 1, has been positively correlated with the threshold voltage [2].

In geological materials, APT is now providing unique information for understanding the thermal history and mechanisms of mineral reaction, mineral exchange and radiation damage. In zircon crystals, precipitates containing Y and Pb are readily observed, as shown in Figure 2. The $^{207}Pb/^{206}Pb$ ratios for nm-scale domains ($<2\times10^4$ atoms Pb) average 0.17 ± 0.04 and 0.43 ± 0.14 for 2.4 and 4.0 billion year old zircons respectively [3], in agreement with SIMS ratios (0.1684 and 0.4269) derived from much larger analysis volumes (hundreds of μm^3).

QDs are self-assembled nanostructures that have unique electronic properties, determined by their physical structure. The high spatial resolution and chemical sensitivity of APT has made it possible to image QDs in InAs/GaAs multi layers [4]. QDs may form into a pillar arrangement when the strain field from one QD layer influences the growth of subsequent layers; however the apparent helical distribution shown in Figure 3 has never previously been reported.

On the biological side, APT has revealed oriented collagen fibers in the dentin of elephant tusks. Figure 4 is a mass spectrum from an apatite-derived calcium and phosphate species, additional inorganic substituents, and carbon/nitrogen containing fragments of organic macromolecules [5].

In metallic glass research, the glass forming ability of high Fe-content glasses for low-cost transformer applications is improved by small copper additions, as imaged in Figure 5. After thermal annealing for 30 minutes at 729 K, $Fe_{75.3}C_{7.0}Si_{3.3}B_{5.0}P_{8.7}Cu_{0.7}$ glasses phase separate into α-Fe precipitates, ultrafine spheroidal ε-Cu-rich precipitates, silicon-depleted $Fe_3(P,B,C)$, and Fe_3C volumes [6].

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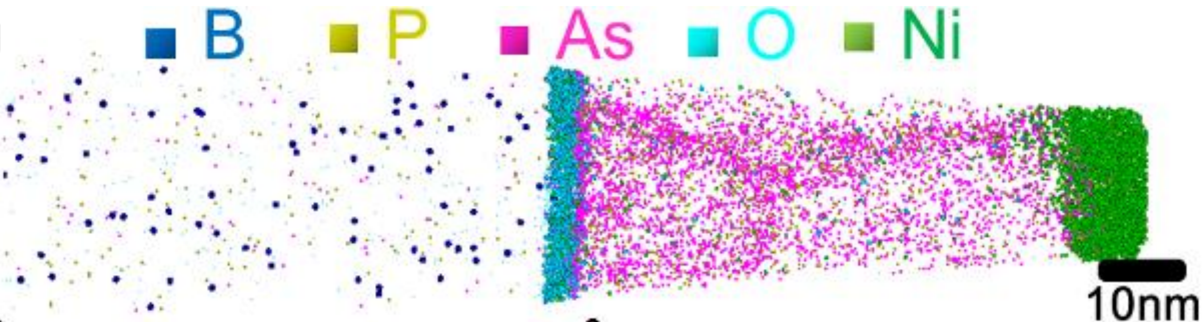

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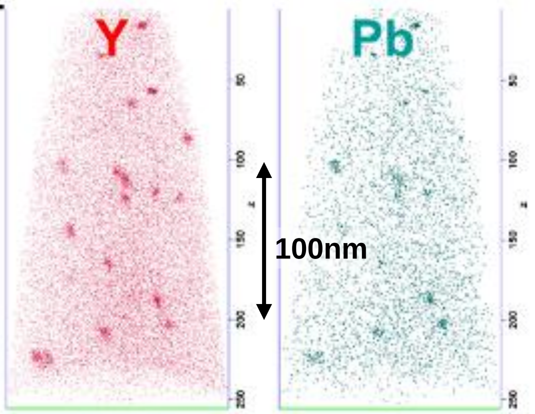

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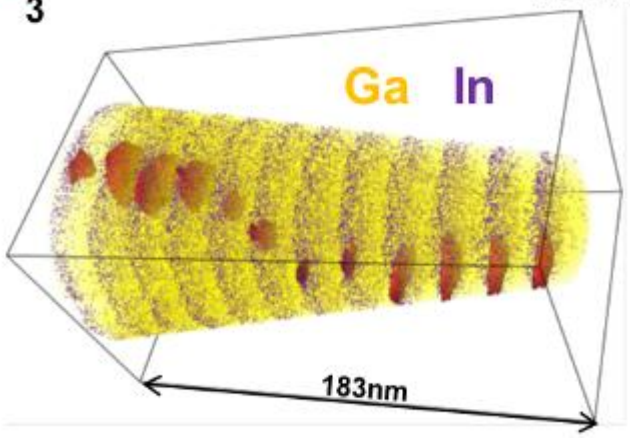

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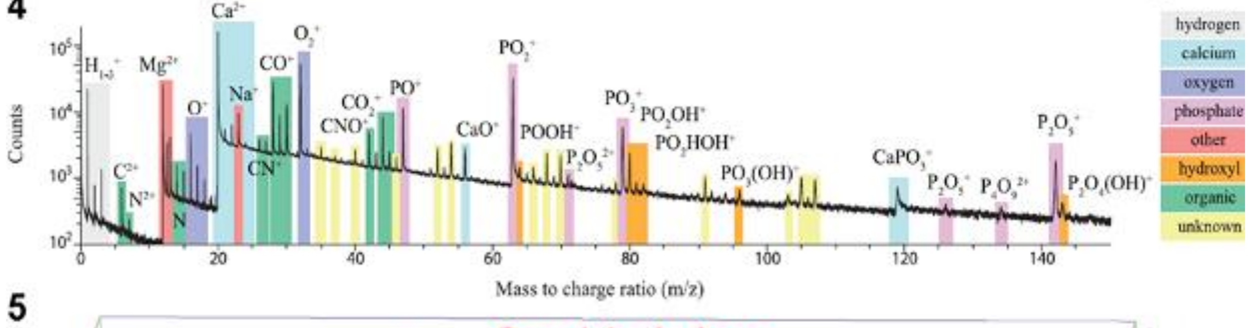

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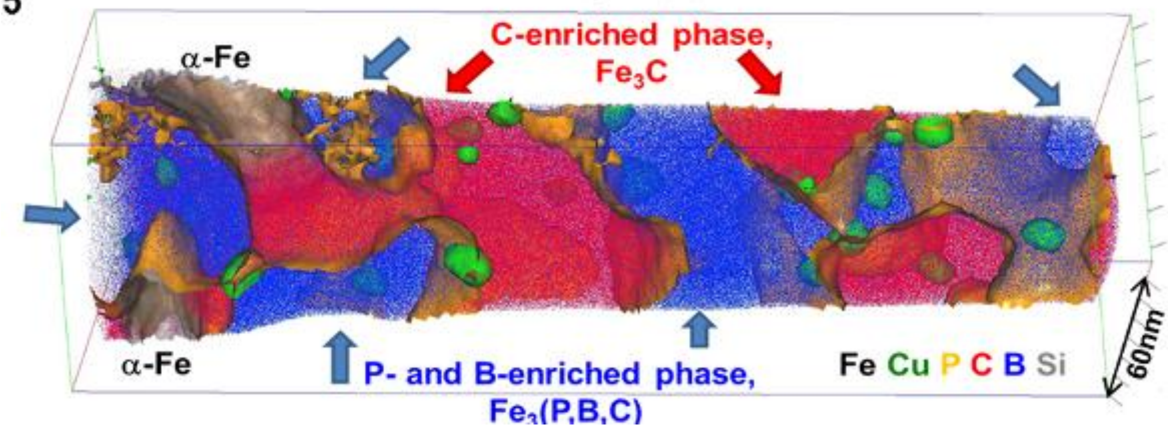

Figure 1. Atom map showing the dopant distribution in a MOS transistor.

Figure 2. Atom maps showing the Y and Pb distribution in a zircon mineral.

Figure 3. Atom map showing the arrangement of quantum dots in GaAs/$Ga_{1-x}In_xAs$ multi layers, iso-concentration surfaces for x > 15% are highlighted in red.

Figure 4. Mass spectrum from a nano-scale fibre within elephant tusk dentin.

Figure 5. Atom map with various composition surfaces highlighting the complex nano-structure observed in this particular metallic glass.