Advances in Atom Probe Tomography Applications

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Atom probe tomography (APT) has been used for over 45 years, “to determine the composition of small volumes of metals, semiconductors, and some ceramics” [1]. Although this statement is still true some 12 years after it was written, it does not adequately capture the recent expansion and maturation of APT into non-metallurgical applications. Historically, the low analysis success rate in non-metallurgical applications has limited the utility of the technique for such materials. However, recent innovations have been shown to provide substantially higher analysis yield on a wide variety of materials [2] enabling a range of meaningful new applications for APT such as quantum wells (QWs) and transistors.

Defects are known to have a significant effect on properties of InGaN multi-quantum-well devices [3]. The availability of low-pulse-energy laser pulsing has allowed for high-quality and low-noise imaging of a V defect centered above a threading dislocation (Fig. 1). This dislocation may change the electrical properties of the QWs due to the resultant segregation of magnesium dopants.

Characterization of complicated microelectronic structures, such as transistors, which contain a variety of materials and interfaces, has been severely limited because of analysis yield limitations. The recent introduction of UV laser pulsing, together with a highly focused, diffraction limited, laser spot, has provided improved yield allowing for regular analysis of real devices such as the n- and p-MOS transistors as shown in Fig. 2.

Applications also exist in the area of organic materials. In the chiton tooth, a polysaccharide-rich scaffold containing a number of proteins templates the formation of ultra-hard nano-crystalline iron oxide (magnetite). The nanoscale interfaces between the mineral phase and the buried organic scaffold are shown in Fig. 3, providing insight into the formation processes and the properties of the composite [4].

In addition to the above, several selected examples of APT applications advances will be presented in the current work, including light emitting diodes [5], microelectronics [6,7], solar cells [8,9], geology [11], and cosmology [10].

[1] MK Miller, Atom Probe Tomography: Analysis at the Atomic Level, Kluwer Academic /Plenum Publishers (2000) p.2.
[2] RM Ulfig *et al*, *Microscopy and Microanalysis* **17**(S2) (2011) p. 714.
[3] CJ Humphreys *et al*, *Springer Proc. Physics* **120** (2007) p. 3.
[4] LM Gordon and D. Joester, Nature **469** (2012) p. 194.
[5] TJ Prosa *et al*, *Applied Physics Letters* **98** (2011) p. 191903.
[6] DJ Larson *et al*, *Inst. Phys. Conf. Series* **326** (2011) p. 012030.
[7] H Takamizawa *et al*, Applied Physics Letters, **99** (2011) p. 133502
[8] PP Choi *et al*, *Microscopy Today* (2012) in press.
[9] DJ Larson *et al*, *Microscopy & Microanalysis* (2012), submitted.
[10] D Snoeyenbos *et al*, *22nd Goldschmid Conference on Geochemistry* (2012), submitted.
[11] P Heck *et al*, *43rd Lunar and Planetary Science Conference* (2012), submitted.

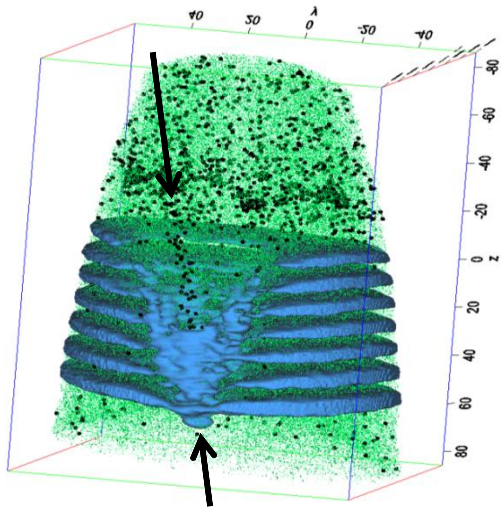

Figure 1. *InGaN multi-quantum well dislocation defect (arrowed) (green=gallium and nitrogen, black=magnesium atoms, blue=indium>0.25 at.% iso-composition surface).*

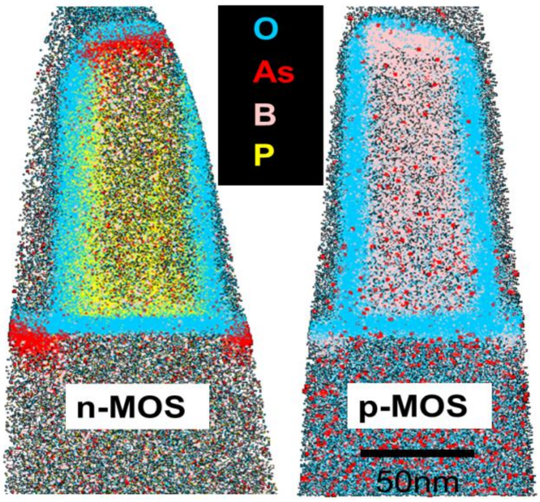

Figure 2. *Atom maps for a pair of transistors with oxide (blue) and dopants (red=arsenic, yellow=phosphorus) visible.*

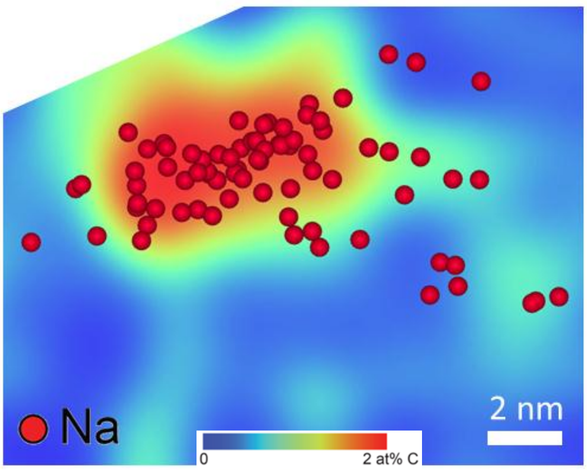

Figure 2. *Chiton tooth composite showing the sodium ion positions (red spheres) along with a carbon concentration map demonstrating the localization of sodium within the 5-10 nm organic fiber.*