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Impurity Measurements in Polycrystalline Materials with Atom Probe Tomography

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In semiconductor device characterization there are several potential applications for APT [1]. Few analysis methods can make measurements of impurity concentrations on three-dimensional structures such as FinFETs. Current applications in planar semiconductor devices include calibrated measurements of impurity concentrations in grain boundaries and in the adjacent silicon. As device volumes shrink the perimeter-to-area ratio increases and grain boundaries and interfaces become significant sites for removal of impurities from the silicon, increasing device resistance. Figure 1 illustrates the device structure with a 40 nm polysilicon gate surrounded by oxide layers on 5 sides.

To calibrate the small volume measurements, large planar structures are measured with both APT and SIMS. In Figure 3, both techniques show a segregation of arsenic to an oxidized interface or interface. APT has the resolution to characterize individual polysilicon grain boundaries very low in oxygen, and this also shows an arsenic segregation coefficient similar to the oxidized interfaces. TEM EELS analysis has been used to verify the atom probe values for the favorable case of high concentration arsenic impurities in silicon [2].

Boron shows a different grain boundary segregation mechanism, as it has a higher solubility in oxide and will accumulate there in proportion to the amount of silicon oxide. APT analysis of boron concentrations in a pFET polysilicon gate do not reveal segregation to the internal grain boundaries in the polysilicon, but accumulates at the silicon oxide interface that surrounds the device. Figure 4 is a boron profile horizontally across the gate length, from one silicon oxide interface to the one on the other side of the gate. Boron segregations to the oxide and increases with increasing silicon oxide thickness. Boron concentration calibration is more complex than the arsenic case as collection efficiencies in the laser assisted atom probe are less than 70% of expected and may vary with sample conditions [3]. Reference materials in a concentration range from 2E19 B/cm3 to 2E22 B/cm3 are used to determine an APT collection efficiency curve over concentrations and material substrates.

Calibrated impurity measurements in a uniform composition material can be straightforward with APT, however composition changes in the sample can effect the reconstruction accuracy and may exaggerate certain features. Ideally the APT sample will include a region representative of a larger planar structure fabricated at an adjacent region on the wafer that can be analyzed with complementary large area analytical techniques.

References

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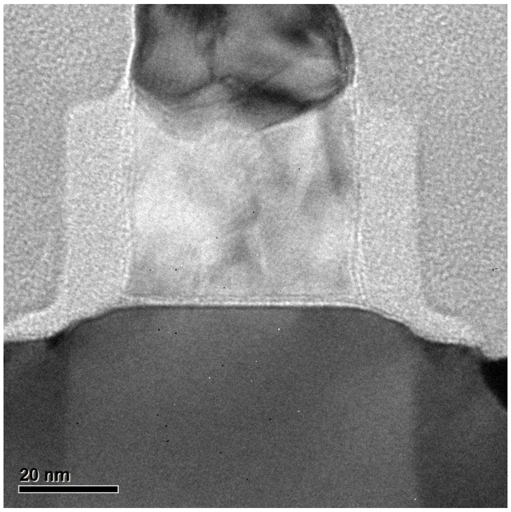


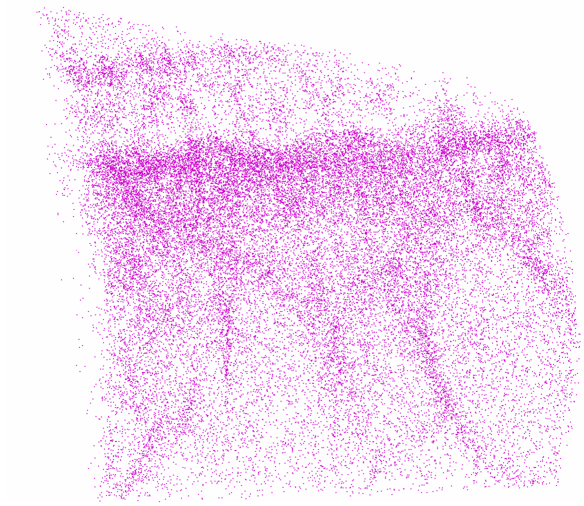
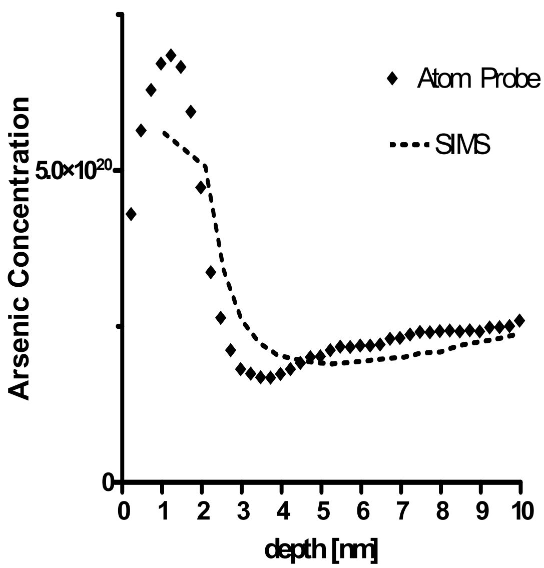


Fig. 1(left) TEM image of a NiSi-contacted polysilicon gate with silicon oxide layers on both sides and the bottom. Fig2 (right) atom probe reconstruction of a NiSi-contacted polysilicon, showing the arsenic impurity only, with segregation or higher density decorating the interface and the polysilicon grain boundaries.



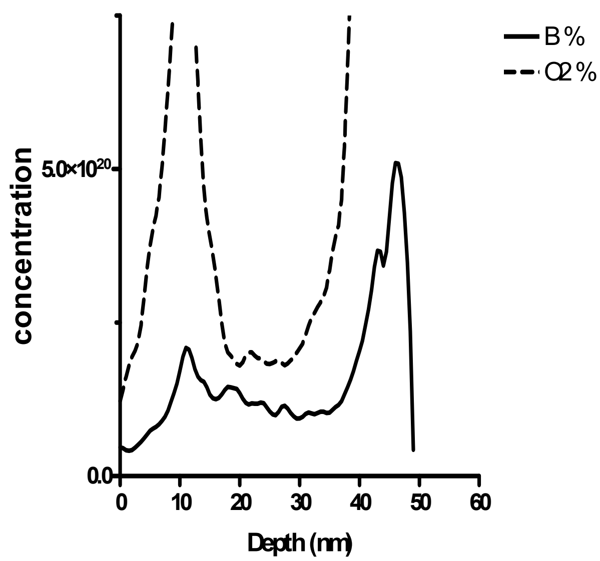


Fig 3. (left) Arsenic profiles from SIMS and APT on a large planar sample showing equivalent arsenic concentrations. The SIMS data is calibrated with a NIST-traceable SRM. APT collection of arsenic is as efficient as the silicon collection. Fig 4. (right) Boron line profile from APT of a boron polysilicon gate. Here the impurity segregates to the silicon oxide interface films, but not to the internal grain boundaries in the gate material.

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