Executive Summary

Title: Dopant Distributions in MOSFET Structures by Atom Probe Tomography

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Introduction

Atom probe tomography (APT) [1] is a powerful method for elemental mapping of materials in three-dimensional (3D) real space with atomic scale resolution. The APT produces 3D-images by controllably extracting atoms (ions) from a specimen with a very high electric field applied to the surface. The high electric field required (a few tens V/nm) is obtained by applying the high electric voltage to the specimen prepared in the form of a sharply pointed needle (tip radius close to 50 nm). The extracted ions are projected onto a position-sensitive detector for recording their location. The depth information is provided by the layer-by-layer evaporation of the specimen. Time-of-flight measurements on the ions provide their chemical identity as a mass-to-charge ratio of the ion.

The APT has characteristics of spatial resolution in three dimensions (~0.5 nm in plane vertical to depth direction, ~0.2nm in the depth), analytical sensitivity (a few tens of atomic ppm), and high detection efficiency (~50%), combined with its abilities to detect all elements.

The progress of selected topics over the past five years including your results

The APT was up to recently restricted to good conductors (metallic materials). Laser-assisted APT expands the application field of APT to not only metallic materials but also to materials with low electrical conductivity such as semiconductors. In addition, the development of a site-specific specimen preparation method using focused ion beam (FIB) technique has further broadened the application areas to include semiconductor devices. Now the APT can provide 3D mapping of the dopant atoms in specific region of MOSFET such as gate or channel [2-4]. The local electrode atom probe (LEAP) [1] developed by IMAGO Scientific Instruments (now Cameca) has increased the field of view to ~100 nm in diameter, which enables observation of the whole MOSFET structure, including poly-Si gate, gate oxide, channel, source/drain extension, and halo. For example, 3D elemental map of full sections of the n- and p-MOSFET from line-and-space pattern samples are shown in Fig. 1 [4]. To clarify the map of the dilute dopants, only 0.1% of the Si atoms are

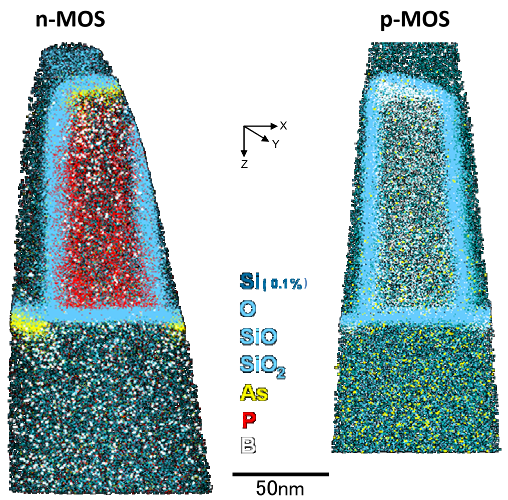

Fig. 1. 3D elemental maps of full sections of the n- and p-MOSFETs (line-and-space pattern samples) with both sides of source/drain extension regions.

plotted in Fig. 1. Elemental maps of O/SiO/SiO_2, As, P, and B in the slice 10nm thick, parallel to the X-Z plane of the n- and p-MOSFETs are shown in Fig. 2. In each region, dopant atoms are visible. (P atoms in the poly-Si gate, As atoms in the source/drain extension, and B atoms in the channel and the halo in the n-MOSFET. B atoms in the poly-Si gate and the source/drain extension, As atoms in the channel, and P atoms in the halo in the p-MOSFET.)

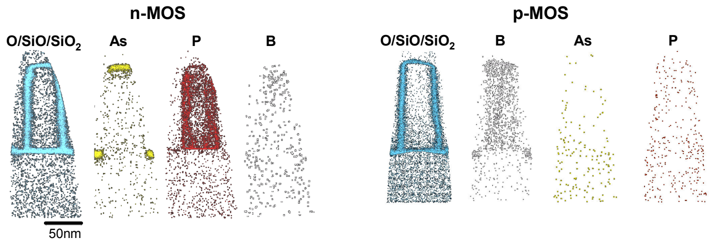

Fig. 2. Elemental maps of O/SiO/SiO_2, As, P, and B in the slice 10nm thick, parallel to the X-Z plane of the n- and p-MOSFETs shown in Fig. 1.

The difficult challenges and potential solutions for the next 10 – 15 years

As with many experimental techniques, the specimen preparation for the APT is the key to a successful experiment. Recent development of the specimen preparation techniques based on recent development of the FIB apparatus shows that the sharp needle atom probe specimens including the specific MOSFET which is investigated by other non-destructive measurement techniques can be fabricated with high accuracy. One example is the research on the correlation between electrical characteristics and dopant distribution observed by the APT.

Recently, contrary to the conventional belief that insulators are very difficult to be observed, demonstration of atom probe analysis of bulk insulating ceramics was reported by using an ultraviolet (UV) pulse laser [5]. This work shows that the application areas of the APT can be expanded to include insulating materials by employing UV laser-assisted field evaporation. The UV laser-assisted APT will enable to analyze the dopant distribution in the MOSFET specimens including side walls.

The combination of the UV laser-assisted APT and the specimen preparation techniques mentioned above will expand the APT analysis to various application areas in the semiconductor devices.

Experts and expertise with references

Atom probe tomography (APT): a technique for three-dimensional compositional imaging and analysis of materials at the atomic scale with high sensitivity [1].

Local electrode atom probe (LEAP): a type of instrument that performs APT with a large field of view and high data collection rates [1].

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