Atom Probe Tomography of Semiconducting Materials

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ABSTRACT

Metrology has been an important infrastructure enabling the exponential increase of device density and exponential decrease of device dimensions leading to a continued miniaturization in the microelectronics industry. Performance of such devices relies on the extreme sensitivity of the electronic characteristics to their nanoscale physical properties. Introduction of new exotic materials combined with innovative design to sustain these technological revolution present significant challenges to metrology. These high demands persuade the usage of new analytic techniques or improvements to the established methods to answer the questions regarding physical phenomenona at a scale which are approaching the resolution limits of most of the conventional metrological techniques. In the present contribution Atom probe tomography (APT) is utilized in quest for establishing a relatively new characterization technique for analyzing semiconducting materials for the quantitative compositional analysis with sub-nm resolution. In the ITRS roadmap the atom probe tomography (APT) is mentioned as one of the promising methods for the quantitative compositional analysis on the required scale. APT is based on the laser assisted field evaporation of atoms from a sharp needlelike specimen. A position sensitive detector provides the spatial information of the ion hits, while, the elemental information is obtained by measuring the time of flight of these ionized atoms. The APT analyses on dopant distribution in source/drain, contact materials, high-κ dielectrics and metal interconnects will be discussed.

Two-dimensional dopant profiling of advanced silicon transistors has become an important technique for obtaining requisite electrical characteristics. The resulting p-n-junctions exhibit high dopant concentration values very close to the surface limiting the junction depth. Knowledge of the spatial distribution of these dopants after annealing is critical for the performance of such devices. The APT study reveals temperature dependent dopant redistribution explaining respective electronic behavior. Another application of the APT is to characterize multilayer stacks such as Ti based silicides. Traditionally, SIMS has been utilized to provide information about the boron redistribution during the formation of Ti silicide. However, APT provides additional information about nano-scale TiB_2 precipitate formation at the TiN/TiSi interface. The achievement of the required reliability of on-chip interconnects is one of the key issues for current and future technology nodes.

The continued reduction of interconnect dimensions and the introduction of new materials and processes create new challenges for the long-term reliability of semiconductor chips. Electromigration is one of the major reliability issues in Cu interconnects therefore Al-alloyed Cu interconnects has been introduced. APT has been utilized to study out-diffusion of Al and to envisage the grain size increase after applying the requisite thermal budget. The performance of the capacitor in DRAM application is quite sensitive to the post deposition annealing. The effect of post deposition annealing on embedded thin film of a $Zr_{(1-x)}Al_xO_2$ based high-κ material is also studied using APT. The data obtained from APT is compared with other characterization techniques such as SIMS and TEM.

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