Mechanical Reliability of FIB-Fabricated Si-Related Materials

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By the recent rapid progress of semiconductor fabrication technology, micron/submicron-sized mechanical elements made of Si-related materials, such as single/poly crystalline Si (SCS/PCS), SiO_x, SiN_x, and SiC, can be precisely fabricated. These materials are commonly used for semiconductor devices and microelectromechanical systems (MEMS), which are typically shaped using photolithography and deep reactive ion etching technologies. As compared with them, focused ion beam (FIB) becomes more powerful tool because of directly fabricating 3D mechanical elements without photo masks. By controlling Ga ion beam energy, we can perform local Ga ion doping as well as conventional sputter processing. To date, many mechanical structures at the micro scale have been made with the FIB techniques. However, an affected layer is definitely made on the processed surface after the FIB fabrication. During the fabrication, due to Ga ions implantation, annihilation of specimen's crystal structure and residual of Ga clusters take place. These changes might negatively affect mechanical reliability of materials.

We specially developed an in-house mechanical reliability evaluation system for nanoscale materials. The designed and fabricated Si MEMS device consists of an electrostatic actuator and capacitive sensor, which are used for directly applying tensile loading to a nanoscale wire-shaped specimen and directly measuring tensile elongation and tensile force of the specimen, respectively. The device that can operate in a field-emission scanning electron microscope (FESEM) enables us to carry out in-situ FESEM observation during tensile testing. By using this test setup, we have evaluated tensile mechanical characteristics of FIB-fabricated nanowire specimens made of SCS, SiO_x, and SiC. The Young's modulus and fracture strength of these materials could be measured directly. It is well known that vacuum annealing is effective to remove Ga clusters and to improve an affected layer originating from FIB fabrication. In this presentation, vacuum annealing dependency on the Young's modulus of the affected layer is discussed. Transmission electron microscopy and energy dispersive X-ray analysis suggest that a change of the affected layer during annealing has provided a change of mechanical reliability of these materials.