東京大学グローバルCOEプログラム　機械システム・イノベーション国際拠点

東京大学 THE UNIVERSITY OF TOKYO

GMSI Global Center of Excellence for Mechanical Systems Innovation

第76回　GMSI公開セミナー

Strain induced large plasticity of nanowires from intrinsic brittle materials

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日時：2011年2月24日（木）15:00 -16:20
会場：東京大学工学部9号館 1F 大会議室

要旨

Bulk materials of Si-, SiC, and SiO_2 are all intrinsic brittle materials. But we observed a brittle to ductile transition from nanowires of these materials by using the self-developed techniques for tensile or bending single nanowires with in-situ atomic resolution transmission electron microscopy.

The plasticity developed as external stress and a unusual large plasticity appeared via a phase transition from crystalline to amorphous under direct atomic resolution observation. Further, all of these amorphous phases (amorphous Si, SiC and SiO_2) behaved unusual large strain ductility up to 200% in elongation at room temperature. At or near room temperature, oxide glasses are known to be brittle and fracture upon any mechanical deformation for shape change. As structural and functional members, oxide glasses (typically SiO_2) are also widely used in electronic devices and microelectromechanical systems, fabricated in the forms of thin films, wires, pillars, particles and cantilever beams. Here we demonstrate that with moderate exposure to electron beam, not only dramatic shape changes in compression for particles but also superplastic tensile elongation larger than 200% at strain rates above 10^{-4}/s for nanowires can be achieved for amorphous silica. Comparing the load-displacement responses without and with the e-beam revealed that the flow stresses were reduced dramatically (up to 4 times). This electron-beam-assisted superplastic deformability in the absence of significant temperature rise is useful for processing amorphous silica and other oxide glasses for their applications in nanotechnology.

The dynamic atomic mechanisms directly revealed by these in situ tensile or bending nanowire experiments show that the phase transitions only appeared at the most strained regions of the bent/tensile nanowires. Our experiments also revealed that low strain rate is critical for the brittle to ductile transition via crystalline to amorphous transformation. This indicates that these observed strain-induced ductility are diffusion controlled and is more pronounced at nanoscale in these nanowires.

Through these studies, we thus provide new routs and examples to study dynamic mechanical properties and their corresponding microstructure evolutions of one- dimensional nanomaterials (crystalline vs. amorphous) under direct atomic scale.

主催：　東京大学グローバルCOEプログラム「機械システム・イノベーション国際拠点」

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