Correlation between nanoscale mechanical strain and electron transport in individual InAs nanowires

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Strain engineering of the electrical and optical properties of semiconductor nanomaterials is an effective way to tailor the performance of nanowire-based devices such as high-speed transistors and sensors [1]. However, the direct characterization of the mechanical and electrical properties of nanomaterials, in particular, the correlation between them is still a challenge. In this work, we directly investigate the intrinsic mechanical and electromechanical properties of individual InAs nanowires under uniaxial tensile stress using in situ transmission electron microscopy.

TEM measurements were carried out using the TEAM 1 microscope [2]. Simultaneous stress and current-voltage (I-V) measurements were enabled by an electrical push-to-pull (EPTP) device in a Hysitron PI95 nanoindentation TEM holder. Nanoscale lattice strain mapping within the nanowire was performed using scanning transmission electron microscopy (STEM) combined with nanobeam electron diffraction (NBED) [3]. NBED diffraction patterns were acquired using a Gatan K2 direct detection camera. Direct and quantitative stress, strain and electrical transport measurements were carried out on individual InAs nanowires. The results showed that the resistivity of the InAs nanowires decreased continuously with increasing tensile stress. The piezoresistance coefficient of the nanowire was found to be about two orders of magnitude larger than that of bulk InAs. This large piezoresistance effect is partly due to the small Young's modulus of the InAs nanowire (~11 GPa) but band gap narrowing of InAs is considered to be the main reason for the resistivity change. Moreover, despite apparent elastic deformation of the nanowire, significant inhomogeneous strain distribution within the nanowire under stress was unveiled by STEM-NBED strain mapping at different stress levels. The inhomogeneous strain distribution at nanometer scale can increase the resistivity of the nanowire by enhancing electron scattering. The findings demonstrate unique mechanical and electromechanical properties of the nanoscale InAs wires and provide new insights of the correlation between mechanical strain and electrical transport properties in free-standing nanostructures.

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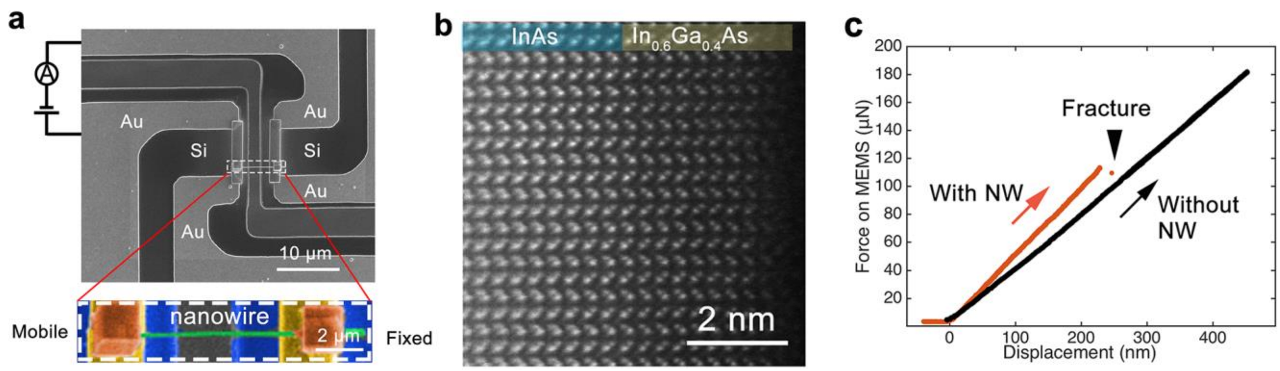

Figure 1. (a) The EPTP device used in the study. The nanowire mounted on the device is also shown. (b) A STEM ADF image showing the core-shell structure of the InAs nanowire. The shell was used to reduce the surface effects. (c) Load-displacement curves of EPTP device with and without nanowire mounted on it.

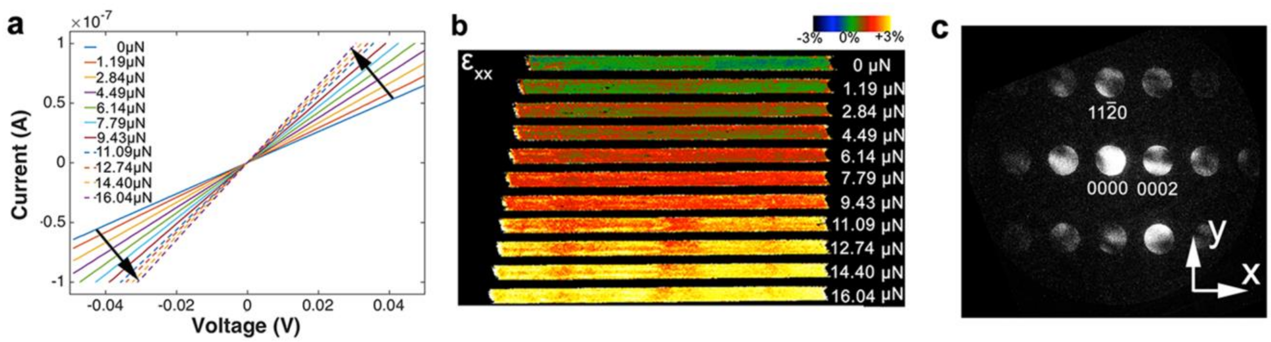

Figure 2. (a) I-V characteristics of an InAs nanowire under different stress levels measured in TEM. (b) Corresponding STEM-NBED strain maps along the nanowire length direction as a function of tensile force applied on the nanowire. (c) A typical NBED pattern used for strain calculation. X direction is along the nanowire length direction.