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A Study on the Modulation of the Electrical Transport by Mechanical Straining of an Individual Titanium di Oxide Nanotube

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The semiconducting behavior and large surface area of 1D titania (tubes, wires, fibers, and rods) have drawn considerable attention for potential application in solar cells [1]. However, the widespread technological use of titania is impaired by its wide band gap (3.2 eV), which requires ultraviolet (UV) irradiation for photocatalytic activation [2]. Traditionally, doping of the titania has been the approach taken for its band-gap engineering [3]. Here, we propose an alternate way to enhance the electrical conductivity of TiO2 using mechanical straining. A recent theoretical work on boron nitride nanotubes (BNNTs) under flattening deformation [4] has predicted the unique possibility of band gap tuning in a 2-5 eV range. This theoretical prediction on BNNT's has been experimentally verified by Bai et al [5] by a series of in situ scanning tunneling microscopy (STM) experiments in a transmission electron microscope (TEM). The crystal structure of the TiO_2 phase affects the photoelectrical current in solar cells [6] and anatase based solar cells are expected to have the highest conversion efficiency [7]. In view of this, we report here, the effect of mechanical deformation on an electrical response of an individual anatase TiO2 nanotube. The in situ electrical measurements were conducted in a high resolution TEM using a STM-TEM holder from "Nanofactory Instruments". The holder consists of a STM equipped TEM sample holder, a controller and a PC with Nanofactory's data acquisition software. All the measurements were carried out on a single tilt STM-TEM holder in a JEM 4000FX TEM, operated at 200 keV.

A series of measured I-V curves at various stages of bending deformation are respectively shown in Fig. 1. The TiO_2 nanotube in contact with the STM tip (curve "a") shows asemiconducting behavior where electrical currents up to 10 nA can be detected under bias voltages up to 25 V. This is due to the intrinsic semiconducting behavior of the TiO_2 nanotube under the applied voltage. As we deform the nanotube by delicate driving of the tungsten tip with the nanotube against the STM tip, current upto 18 nA can be observed (curve "b") for the deformed state. With the increase in deformation, (the nanotube making a large bending curvature), the current is dramatically increased to 25 nA with start off voltage of 7.5V bias. In a large bias regime, the I-V curve can be differentiated to obtain a resistance R of the nanobelt (R ~ dV/dI,). We found that for this deformed state, the resistance of the nanotube was decreased to 0.34 GΩ from ~ 0.86GΩ in the state corresponding to the nanotube just in contact with the STM tip. Based on metal- semiconductor-metal model, the resistance, resistivity, carrier concentration and carrier mobility were extracted. The current-voltage characteristics of each individual TiO_2 nanotube revealed that under bending deformation within the elastic limit, the electrical conductivity of a TiO_2 nanotube can be enhanced. Analysis based on a metal- semiconductor-metal model suggests that in-shell, surface defect-driven conduction modes are responsible for the modulated semiconducting behaviors.

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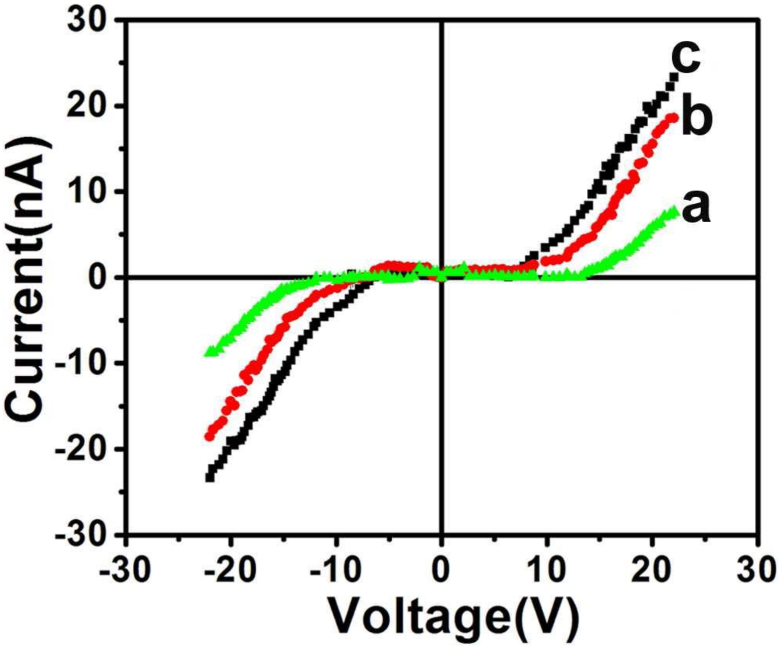

Fig. 1: Series of measured I-V curves at various stages of bending deformation