Ambipolar conduction and high mobility InAs nanowire transistors by surface modification

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Compared with 3-D and 2-D materials, 1-D nanowires have huge surface-to-volume ratio, which implies that surfaces of nanowires may have a large impact on nanowire device performance. Studies of nanowire surface effects can help to explain studies from various groups and will lay a foundation for many possible applications of nanowire devices, including sensors. InAs is a direct, small bandgap material (0.354 eV), which is potentially a good electronic and IR optoelectronic device candidate. However, up to now all the reported InAs nanowire transistors show only n channel conduction, with high mobility reported from nanowires with diameters of 50 nm or even larger. The origin of these phenomena is probably from the large amount of surface states which pin the Fermi level in the conduction band at the InAs nanowire surface.

We have demonstrated p channel conduction and high mobility in thinner (20 nm) InAs nanowires grown by a solution-liquid-solid (SLS) method and passivated with either ligands used in growth or 1-octadecanethiol (ODT). The initial substrate for single-nanowire field effect transistor fabrication consists of a heavily doped p-type Si substrate, which serves as a back gate, with a 40 nm thermal SiO_2 gate insulator and metal alignment marks for subsequent electron beam lithography (EBL). A suspension of the InAs nanowires in isopropanol and toluene is dropped onto the wafer and the solvent is allowed to evaporate. SEM imaging is performed to locate the nanowires relative to the alignment marks. EBL using polymethyl methacrylate (PMMA) resist is used to define openings for the source and drain contacts. The source/drain contacts were formed by electron beam evaporation of Ni and Au, followed by lift-off patterning. Figure 1 shows p channel and n channel conduction for 20 nm Cd doped InAs nanowires and only n channel conduction after O_2 plasma treatment [1]. Figure 2 shows the mobility improvement of 20 nm InAs nanowire transistor after ODT passivation (from 740.3 cm^2/Vs to 1234.8 cm^2/Vs). The mobility of our 20 nm InAs nanowires is comparable with the mobility from reported 50 nm nanowires, which is a large improvement considering the 40 nm electron de Broglie wavelength of InAs. Electrospray ionization (ESI) mass spectroscopy and X-ray photoelectron spectroscopy (XPS) confirm that there are hexadecylamine (HDA) and tetradecylphosphonic acid (TDPA) molecules on Cd doped InAs nanowires. XPS studies of ODT-treated nanowires also confirm that the ODT molecules are bond to InAs nanowires through In-S bonds (as shown in Fig. 3a and 3b). It is believed that these molecules help to passivate the surface states on the InAs nanowires so that Fermi level at the nanowire surface is not pinned in the conduction band. This is the reason why we can observe p channel conduction from both Cd doped InAs nanowires and ODT passivated InAs nanowires. Also the reduction of surface states on the nanowire surface means less scattering of the body electrons from the surface states, which may explain the mobility improvement after ODT passivation.

1. Q. Hang, F. Wang, W. E. Buhro and D. B. Janes, ‘Ambipolar conduction in transistors using solution grown nanowires with Cd doping’, *Appl. Phys. Lett*., in print.

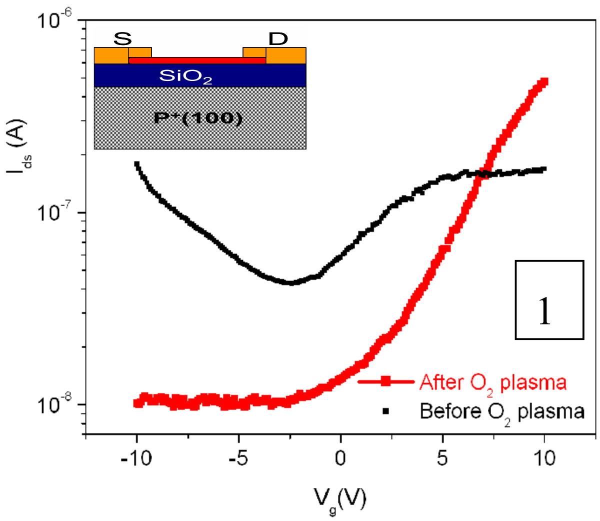

Fig. 1 Measured transfer curves for Cd doped InAs nanowire transistors. The black curve shows the ambipolar conduction in the as fabricated device, the red curve shows n channel conduction of the device after O_2 plasma treatment. The inset shows the cross-section of representative nanowire devices.

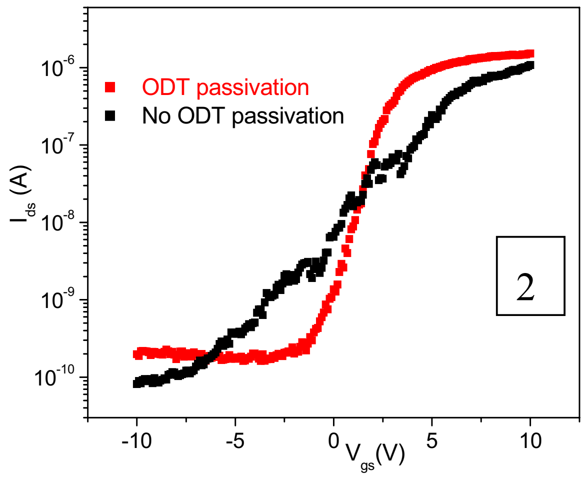

Fig. 2 Transfer characteristics at V_{ds}=100 mV for 20 nm InAs nanowire field effect transistor before and after ODT molecule passivaiton.

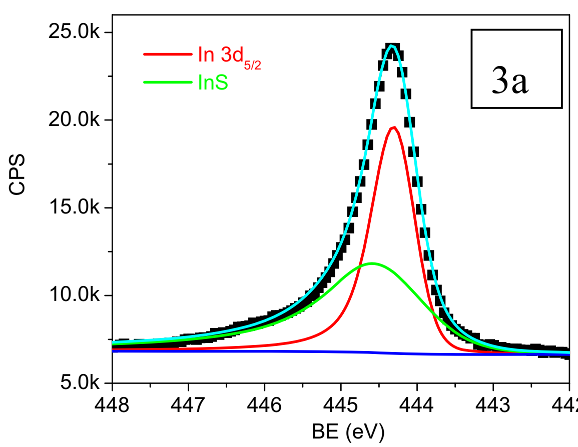

Fig. 3a XPS of InAs nanowires after ODT passivation showing InS component as well as InAs component.

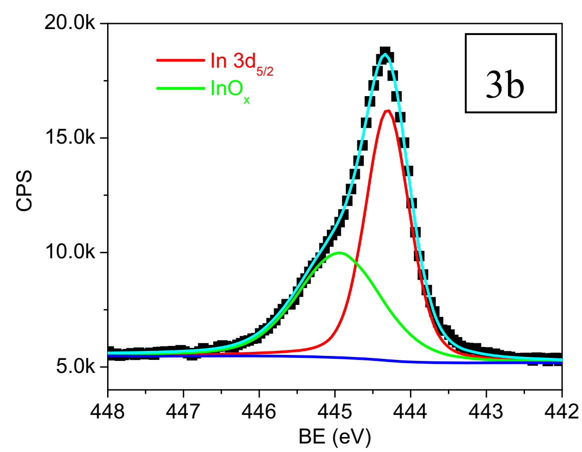

Fig. 3b XPS of InAs nanowires without ODT passivation showing InO_x component as well as InAs component.