Interconnection and characterization of single InAs/InP nanowires

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The advancement in the semiconductor nanowires growth allowed the fabrication of a variety of heterostructured nanosystems, such as the fabrication of quantum dots (QDs) in nanowires (NWs) that are widely impacting research on the realization of a great variety of innovative devices for nanoelectronics, optoelectronics and metrology. Moreover nanostructured NWs with QDs are considered as promising systems for implementation of spin 'qubits' in proposed schemes for quantum computation [1] . In this work we electrical characterized InAs/InP nanowires with a 45±10 nm diameter and a length of about 2 µm, including a quantum dot (QD) region defined as a 20 nm long InAs island sandwiched between two epitaxial 5 nm-thick InP layers (Figure 1a). The difference in band gap between InAs and InP was used to form tunnel barriers, restricting the motion of electrons to very small 'box-like' volumes. These nanostructured nanowires allowed the realization of a single-electron transistor (SET) with enhanced electrometer performance, due to (i) the very high quality of the heterostructure interfaces, (ii) the possibility to control and engineer the electronic structure and properties of the QDs, (iii) the tunability of the electronic spectrum of an InAs/InP NW QD by applying a transverse electric field enhancing the SET working temperatures up to beyond 50 K from the usual ∼10 K offered by this technology [2].
However the electrical interconnection of individual nanowires for large-scale integration in macroscopic circuits is still a difficult task. So far, different techniques [3, 4] such as electron beam lithography (EBL) and ion beam lithography (FIB) have been employed for patterning beyond the intrinsic physical limitations of optical lithography. However, none of these methods equals the advantages of photolithography for low cost and high throughput.
In this respect we employed a rapid, reliable and reproducible approach based on direct-write laser lithography to electrically interconnect individual semiconductor nanowires, with very high spatial resolution (around 150 nm) and without the need of expensive and laborious systems (EBL, FIB).
First of all, the InA/InP nanowires were dispersed onto an oxidized (SiO_2 thickness 300 nm) silicon substrate by drop casting and subsequent drying at room temperature. Then, a positive photoresist was spin coated over the nanowires and, after the selection of a single nanowire by imaging via an optical micro-camera, a one-step exposure was performed to define both the source and drain nanocontacts and their micrometer pads in a very short time (Figure 1b). The direct writing was performed by means of a DWL 66FS laser lithography system provided of a 405 nm laser diode.
After the laser exposure the sample was developed and subsequently, contacts were fabricated by thermal evaporation of Cr/Au (10/95 nm) and lift-off process. A passivation step is necessary to be performed prior to metal evaporation in order to remove the native oxide from the NW contact areas. This was achieved by dipping the sample into a highly diluted $(NH_4)_2S_x$ water solution heated at 44°C for an optimized time of 115-130 s.

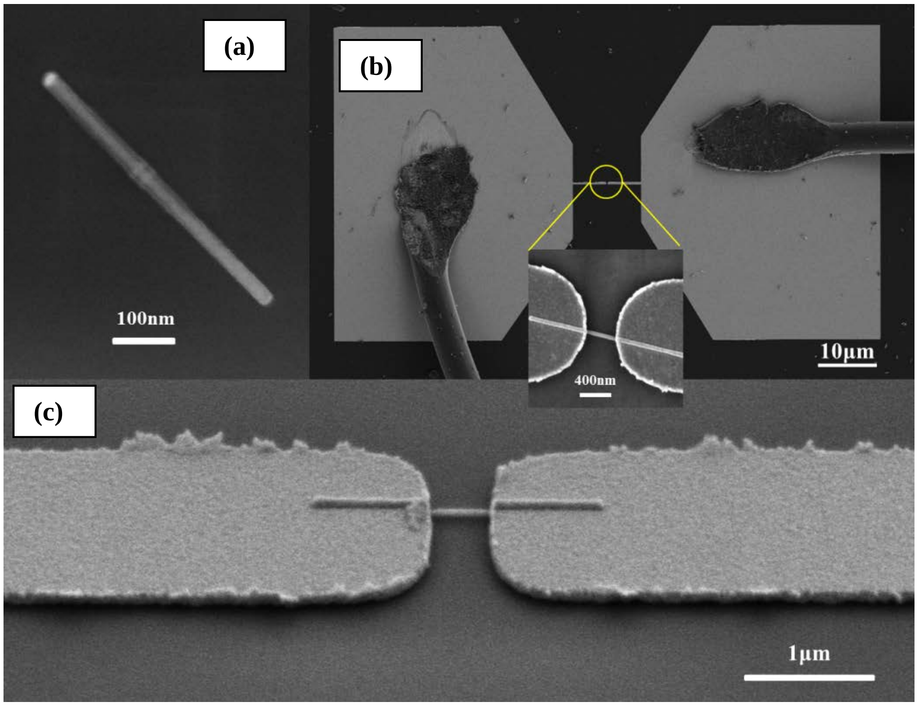

Figure 1. *SEM images of* ***(a)*** *45±10 nm diameter InAs/InP nanowires with a QD region defined as a 20 nm long InAs island sandwiched between two epitaxial 5 nm-thick InP barriers;* ***(b)*** *contact pads and nanoelectrodes;* ***(c)*** *a typical InAs/InP heterostructured nanowire deposited on a SiO2/Si substrate and contacted by two Au/Cr electrodes.*

The electrical measurements were performed inside a cryogen free superconducting magnet with a variable temperature insert (VTI). Figure 2 shows the temperature dependence of the I-V characteristics from a typical nanowire junction. The resistance increases significantly with decreasing the temperature up to reach values in the MΩ range at the minimal temperature (2.5K). At room temperature the resistance is around 200 kΩ with a current-voltage characteristics which remain linear down to about 70 K. Then it changes to a typical sigmoidal shape with a non-conducting region at low bias and clear steps which can be ascribed to single electron tunneling events in the QD island (inset of figure 2, blue line). This process is more evident in the measured dI/dV spectrum which exhibits clear peaks (inset of Figure 2, red line).

In conclusion, we report on an electric characterization of a single InAs/InP nanowire based quantum dot rapidly interconnected by using a method based on direct laser writing without the need of expansive and time-consuming systems. Further plans are related to the fabrication of planar gates using the same technique in order to explore the response of our SET device by varying the transverse electric field applied.

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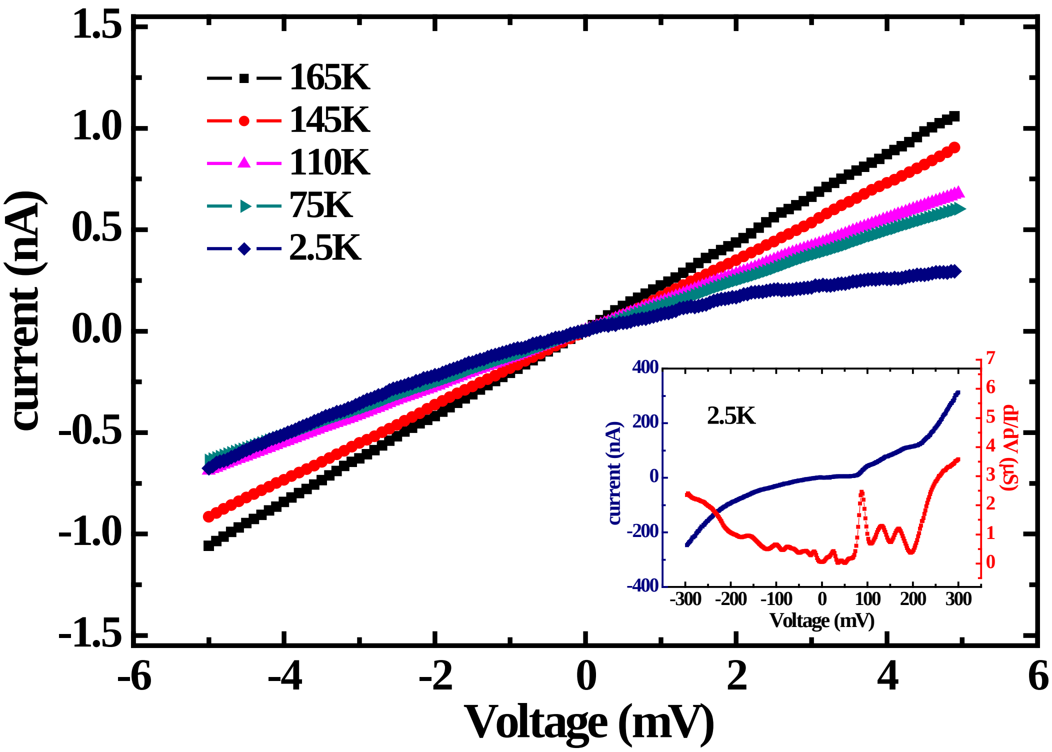

Figure 2. *I-V characteristics and temperature dependence of a nanowire junction. The inset shows the I–V curve (blue line) and the measured dI/dV spectrum (red line) at low temperature (2.5 K).*