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Electrical transport and AFM microscopy on V_2O_{5-X}–polyaniline nanorods

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Abstract

With the aim of obtaining nanodevices as rectifiers or transistors, we obtained (V_2O_{5-X}–polyaniline) nanorods, as it has been previously described, where the polymerisation of aniline is favoured by reduction of V_2O_5. We measured the $I(V)$ characteristics and electrical resistance in the temperature range from RT to 140 K, on nanorods (< 20-nm thick and 300–800-nm long) deposited on a sample holder, where six inter-digitated metallic contacts were previously made by lithography. Using AFM microscopy in tapping mode, we examined the samples and selected some that contacted either two or four wires. In both cases, the $I(V)$ characteristics were clearly nonlinear and symmetrical with respect to both axes. Electrical conductivity values at RT are near 10^{-1} (S/cm). After that, a rectifying effect could be obtained if we were able to displace the characteristics on the axis. When the temperature was lowered below 140 K, electrical resistivity increased abruptly.

Keywords: Vanadium oxide–polyaniline nanorods; Conductivity

1. Introduction

Recently, there has been a great interest on new types of nanoscale devices based on nanowires or nanotubes. Especially carbon nanotubes are currently studied in great detail due to their remarkable electrical transport properties [1]. Model nanodevices such as field-effect transistors from individual nanotubes have been reported [2,3]. However, the reproducible implementation of nanotubes into electrical devices is complicated because tubes exist in different chiralities and diameters [4]. Moreover, since the raw material consists of a dense network of closely connected nanotubes, individual tubes are often obtained by ultrasonic agitation, which might introduce defects into the tubes. Although some control over tube diameter has been achieved during synthesis on patterned substrates [5], no procedure is available to obtain pure tubes of one specific type. Therefore, nanowires that are more homogeneous in structure are of considerable interest. Possible alternatives are nanotubes of WS_2 [6] silicon nanowires [7], nucleic acid strands [8] or vanadium pentoxide nanotubs [9].

2. Experimental results

Here we present the electrical properties of individual nanowires composed of vanadium pentoxide and polyaniline, V_2O_{5-X}–Pa. These heterofibres have a ribbon-like structure similar to the vanadium oxide fibres [10], both in shape and dimensions: they are 1.5 nm in height, 10–40 nm in width and up to 300–800 nm in length.

The detailed structure of V_2O_{5-X}–Pa fibres was searched using the atomic force microscope (AFM) in tapping mode, Fig. 1, and the results show a measured width of 20–40 nm. Samples for electrical transport measurements were prepared by a procedure similar to the one employed for deposition of V_2O_5 onto bare SiO_2 surfaces, described in [10]: individual fibres were deposited on aminosilanised substrates, wherein six interdigitated electrodes had previously been deposited using adsorption times of several minutes and V_2O_5 sol concentration of 10^{-2} M. After deposition the whole structure was immersed in Aniline /Acetonitril solution for 15 h, allowing the aniline to polymerize on the surface of V_2O_5 fibres.

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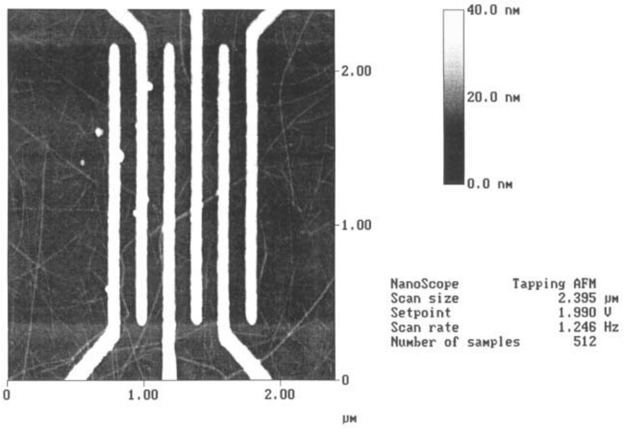

Fig. 1. Representative scanning AFM image of individual V_2O_{5-X}–Pa fibres adsorbed on an aminosilanised SiO_2 surface.

We performed electrical measurements on different fibres, with either two or four electrical contacts, see Fig. 2.

Nonlinear symmetric $I(V)$ characteristics were obtained at room temperature and a contact resistance as big as a few GΩ was deduced by the comparison between two- and four-probe measurements. The effective cross-section of the samples is known only at approximately 1.5×20 nm, so we can estimate the conductivity value $0.10 < \sigma < 0.25$ (S/cm) depending on the samples. This conductivity is much higher compared to vapour deposited V_2O_5 ($\sigma = 10^{-6}$ (S/cm) [11]), rf-sputtered ($10^{-4} < \sigma < 10^{-3}$ (S/cm) [12]) and bulk samples of the hybrid V_2O_5–Pa synthesised by direct reaction of aniline with V_2O_5 hydrogels ($10^{-2} < \sigma < 10^{-6}$ (S/cm) [13]).

In order to evaluate the effect of polyaniline on electrical conductivity, we can compare with electrical measurements on V_2O_5 fibres [10], in which the conductivity has been measured using two different kinds of electrodes: measurements on similar samples to V_2O_{5-X}–Pa, wherein the individual fibres are deposited on prefabricated electrodes show low conductivity values ($10^{-4} < \sigma < 10^{-3}$ (S/cm)), but when AuPd electrodes were lithographically deposited over V_2O_5 fibres, the conductivity value increased to about 0.5 (S/cm), higher than in the present case with V_2O_{5-X}–Pa fibres. This means that, although the polyaniline improves electrical conductivity in three orders of magnitude, the conductivity is lower than when AuPd electrodes are deposited on top of V_2O_5 fibres. The nonlinearity of $I(V)$ characteristics is evident in both cases, but it is more striking on fibres with polyaniline. This effect could be used to construct a field-effect transistor [14].

We measured the resistance $R(T)$, from room temperature down to 140 K, below which the resistance is too big to be measured (> 100 GΩ). Due to this small range in temperatures, it is not possible to extract any information on the conductivity mechanism from the shape of $R(T)$ dependence.

3. Discussion

It is generally assumed that the electrical conductivity mechanism in V_2O_5 is via hopping between V^{5+} and V^{4+} impurity centres. The amount of V^{4+} can reach up to 10% of the total amount of vanadium atoms, depending on the preparation method. In our case the polyaniline would increase the possible amount of V^{4+}, since the lack of positive charge of vanadium ions can be compensated by holes in the polyaniline. In order to analyse the effect of polyaniline, we compare the results on individual V_2O_{5-X}–Pa fibres with electrical measurements on individual V_2O_5 fibres [12]: for similar fibres and electrodes, the electrical conductivity value is higher on V_2O_5–Pa fibres (0.1 S/cm), but it is still higher on V_2O_5 fibres with AuPd electrodes deposited on top (0.1–1 S/cm). In a further work, we could make electrical measurements on V_2O_{5-X}–Pa fibres with electrodes deposited on top. Nonlinear symmetric characteristics $I(V)$ are shown, more pronounced on fibres with polyaniline. When the temperature is lowered the resistance increases sharply, being as high as 100 GΩ at 140 K.

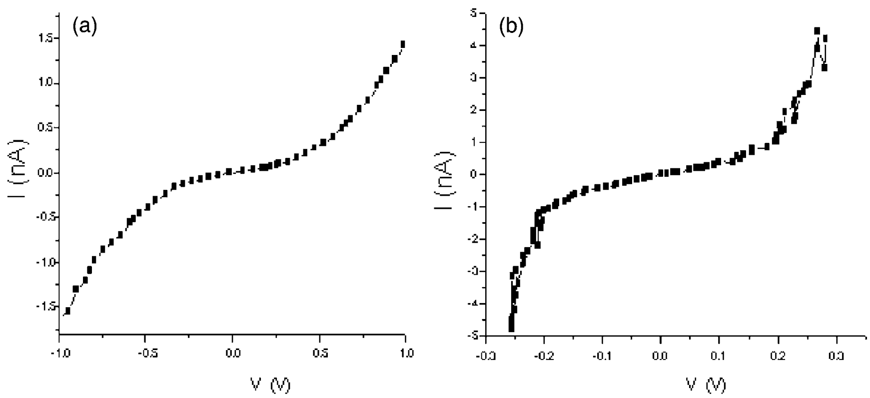

Fig. 2. $I(V)$ characteristics at room temperature: (a) two-probe and (b) four-probe measurement.

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