Supplementary material (ESI) for Nanoscale

SUPPLEMENTARY INFORMATION

Fig. S1 summarises the results of thermolysis of Pd hexadecanethiolate in air. Thermogravimetric data (Fig. S1a) showed weight losses of around 72% weight loss at 250 ºC corresponding to thiol desorption and 12% at 150 ºC due to solvent evaporation. The electrical resistivity measurement on the thermolysed film as function of temperature is shown in Fig. S2b. The resistivity value is found to be a similar order of magnitude to the bulk metal. X-ray diffraction data collected on the thermolysed film confirmed the formation of Pd metal (see Fig. S1c). The diffraction peaks at 2.24, 1.94 and 1.37 Å correspond to (111), (200) and (220) respectively (JCPDS- 461043). Formation of small, interconnected Pd nanoparticles on thermolysis is evidenced by SEM image shown in Fig. S1d. The nanoparticles size ranges from 20 to 40 nm. EDS analysis on the thermolysed film revealed the carbon content is less than 10%.

Soldering action was first examined by placing a 7 μm conducting carbon fibre across Au gap electrodes (1.1 mm) on a glass plate using forceps (see Fig. S2a). I-V behavior prior to thermolysis (Fig. S2b) is non-linear with a typical resistance of ~ 0.5 MΩ at 1V. Obviously, the contact between the fibre and the electrode metal is non-metallic. The circuit showed negligible current when both ends of the fibre were deposited with drops of Pd precursor in toluene (Fig. S2c). The fibre lost its contact with the electrodes as the insulating Pd precursor crept beneath the fibre. The substrate was then thermolysed at 250 ºC for 10 minutes resulting in highly conducting metallic Pd. I-V behavior following thermolysis was linear and the resistance measured was 200 Ω (Fig. S2d). Although this experiment could not directly provide an estimate for the contact resistance, it clearly demonstrated that the Pd solder enabled contact was ohmic.

In another instance, conducting Ag epoxy paint (Pelco Ltd.) was applied to a fibre-electrode contact, and the resistance of the circuit was found to be 15 kΩ. The high value of resistance obtained in this case may be due to the colloidal nature of the Ag paint containing organic stabilisers.

Conversion of Pd precursor to Pd by high applied electrical field was attempted as an alternative to thermolysis (Fig. S3). For this purpose, a carbon fibre was placed between Au contact pads spin-coated with the Pd precursor (instead of pouring drops at both the ends). Initially, there was hardly any current in the circuit (curve 1 in Fig. S3a). An external bias of 30 V was applied across the Au electrodes for a few seconds and then the I-V measurement was performed with a ±1 V sweep (curve 2). The I-V data became linear with a resistance value of 4 kΩ. This observation is interesting, as in this case, the soldering action was realised electrically instead of through sustained heating of the entire sample. Pd nanocrystal aggregates which resulted from the electrical breakdown of the precursor were seen below the fibre binding to the electrode surface (see Fig. S3b and the inset). The resistance observed in this case is definitely higher compared to the value (200 Ω) obtained by thermolysing the precursor (see Fig. S2d). This must be primarily due to the presence of carbon impurities along with the metal solder as the duration of electrical activation may not have been sufficient to liberate thiol chains. These preliminary investigations on carbon fibre based circuitry provided a micro-scale circuit with carbon as an active element which could be compared to nano-scale CNT circuits. More examples of self assembly of CNT across the gap electrodes are shown in Fig. S4.

FIGURE CAPTIONS

Figure S1. Metallisation of Pd hexadecanethiolate (a) TGA plot showing the decomposition of Pd hexadecanethiolate in air. (b) Four probe electrical resistivity as a function of temperature, (c) X-ray diffraction pattern and (d) SEM image showing the morphology and EDS analysis of thermolysed Pd film.

Figure S2. (a) Optical image showing a carbon fibre soldered on a Au electrode using Pd hexadecanethiolate. I-V characteristics of the carbon fibre (b) as-placed on the Au electrode, (c) after adding Pd precursor and (d) after thermolysis at 250 ºC for 10 minutes.

Figure S3. (a) SEM image showing a carbon fibre across the Au gap electrode and inset showing soldering material holding the carbon fibre after application of external bias. (b) I-V characteristics of the carbon fibre soldered with Pd precursor spin-coated on the Au gap electrodes. Curve (1) carbon fibre physically placed, curve (2) after applying external bias.

Figure S4. Three more examples of single CNT circuits self assembled using our method.

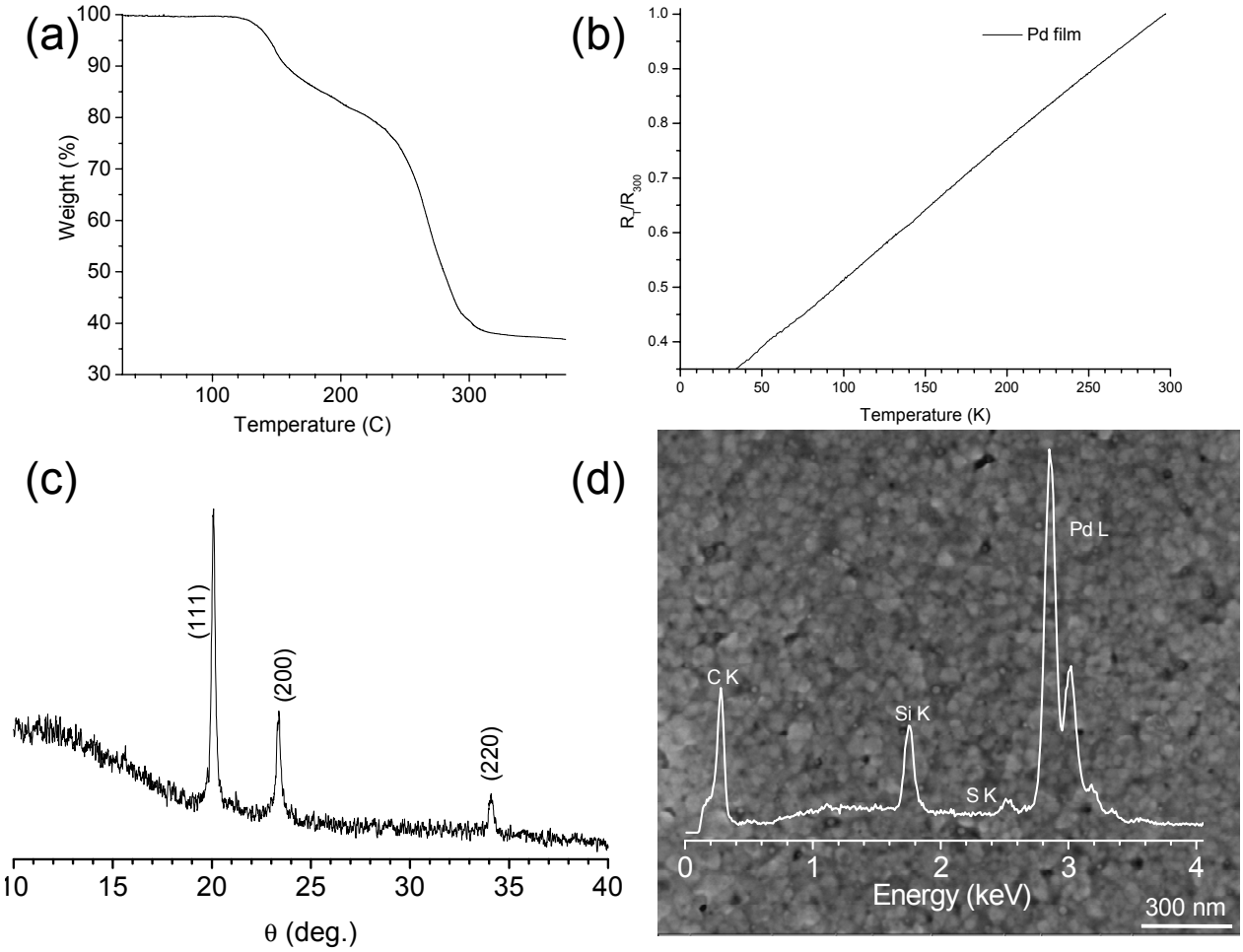

Figure S1

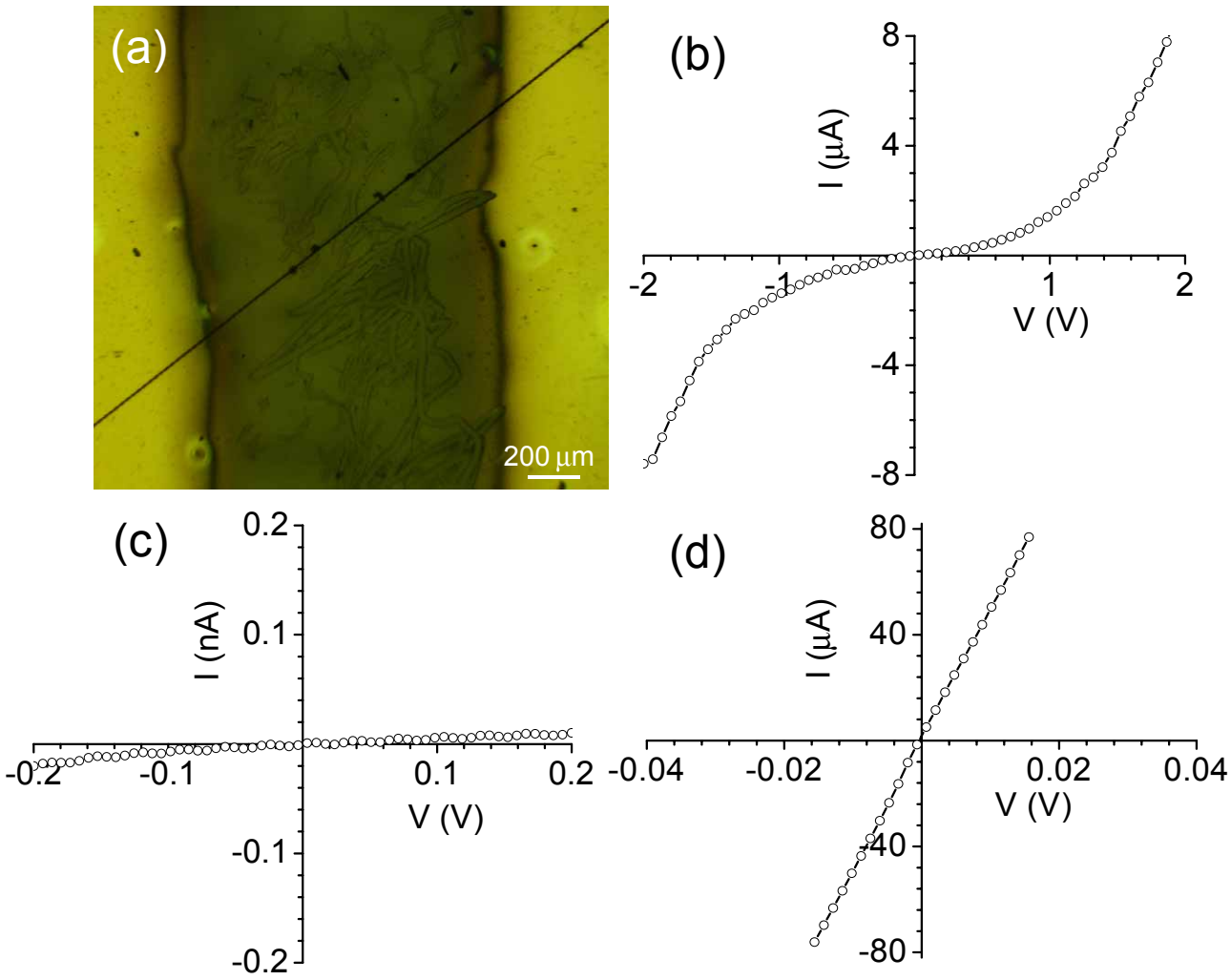

Figure S2

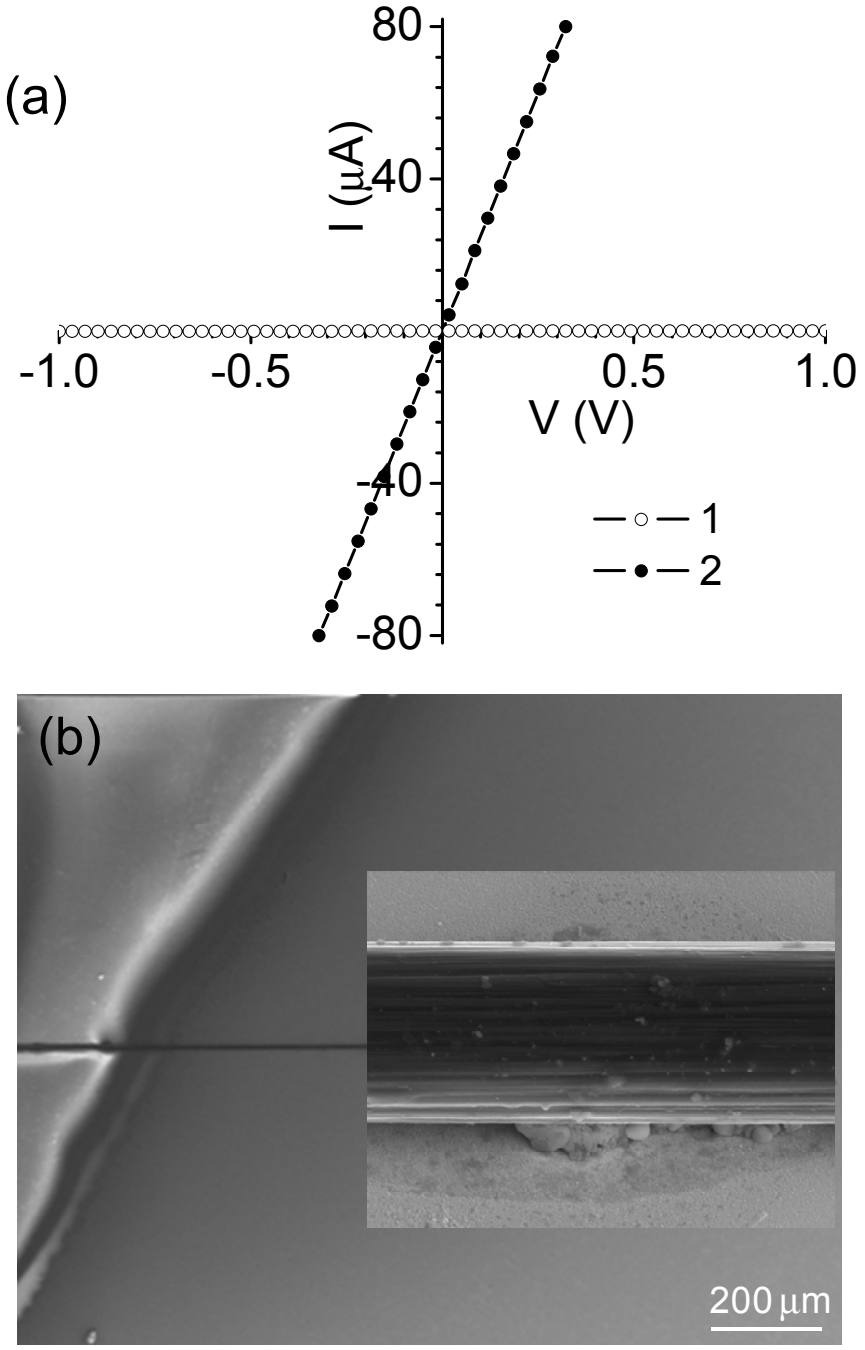

Figure S3

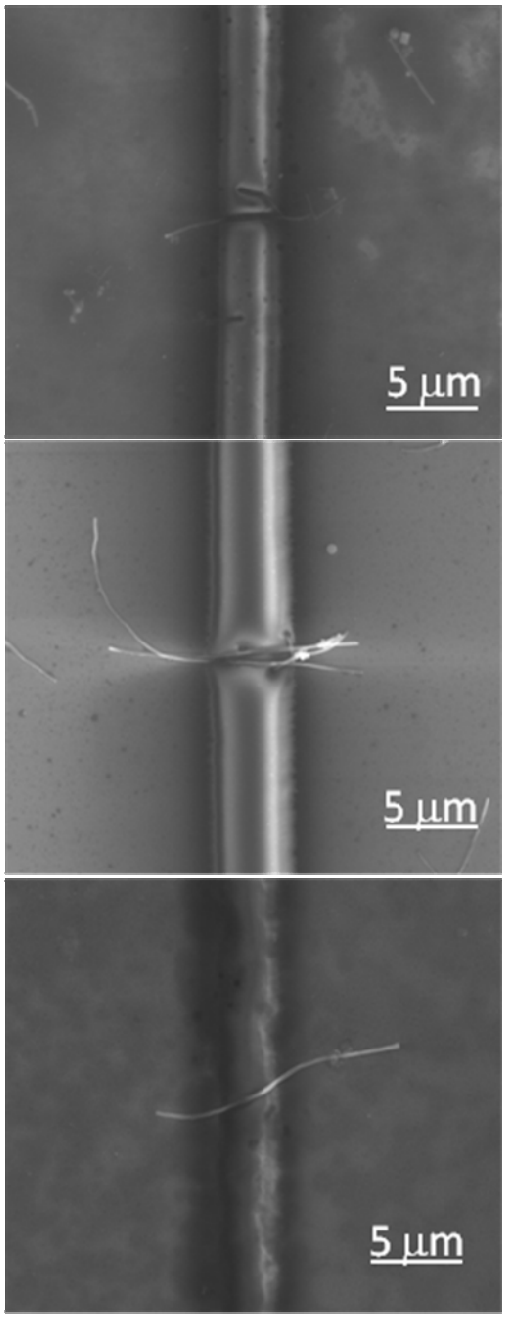

Figure S4