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DC Characterisation of C_{60} Whiskers using Deposited and Contacting Electrodes

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C_{60} whiskers are needle-like fullerene structures, formed through polymerisation of individual C_{60} molecules. A low-cost, room temperature technique for their growth has recently been demonstrated and subsequent electrical characterisation have revealed promising results. Despite the potential for improved electron transport at smaller diameters, data on electrical resistivity have so far been limited to C_{60} whiskers with diameters of several microns. Here, results of two-terminal measurements on a sub-micron diameter C_{60} 'nano'whisker are reported for the first time. Electrical contact is established through FIB-deposited Pt electrodes, and a low resistivity of 17 Ω cm is measured. In parallel, work has begun on the use of a micromachined probe to establish non-invasive contacts with the sample. Results of early trials on a larger diameter C_{60} whisker are presented, demonstrating the feasibility of the technique.

Since the discovery of fullerene C_{60}, advances in the field of fullerene chemistry have led to a number of interesting developments, such as the carbon nanotube. The C_{60} molecule is reactive owing to the presence of strained double bonds within its structure. Cycloaddition reactions are known to occur in high temperature, high pressure environments, and in the presence of ultraviolet radiation. In all cases, C_{60} molecules undergo polymerisation through a 2+2 cycloaddition mechanism, in which parallel double bonds on adjacent molecules break and reform into four-membered cross-linking rings. The process results in a lowering of energy through a reduction in molecular strain. Recently, Miyazawa *et al.* [1] reported a technique for the growth of C_{60} whiskers from solution, at room temperature. The whiskers grow with uniform diameter to lengths of several hundred microns and diameters up to several microns. In simplified form, they can be visualised as linear arrangements of C_{60} molecules, linked by a series of covalent bonds in 1-, 2- or 3- dimensions. Electrical characterisation on individual, suspended C_{60} whiskers with diameters of several microns have revealed low room temperature resistivity; orders of magnitude lower than for bulk C_{60} crystals. Lower resistivities are expected in whiskers with sub-micron diameters ('nano'whiskers), however, no supportive data is provided in the literature.

Platinum (Pt) electrodes were deposited via focused ion beam (FIB) on a C_{60} nanowhisker with a diameter of approximately 400 nm. The FIB process employed a beam of gallium (Ga) ions, generated at 30 keV and between 2-6 pA/cm^2. Preliminary electrical measurements suggested the presence of a thin conducting film in regions between newly-deposited electrodes. Fortunately, the film could be removed by FIB-etching using a low-energy beam of Ga ions, allowing electrically isolated contacts to be achieved. Two-terminal current-voltage (I-V) data were extracted between various electrode pairs using a Hewlett Packard 4155B Parameter Analyser. Resistivity data varied considerably along different sections of the nanowhisker, with the lowest resistivity measuring 17 Ωcm. Higher resistivities in other sections were possibly due to structural damage sustained during FIB processing. An additional cause may be due to the implantation of Ga ions into the sample, which is likely to have disrupted the periodicity of the single crystal structure, reducing carrier mobility.

In order to reduce the influence of deposited electrodes on the sample and measurand, an alternative means of establishing electrical contact was sought in the form of a micromachined four-point probe (μ-4PP) [2]. The probe contained compliant gold-coated silica cantilevers on a 4 μm pitch, supported on a Si die. Samples were brought into contact with the cantilevers using a high-resolution x-y-z positioning stage, however, difficulties were experienced when trying to establish electrical contact with the narrowest whiskers. Increasing the contact pressure to improve the chances of electrical contact often resulted in whisker fracture, as such measurements were limited to whiskers having diameters of 5 μm or more. Unfortunately, the high impedance of such whiskers limited currents to the pico-ampere range. Such currents were below the threshold required for four-terminal measurements to be made with the μ-4PP system, however, two-terminal measurements were still possible. Measurements were taken with nitrogen blown across the sample to reduce the interelectrode leakage current, and a resistivity of 2.3×10^8 Ω cm was measured for a 10 μm diameter whisker. The true resistivity is likely to be considerably lower than this, however, as the result includes significant contributions due to contact resistance between the whisker and the active electrodes.

In summary, two-terminal measurements have been made on C_{60} whiskers using FIB-deposited and contacting electrodes. DC data on a C_{60} nanowhisker is presented for the first time, and the lowest recorded resistivity is consistent with an empirical trend reported in the literature. The result supports the suggestion of finding applications for C_{60} nanowhiskers in electronic devices of the future. Measurements on a larger diameter C_{60} whisker indicate the feasibility of the technique for obtaining electrical measurements through the use of non-invasive contacts. Work is in progress to modify the μ-4PP system to allow four-terminal data to be extracted at lower currents, and trials are planned to obtain four-terminal data from a C_{60} nanowhisker in time for presentation at the conference. Such data is important to improve the objectivity of evidence supporting the use of C_{60} nanowhiskers in electronic applications.

[1] K. Miyazawa, Y. Kuwasaki, A. Obayashi and M. Kuwabara, "C_{60} nanowhiskers formed by the liquid-liquid interfacial precipitation method", *Journal of Materials Research*, Materials Research Society, vol. 17 (1), pp. 83-88, Jan. 2002.

[2] C.L. Petersen, T.M. Hansen, P. Bøggild, A. Boisen, O. Hansen, T. Hassenkam and F. Grey, "Scanning microscopic four-point conductivity probes", *Sensors and Actuators A*, 96, pp. 53-58, 2002.

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