1-1-2010

Inkjet printed conducting gel-carbon nanotube materials

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Recommended Citation

Aldalbahi, A and in het Panhuis, Marc: Inkjet printed conducting gel-carbon nanotube materials 2010, 143-144.
https://ro.uow.edu.au/scipapers/682

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Abstract
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Keywords
carbon, nanotube, materials, inkjet, printed, conducting, gel

Disciplines
Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Publication Details
Aldalbahi, A. & in het Panhuis, M. (2010). Inkjet printed conducting gel-carbon nanotube materials. Optoelectronic and Microelectronic Materials and Devices (COMMAD), 2010 Conference (pp. 143-144). United States: IEEE.

Inkjet printed conducting gel-carbon nanotube materials

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Abstract: The inkjet printing of CNT-biopolymer composite inks onto solid and gel substrates was investigated. Changing the substrate from glass to gel resulted in an increase in the resistance of printed materials from 9.85 kΩ/cm to 39.42 kΩ/cm.

1 Introduction: Carbon nanotubes (CNTs) have unique electronic, mechanical, optical and thermal properties which make them interesting as a material for nanotechnology applications. A recent processing method for fabrication of conducting CNT materials involves inkjet printing of CNT-based inks [1]. The advantage of inkjet printing over other solution based approaches is resolution, scale-ability and reproduce-ability.

Carrageenan is a generic name for a biopolymer family of water soluble, linear sulphonated galactans extracted from red seaweed which are known for their gel forming and thickening properties [2].

In this work, the anionic biopolymer ι-carrageenan (IC) is used to prepare aqueous inks consisting of dispersed single-walled (SWNT) and multi-walled carbon (MWNT) nanotubes. These inks are then inkjet printed into transparent and conducting patterns on solid and gel substrates.

2 Experimental details:

2.1 Ink preparation: Solutions of IC (CO Kelco, Genuvisco CI-123, 0.8 % w/v) were prepared by adding 120 mg of IC to 15 ml of Milli-Q water (18 MΩ cm) under stirring for 3 hours at ~70 °C. Free-standing biopolymer (gel) substrates were prepared by evaporative casting (35 ºC for 24 hours) of IC solutions into cylindrical plastic containers.

Homogenous IC-CNTs dispersions (viscosity 13.5 ± 0.1 cP) of SWNT (Unidym Inc, lot# P0261) and MWNT (Nanocyl S.A., lot# 090901 were prepared using a Branson 450 (400 W, Ultrasonics Corp.) digital sonicator horn with a probe diameter of 10 mm, in pulse mode (0.5 s on/off).

2.2 Inkjet printing: IC-MWNT and IC-SWNT conductive patterns were jetted using a custom-built inkjet printer [3]. This printer consists of piezo Xaar 126-80 industrial printheads, with 126 nozzles, each jetting 80 pL drops at up to 5,200 Hz. Rectangular patterns (one layer, 17 mm x 60 mm) were printed onto glass (microscope slide) and gel (thickness ~ 45 μm) substrates.

2.3 Characterisation: Scanning electron and optical microscopy were carried out using a JEOL JSM-7500FA and a LEICA Z16APO, respectively. For electrical resistance measurements printed patterns were contacted with conducting silver paint. Current (*I*) – voltage (*V*) characteristics were determined under controlled ambient conditions in air (21 ºC, 45 % relative humidity) using a waveform generator (Agilent 33220A) interfaced with a digital multimeter (Agilent 34410A). Thickness was determined using a contact profilometer, Veeco Dektak 150 with a 12.5 μm tip and 5.00 mg force.

3 Results and Discussion: Rectangular patterns (17 mm x 60 mm) of IC-SWNT and IC-MWNT were inkjet printed onto glass and gel substrates (Fig. 1). The optical transparency of CNT printed onto the solid substrate was lower compared to that on the gel substrate. For example, the transmittance values (at 550 nm) for IC-MWNT on glass and gel substrates are 74% and 88%, respectively. It is clear from Fig.1 that deposition onto the gel substrate results in a different morphology compared to the glass substrate.

The resistance values increased with channel length (Fig. 2). The total resistance (R_T) was found to scale linearly according to:

$$R_T = (l / \sigma A) + R_C, \qquad (1)$$

where l, A, σ and R_C are the sample's length, cross-sectional area, electrical conductivity and electrode-sample contact resistance, respectively. The straight line fits for the printed patterns on glass and polymer film are shown in Fig. 2. The slope is used to calculate conductivity yielding 2.0 ± 0.1 S/cm and 0.28 ± 0.09 S/cm for MWNT and SWNT printed on the solid substrate, respectively.

The appearance and electrical characteristics of the printed patterns on the gel substrate are different compared to those observed on the solid substrate. Optical microscopy (Fig. 1) reveals that the pattern on the gel substrate is not continuous; rather it consists of discreet lines.

However, the inkjet printer deposits the same amount of material onto each of the substrates. The difference in appearance may suggest that part of the pattern is below the surface. Resistance measurements are in support of this observation. For example, the resistance of printed MWNT materials on the gel substrate (39.42 kΩ/cm) is 4 times higher than those printed onto the solid substrate.

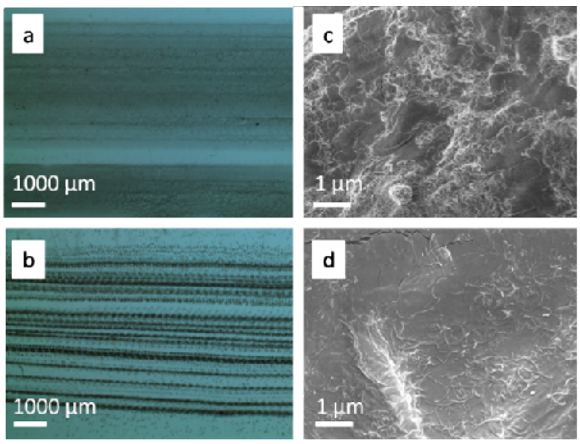

Fig. 1. Optical (a and b) and scanning electron (c and d) microscopy images of printed patterns on solid and gel substrates, respectively.

4 Conclusion: Conducting CNT composite materials were deposited on solid and gel films by inkjet printing of dilute suspensions of SWNT and MWNT in iota-carrageen. Changing the substrate from glass to biopolymer increase the resistance of printed MWNT materials from 9.85 kΩ/cm to 39.42 kΩ/cm.

We believe this is related to fluid exchange between the substrate and the ink. This work contributes to the development of conducting materials embedded in hydrogels, which could function as flexible, biocompatible conductors for implanted sensors, controlled drug delivery systems and other devices.

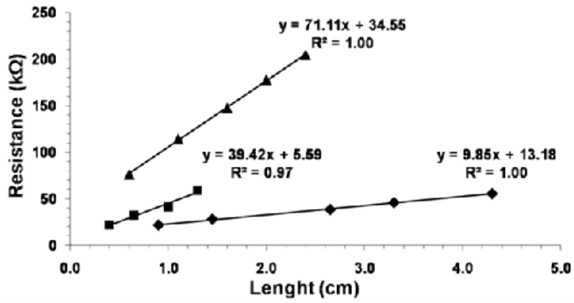

Fig. 2. Resistance vs. length for inkjet printed patterns of SWNT on solid substrate (triangles), MWNT on solid substrate (diamonds) and MWNT on gel substrate (squares). The straight lines are fits to equation 1.

Acknowledgements

This work has been supported by the University of Wollongong, Australian Research Council (ARC), and ARC Future Fellowship (M. in het Panhuis). We thank CP Kelco, D. McCallum and T. Romeo for provision of materials, assistance with printing and electron microscopy, respectively.

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