Horizontally aligned carbon nanotube networks: a route toward highly conductive, flexible & controllably transparent electrodes, field emitters and infra-red sensors

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Flexible, highly conductive and transparent electronic materials are critically important areas of active research. Metals, although being excellent conductors are largely brittle and have increasingly poor conductance when strained. Moreover, metals are optically opaque at the technologically relevant sub-100 nm node. Serpentine Au thin films embedded in elastomeric membranes have gone some way towards solving the flexibility problem. Transparent conducting metal oxides, such as increasingly expensive indium tin oxide, open up the field of optoelectronics. Simultaneously achieving high transparency and high conductivity is the ultimate goal. Conductive polymers including untreated, and poly-ethyl glycol enhanced, Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) have had some success, however sheet resistances require further improvement and the observed non-constant variation in optical transmission with wavelength across the NIR-vis spectra result in an undesirable characteristic blue hue in most PEDOT:PSS derivatives. Carbon-based materials show significant promise and solve many of these problems. Here we report on the fabrication, characterisation and application of thin films comprised of random and aligned horizontal carbon nanotube (H-CNTs).

Figure 1 (a)-(d) illustrates a CNT shearing and transferral process for the fabrication of aligned H-CNT films on polycarbonate substrates, such as polypopylene carbonate (PPC) and polyethylene terephthalate (PET), developed by us [1]. We have also successfully demonstrated the ability to pattern and control the transparency of these films by O_2 reactive ion etching (Fig. 3(b), (c), (d)) [1]. An alternative approach to transparency control has been investigated. By reducing the length of the source CNT material we have shown that it is possible to control the transferred H-CNT films conductivity and optical transmissivity. For CNTs of length > 50 µm we find that the aligned MWNTs adhere strongly to the untreated PC substrates. Whilst for lengths < 50 µm an adhesion promoter (aminopropyl-triethoxysilane, APTS) largely improves the transferred films uniformity, especially when transferring onto ITO, SiO_2, and other natively hydrophobic surfaces (Fig. 3(a)). Our most opaque and highly conductive films have sheet resistances of the order of 1.2 Ω/□ with an optical transmission of 10%. We have also investigated the use of these rolled CNT films as field emitters, which have been compared to vacuum filtrated random networks, and screen printed networks [2].

Free-standing aligned H-CNT networks have also been fabricated (Fig. 2 (a)-(d)). These suspended networks are structurally maintained by inter-CNT Van der Waals forces and can be pulled to span significant lengths. CNTs are known to be strongly absorbing in the infra-red (IR) spectrum making them ideal as IR sensors. Figure 2(e) shows a typical current response of the suspend H-CNT films when irradiated with IR radiation [3].

In this presentation the results outlined above will be developed and an overview of some of the on-going work taking place within Cambridge's Electronic Devices & Materials group will be discussed.

Keywords: Carbon nanotubes, flexible, horizontally alignment, transparent, field emission, infra-red sensors

References

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Figures

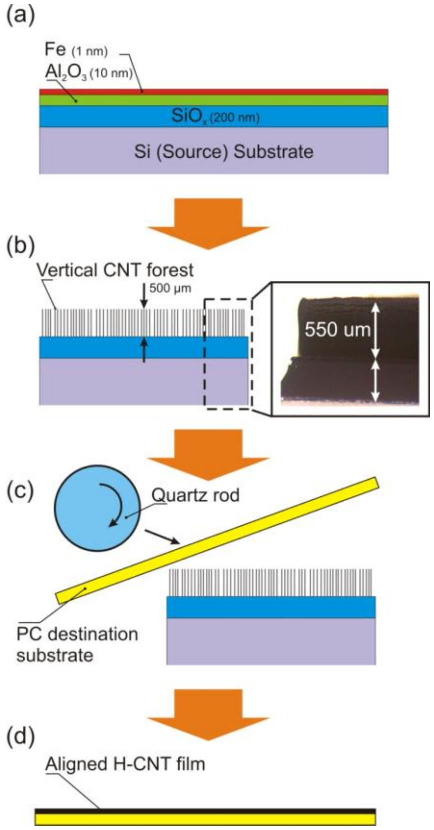

FIG. 1: (a)-(d) Horizontally aligned sheared H-CNT film fabrication and transferral process onto PC destination substrates [1].

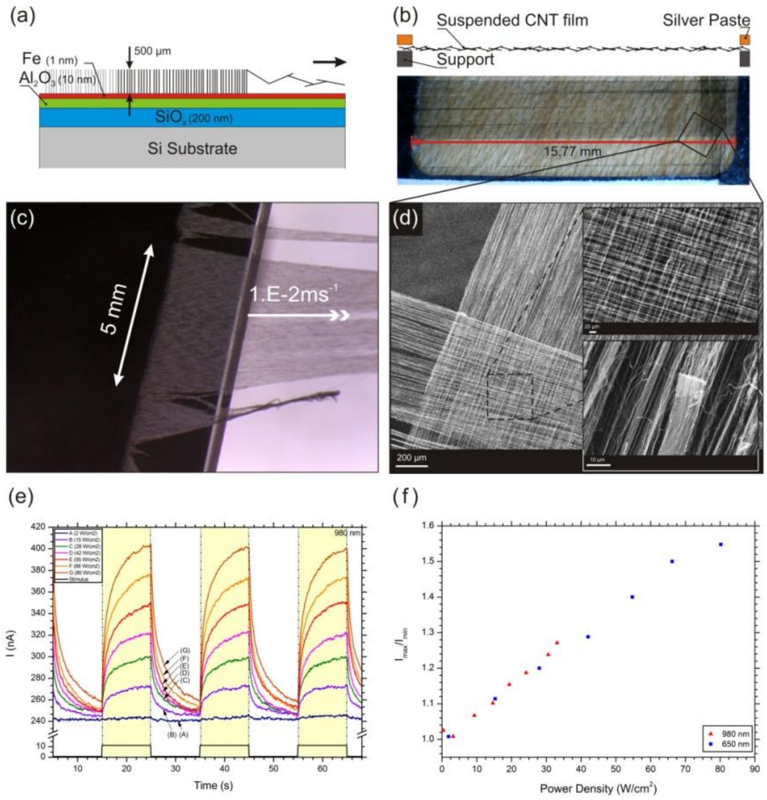

FIG. 2: (a)-(c) Fabrication process of suspended H-CNT films for planar IR sensor [3]. (d) SEM micrographs of suspended CNT array. (e) 980 nm IR response (power density, 2-80 W/cm^2). (f) Emission current showing a strong dependence on the incident power density at 650 nm and 980 nm excitation [3].

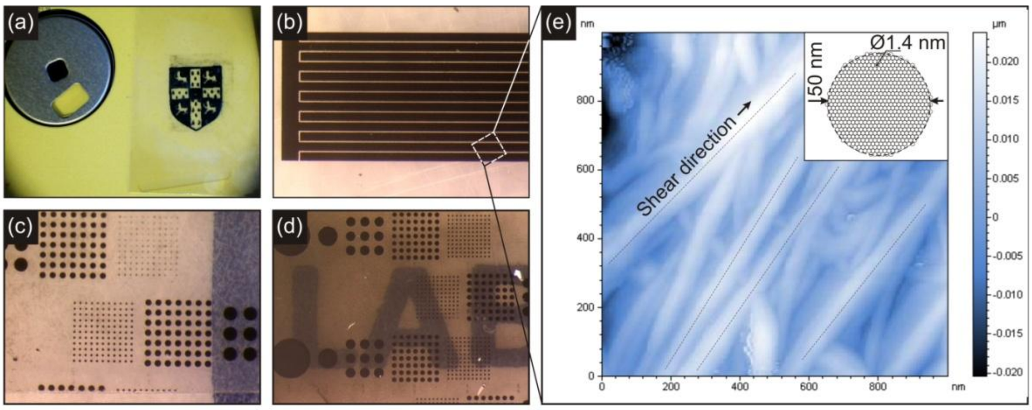

FIG. 3: *LEFT*. (a)-(d) Optical micrographs of shear aligned H-CNT films on PET/ITO/APTS, PET and PPC, where O_2 RIE patterning and transparency control have been used. (e) AFM of H-CNT film [1].