SELF-ASSEMBLING CARBON NANOTUBES FOR ELECTRONIC APPLICATIONS

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Due to their exceptional electrical, mechanical and chemical proprerties, carbon nanotubes are very promising building blocks for future nanoelectronic technologies. In particular, nanotube field effect transistors (CNT-FETs), in which a single nanotube with a diameter of ~1 nm is used as the channel, compete favorably with state of the art silicon devices, at comparable geometry. Larger diameter tubes (~10 nm) on the other hand can be used to build nanotube-based nano-electro-mechanical systems (CNT-NEMS), which are small versions of conventional MEMS but with exciting new properties related to their nano-scale. The future of nanotube-based devices in nanoelectronics is to a large extent related to the development of bottom-up self-assembly techniques. Indeed, if individual prototypes can demonstrate a great potential, integration issues are critical, even for low density applications. The presented work focuses on the chemical self-assembly of nanotubes and its use for the realisation of nanotube-based electronic devices.

Our laboratory has developed a wet self-assembly technique that allows the selective placement of nanotubes at predefined location on a substrate. It relies on the local functionalization of the substrate by a patterned molecular monolayer of an amine-terminated silane[1-3] (Fig. 1a). The method is versatile as it works for both single-wall and multi-wall nanotubes and for both individual nanotubes and networks of nanotubes. We use it as a general technique to built CNT-FETs, optoelectronic devices and CNT-NEMs:

- Field effect transistors prepared in that way (Fig. 1b) have very good performances[2] and can be optimised by post fabrication chemical treatments[3] (Fig. 1c). Moreover, they can be used as extremely sensitive gas sensors[3]. We also investigated recently the high frequency (GHz) behaviour of nanotube transistors based on multiple nanotubes channels[4,5] and demonstrated in particular the highest reported transition frequency of 8 GHz for such a nanotube-based FET[5] (Fig. 2).
- Further elaborating upon the chemical tailoring of the self-assembled CNT-FET devices, we have developed a new class of optoelectronic devices consisting of optically gated CNT-FETs[6]. Upon photoexcitation, the device can be used as an optically driven current modulator or as a non volatile memory element. The memory device works on an 'optical write / electrical erase' basis (Fig. 3).
- Finally, new nano-electromechanical systems (NEMS) based on multiwall nanotubes can also be self-assembled with this technique[7]. An example of very efficient electro-mechanical switch based on an individual and partially suspended nanotube is reported. In such a switch, the current between the nanotube and an underlying actuating electrode changes by several orders of magnitude within a <100 mV change of the actuating bias (Fig. 4c).

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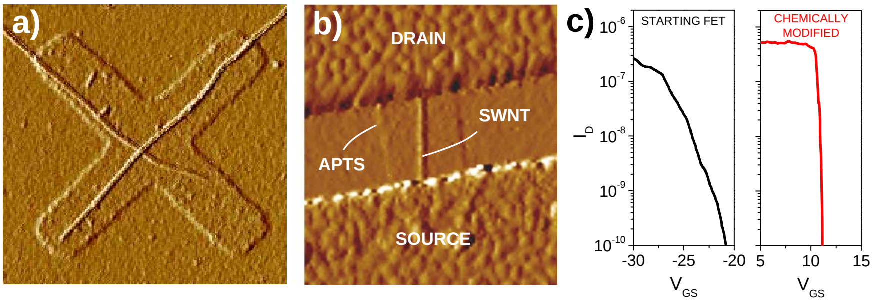

Figure 1: a) AFM image of single-wall nanotubes selectively deposited on a pattern monolayer of APTS (work done in collaboration with Motorola). b) AFM image of a self-assembled nanotube transistor. b) Transfer characteristics of an as made and chemically treated device. The starting transconductance only reflects the thick gate oxide used in this particular experiment.

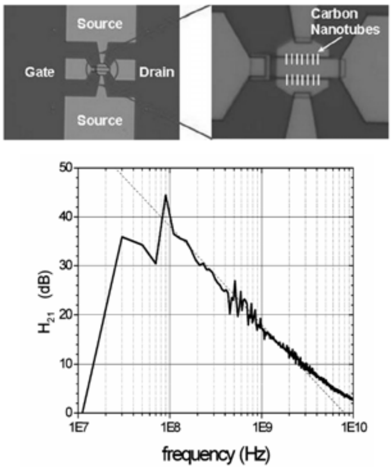

Figure 2: SEM image of an HF-nanotube transistor structure and the corresponding current gain 10 log10(|H21|²) extracted from the de-embedded S-parameters. The device is biased at V_{DS}=1V and V_{GS}=0V. The extracted cut-off frequency (f_t) is 8 GHz.

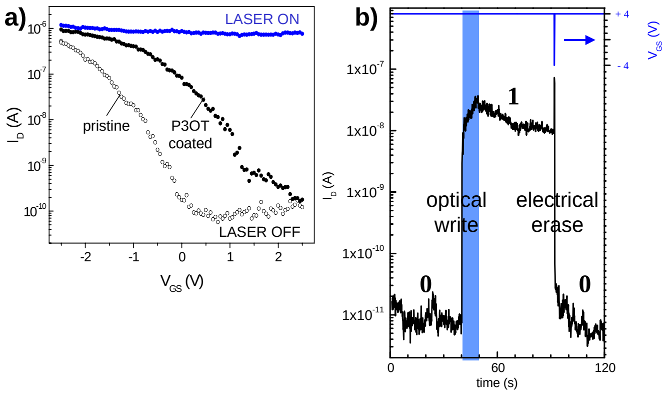

Figure 3: a) Transfer characteristics of a CNT-FET covered with a 5nm thick film of P3OT in dark and illuminated conditions (λ=457nm). The current at V_{GS}=+2.5V increases by 4 orders of magnitude when the laser is turned on. b) Principle of the optical memory. The blue shaded area correspond to "laser ON". A V_{GS} pulse of 100 ms at -4V resets the memory.

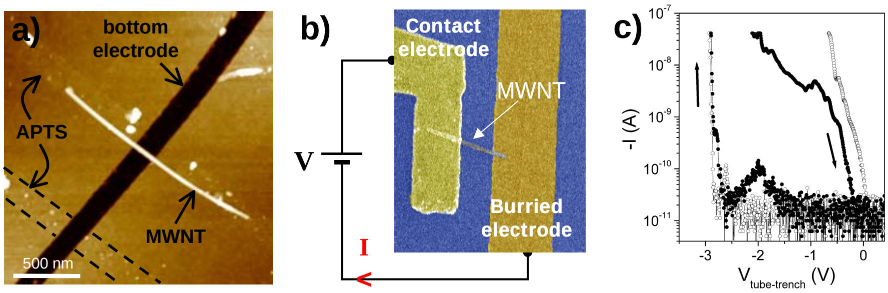

Figure 4: a) AFM image of an individual multiwall nanotube selectively placed on an APTS stripe over a buried electrode. b) SEM image of an individual nanotube connected in cantilever geometry and suspended over a buried electrode. c) Electrical response of the nanotube NEMS device presented in b). The current increases by several orders of magnitude when the bias reaches a threshold corresponding to the pull-in voltage (tube in contact with the buried electrode).