Optoelectronic switch and memory devices based on polymer functionalized carbon nanotube transistors

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Associating carbon nanotubes with conjugated polymers or molecules has been recently recognized as an efficient way to improve performances of organic electronic devices and to achieve new functionality, in particular for optoelectronic applications. This approach maintains the main advantages of organic electronics for low cost, flexible and/or transparent applications. A particularly interesting example of such a nanotube/polymer combination consists of a carbon nanotube field effect transistor coated with a polymer thin film (1; 2). Indeed, such a device can ideally combine the very high carrier mobility of carbon nanotubes (100000 $cm^2/V.s$) with the excellent optical properties of polymers (or molecules in general). Carbon nanotube transistors can, by themselves, emit or detect photons at wavelengths defined by the nanotube chirality. But, to extend their capabilities in optoelectronics, it is important to be able to tune these wavelengths independently of the nanotube structure. Functionalizing the nanotube with a polymer is an efficient way to achieve such a goal. In the present study (2), we demonstrate that drastic photo-induced modifications of the electrical characteristics of self-assembled (3) nanotube transistors functionalized by photo-conductive polymers can be achieved.

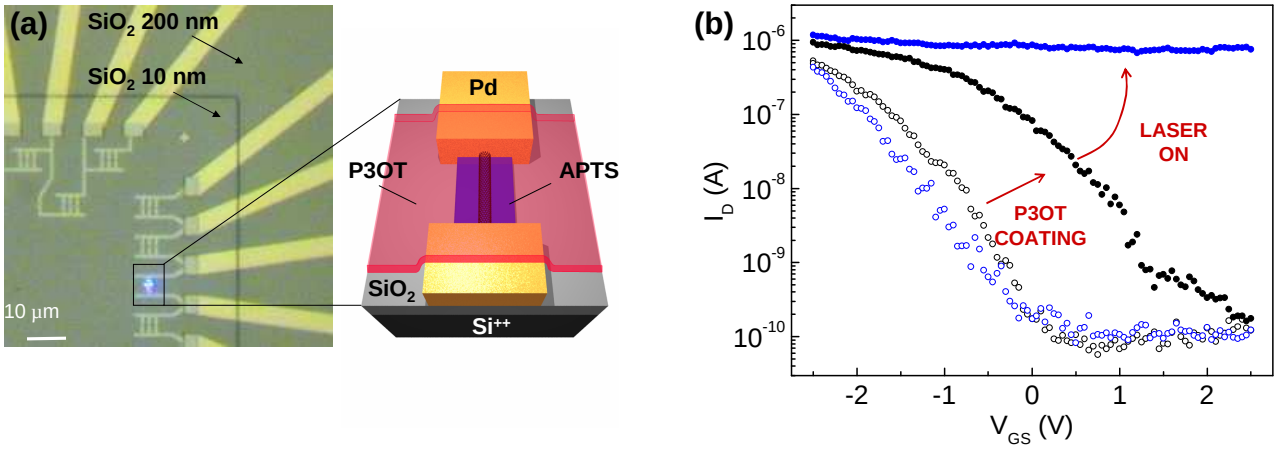

Figure 1 Self assembled CNTFETs and their response to the polymer photoexcitation. (a) Optical microscope picture of the sample showing a series of self-assembled CNTFETs and the blue laser spot focused on an individual transistor. Right: scheme of the CNTFET showing a single nanotube connected by Pd electrodes separated by $\sim$ 100 nm and coated by the P3OT film. (b) Transfer characteristics $I_D(V_{GS})$ at V_{DS}= -400 mV of an 'as-made' CNTFET in the dark (open black circles) and upon illumination (steady state, λ = 457 nm, P= 60 μW, spot size $\sim$2 μm) (open blue circles) and of the same transistor coated with P3OT ($\sim$ 5 nm thick film) in the dark (filled black circles) and upon illumination (filled blue circles).

The figure 1 shows that the polymer film acts as a wavelength dependent 'optical gate', which is significantly more efficient than a conventional electrostatic gate. The process impacts both the on- and the off-states of the transistor with a maximum change of conductance reaching four orders of magnitude between the dark and illuminated states. Depending on the applied biases and polymer characteristics the device can be optimized

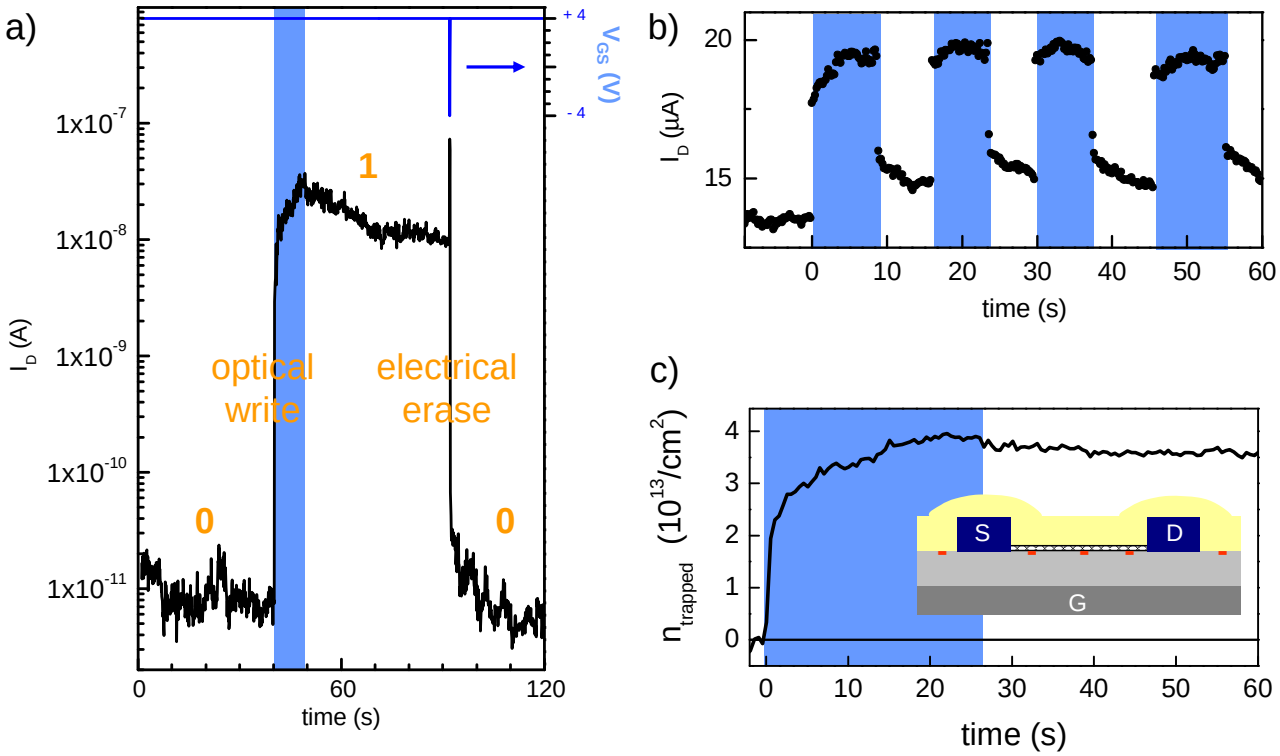

Figure 2 Optical memory and switch based on the OG-CNTFET (a) $I_D(t)$ response at V_{GS}= +4 V of an OG-CNTFET to a light pulse at $\lambda = 457$ nm (laser on in the blue shaded area). The current magnitude difference before and after illumination allows memory applications. The memory erase action is also shown. After the light pulse has been applied, a short (100 ms) negative V_{GS} pulse at -4 V is used to bring the device back to its initial state. (b) $I_D(t)$ response at V_{GS}= -3 V of a device composed of multiple nanotubes to a light pulse at $\lambda = 457$ nm. The negative gate bias allows rapid optically driven modulation of the current. (c) Evaluation of the trapped electrons density $n_{trapped}$ obtained by comparing the $I_D(t)$ response at V_{GS}= +4 V with the transfer characteristic $I_D(V_{GS})$ in the dark. An I_D increase of 3 orders of magnitude for $V_{GS} = +4$ V is equivalent to a negative gate shift of -5 V, created by 4.10^{14} charges/cm^2 ($Q = C_{ox}V_{GS}$) at the Si++/SiO_2 interface. Because the APTS layer is $\sim$ 1 nm thick (SiO_2 is 10nm thick), the same effective equivalent potential on the nanotube is created by $\sim 4.10^{13}$ charges/cm^2. The inset shows those interfacial traps (red dashes).

as a memory element (Fig 2a) or as an optical switch (Fig 2b). On the basis of a set of experiments performed with either CNTFETs or P3OT thin film transistors (TFT), we propose a mechanism based on the trapping of photo-generated electrons at the nanotube-gate dielectric interface. The results are consistent with the generally observed p-type conduction in organic TFTs (4). Thanks to its very high charge sensitivity, the nanotube transistor proves a good tool to study the spatial distribution and relaxation rate of trapped carriers in organic thin films transistors (Fig 2c). In particular, the non exponential type of decay of the persistent photo-conductivity in TFTs can be studied with improved sensitivity using a nanotube transistor as charge sensor.

References

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