DYNAMIC PERFORMANCES OF CARBON NANOTUBE TRANSISTORS AND PROGRAMMABLE DEVICES FOR ADAPTIVE ARCHITECTURES

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Carbon nanotubes (CNTs) are known to have exceptional electronic properties. Still, the future integration of carbon nanotube transistors into conventional/mainstream integrated circuits remains unlikely. Indeed, the improvement in performances may not be sufficient to justify the immense efforts necessary to tackle the serious issues of precise placement of individual CNTs and device performance variability. However, CNTs benefit from decisive advantages that can open new perspectives in *unconventional* type of circuits. Among the intrinsic properties of CNTs two are of particular importance in this context: *(i)* their exceptional transport properties (carrier mobility $>10^5$ $cm^2/V.s$, ballistic transport over several hundreds of nm…) allow developing electronic devices operating at very high frequencies and *(ii)* these properties are preserved to a large extend when CNTs are integrated in various types of environments among which one finds: above-IC and unconventional substrates (such as plastic ones).

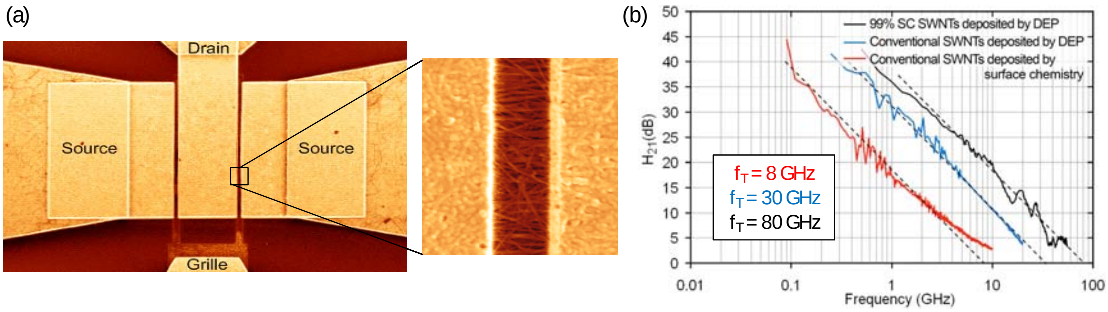
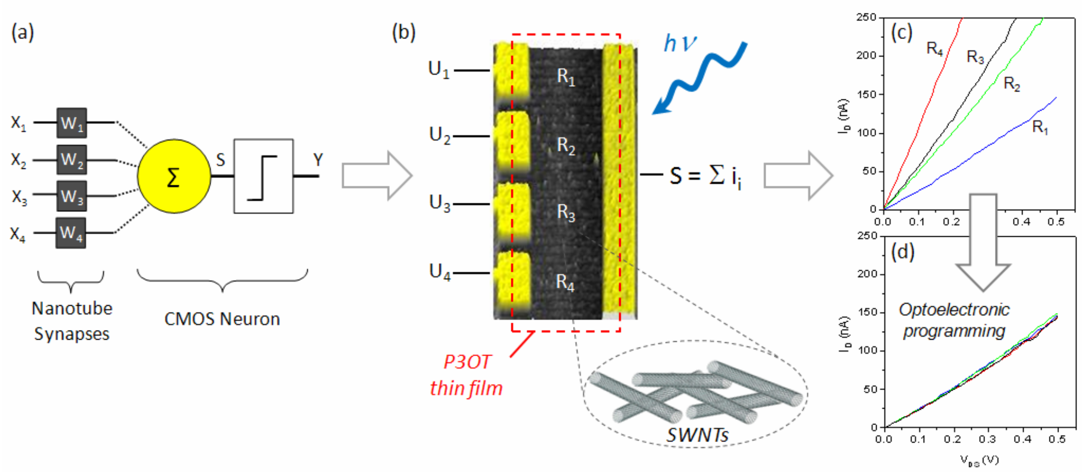


Fig. 1 (a) SEM image of an HF transistor, the channel of which is a network of dense and aligned CNTs deposited by DEP [1]. (b) Current gain as a function of frequency for three types of CNT networks and the corresponding cut-off frequencies. The use of purely semiconducting CNTs allows reaching 80 GHz [3].

In this presentation, I will first present our most recent results on high frequency CNT transistors. We showed earlier that the use of dense and well aligned CNT networks allows reaching operating frequencies as high as 30 GHz [1] and that the proposed process flow is compatible with flexible substrates [2]. In 2009, we demonstrated that the use of high purity CNTs containing 99% of semiconducting chiralities allows improving f_T up to the record value of 80 GHz, without the need for CNT alignment [3]. CNTs networks thus prove to be very serious candidates for high-speed 'macro'-electronic applications in range of frequencies out of reach for other organic materials.

But even if nano-objects with well defined structures and original electronic properties, such as CNTs, are of great interest for the development of new generation of circuits (especially when co-integrated with silicon-based electronics), it is expected that conventional circuit architectures developed so far for the CMOS technology will not be ideally suited for these new objects, in particular because these architectures can barely cope with any significant variability among as-built devices, which is an inherent particularity of nano-devices. Conversely, adaptive circuits, such as neural networks, represent a challenging approach which intends to take advantage of the rich functionality of nano-size building blocks and at the same time to manage variability by means of a learning (or a training) step. In this context, carbon nanotube field effect transistors (CNTFETs) functionalized with a thin film of photoconductive



polymer are of special relevance as they combine exceptional electrical performances with additional functionalities such as light sensing and memory capabilities.

Fig. 2 (a) Principle of a simple perceptron, the basic building block of neural network circuits. Input signals (x_i) are weighted using the synaptic weights (w_i). The neuron computes the sum $\Sigma(x_i.w_i)$ and compares it to a threshold value to trigger an output signal. (b) AFM image of a prototype implementation of such perceptron using CNT programmable devices to store the synaptic weights. (c) Example of programming. The initially dispersed resistivity values of the 4 devices (R_1 to R_4) can be adjusted to arbitrary values with high precision.

In a second part of my presentation, I will show that these optically-gated CNTFETs (so called OG-CNTFETs) [4,5] have all the required characteristics of artificial synapses, the basic building blocks of adaptive circuits. In particular, they can be operated as 2-terminal devices with a non-volatile memory effect, efficient programmability, large dynamics and remarkable tolerance to variability [6]. The capability to program independently multiple devices is also established and a way to implement these nano-synapses into circuits is proposed. Using thin silicon wires as gate electrodes with a scaled-down oxide layer, we show that the programming steps can be performed using sub-μs electrical pulses, thus allowing high speed training.

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