Carbon Nanotube Electronic and Optoelectronic Devices and Circuits

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As the scaling of silicon-based devices is approaching its limits, intense efforts are made to find ways to supplement silicon electronics. One of the most promising systems for this purpose is carbon nanotubes (CNTs). Although a variety of different electronic devices based on CNTs have been demonstrated, most of the emphasis has been placed on CNT field-effect transistors (CNTFETs). In these devices a single semiconducting CNT molecule replaces silicon as the transistor channel. The resulting devices have superior characteristics, but also pose a set of new challenges. These include understanding the new physics of transport in one-dimension, deciphering the different device scaling laws, understanding charge-transfer and the formation of barriers at metal-nanotube interfaces, doping them, etc. In my talk I will discuss these issues and demonstrate solutions that allow the fabrication of not only individual devices with excellent characteristics, but also more complex integrated circuits, such as ring oscillators, based on a single CNT molecule. [1] In our effort on CNT optoelectronics we are mostly interested in the electrical production of excitations in CNTs. This we accomplish in two different ways. In one mode, excitations are generated by independently injecting electrons and holes in the channel of an ambipolar CNT field-effect transistor (FET). [2,3] Radiative e-h recombination in such a system produces single nanotube molecule light sources. [2] In a different approach we take advantage of the strong e-h interactions and inefficient electron-phonon interaction in CNTs that allows for efficient intra-CNT impact excitation by hot carriers under unipolar transport conditions. [4,5] Our theoretical analysis shows that impact excitation rates are much higher in CNTs compared to 3D solids. [6] Examples of naturally occurring [5] and fabricated [4] structures that emit unipolar electroluminescence will be discussed. Finally, we will discuss the inverse process of light absorption generated currents (photoconductivity) in CNTs [7, 8] and their potential uses. [1] For reviews of our work on CNT electronics see: Ph. Avouris, MRS Bull., 29, 403 (2004); Proceedings of IEEE 91, 1772 (2003); Ph. Avouris, J. Chen, Materials Today, 9, 46 (2006). [2] J. A. Misewich, R. Martel, Ph. Avouris, et al., Science 300, 783 (2003). [3] M. Freitag, et al. Phys. Rev. Lett. 93, 076803 (2004). [4] J. Chen, V. Perebeinos, M. Freitag, J. Tsang, Q. Fu, J. Liu, Ph. Avouris, Science 310, 1171(2005). [5] M. Freitag et al., Nano Lett. 6, 1425 (2006). [6] V. Perebeinos, Ph. Avouris, Phys. Rev. B 74, 121410(R) (2006). [7] M. Freitag, Y. Martin, J. A. Misewich, et al., Nano Lett. 3, 1067 (2003). [8] X. Qiu, M. Freitag, V. Perebeinos, and Ph. Avouris, Nano Lett. 5, 749 (2005)

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