Insights in optical properties of bundled carbon nanotubes for telecommunications applications: a preliminary comparative study with individualized carbon nanotubes

M. Gicquel[1], P. Turban[2], A. Moréac[2], R. Fleurier[3], A. Maalouf[4], H. Nong[1], S. Loualiche[1]

[1]Laboratoire FOTON, UMR CNRS 6082, INSA, 20 Avenue des Buttes de Coësmes CS 14315
35043 Rennes Cedex, France
[2]IPR, UMR CNRS 6251, Université Rennes 1, 263 Avenue du Général Leclerc, 35 042 Rennes
Cedex, France
[3]Laboratoire d'Etude des Microstructures, ONERA, 29 Avenue de la division Leclerc, 92322
Châtillon Cedex, France
[4]Laboratoire FOTON, UMR CNRS 6082, ENSSAT, 6 Rue de Kerampont, BP 80518, 22305
Lannion Cedex, France

maud.gicquel@insa-rennes.fr

Contact author : maud.gicquel@insa-rennes.fr

Among nanomaterials with great potential for optical devices (light emitting diodes, lasers, semiconducting optical amplifiers, ultrafast switches), carbon nanotubes (CNT) take a particular place near classical semiconducting nanostructures (quantum wells and dots). Indeed, these 1D-nanomaterials demonstrate original and efficient excitonic optical properties [1,2], and the large-scale production of CNT, as well as the relative process simplicity required for CNT-based devices should most probably open the way towards low-cost devices. Finally, CNT-based devices are still research challenges in nanooptics and our work particularly aims at demonstrating ultrafast switches for telecommunication applications, in optical fiber networks.

Since the discovery in 2002 that CNT can emit light [3], an impressive number of research studies focused on their intrinsic optical properties [4]. This jump in optical research on CNT was made possible thanks to a powerful physico-chemical process that leads to CNT individualization. However, when CNT are in bundles (or in ropes), which is the naturally form of as-grown CNT, optical properties of CNT are drastically modified. We performed a structural analysis of spray-deposited bundled CNT films, using scanning tunnelling microscopy (STM). Figure 1A provides a (175X175 nm^2)-sized STM image of our simple-processed bundled CNT-samples. In a rope, there are statistically 1/3 metallic and 2/3 semiconducting CNT, which are strongly linked by Van der Waals interactions, resulting in an intertube distance of ~0.3 nm [5]. We suggest below that this intertube narrow distance in CNT bundles is useful for ultrafast switching applications.

We present here a comparative study on linear optical properties of individualized CNT and bundled CNT. We use therefore visible-infrared absorption and Raman spectroscopies. Thus, highlighting the benefit of bundling for CNT-based ultrafast optical devices, which are simply processed in comparison with individualized CNT-based devices, we finally demonstrate the femtosecond-scale optical switch of bundled-CNT, at 1550-nm telecom wavelength.

In figure 1B, we present absorption spectra of both CNT types. We show that bundling effect induces redshifting and broadening of first optical transitions of semiconducting CNT, around 1300 nm. We suggest that both effects are advantageous for telecom applications, where 1550 nm-wavelength-window is exploited in long-haul optical fiber and, multiplexing-wavelength technique is used to enhance the high-bit-rate of telecom signal. Furthermore, the vibration modes of CNT were probed using Raman spectroscopy at 785nm-excitation wavelength. We focus on radial breathing modes (RBM), which highlights qualitatively the various CNT diameters in the samples [6]. Even if we find qualitatively the same diameters in individualized and bundled CNT-based samples (with diameter average of ~1 nm), Raman spectra of both CNT types demonstrate typical features. Among them, we note the presence of a “roping peak” around 270 cm^{-1} for bundled CNT, confirming the strong extent of bundling in our samples [7], and we highlight modifications of phonons-excitons interactions and resonant probed-semiconducting CNT.

Finally, we tested the absorption dynamics of bundled CNT using femtosecond pulses in pump-probe experiments. We report a typical switching time of 0.41 ps at 1550 nm telecom-wavelength-excitation, which is suitable for 500 Gb/s bit-rate telecom signal treatment, far beyond the 160 Gb/s rate of test-systems. This ultrafast switching is most attributed to charge transfer from semiconducting to neighbouring metallic CNT [8]. The vicinity of CNT in bundles is also an asset for ultrafast all-optical telecom applications and insertion of bundled CNT in resonant optical microcavities are in progress, in order to enhance light-matter interaction.

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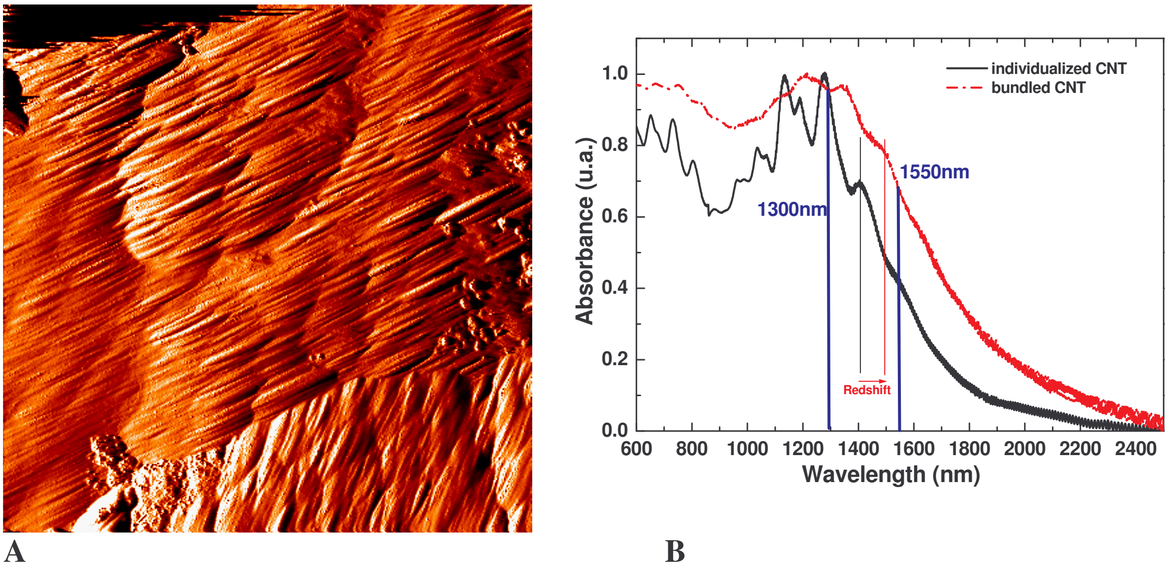
Figure:



<u>Figure 1:</u> A) STM image of bundled CNT (175X175) nm^2, B) Normalized absorbance of individualized and bundled CNT in visible-infrared window.