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Carbon nanotubes incorporated-hybrid waveguides for photonics applications

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Abstract: Semiconducting carbon nanotubes (CNT) exhibit large nonlinear- and strong quasi-one dimensional excitonic optical properties. Their integration in integrated waveguides could lead to very efficient light-emitting devices or optical signal processing functions. We described the fabrication and optical characterization of hybrid planar waveguides incorporating CNT. Ways of further enhancing light interaction with the CNT namely ridge waveguides processing and CNT alignment are also presented.

Introduction:

Carbon nanotubes (CNT) and graphene have attracted large research interest due to their unique optical, electrical, chemical and mechanical properties. Semiconducting carbon nanotubes have found photonics applications as nanoscale light emitters and photovoltaic devices[1] or as saturable absorber for passive mode locking of different laser types or optical switching[2]. Indeed, LED operations have been demonstrated using CNT[3] as well as CNT guided luminescence[4] and optical gain[5]. All-optical signal processing functions have also been developed using highly nonlinear waveguides. Wavelength conversion based on four wave mixing has been obtained using CNT deposited on top of tapered fiber[6], D-shaped fiber[7] or integrated waveguide based on Ge doped silica[8]. In these devices, CNT were interacting with the optical beam through evanescent field. To further benefit from the very large nonlinear refractive index of CNT, which surpasses that of silicon by several orders of magnitude, we proposed to use direct interaction between the CNT and the laser beam.

Fabrication:

A hybrid structure composed of a lower polymer cladding made of benzocyclobutene (BCB) and silicon nitride (SiN_x) core incorporating single-walled carbon nanotubes (SWCNT) was designed.

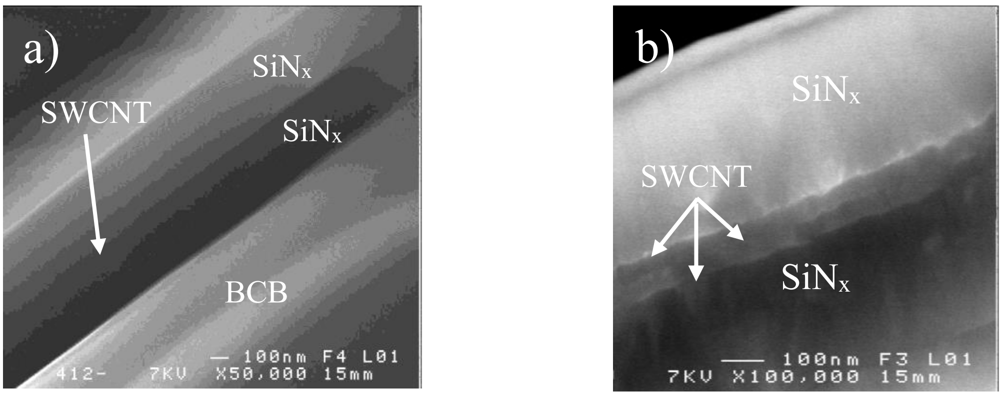

Fig. 1: SEM pictures of planar waveguides incorporating a) one SWCNT layer or b) three SWCNT layers.

BCB (5µm thick) was deposited on Si substrate by spin-coating from solution at a speed of 1500 rpm followed by soft bake at 120°C for 2 minutes and hard bake under nitrogen at 250°C for an hour. The waveguide core is made of two SiN_x layers between which one or three thin SWCNT layers are deposited by spray coating. The SiN_x layers were deposited by sputtering and their total thickness is

640 or 870 nm for one- or three SWCNT layers cavity respectively (*Fig. 1*). For the second sample, a 30 nm-thick spacer was deposited between the three SWCNT layers (*Fig. 1b*). SWCNT surrounded by micelle were obtained by mixing 10 mg of pristine HiPCO single-walled CNT powder to a 20 ml of 2% sodium cholate water solution followed by sonication for 1 hour, ultracentrifugation at 25000×g for 1 hour and filtration of the upper suspension layer. Linear absorption spectra indicate that the SWCNT first excitonic transition energies are suitable for 1550 nm-window photonics applications[2].

Optical characterization and discussion:
Planar waveguides with air as upper cladding were first characterized. To minimize coupling losses, microlensed fibers with optical mode diameter of 2.2 µm were used to launch a broadband laser source around 1550 nm into the waveguides. Optical propagation at 1550nm in 3.5 mm long-waveguides was confirmed by imaging the output facet of the waveguide on an infrared camera through a high magnification and numerical aperture microscope objective (*Fig. 2a*).

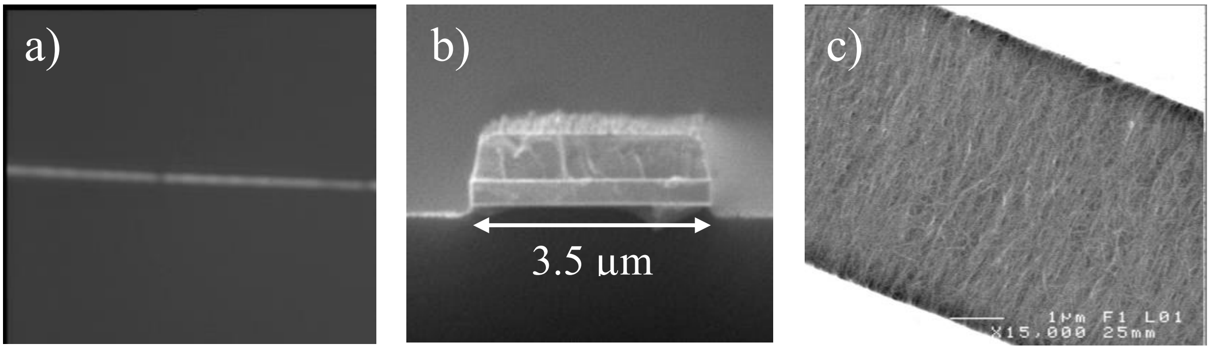

Fig. 2: a) Intensity profile of the planar SWCNT incorporated-waveguide output, b) SEM picture of ridge SiN_x waveguide with BCB lower cladding (resin was not removed) c) SWCNT aligned by dielectrophoresis between gold electrodes.

Ridge waveguides have been processed using standard i-line photolithography and SF6 based reactive ion etching (*Fig. 2b*) process for samples with BCB lower cladding layers and SiN_x core without SWCNT. For samples incorporating SWCNT in the waveguide core, worm-like defects occurs during the post-exposure bake. A modification of the thermal steps of BCB curing and photolithographic process could help overcoming these defects[9]. Interaction of SWCNT with the optical beam could be further improved by aligning SWCNT. To this end, electrophoresis experiments[10] have been performed. *Fig. 2c* shows the preliminary results obtained on the alignment of SWCNT. Transferring this technology to integrated waveguides incorporating CNT should pave the way to the development of efficient devices dedicated to optical signal processing or light emission.

Conclusion:
Waveguides with BCB lower cladding and SWCNT-incorporated SiN_x core have been processed. If problems occurring during photolithographic steps have hindered the optical characterization of ridge waveguides, optical propagation through the planar structure has been observed. These results prove that waveguides with SWCNT incorporated-core could be very promising structures to implement nanoscale light emitters or optical signal processing functions.

References

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