Integrated polymer waveguides incorporating nonlinear chromophores for all-optical signal processing

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Integrated polymer waveguides incorporating nonlinear chromophores for all-optical signal processing

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Abstract: In order to obtain non-linear waveguides for all-optical signal processing, new nonlinear polymer waveguides incorporating chromophores have been designed and processed using standard photolithographic steps. Polymer refractive index changes with chromophore concentration are presented. Waveguides exhibiting single mode propagation and high optical field confinement are demonstrated and optical propagation losses of 4.1 dB/cm at 1550 nm are measured.

Introduction:

Passive and active optical components for applications in optical fiber communications, optical interconnects inside and between CMOS chips, and in biophotonics (integrated sensors, lab-on chips) are readily available due to progresses in silicon photonics technologies. One of the major future challenge still concerns the development of compact optical components operating at low power, to process high-bit rate signals (about 100 Gbit/s and above). Although several high-speed components have been demonstrated using the high third-order nonlinearity of silicon based waveguides[1], these devices suffer from limitations arising from two-photon absorption (TPA) and free-carrier absorption processes in silicon. To overcome these detrimental effects, integrated structures based on higher bandgap materials, such as AlGaAs, GaInP or chalcogenide glasses have emerged[2]. An alternative approach, which we describe in this paper, could take benefit from the potentially larger third-order susceptibility $\chi^{(3)}$ of organic based materials. Indeed, nonlinear refractive index (n_2) values for organic materials like Polydiacetylene para-toluene sulfonate (PDA-PTS) or Poly(p-PhenyleneVinylene) (PPV) can reach 2.10^{-16} $m^2.W^{-1}$ which is one order of magnitude larger than conventional inorganic semiconductors ($Al_{0.2}GaAs$, Si) or chalcogenides (As_2Se_3).

Design and fabrication:

A molecular engineering methodology is now emerging to further improve the nonlinear efficiency of these organic molecules[3]. The current knowledge of the structure-property relationships indicates a certain number of important trends[4] to design efficient third-order NLO materials as increasing the conjugation length for quasi one-dimensional molecules (such as polymethines), enhancing the intramolecular charge transfer by heteroatomic conjugation incorporation or designing quadrupolar (D-π-A-π-D like DDMEBT molecule[5] used by Koos and co-workers to demonstrate all-optical demultiplexing[5]) and octupolar structures. Following these guidelines, quadrupolar molecules based on pyrimidine and triphenylamine units with a D-π-A-π-D structure[6] have been synthesized via short and high-yielding reactions. Polymeric buried waveguides with different core dimensions have been processed using standard i-line photolithography and reactive ion etching process. PMATRIFE (Poly(2,2,2 MethAcrylate of TRIFluoro-Ethyl) was used for both lower and upper claddings (n=1.41 at 1.55 μm). The waveguide core of the structure is made from chromophores (*Fig. 1a*) incorporated (20 % by weight) in PolyMethyl MethacrylImide (PMMI). *Fig. 1b* shows the cross section of one of the processed waveguides. Using the prism coupling technique, the refractive index of this core layer was measured to range from n=1.515 to 1.55 at a wavelength of 1.55 μm depending on the chromophores concentration (see *Fig. 1c*). UV-Visible spectra (not shown) of chromophores dissolved in in CH_2Cl_2 show two absorption bands located at 301 and 427 nm. All polymer layers were deposited by spin-coating. To avoid subsequent dissolution, thin inorganic barriers layers (SiO_2 or SiN_X) were

deposited by PECVD between the different organic layers. The core dimensions were designed using Olympios software to maximize the optical density in the nonlinear region of the waveguide.
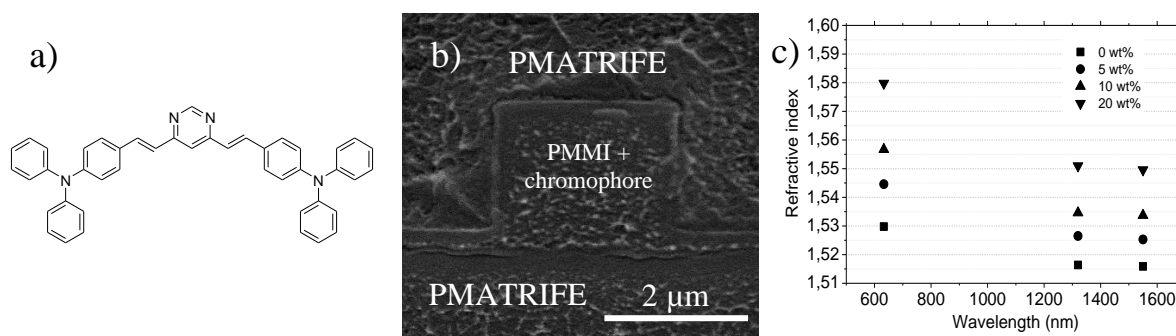

Fig. 1: a) Molecular structure of the chromophores, b) SEM image of the waveguide cross section and c) Wavelength dependence of the core material refractive index for different chromophore concentrations.

Optical characterizations of waveguides:

To minimize coupling losses, microlensed fibers were used to launch a broadband laser source around 1550 nm into the waveguides and to collect outcoming light. Using far field experiments, mode diameter of 2.2 µm were measured at 1550 nm for microlensed fibers. Single mode propagation in the waveguide 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*). A 2.4 µm mode field diameter was measured (at $1/e^2$) by comparing this intensity profile to that of microlensed fibers. Waveguide propagation losses of 4.1±0.3 dB/cm were determined using the cut-back technique (*Fig. 2b*). Several waveguides of the same size (width=1.5 µm, height=2 µm) were characterized for three different sample lengths (0.4, 1.2 and 1.6 cm) without facet polishing after cleaving.
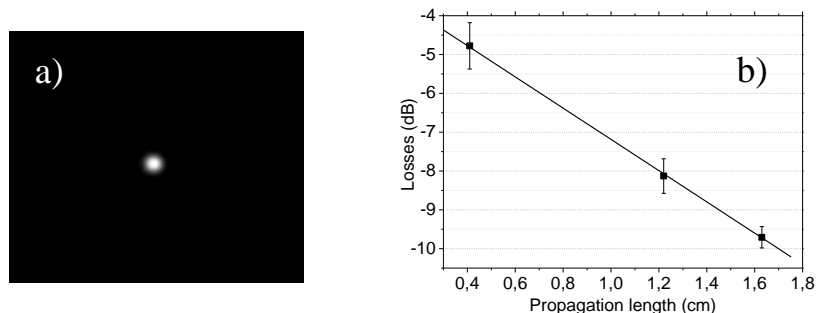

Fig. 2: a) Intensity profile of the waveguide output (w=1.5 µm, h=2 µm) b) Loss measurements of the polymer waveguide (w=1.5 µm, h=2 µm) derived from the by cutback method.

Conclusions:

Nonlinear molecules potentially fulfilling simultaneously the main requirements of all-optical processing applications (large nonlinear refractive index n_2 at 1.55 µm, reduced losses related to TPA around 1.55 µm and ultrafast response (<ps) of the nonlinear refractive index) have been synthesized. The fabrication process of single mode organic-based nonlinear waveguides exhibiting propagation losses of 4.1±0.3 dB/cm has been described. These results show that the incorporation of nonlinear chromophores in standard polymers could be a way to implement waveguides dedicated to efficient all-optical signal processing.

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