Doping optical devices with erbium complexes or lead chalcogenide nanoparticles leads to substantially improved performance that could prove useful in telecommunications.

The increasing demands of broadband telecommunications have triggered the emergence of molecular photonics. The abundance and flexibility of structures that characterize the field, as well as its position at the crossroads of physics, chemistry, and device engineering, promise new approaches to challenging problems. For example, electro-optic polymers exhibit huge bandwidths (>200GHz) for modulating and switching applications. By the same token, achieving a noticeable gain in the 1.55µm telecommunications domain in polymer waveguides remains a challenge because organic environments limit the IR luminescence efficiency of active emitters. This is due to a reduction of near-IR emission processes which is related to the relatively high vibrational frequencies of the organic chemical bonds.

Here we propose two kinds of near-IR emitters in a polymer matrix: special erbium-organic complexes and lead selenide (PbSe) nanoparticles intended to show near-IR luminescence and gain at the material and waveguide level.

A first solution: special erbium complexes in polymers
Linking organic molecules to erbium through a phosphoryl group protects erbium ions from the reduction processes of near-IR emission that occur in more classical lanthanide organic complexes. Reasonable gain coefficient values (about 1cm⁻¹) of an erbium-complex-doped PMMA (polymethylmethacrylate) film are measured at 1540nm by amplified spontaneous emission (ASE). Figure 1 shows plots of ASE emission as a function of pump-power density and interaction lengths (signal propagation distance).

We developed rib single-mode waveguides made of erbium-doped PMMA using standard lithographic and reactive ion-etching techniques. For gain and loss measurements, pump (980nm) or signal lights (1550nm) were coupled into the waveguide using a 980/1550 wavelength-division multiplexer fiber coupler. ‘On-off’ gain measurements were carried out by comparing the outgoing 1550nm signal with and without pumping. Internal losses do not exceed 1.4dB/cm. From the on-off and loss data we inferred a net gain value of 1dB/cm for very moderate pump-power values (30mW) (see Figure 2).

This result represents the first experimental evidence of a positive net gain in a single-mode erbium-doped polymer waveguide.

Figure 1. (Left) Emission at 1.55µm, as a function of pump intensity, for a 2mm interaction length. The discontinuity observed at 600mW/cm² indicates the onset of a gain regime. (Right) Variation in 1540nm emission with the length of the excited region for a 700mW/cm² pump intensity.

Figure 2. Plot of the optical on-off and net gains at 1540nm as a function of pump power.¹

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A second solution: PbSe quantum dots in polymers

Colloidal PbSe nanocrystal quantum dots have attracted considerable interest due to their potential advantages in telecommunications and near-IR lasers. The absorption and luminescence spectra of these materials are tunable over a broad wavelength range by controlling the average particle size.

Using experimental conditions identical to those for erbium-doped materials, we showed the near-IR gain properties of PMMA films doped with PbSe quantum dots. Figure 3(a) shows emission spectra from one such film for various pumping intensities. A breaking point typical of an amplifying emission regime is illustrated in Figure 3(b). From this data, we infer gain coefficients up to 6.68 cm$^{-1}$, a value substantially higher than that of erbium-containing materials. These properties indicate the potential use of PbSe quantum dots as integrated amplifiers and microlasers for optical communications.

Preliminary results from PbSe-dot-doped polymer waveguides show promising gain properties, with values up to 2.5 dB/cm over the whole C band.

We have managed to overcome the problem of near-IR nonradiative decay phenomena in organic matrices and to show positive gain values in polymer films and waveguides in the 1.55μm telecommunications spectral domain. These results suggest interesting possibilities vis-à-vis the development of polymer-based integrated optical circuits. The potential for mounting a challenge to the best-integrated amplifiers (erbium-doped phosphates with net gain values of 4.1 dB/cm) reported to date is a product of the multifunctional character of polymer-based materials, for example, by combining IR amplification with electro-optic properties at the level of elementary matter.

The most challenging issues in this field are to show both high gain per interaction length unit (typically higher than 5 dB/cm) and the multifunctional character of these materials at the device level. We plan to focus on these issues as next steps.

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