Optical gain in DNA-DCM for lasing in photonic materials*

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We present a detailed study of the gain length in an active medium obtained by doping of DNA strands with 4-(dicyanomethylene)-2-methyl-6-(4-dimethylaminostyryl)-4H-pyran dye molecules. The superior thermal stability of the composite and its low quenching permit one to obtain an optical gain coefficient larger than 300 cm^{-1}. We also demonstrate that such an active material is feasible for the infiltration into photonic nanostructures, allowing one to obtain fluorescent photonic crystals and promising lasing properties.

Nanoengineered devices and metamaterials are offering nowadays novel ways of controlling light propagation and amplification ranging from random systems [1] to photonic crystals [2]. Nanostructured lasers are typically realized on a subwavelength structured dielectric matrix, either periodically or randomly, in which an active medium is inserted to provide optical gain. Their optimization has often been focused on the increase in the matrix quality and refractive index contrast, while recently more efficient active media like fluorescent polymers [3,4] or dye doped semiconductors [5] have proven to enhance light amplification.

Within these novel materials, DNA strands intercalated with dye molecules have been proposed as efficient and stable gain media [6]. The superior thermal stability of the composite (up to 250°C) and its low quenching owing to a controlled proximity of the dye molecules attached to the DNA provide an enhancement of the emitted integrated luminescence with respect to the conventional polymer-dye composite [7]. This makes DNA-based dyes as optimal candidates to infiltrate nanostructures and to realize novel active photonic devices. Direct-gain measurements are the best way to compare the optical amplifications and efficiencies of active media [8,9]. At variance with simple luminescence experiments, gain studies are not affected by the sample thickness uncertainty or by variations in the outcoupling owing to the edge roughness.

We report on the characterization of the optical amplification of DNA films intercalated with a 4-(dicyanomethylene)-2-methyl-6-(4-dimethylaminostyryl)-4H-pyran (DCM) laser dye (DNA-DCM) by measuring the optical gain coefficient *g*, which reaches values as large as 300 cm^{-1}. We demonstrate how this material can be used to introduce an efficient gain into self-assembled photonic nanostructures.

Figure 1(a) shows the optical gain coefficient *g* as a function of the DNA-DCM weight percentage. The optimal amplification efficiency is obtained for a dye density between 2 and 3 wt. %, while at higher concentrations quenching phenomena decrease the effective optical amplification.

Figure 1(b) shows the optical gain coefficient as a function of the pump power for an optimal DNADCM ratio of 3 wt. %. For energies higher than 4 nJ/μm^2, the gain coefficient saturates, while above 9 nJ/μm^2 the gain reduction is due to optical damage.

We have also performed a lasing experiment on samples, with and without DNA, obtaining random lasing (RL) [10-12]**.**

In Fig. 2(a) the normalized emission intensity is plotted versus the wavelength for different pump pulse energies. The spectral FWHM narrows from 85 to 15 nm by increasing the pump energy. Figure 2(b) shows the peak intensity (open squares) and FWHM (open triangles) as a function of the pump energy. This demonstrate the clear efficiency advantage of this material as the lasing threshold occurs at energy denisities 10 times lower respect same sistem doped with standard dye.

In conclusion we measured optical gain coefficients with values as high as 300 cm^{-1}, with low quenching, and large thermal stability. Careful characterization of the gain length in the active material allows one to predict the lasing threshold and to efficiently design novel light-emitting nanostructures.

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Figure 1

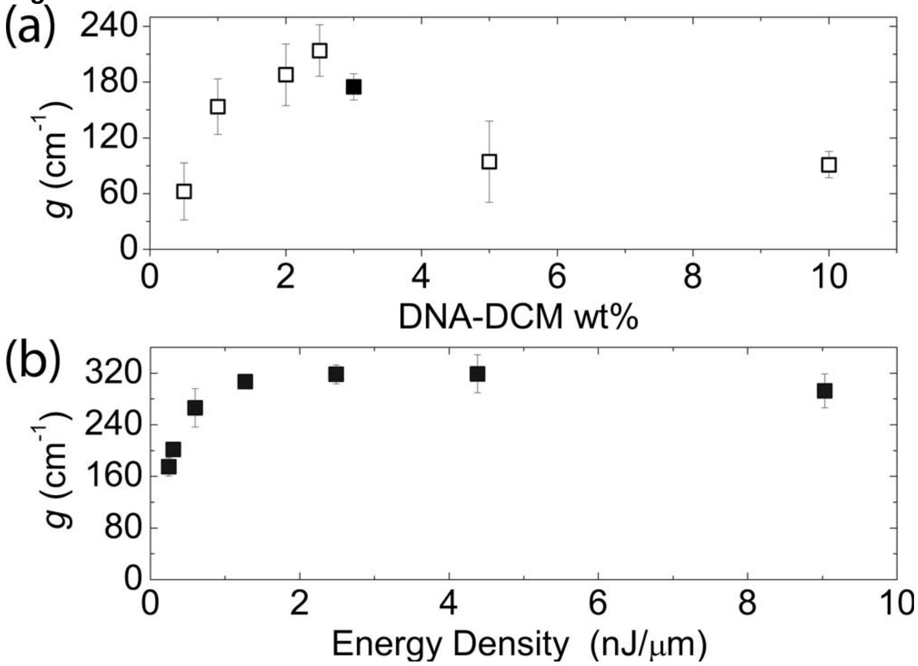

Figure 2