Laser dynamics and optical switching in organic distributed feedback lasers

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Conjugated polymers are very attractive materials for plastic lasers and amplifiers and many devices have so far been demonstrated.[1] Efforts have been devoted to improve laser performances by engineering the materials and the laser configurations[1], while little is known about the photon-exciton and laser dynamics within the device under operation, the role of morphology and the possibility to perform optical switching

In this work we study a Distributed Feedback (DFB) laser, based on poly(9,9-dioctylfluorene-cobenazothinole) (F8BT), made by deposition onto pre-patterned substrates (planarized DFB) or by soft-lithography onto the organic film (imprinted DFB). The latter is a fast, cheap and industrial compatible process. We time-resolve the laser-pulse build-up dynamics in the ps time domain and investigate the role of morphology and, by using an additional gating pulse, we switch off the laser action. The DFB master grating (period of 350 nm) for surface emitting laser was fabricated by Electron Beam Lithography on a quartz substrate, the polymer was dissolved in toluene solution and spin coated onto the substrate. The laser was pumped by 200-fs laser pulses at 400 nm and emitted at ~580 nm.

Figure 1 shows the normalized temporal evolution of the transient transmission, obtained by Pump&Probe technique, at 580 nm, which corresponds to the dynamics of the population of the upper laser level, for the DFB *lasing* device (empty circles) and for the polymer without the grating (crosses). The two kinetics shows an abrupt change of behaviour ~1.7 ps after excitation where very rapid decay corresponds to fast depopulation due to laser action. The laser dynamics can be described by a set of coupled rate equations (the result is shown as continuous line) showing that population inversion is achieved immediately, while laser pulse formation requires a build-up time, which is ~1.7 ps in this case, the emitted pulse duration is ~280 fs and the photon cavity lifetime 105 fs. These parameters are very important to obtain a deeper understanding on the organic laser behaviour, in order to fabricate more efficient materials and devices. A series of further experiments allowed us to determine loss and feedback mechanism in the device.

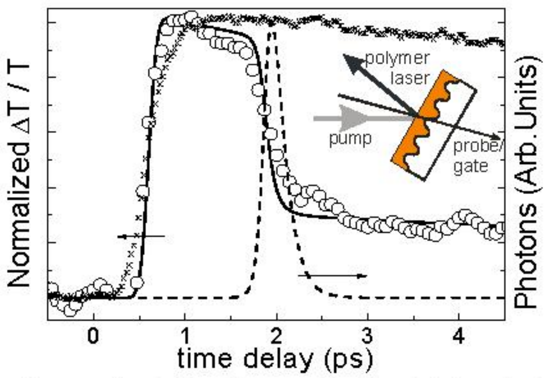

Fig. 1: Temporal evolution of the normalized transient transmission changes ΔT/T at 580 nm probe wavelength, on the DFB device under *lasing operation* (circles) and out of the device (crosses). The solid line is the fitting curve and the dashed line is the normalized output pulse obtained from the model. Inset: scheme of the experiments.

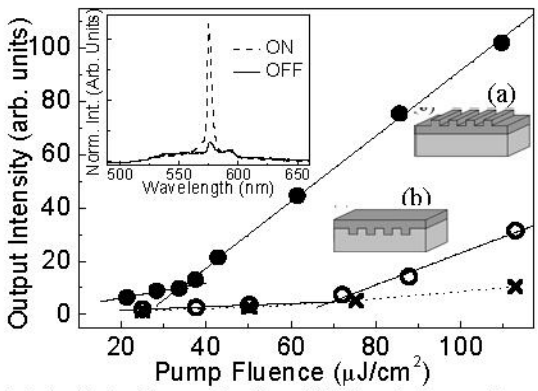

Fig. 2: Output intensities as a function of the absorbed pump fluence. Open circles: planarized DFB, filled circles: imprinted DFB; the continuous lines are linear fit to experimental data. Crosses: Amplified Spontaneous Emission out of the DFB. Left inset: output spectra of the laser and of the switched off laser.

The comparison between the planarized (scheme (b) in Fig. 2) and the imprinted (scheme (a) in Fig. 2) DFB lasers shows that the latter, even though a lower quality copy of the master at morphological level, exhibits better performance than the planarized structure. The characteristics in figure 2 shows, that the imprinted device has a lower threshold an a higher slope efficiency. A qualitative explanation can be provided in terms of optical contrast, in fact a dominating index coupling mechanism is observed and the effect of higher contrast seems to be so important to largely overcome the losses due to pattern defects caused by imprinting.

Moreover we optically switch off the lasing device by using a gating pulse that introduces photoinduced absorption losses. This process is efficient during laser build-up time, after this time the laser pulse is produced and no switching is possible. Note that using the proper energy of the switcher pulse we could achieve complete shut down of the polymer laser (inset in Fig.2). Various experiments and a set of rate equations tacking into account also photo-induced absorption and carrier generation allow to study the switching mechanism and capabilities.

[1] M. . D. McGehee and A. J. Heeger, Adv. Mater. (Weinheim, Ger) **12**, 1655 (2000) and references therein; N.Tessler, Adv. Mater. (Weinheim, Ger) **11**, 363 (1999) and references therein.
[2] M. Zavelani-Rossi, S. Perissinotto, G. Lanzani, M. Salerno, G. Gigli, *Appl. Phys. Lett.* **89**, 181105 (2006).