Efficient organic distributed feedback lasers with active films imprinted by thermal nanoimprint lithography

A. Retolaza[1], I. Alonso[1*], D. Otaduy[1], A. Juarros[1], S. Merino[1], M.G. Ramirez[2], P.G. Boj[2], V. Navarro-Fuster[2], I. Vragovic[2], J.M. Villalvilla[2], J.A. Quintana[2], M.A. Diaz-Garcia[2]
[1]Micro and Nano Manufacture Unit, Tekniker-IK4, Avda. Otaola 20, 20600, Eibar, Spain
[2]Instituto Universitario de Materiales de Alicante, Universidad de Alicante, 03080 Alicante, Spain
[*]Dept. of Applied Physics II, University of the Basque Country, Paseo de la Universidad 7, 01006, Vitoria, Spain
aretolaza@tekniker.es

Abstract

Organic solid-state lasers (OSLs) have been a subject of intense research for many years [1] mainly due to the various advantages of organic materials, such as easy processability, chemical versatility, wavelength tunability and low cost. Among the various types of resonators used in the field of OSLs, distributed feedback (DFB) structures are probably the most extensively studied. As compared to other types of lasers, DFBs present several advantages, such as easy deposition of the organic film, low thresholds, single mode emission and no need of mirrors. In addition, DFBs have potential for new applications in the field of biosensing and chemical sensing, that are currently receiving a great deal of attention [2,3]. Among the methods generally used for grating engraving, nanoimprint lithography (NIL) [4] is one of the most promising technologies, even for future industrial applications, due to its high throughput, high resolution (sub-10 nm) and low cost.

From the materials point of view, a wide variety of materials has been used to fabricate the active layers of organic DFBs [1]. Among them, our group has focused in the last years in polystyrene (PS) films doped with perylenediimide derivatives (PDIs) [5], mainly due to their excellent thermal and photostability properties, as well as their high photoluminescence quantum efficiencies. In addition, these materials are particularly interesting in the field of data communications based on polymer optical fibers because they emit at wavelengths around 570 nm, inside the second low-loss transmission window in poly(methylmethacrylate). We recently reported [6] low-threshold and highly photostable (under ambient conditions) DFB lasers, based on PDI-doped films, in which the DFB gratings were fabricated by thermal-NIL on a resist and then transferred to the substrate (SiO_2). In view of the good performance of these lasers, we thought about possible ways to further improve their performance. A very attractive strategy consists in engraving the DFB gratings directly on the active material, instead of on the substrate, in order to simplify the fabrication process and therefore reduce the cost of the devices.

In this presentation we report on the fabrication and characterization, under optical pump, of organic DFB lasers based on PS films doped with a PDI derivative (PDI-C6, Figure 1a) as active material [7]. The use of thermal-NIL to imprint the gratings directly on the active film (see scheme of the device geometry in Figure 1b) has allowed, as opposed to room temperature or solvent-assisted techniques, high grating quality and excellent modulation depth (Figures 1c and 1d). In addition, the process is very simple (only one step) with no need of etching methods to transfer them to the substrate. It is also remarkable that the high-temperature treatment (155ºC for 900 s) used in the NIL process does not negatively affect the thermal stability and the optical properties of the active films. The emission wavelength of the devices was tuned between 565 and 580 nm by film thickness variation (Figure 2) and results were successfully modeled by considering an average effective index ("Model average n_{eff}") or an average thickness of the active film "Model *h+(d/2)*". These devices combine a simple and low-cost preparation method with good laser characteristics, i.e. thresholds of 1 µJ/pulse, single-mode emission with linewidths below 0.2 nm and photostability half-lives of $\sim 10^5$ pump pulses under ambient conditions. In comparison to more standard DFBs with gratings on the substrate, their fabrication is much easier, while they show a similar laser performance.

Acknowledgements

This work has been funded by the "Ministerio de Ciencia e Innovación" and the European Community (FEDER) through the grant MAT2008-06648-C02. It was also partially supported by a CSIC fellowship within the program JAE.

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Figures

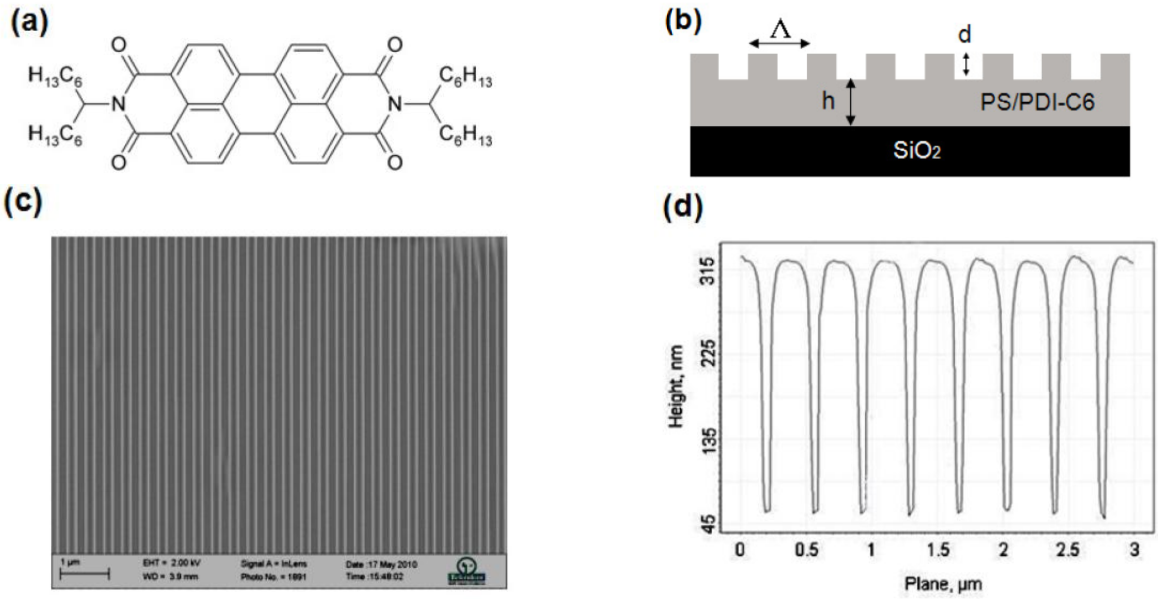

Figure 1. (a) Chemical structure of PDI-C6; (b) Schematic of the DFB device (Λ = 368 nm, *d* = 260 nm, *h* = 320-890 nm), (c) SEM image and d) AFM profile of the grating engraved on the active film.

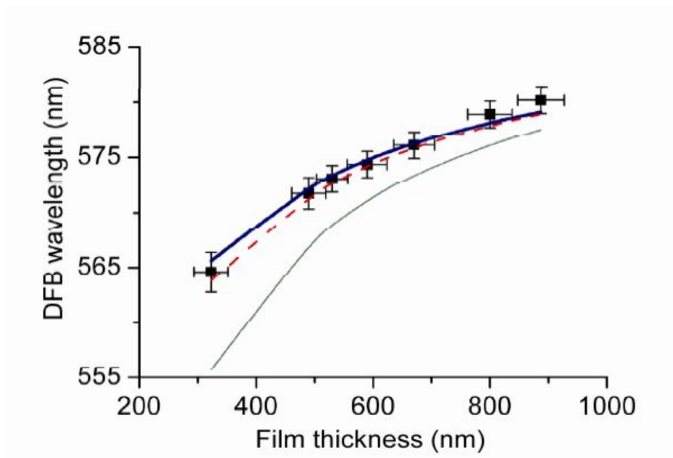

Figure 2. Laser wavelength of DFB devices with active films of different thickness *h*. Symbols: Experimental data; Thick full line: "Model *h*+(*d*/2)"; Dashed line: "Model average n_{eff}"; Thin full line: "Model *h*".