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

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

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Outline

- Organic Distributed Feedback (DFB) lasers
- Fabrication process: Nanoimprint Lithography (NIL)
- Optical characterization: DFB lasers
- Summary of the work

Basic elements of a laser

- **Active medium**: Organic / Inorganic material
  $\rightarrow$ Light emission

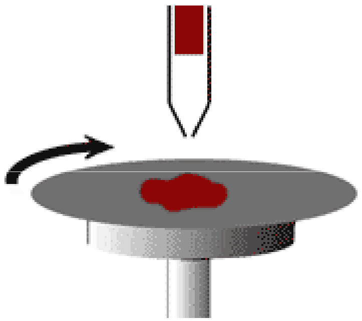
- **Pump**: Optical / electrical
  $\rightarrow$ Amplified Spontaneous emission (ASE)

- **Resonator**: Mirrors / Bragg Gratings
  $\rightarrow$ Intensification of light field

Why organic material for lasers?

- **Active medium**:

- Broad photoluminiscence spectrum: the laser wavelength can be tuned over a wide range.
- If soluble: easy processability.



Spin-coating

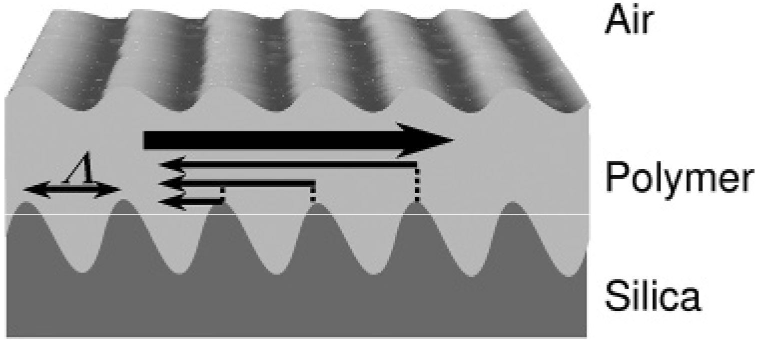
- Versatility of organic chemistry: properties can be tuned by structural modifications.
- Low cost

❖ Organic materials doped with dye molecules or **small semiconducting molecules**

- No PL quenching (In many cases)
- Lower thresholds
- Useful materials to achieve laser emission by electrical pumping (transport properties))

Why distributed feedback (DFB)?

- **Resonator**: distributed feedback (DFB)



Light propagating in a waveguide mode is scattered from the periodic structure to create a diffracted wave propagating in some new direction.

- Low thresholds
- Easy to achieve single mode emission
- No need of mirrors

⬇

Data communication
Biosensing

Previous works

Microelectronic Engineering **87**, 1428 (2010)

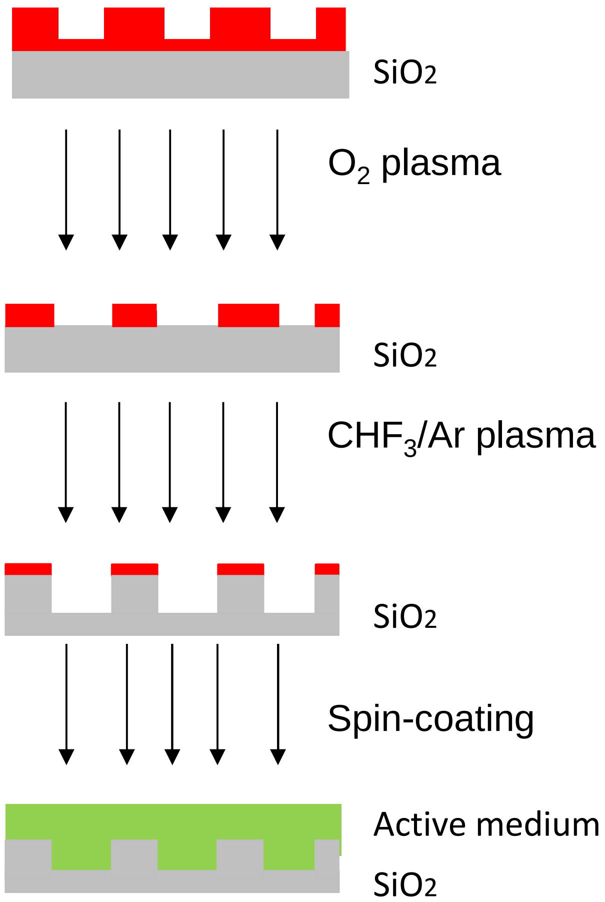
Highly photostable solid-state organic distributed feedback laser fabricated via thermal nanoimprint lithography

V. Trabadelo [a,*], A. Juarros [a], A. Retolaza [a], S. Merino [a], M.G. Ramírez [b,c], V. Navarro-Fuster [b,c], J.M. Villalvilla [b,c], P.G. Boj [b,d], J.A. Quintana [b,d], M.A. Díaz-García [b,c]

APPLIED PHYSICS LETTERS 97, 171104 (2010)

Highly photostable organic distributed feedback laser emitting at 573 nm

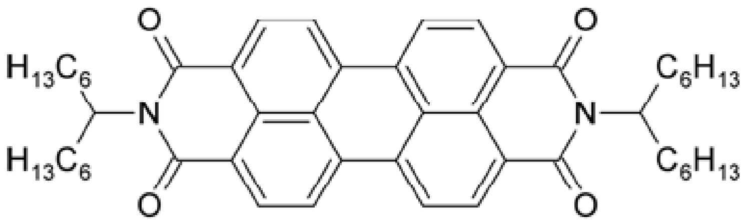
Victor Navarro-Fuster,[1] Eva M. Calzado,[1] Pedro G. Boj,[1] José A. Quintana,[1] José M. Villalvilla,[1] María A. Díaz-García,[1,a)] Vera Trabadelo,[2,b)] Aritz Juarros,[2] Aritz Retolaza,[2] and Santos Merino[2]



Recent work

- **Active medium**: polystyrene doped with 0.5 wt% of a perylendiimide derivative.

Díaz-García et al., *J. Phys. Chem. C* ***111****, 13595 (2007)*
Díaz-García et al., *Appl. Opt.* ***46****, 3836 (2007)*



PDI-C6

- **Pump**: optical pump. Pulsed 532 nm Nd:YAG laser.
  Operating in ambient conditions

- **Resonator**: distributed feedback (DFB). Depth = 260 nm

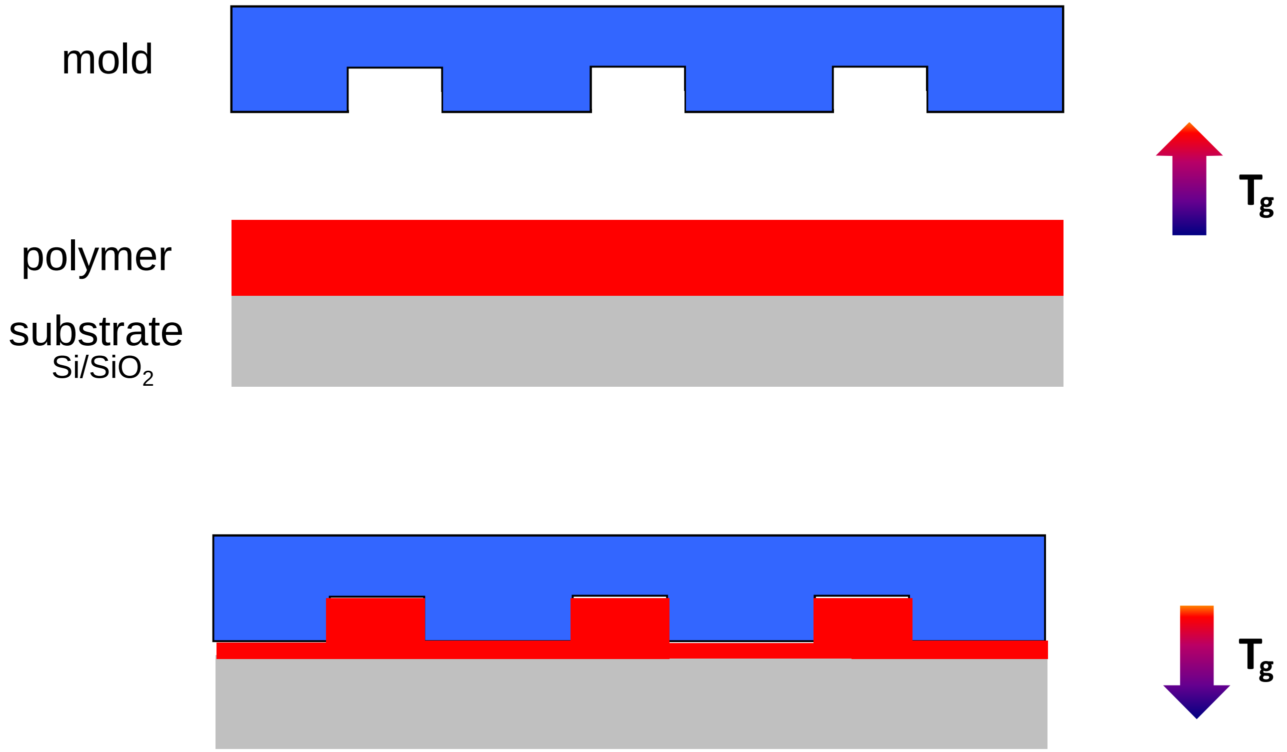
Bragg condition

$$m\,\lambda_{Bragg} = 2n_{eff}\,\Lambda$$

$m = 2 \rightarrow \Lambda = 368$ nm

Fabrication by direct Nanoimprint Lithography

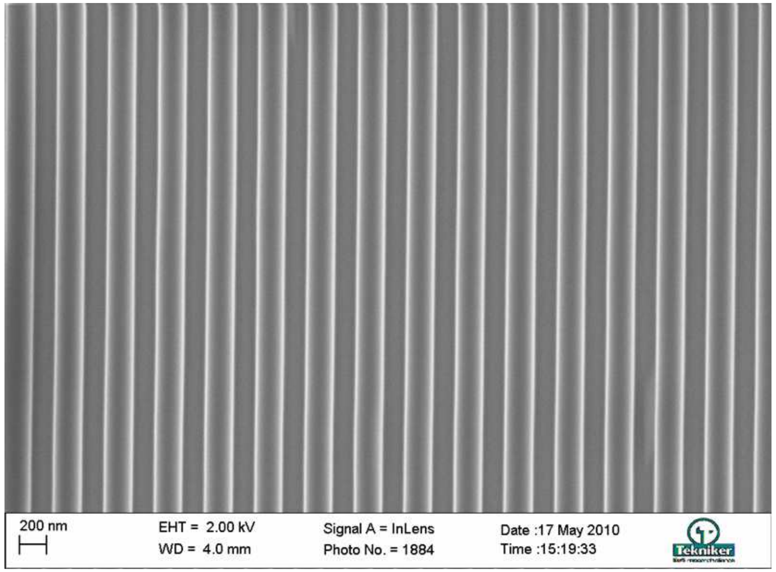
Thermal Nanoimprint Lithography

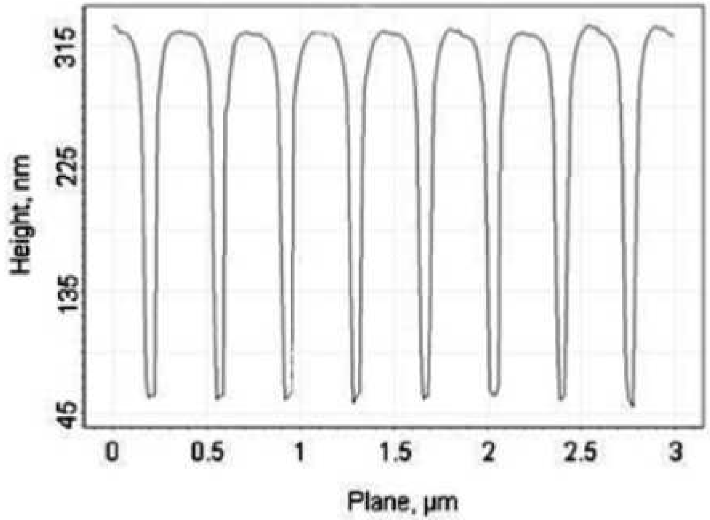


-High resolution
-High throughput
-Low cost

Fabrication of the resonator

- h= 320-890 nm; Λ= 368 nm; d= 260 nm
- Jenoptik HEX03
- Under vacuum, 155ºC, 15kN, 900s, 50ºC
- Degradation (DTA/DSC)

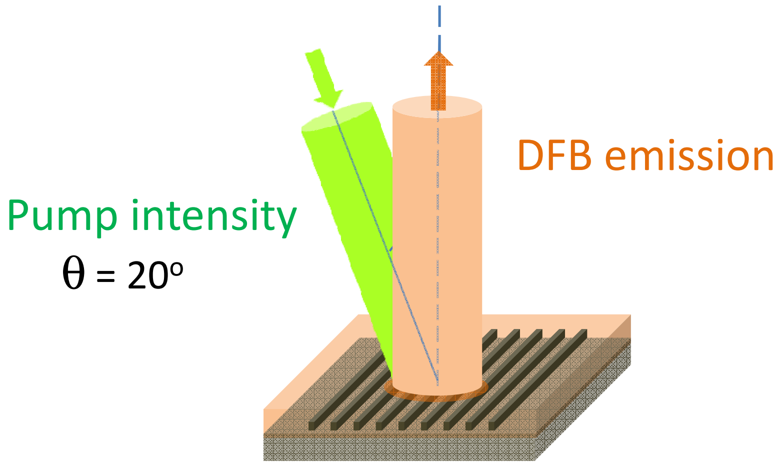




High quality and excellent modulation depth

Optical characterization

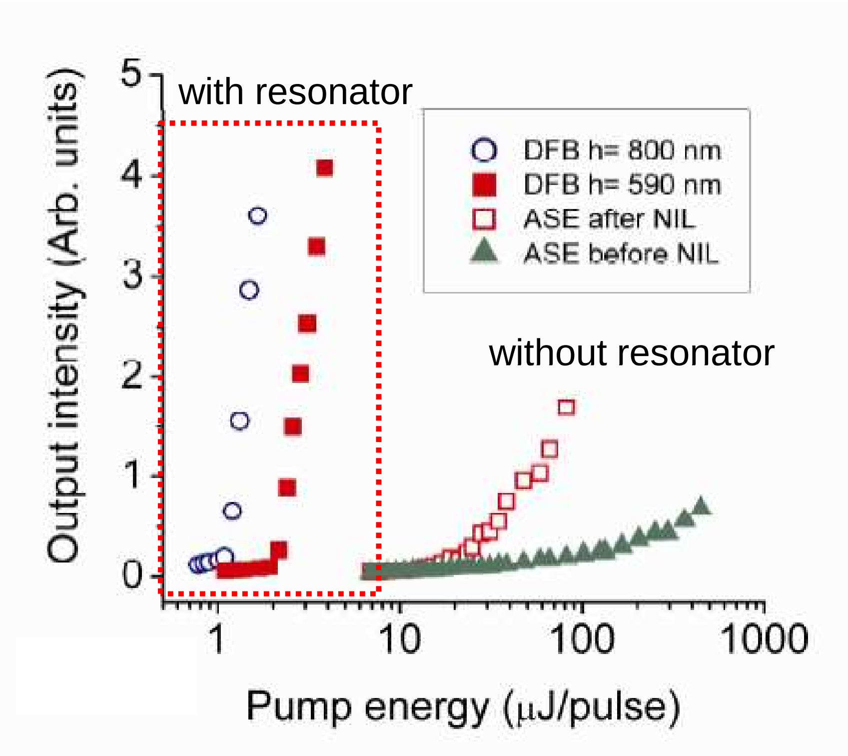
Optical pump: pulsed Nd:YAG laser (10 ns, 10 Hz) operating at 532 nm.
ambient conditions

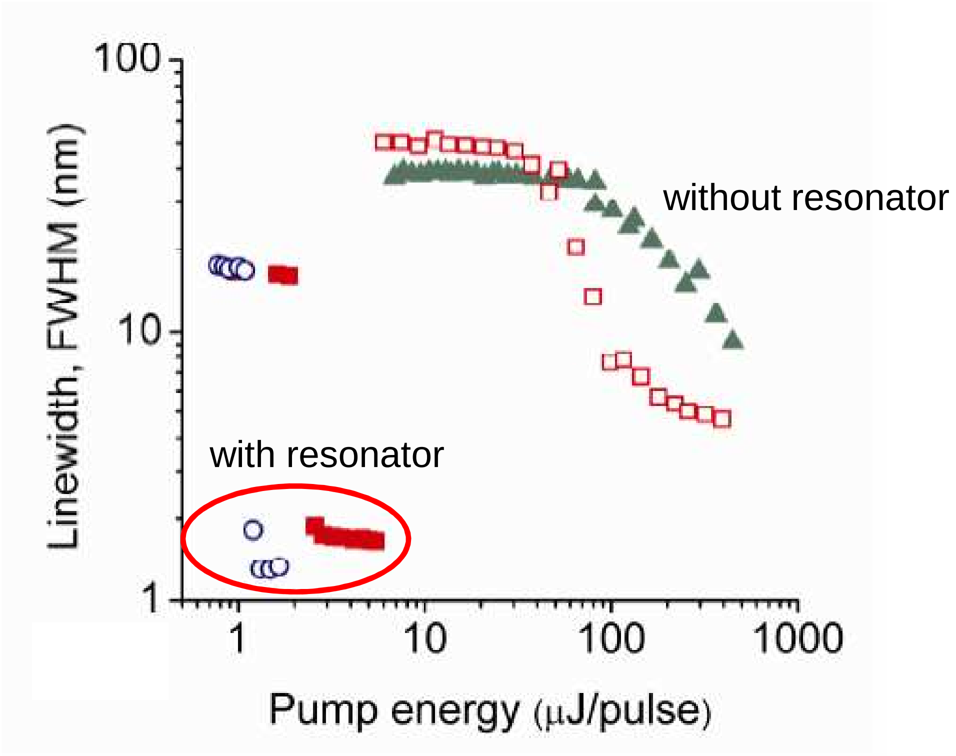


Incident spot diameter: 1.2 mm

* Lasing threshold
* Emission linewidth
* Photostability
* Laser tunability by changing the thickness of the active medium

Optical characterization: Lasing threshold and emission linewidth

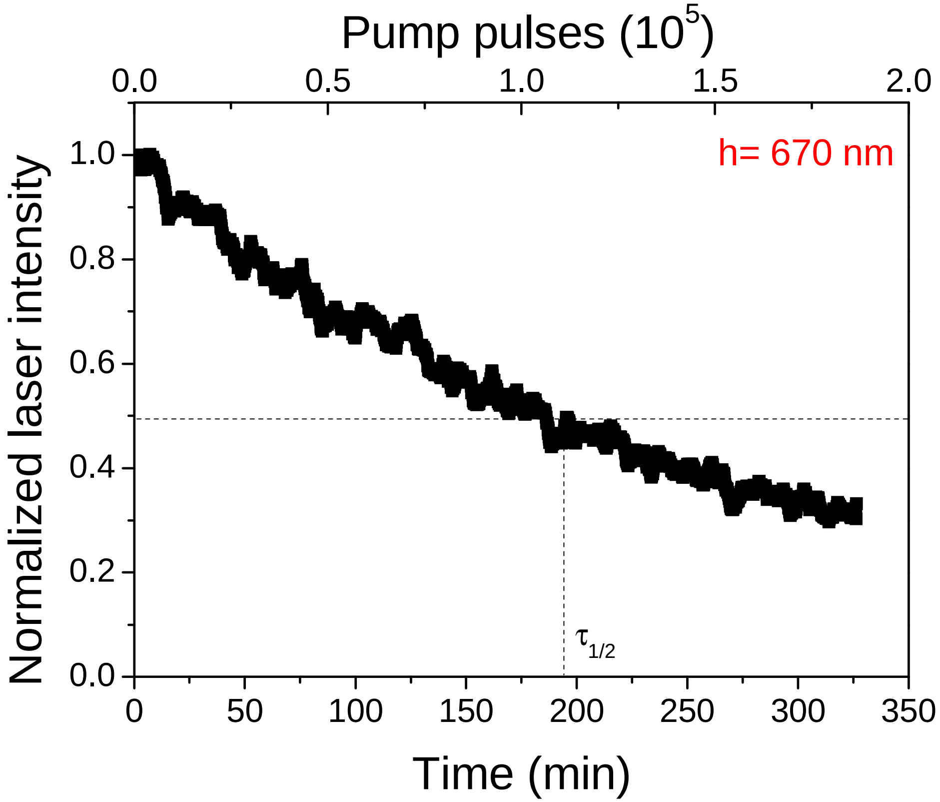




Low threshold (~100 times lower)

Narrower linewidth

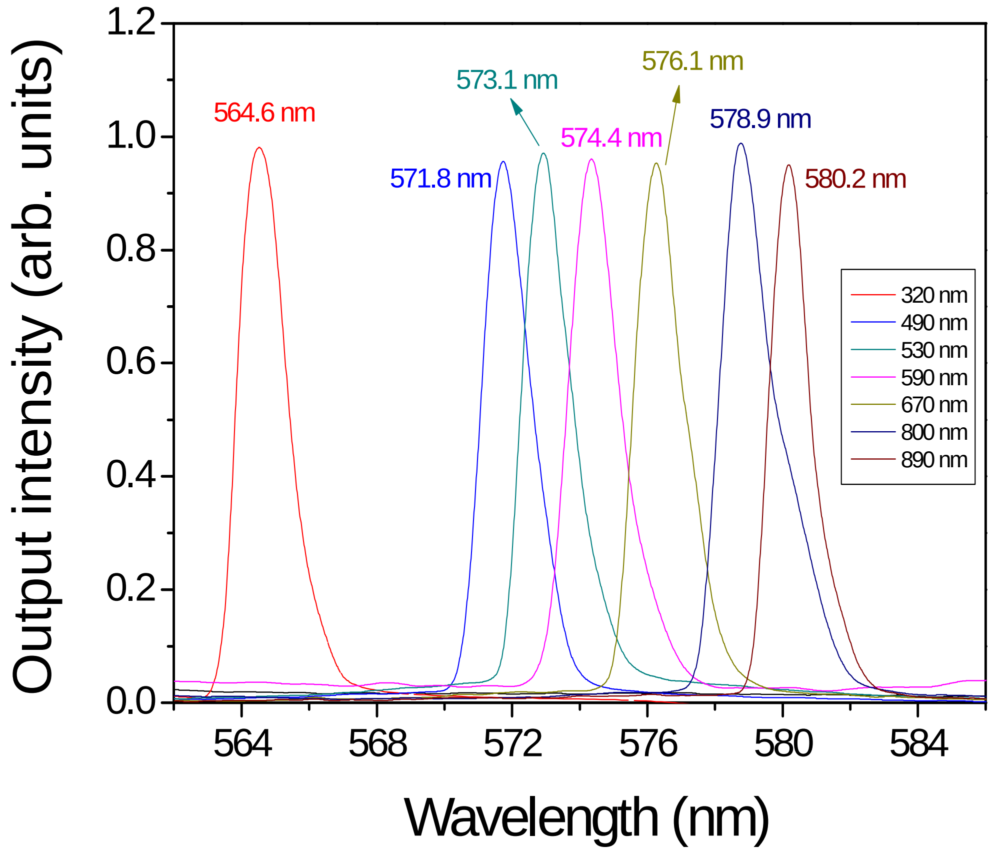
Optical characterization: Photostability



Highest photostability in ambient conditions

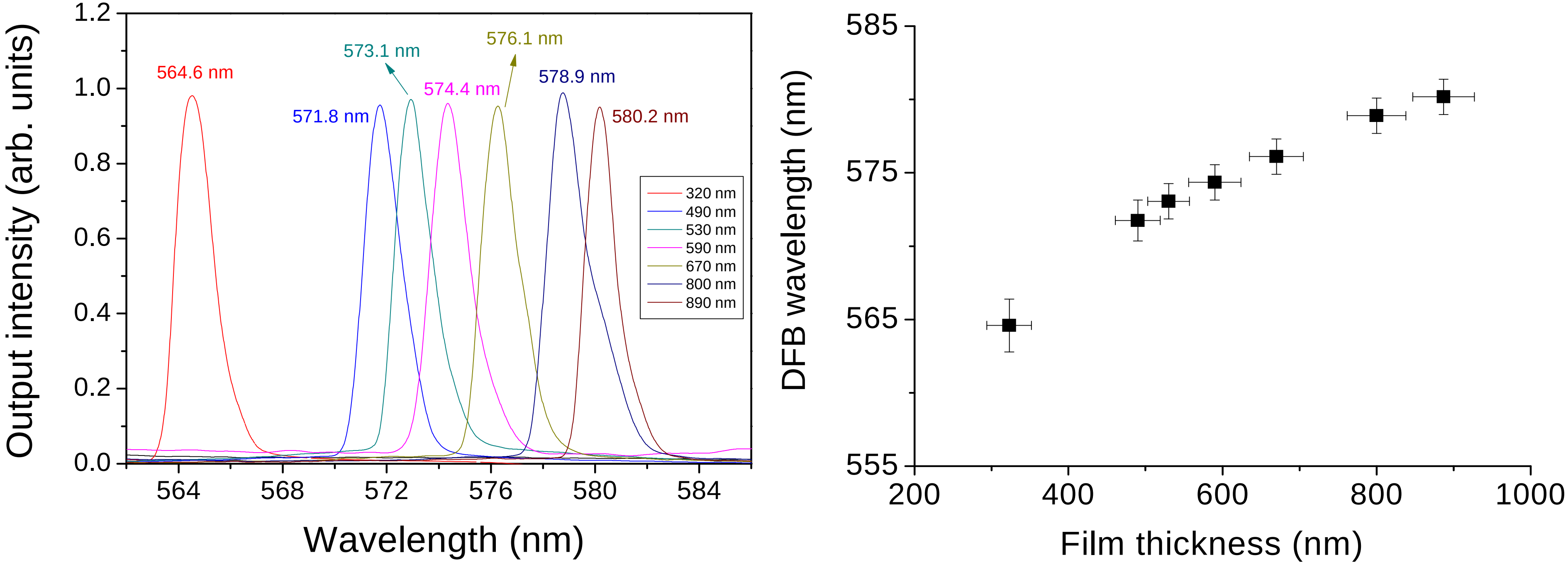
Photostability halflife $\tau_{1/2}$: ~ 1.1 x 10^5 pulses (10 ns, 4 μJ·p^{-1}) at 10 Hz

Optical characterization: Emission spectra

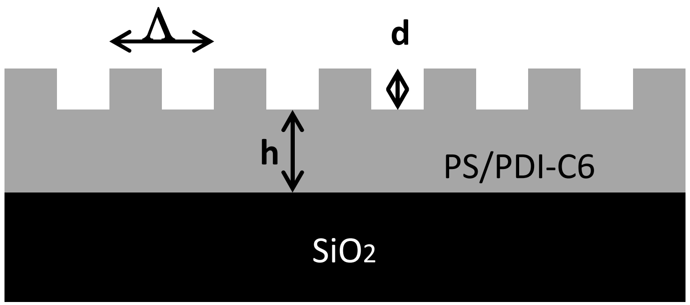


Grating depth 260 nm
Grating period 368 nm
Single mode emission
Tunability of the wavelength

Optical characterization: Effect of the thickness variation



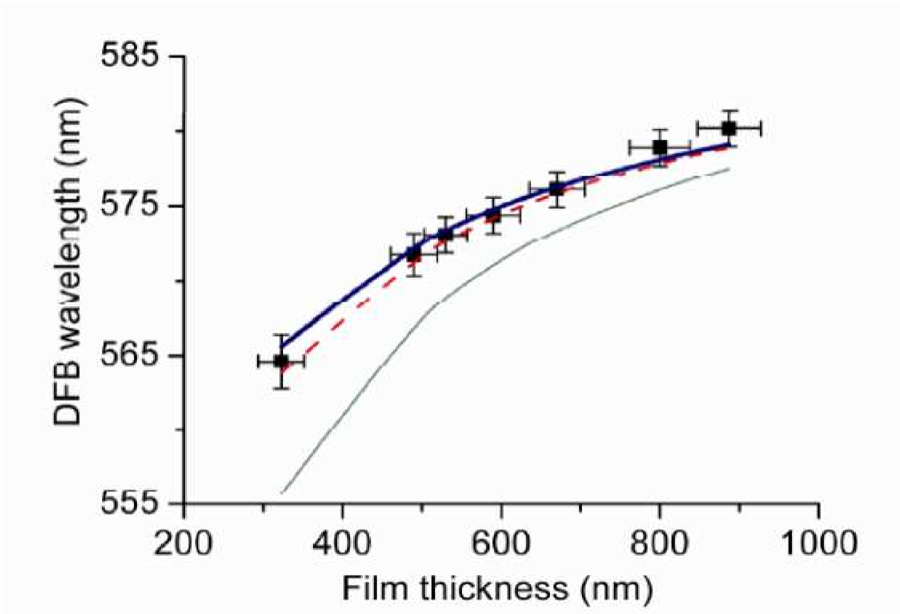
Optical characterization: Modeling



Model *h*: waveguide of thickness *h*

Model *h+(d/2)*: waveguide of thickness *h+(d/2)*

Model n_{eff}: average effective refractive index



$$n_{eff}^{av} = \sqrt{\left(n_{eff,h}^2 + n_{eff,h+d}^2\right)/2}$$

- ■ *Experimental*
- \- *Model h*
- \- *Model h+(d/2)*
- -- *Model n_{eff}*

Summary of the work

- Fabrication and morphological characterization of second order DFB laser devices on PS film doped with a perylendiimide derivative via direct thermal NIL.
- Optical characterization of the devices:
  - Low threshold (~100 times lower than ASE threshold)
  - Highly photostable (halflife ~10^5 pulses at 4 μJ·p^{-1})
  - Single mode emission
  - Tunability of the DFB laser emission wavelength

- Modeling of the DFB laser emission wavelength tunability

- Low-cost and high-sensitivity biosensing devices?

Acknowledgements

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Thank you for
your attention!