Efficient organic distributed feedback lasers fabricated by thermal nanoimprint

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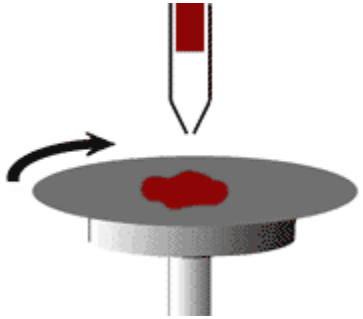
Why organic materials for lasers?

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

- If soluble: easy processability.

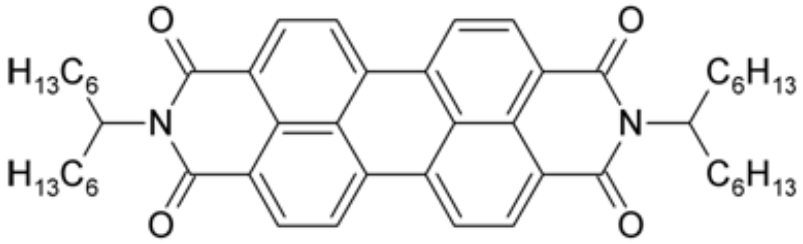


- Versatility of organic chemistry: properties can be tuned by structural modifications.

3 basic elements to have a laser:

- **Pump** (optical): pulsed Nd:YAG laser (10 ns, 10 Hz) operating at 533 nm.

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



Very photostable amplified spontaneous emission (ASE) at low thresholds.

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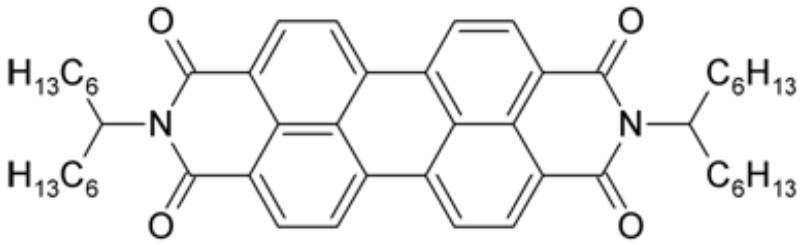
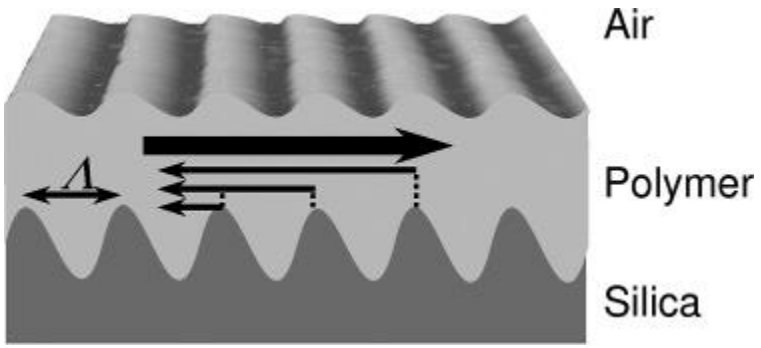


Emission close to 570 nm

(second low-loss transmission window in PMMA)

3 basic elements to have a laser:

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

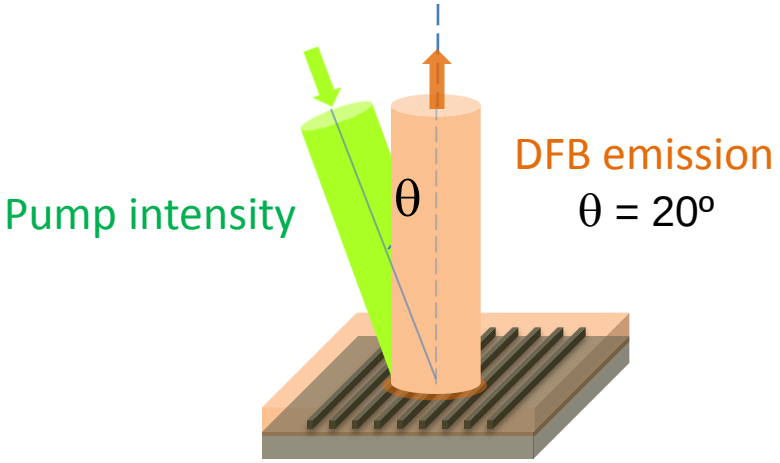


Bragg condition

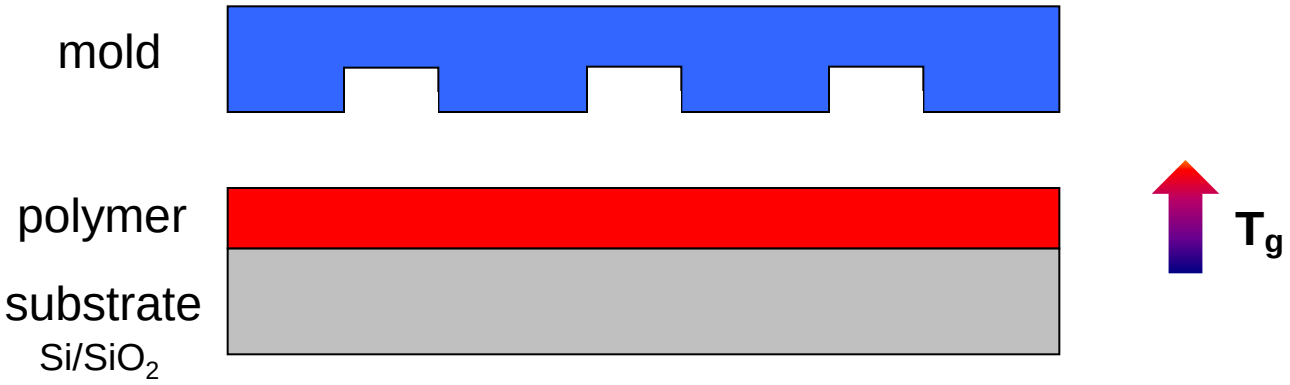
$m\,\lambda_{Bragg} = 2n_{eff}\,\Lambda$

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

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



Thermal Nanoimprint Lithography



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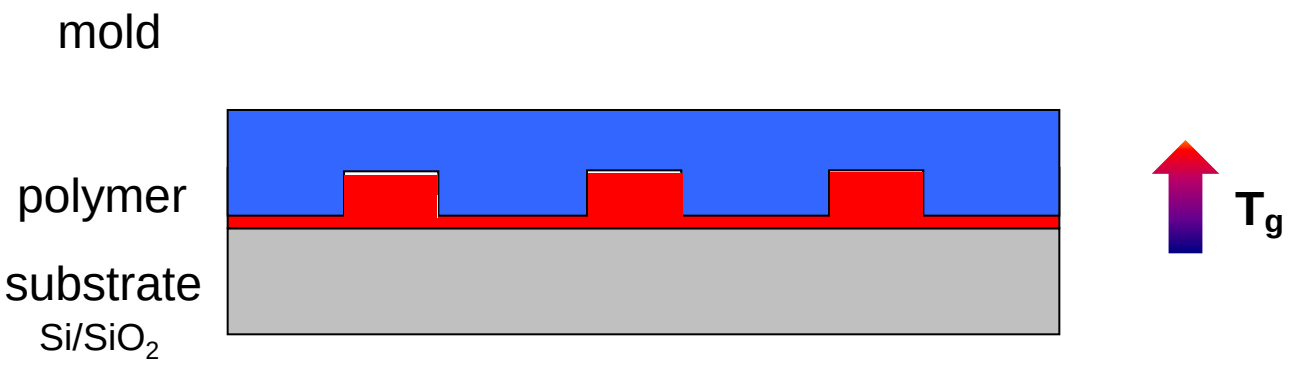

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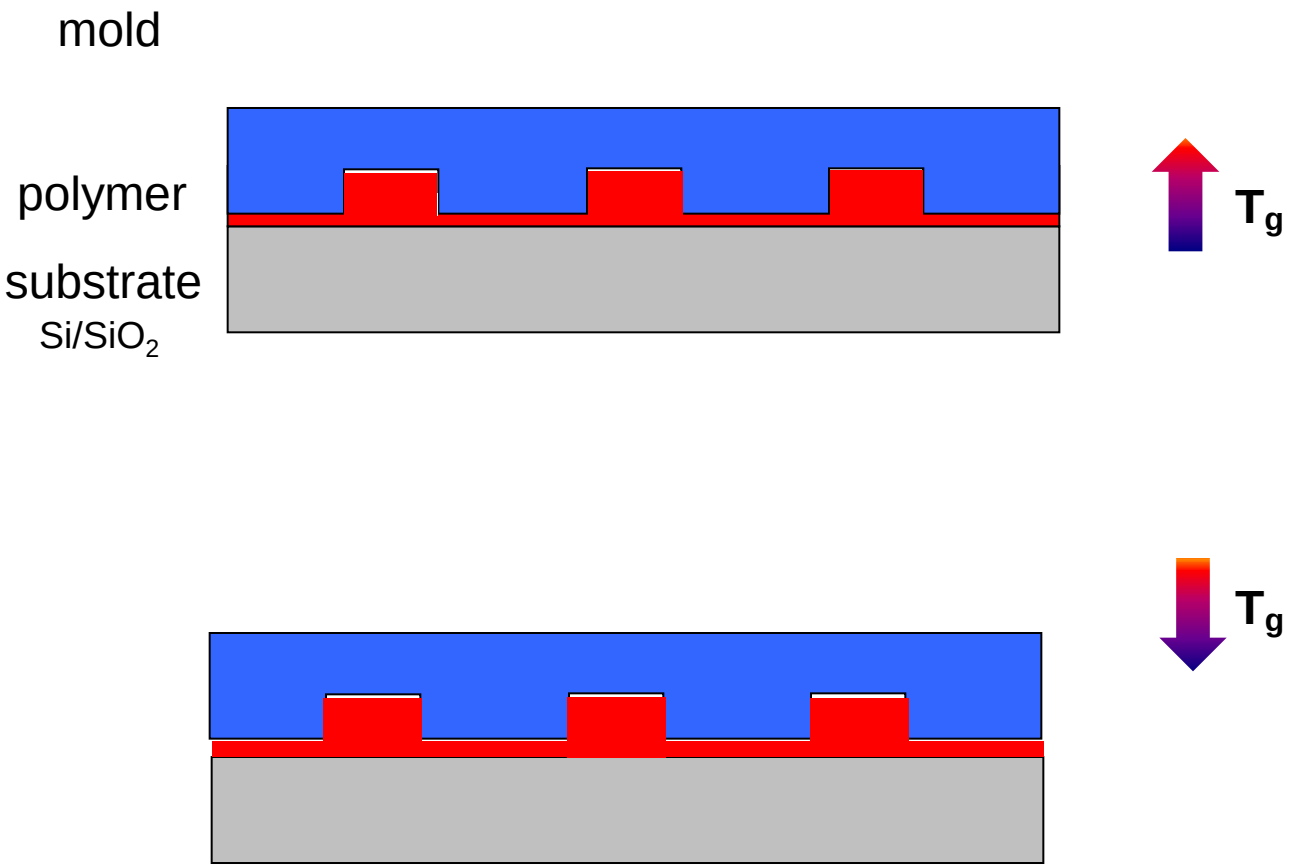

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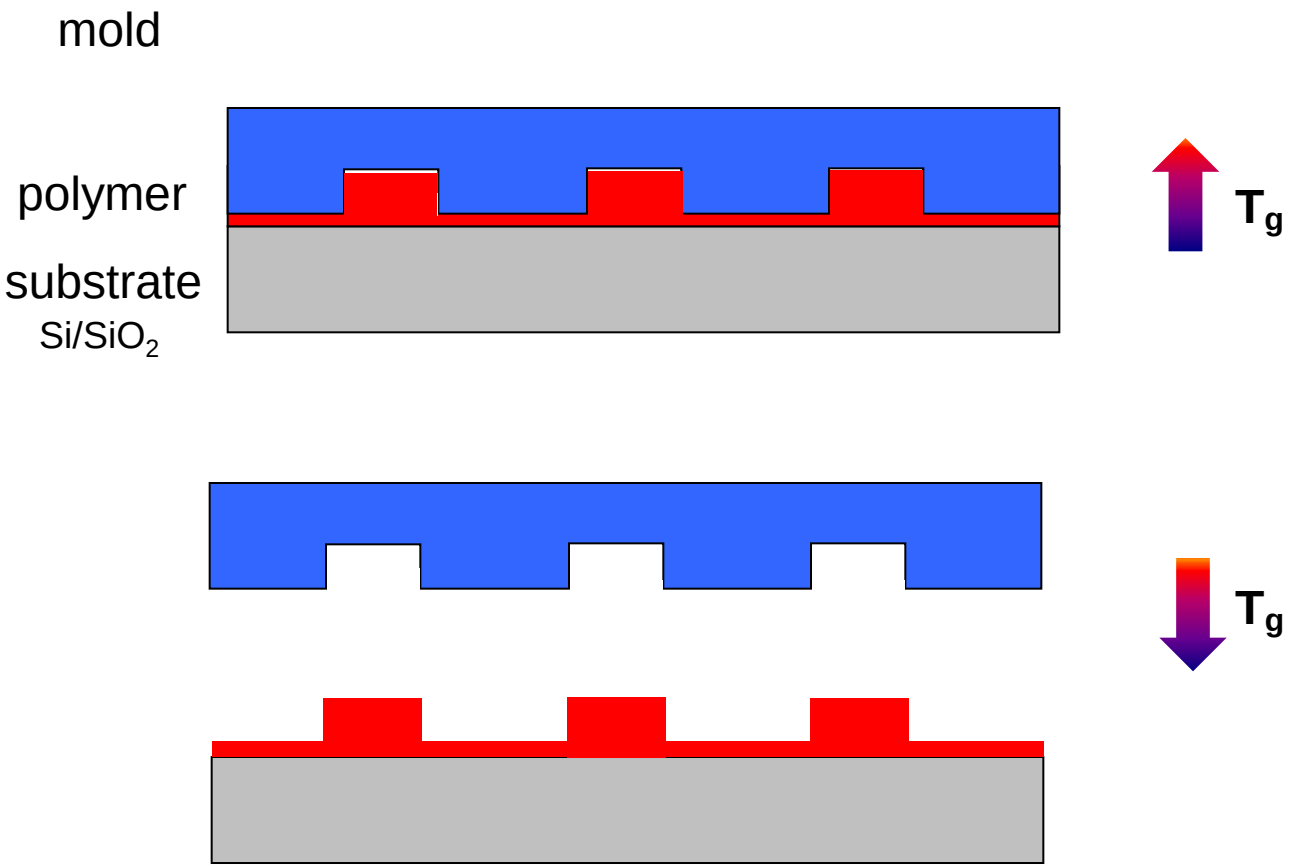

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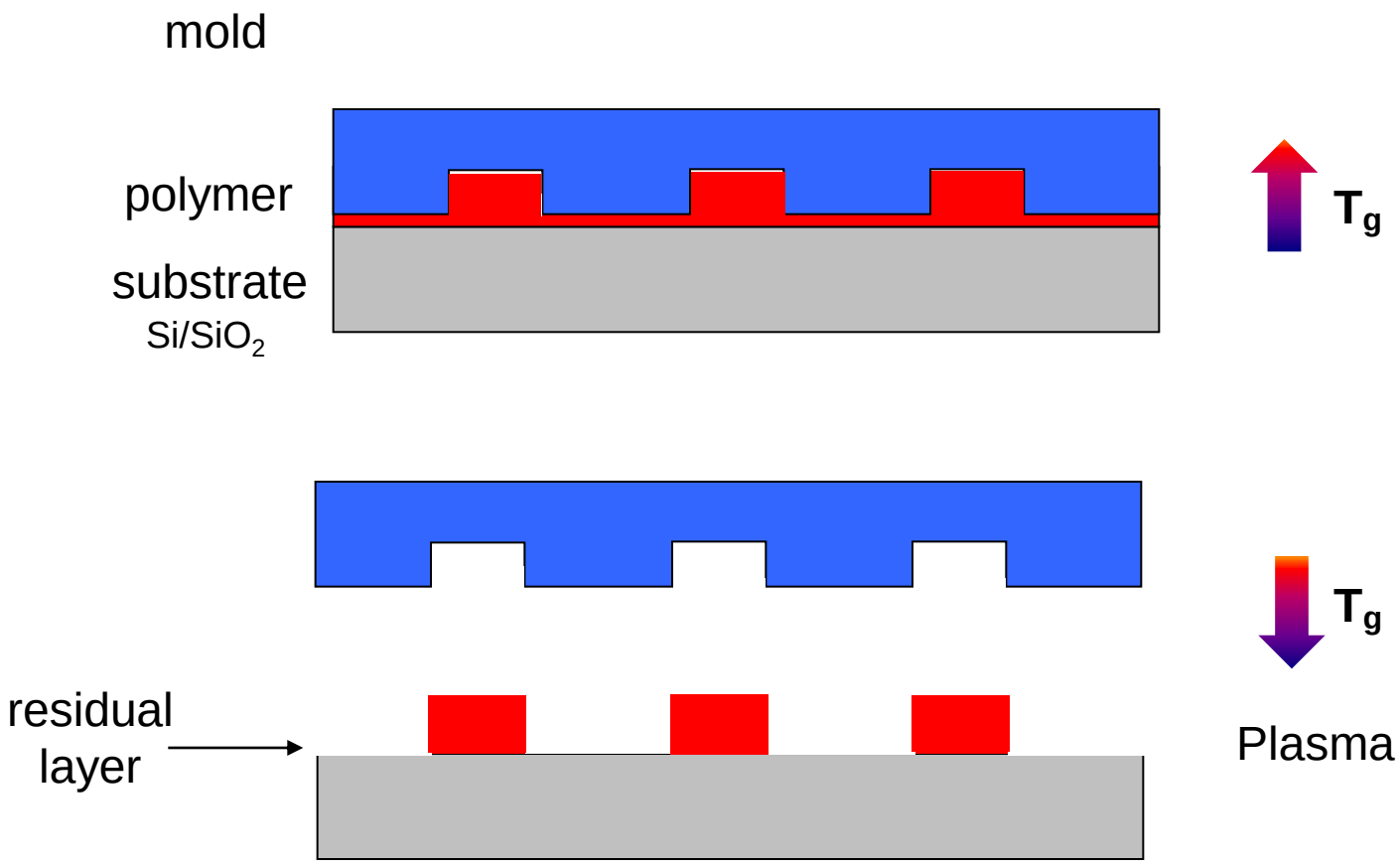

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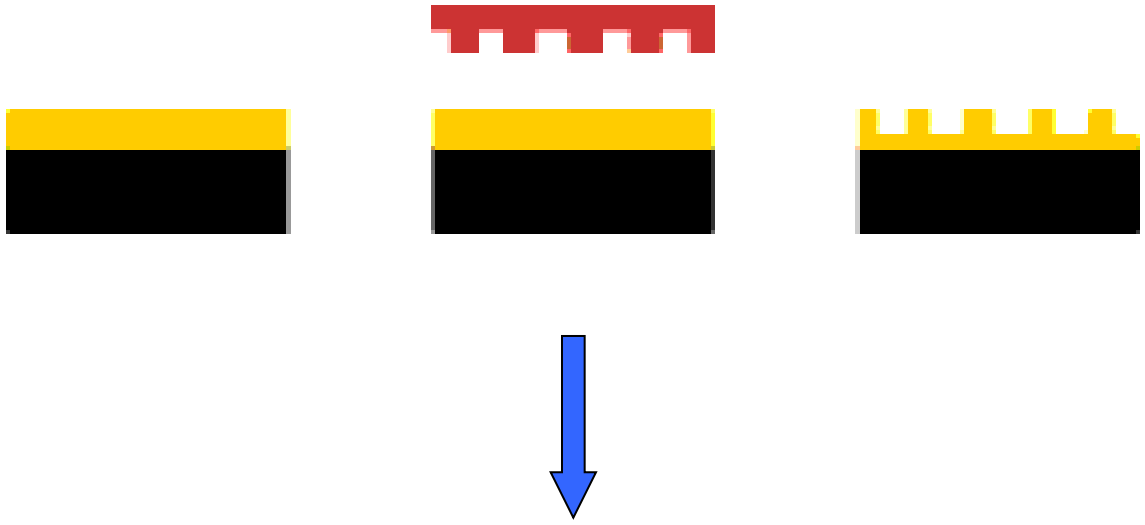


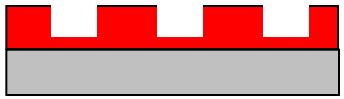
- High throughput

- Low cost

- High fidelity pattern transfer

Fabrication of the resonator: SiO_2 gratings

NIL onto mr-I8030E



- Jenoptik HEX03
- 20000 N
- 180 ºC
- 900 s

Fabrication of the resonator: SiO_2 gratings

NIL onto mr-I8030E

- Jenoptik HEX03
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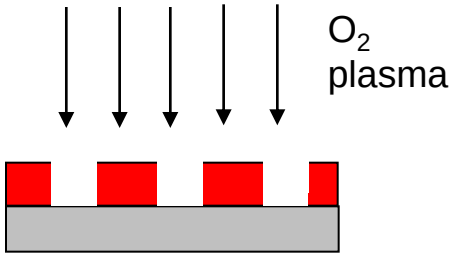
- 900 s

Residual layer etching



- 20 sccm O_2
- 20 mTorr
- 20 W

Fabrication of the resonator: SiO_2 gratings

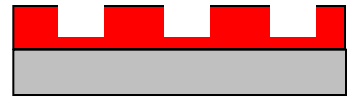
NIL onto mr-I8030E

↓

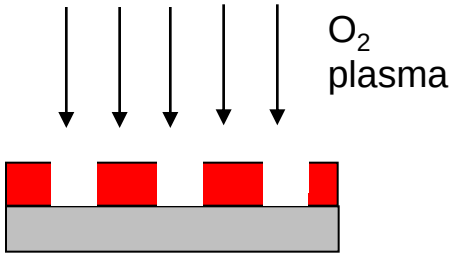
Residual layer etching

↓

SiO_2 etching



- Jenoptik HEX03
- 20000 N
- 180 ºC
- 900 s



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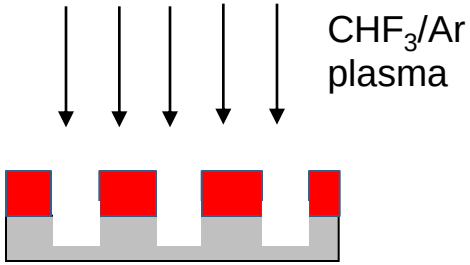
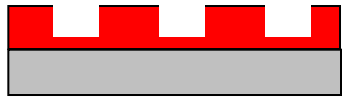


- 25 sccm CHF_3
- 25 sccm Ar
- 30 mTorr
- 200 W
- DEPTH:
  - 340 nm (10 min.),
  - 220 nm (6 min.),
  - 105 nm (3 min.)

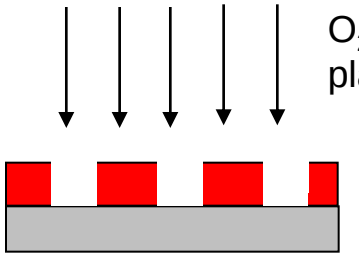
Fabrication of the resonator: SiO_2 gratings

NIL onto mr-I8030E



- Jenoptik HEX03
- 20000 N
- 180 ºC
- 900 s

Residual layer etching



- 20 sccm O_2
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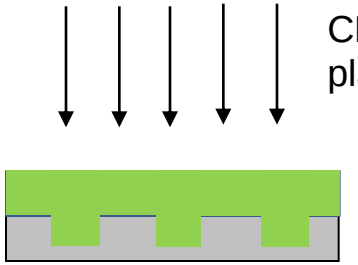
- 20 W

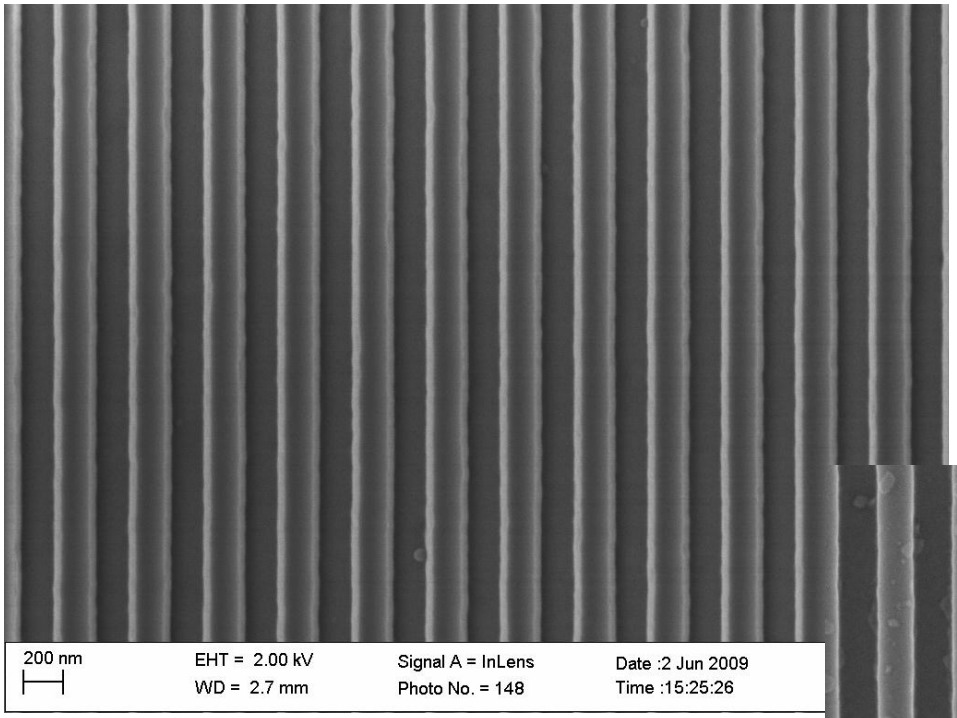
SiO_2 etching



- 25 sccm CHF_3
- 25 sccm Ar
- 30 mTorr
- 200 W
- DEPTH:
  - 340 nm (10 min.),
  - 220 nm (6 min.),
  - 105 nm (3 min.)

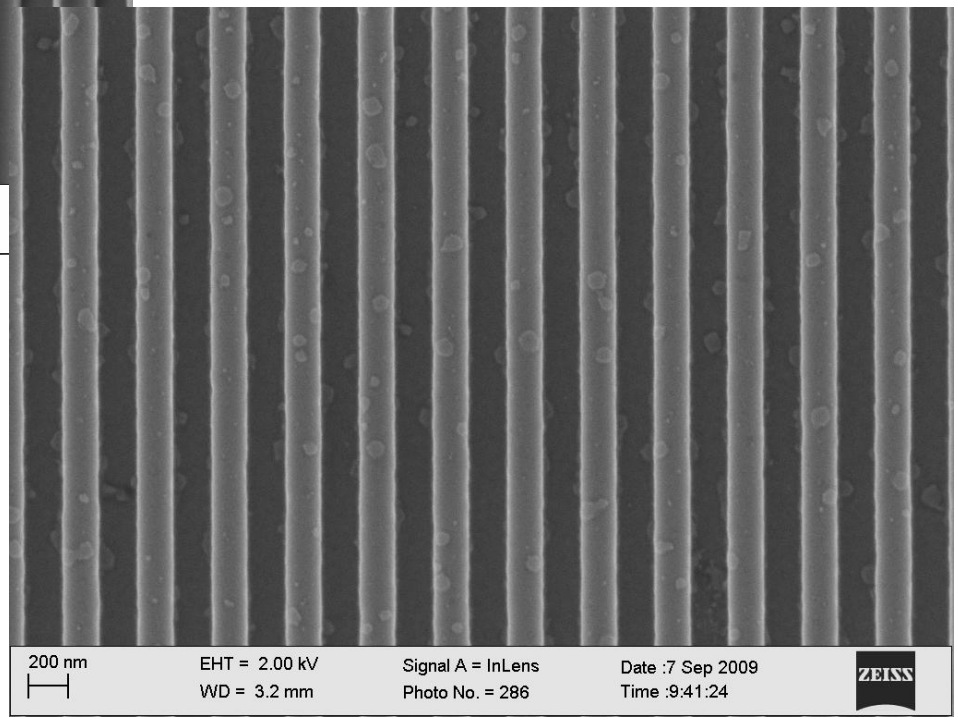
Spin-coating of the doped PS

Fabrication of the resonator

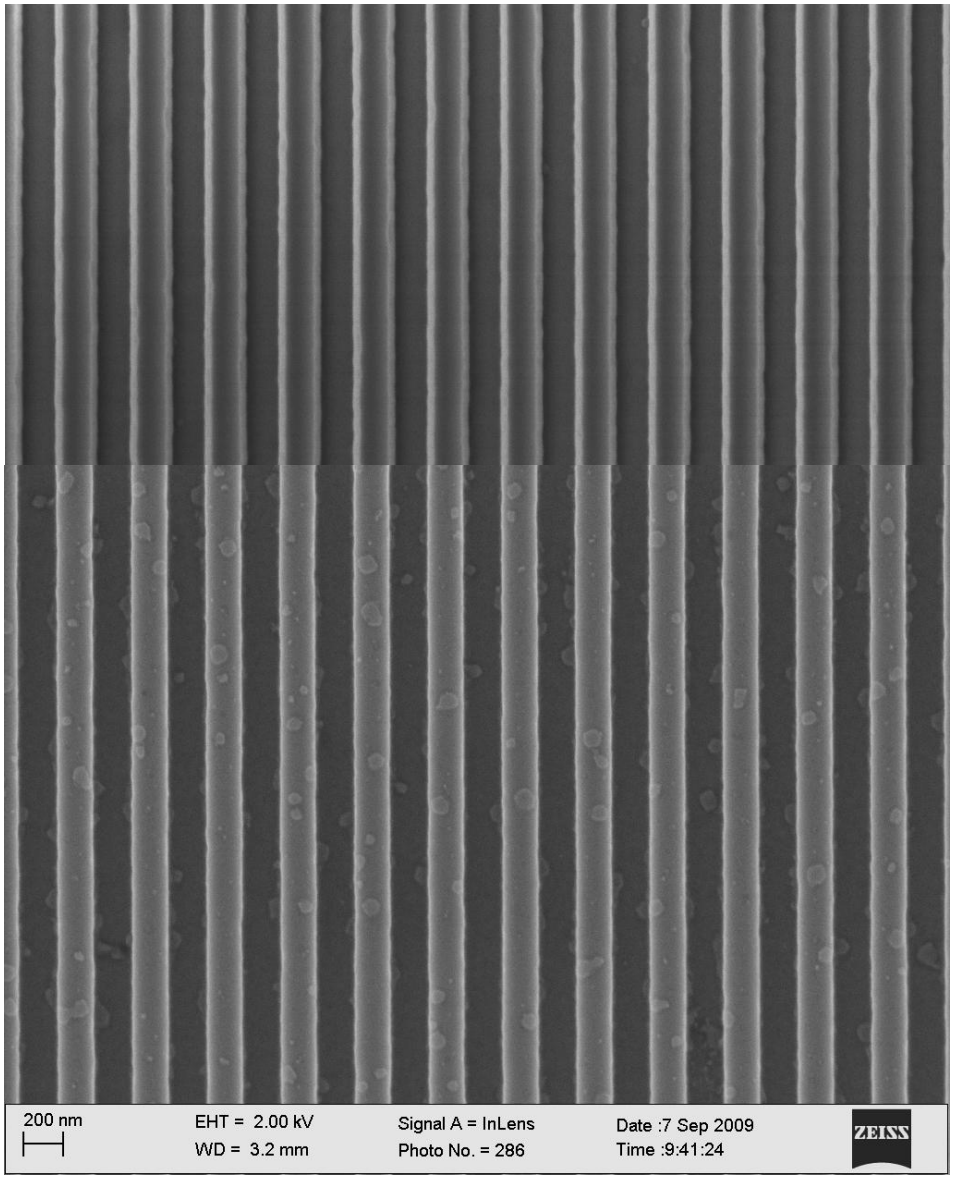


SiO_2

Si stamp



Fabrication of the resonator



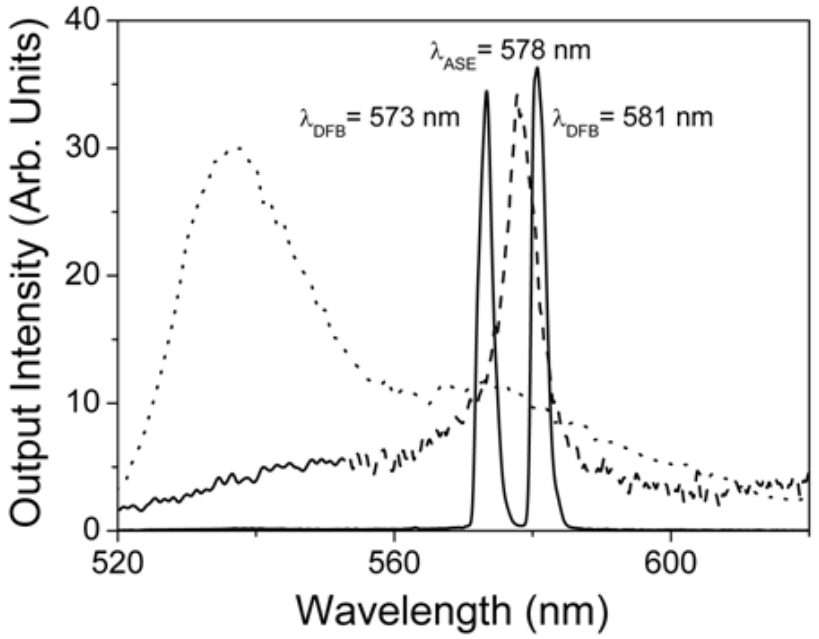
SiO_2

No loss of lateral dimensions

Si stamp

Optical characterization

1.1 μm thickness (0.75 wt%)*



λ_{ASE} = 578 nm

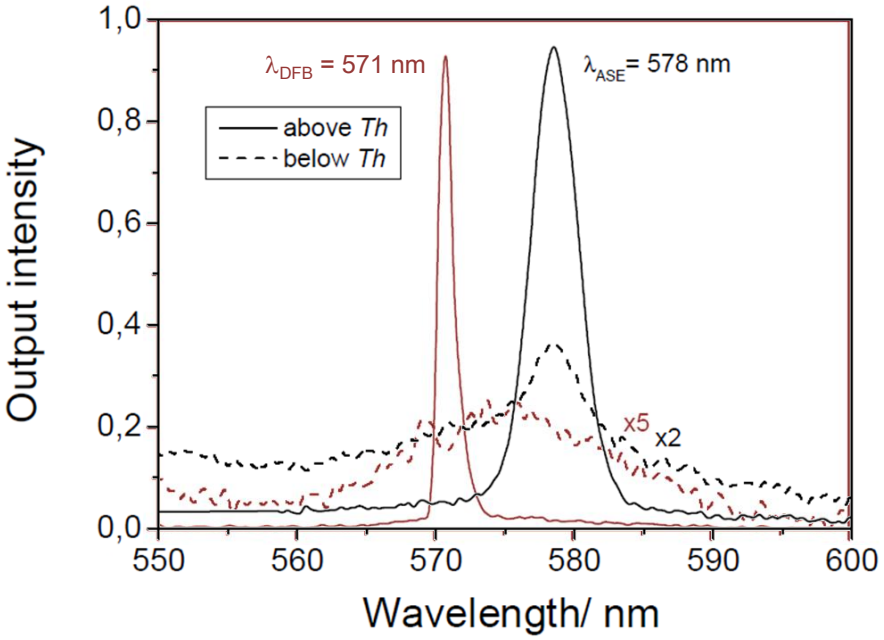
FWHM 6 nm

λ_{DFB} = 573 nm

λ_{DFB} = 581 nm

FWHM 2 nm

0.6 μm thickness



λ_{ASE} = 578 nm

FWHM 5 nm

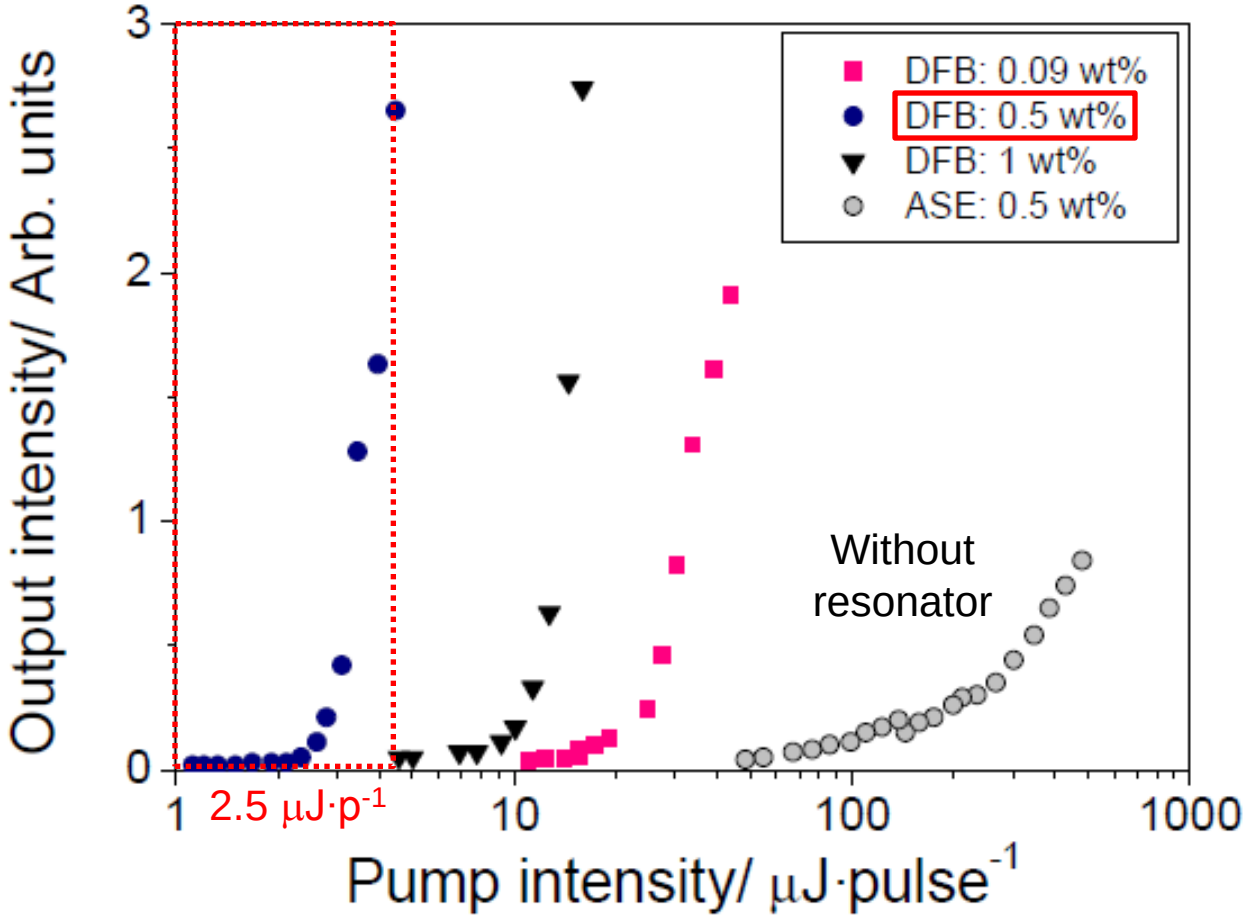
λ_{DFB} = 571 nm

FWHM < 2 nm

* V. Trabadelo *et al.*, *Microelectronic Engineering*, **87**, 1428–1430 (2010)

Optical characterization

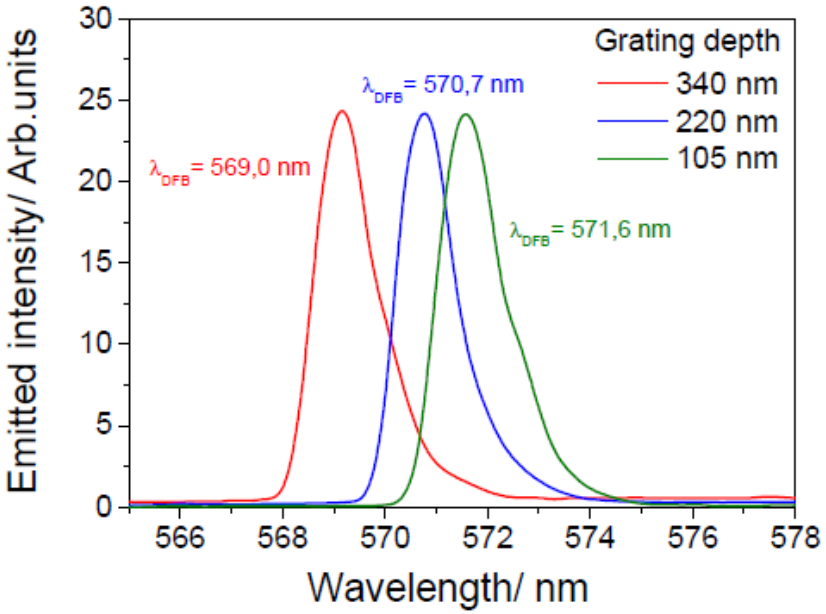
Lasing threshold

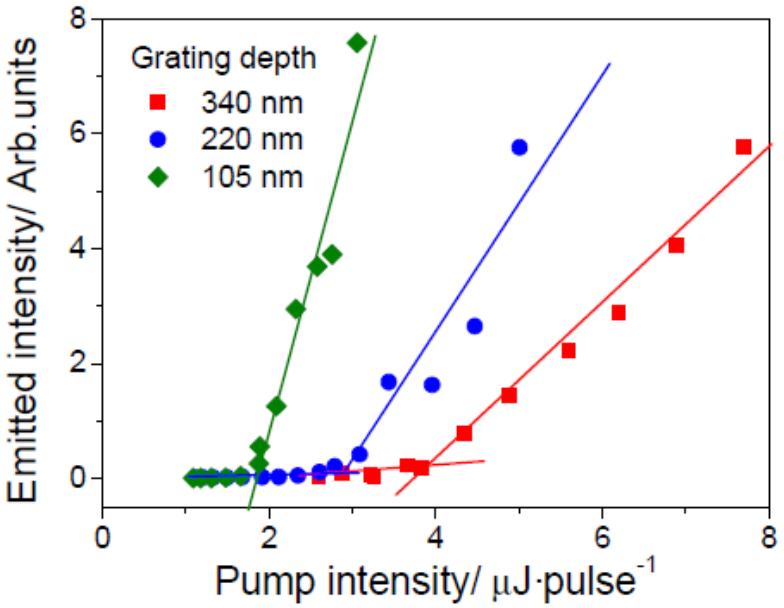


Optical characterization

Grating depth

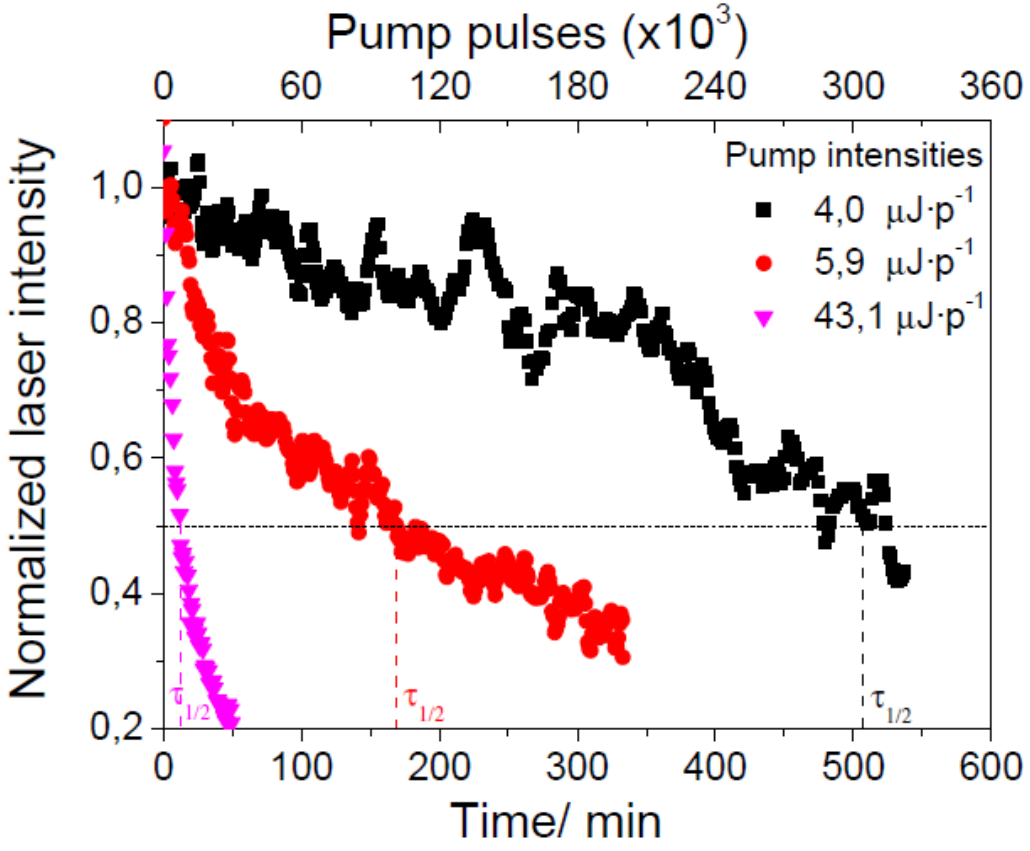
Influence on the laser emission wavelength and threshold





Optical characterization

Photostability



Photoestability halflife $\tau_{1/2}$: ~ 3 x 10^5 pulses (10 ns, 4 μJ·p^{-1}) at 10 Hz

Fabrication of the resonator: gratings on doped PS

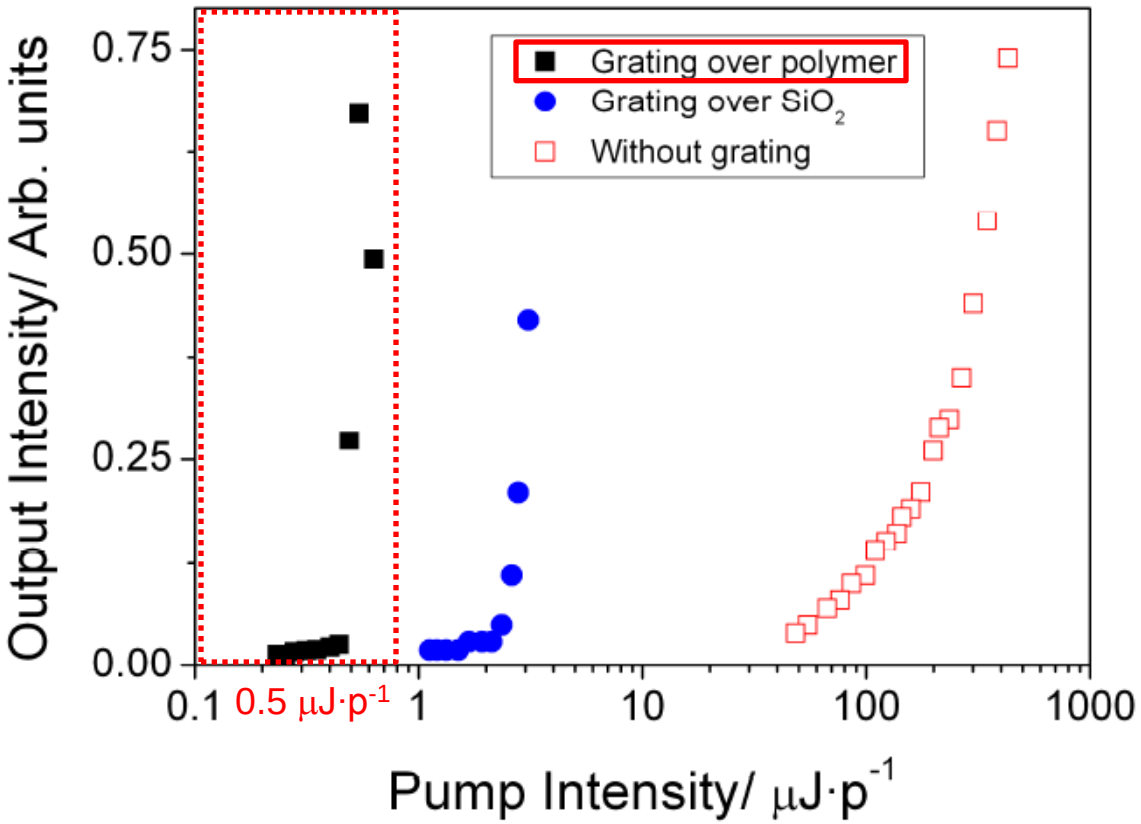
NIL onto doped PS

- Jenoptik HEX03
- 15000 N
- 155 ºC
- 900 s

Easier processing!

Optical characterization (ongoing work)

Lasing threshold



- Film thickness: 880 nm
- Grating depth: 230 nm
- Emission at 578 nm

Conclusions

We have fabricated and characterized second-order DFB organic laser devices:

- Active medium: PS film doped with a perilendiimide derivative.
- Resonator fabricated via thermal NIL (Λ= 368 nm):
  - SiO_2 Bragg grating
    - single-mode (one peak at 571 nm)
    - low threshold (~100 times lower than ASE threshold)
    - highly photostable (halflife ~ 3 x 10^5 pulses at 4 $\mu J \cdot p^{-1}$)
  - Bragg grating on active medium
    - easier processing
    - even lower threshold

Acknowledgements

➢ Financial support:

- Spanish Government MEC and the European Community (FEDER). Grant MAT2008-06648-C02

- CSIC fellowship within the program JAE.

➢ V. Esteve for technical assistance.

Thank you for your attention!

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