Institut des Nanotechnologies de Lyon UMR 5270

Fabrication of twisted bilayer photonic crystals (*moirés*) by Nano Printing Stepper (NPS) process

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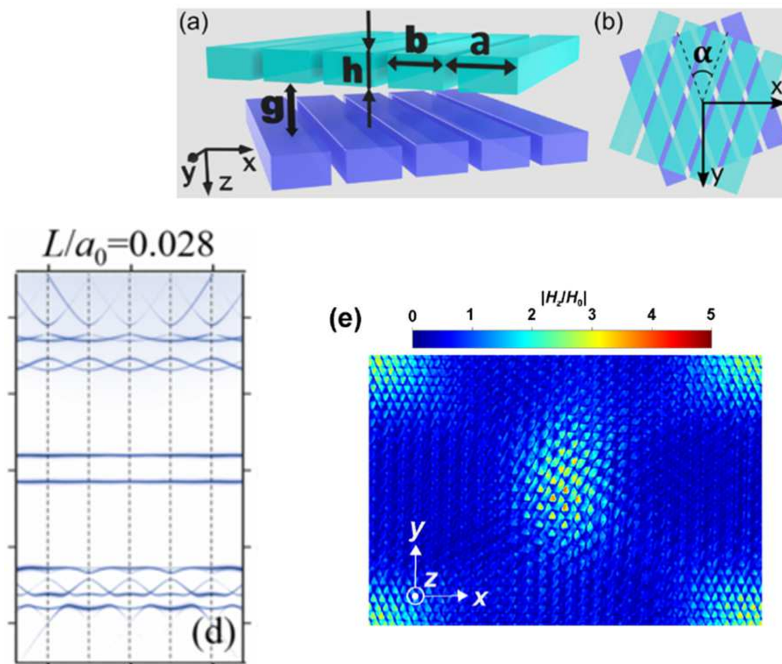
Hai-Son Nguyen, Xavier Letartre

J-NIL 11/05/2023

Context (1) : twisted bilayer photonic crystals

Novel photonic concepts

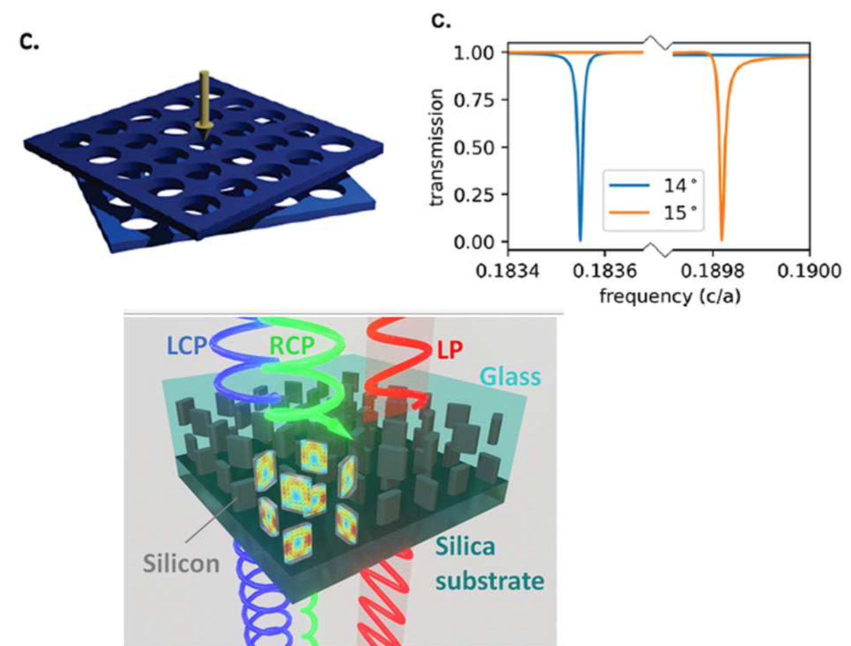
- Non trivial topology
- Extreme slow light
- Localization/Delocalization of light



Yi, C. H., et al (2022). *Light: Science & Applications*, *11*(1), 289.
Tang, H et al. (2021). Light: Science & Applications, 10(1), 157.
Nguyen, D. X., et al. (2022). Physical Review Research, 4(3), L032031.
Wang, P., et al. (2020). Nature, 577(7788), 42-46.

Novel photonic devices

- Filters
- Chiral devices
- Polarization control of light



Lou, B., et al (2022). ACS Photonics, 9(3), 800-805.
Salakhova, N. Set al. (2023 *Physical Review B*, *107*(15), 155402.
Lou, B., et al. (2021), *126*(13), 136101.
Qin, H., et al. (2023).. *Light: Science & Applications*, *12*(1), 66.

Many theoretical studies …

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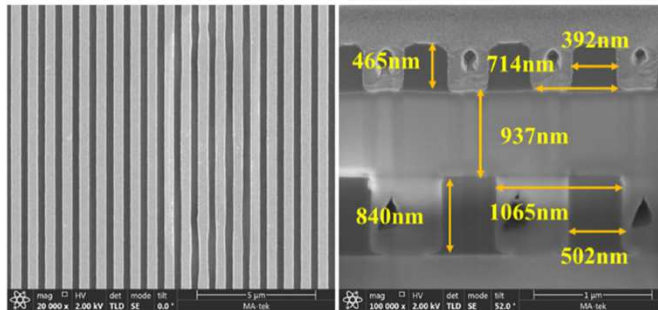
Context (2) : fabrication process

"Standard" fabrication process

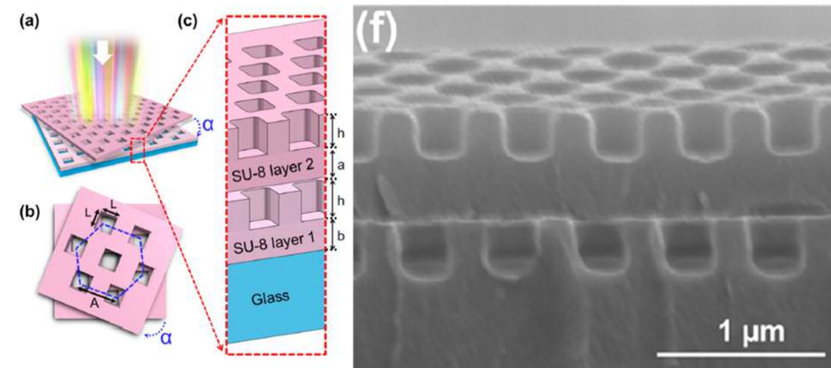
- 1st s-beam lithography, planarization, 2nd e-beam lithography (+ alignement)



Zhang, J., et al. (2020). Photonics Research, 8(3), 426-429
and many other papers !

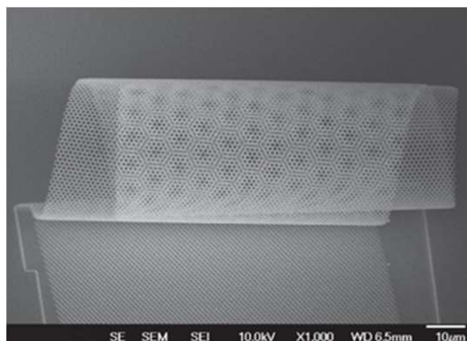
Nanoimprint

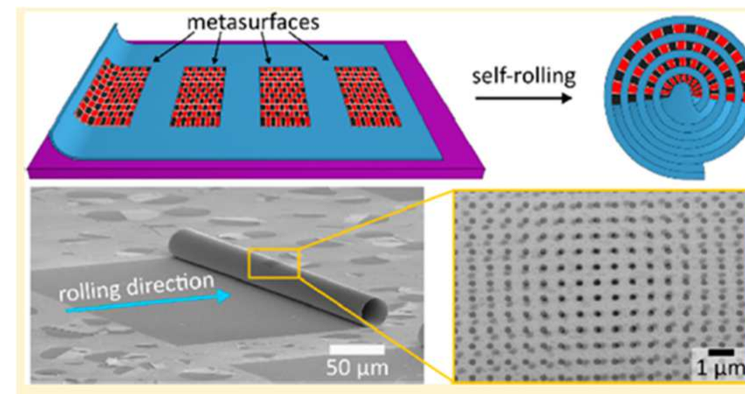
- Reversal NIL process



Chen, M. et al. (2023). Nanophotonics.
Bergmair, et al. (2011). *Nanotechnology*, *22*(32), 325301.

Self-rolled multilayer





Bermúdez-Ureña, E., et al (2019) ACS Photonics, 6(9), 2198-2204.
Danescu, A. (2018). *Nanotechnology*, *29*(28), 285301.

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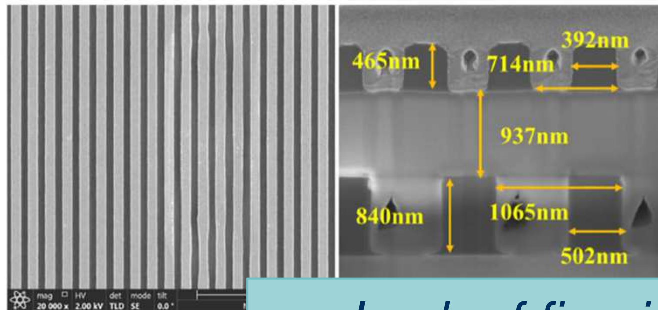

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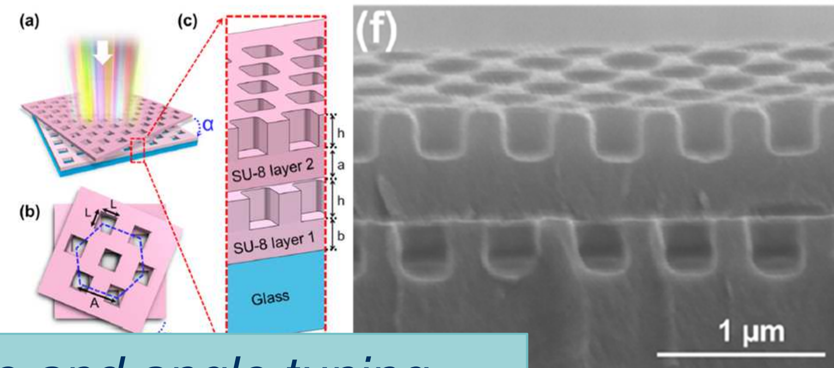
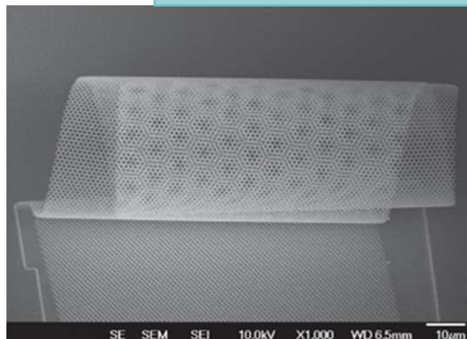
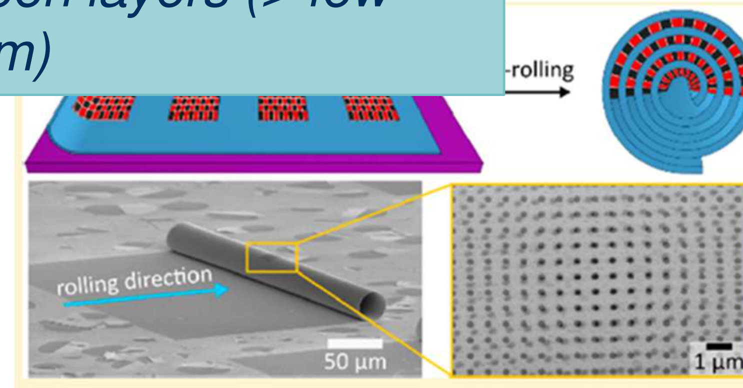


, *22*(32), 325301.

Self-r





Bermúdez-Ureña, E., et al (2019) ACS Photonics, 6(9), 2198-2204.
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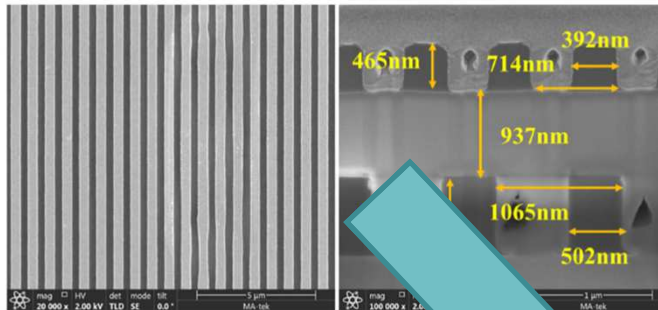
Lack of fine in-plane and angle tuning between layers
High distance between layers (> few 100nm)

Objectives : twisted bilayer photonic crystals

"Standard" fabrication process

- 1st s-beam lithography, planarization, 2nd e-beam lithography (+ alignement)



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Nanoimprint

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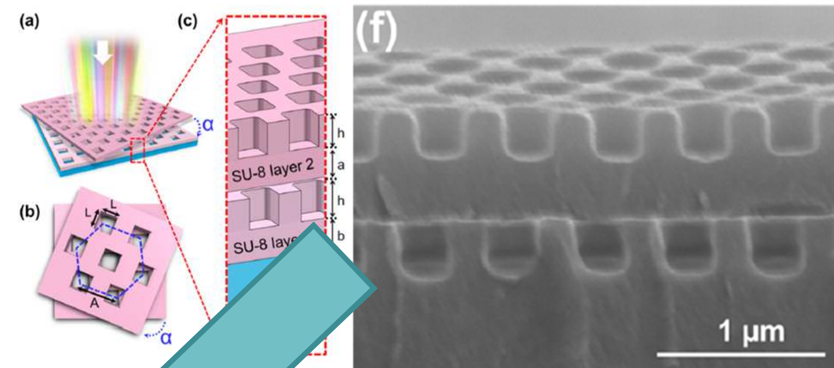
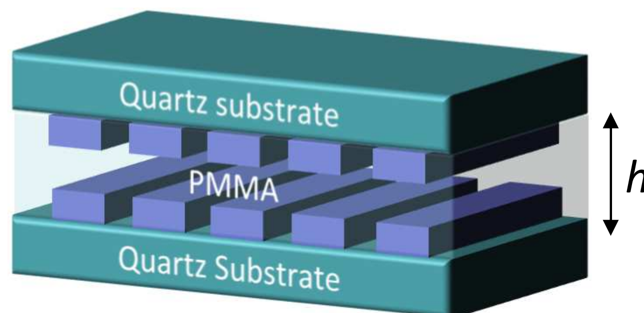


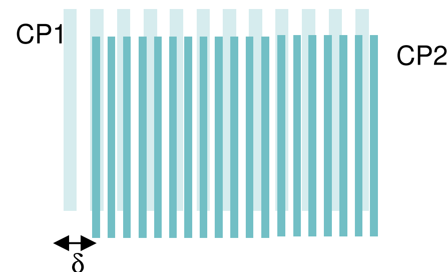
Ch... (2023). Nanophotonics.
Be... al. (2011). *Nanotechnology*, *22*(32), 325301.

Standard process + Nano Printing Stepper

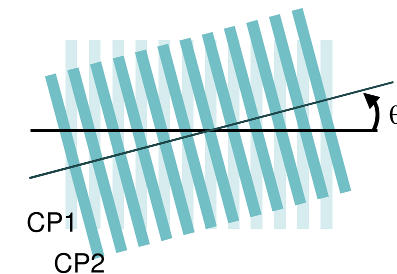
- Fine control of the distance *h* between both grating layers



- Accurate in-plane tuning



- Accurate angle tuning



Objectives : twisted bilayer photonic crystals

"Standard" fabrication process

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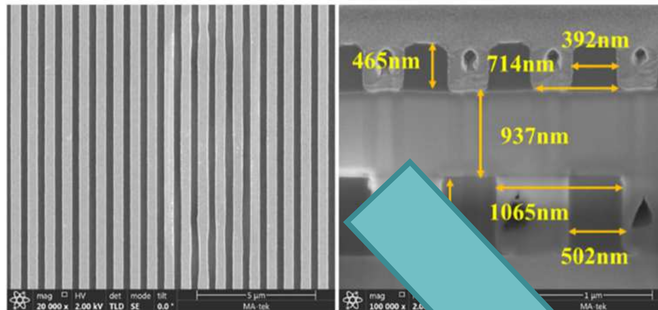

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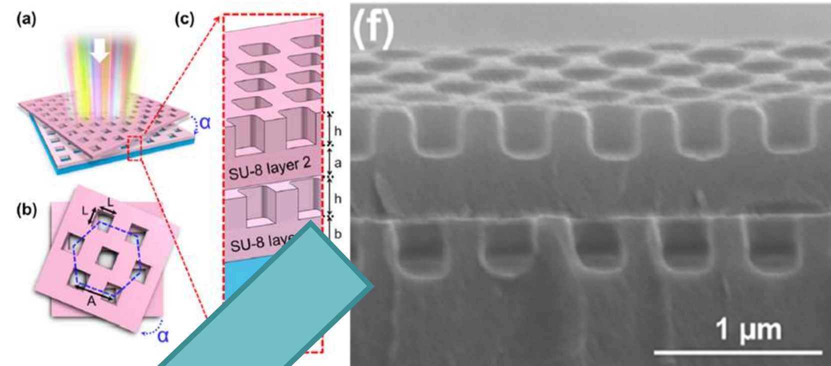
Nanoimprint

- Reversal NIL process



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Standard process + Nano Printing Stepper

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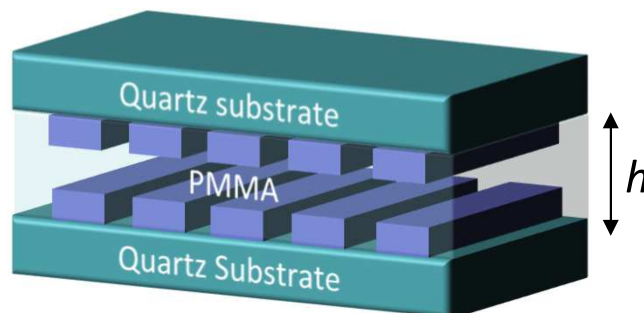

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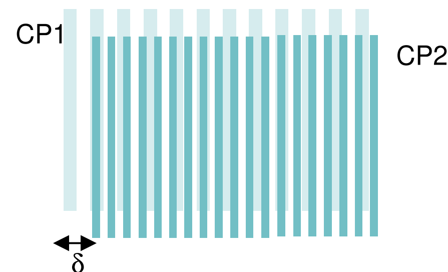

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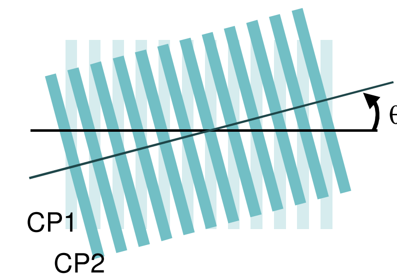
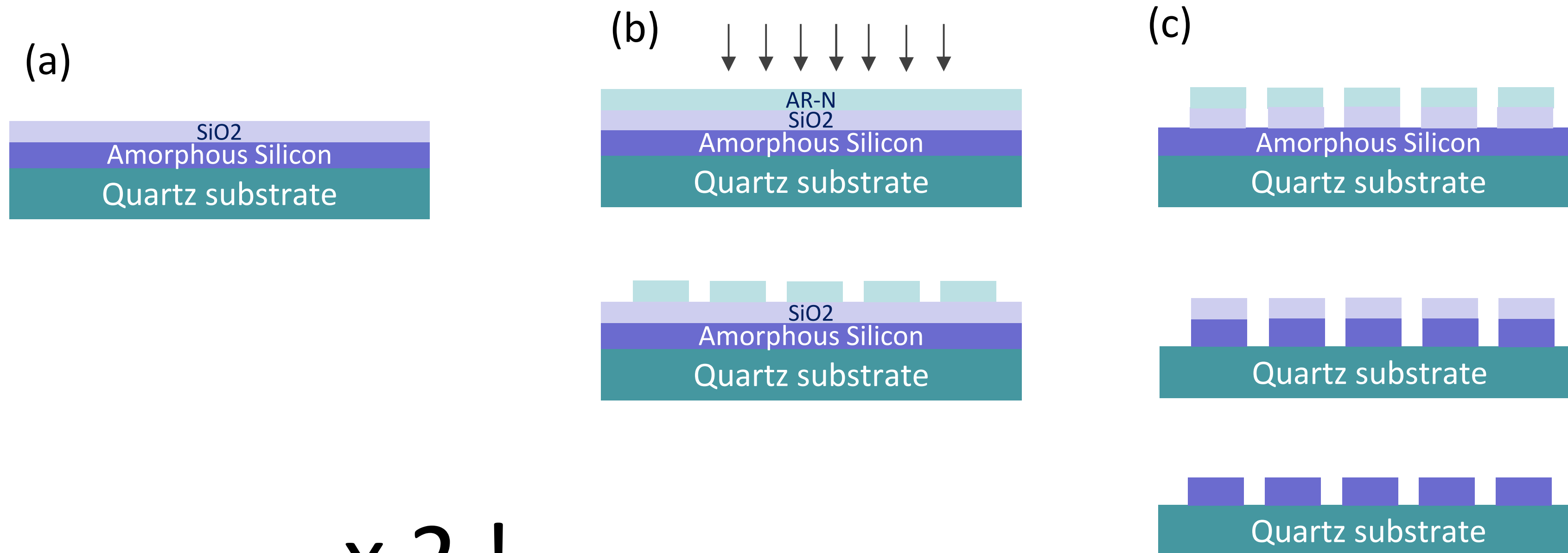


- + wafer bonding (PMMA)

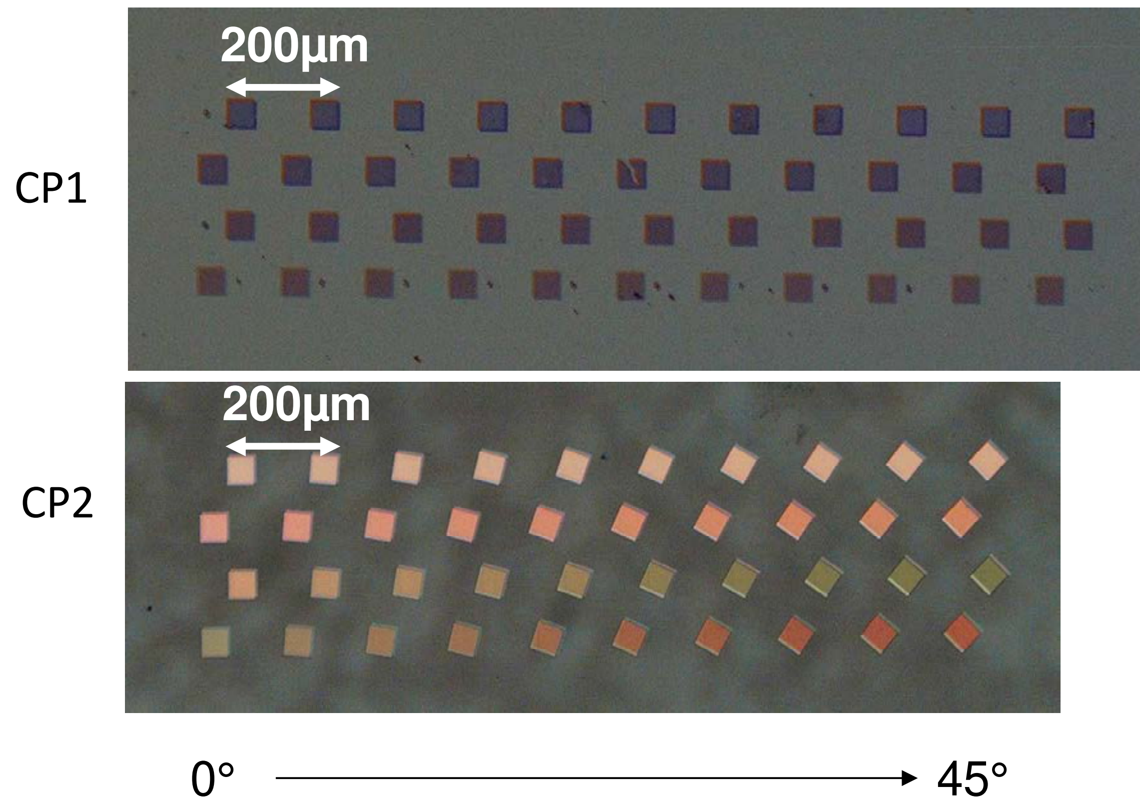
Technological steps (1)

- 1) Fabrication of each grating layer (two samples):
  - (a) Amorphous silicon and SiO2 deposition (PECVD)
  - (b) E-beam lithography of alignement marks + PhC
  - (c) Dry etching (ICP)



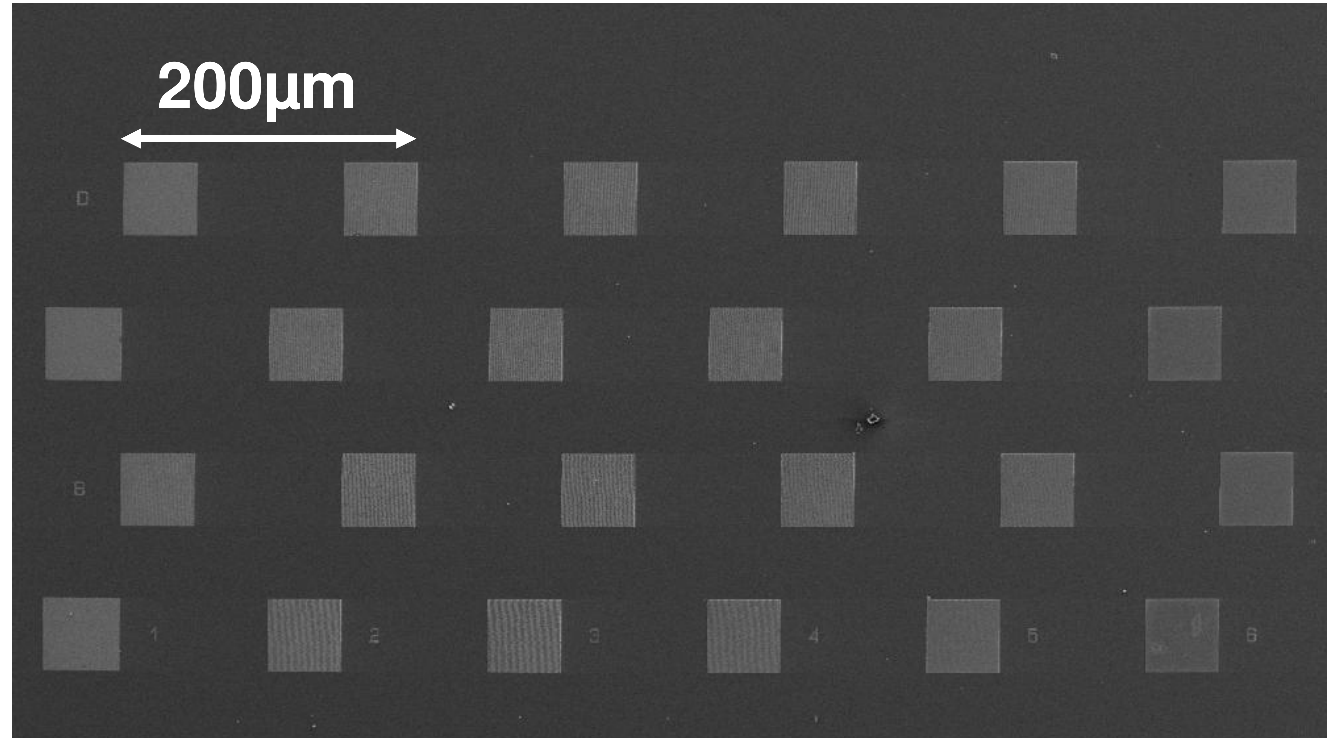
Technological steps (1)

- 1) Fabrication of each grating layer (two samples):
  - µscope images



Technological steps (1)

- 1) Fabrication of each grating layer (two samples):
  - SEM images of the first floor



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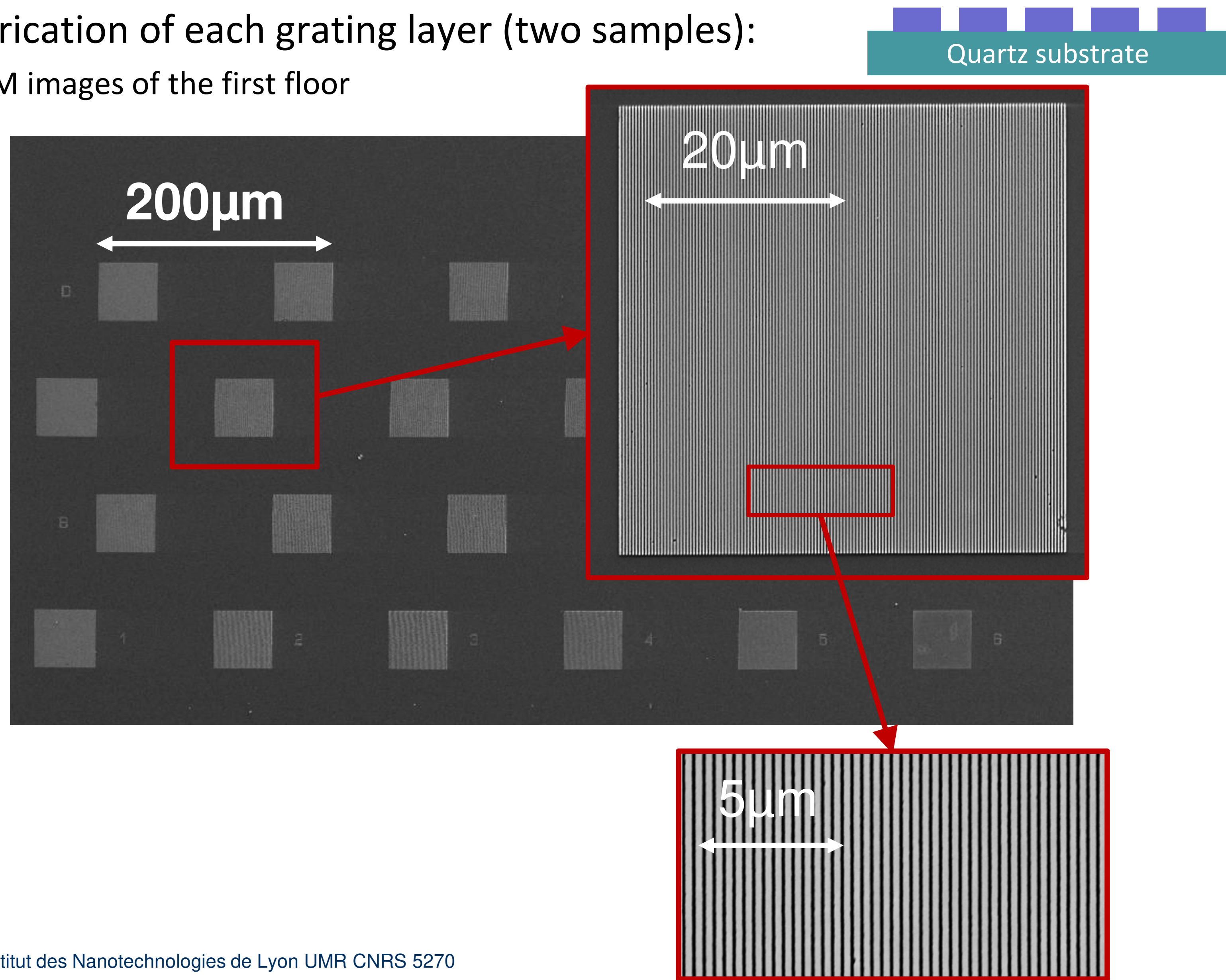
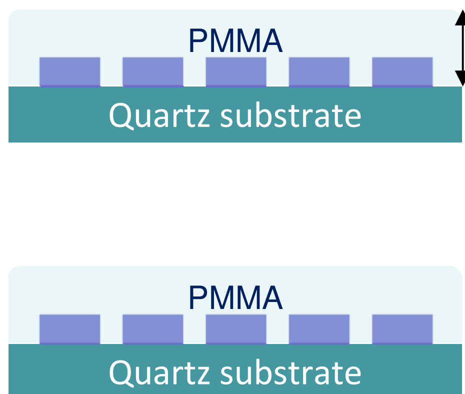
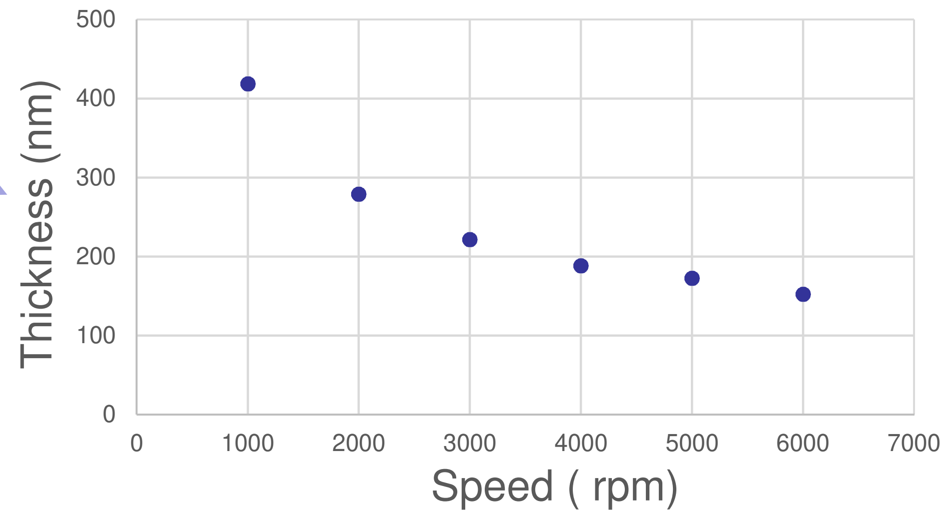


Technological steps (2)

- 2) Bonding by using Nano Patterning Stepper :
  - (a) Spin coating of PMMA

(a)

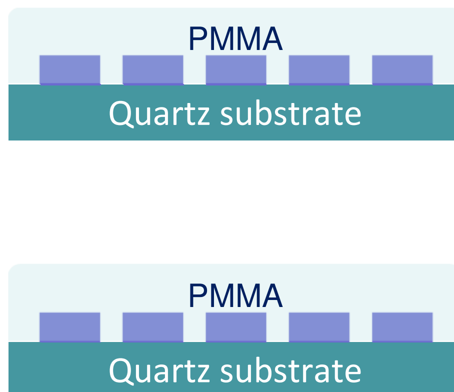




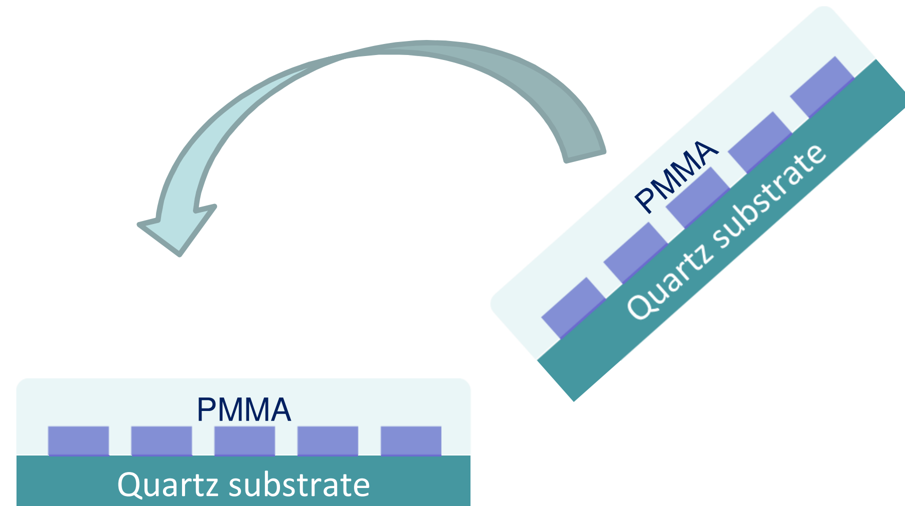
Technological steps (2)

- 2) Bonding by using Nano Patterning Stepper :
  - (a) Spin coating of PMMA
  - (b) Alignment & bonding (+ Temperature, Time and Pressure optimization)
  - (c) well done !

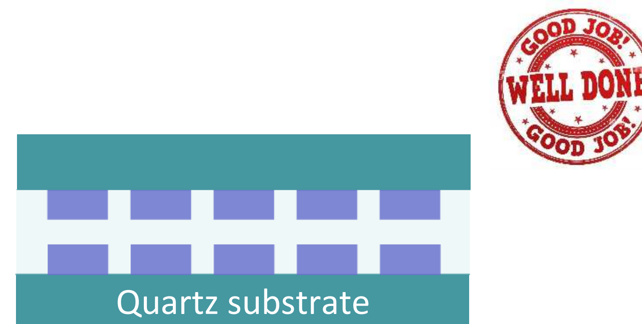
(a)



(b)

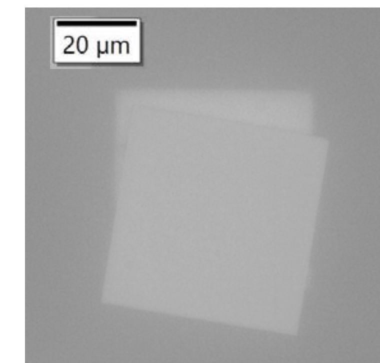


(c)



First results

- Bonding ok
- Slight misalignement (but human mistake !) of about 1°



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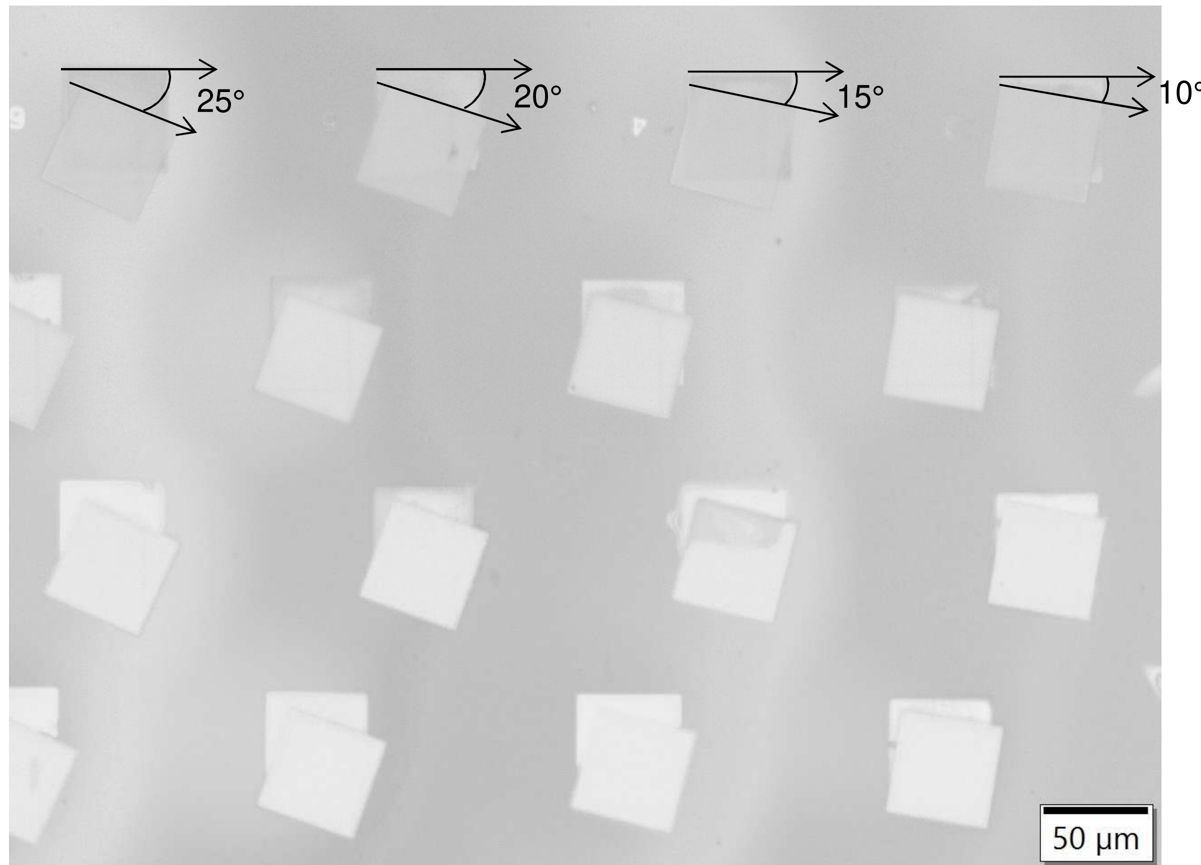
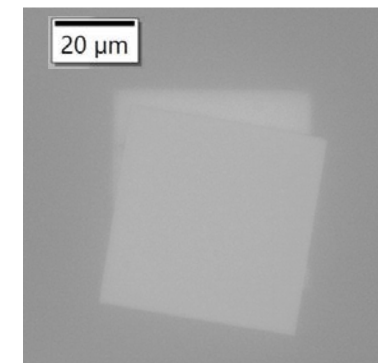
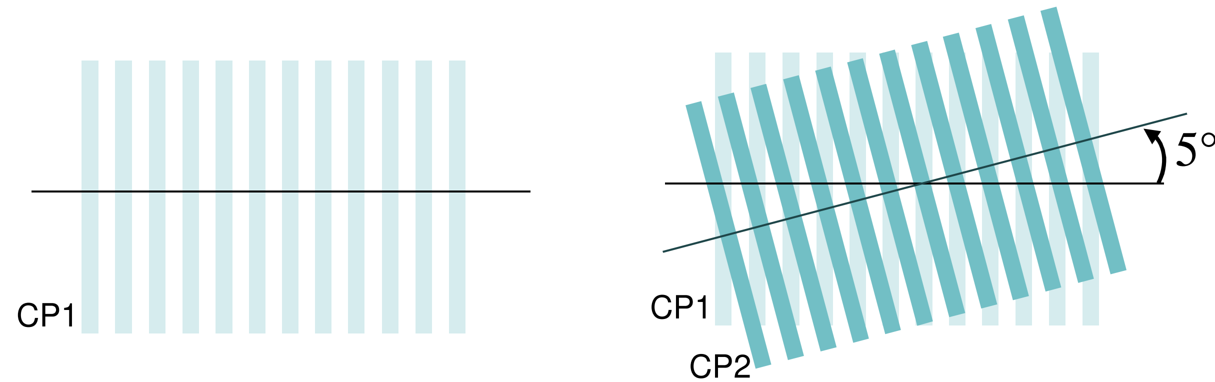
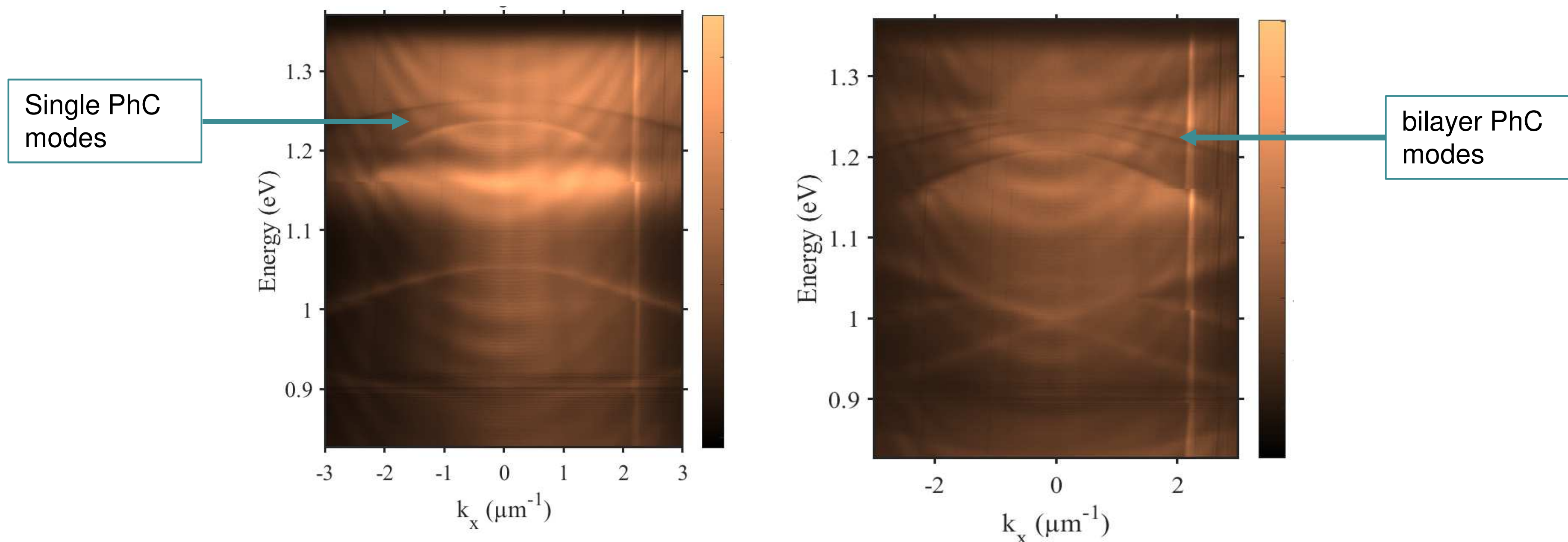




First optical measurements

- IR Fourier space imaging of single and bilayer photonic crystals



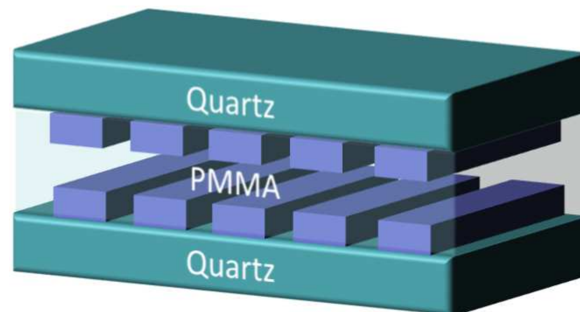


Validation of the fabrication process

inl

Conclusion and Perspectives

- Fabrication of bilayer photonic crystals :
  - E-beam lithography of photonic crystals and alignment marks: patterning on a-Si layers on transparent substrates
  - Bonding and alignment thanks to NPS process
  - Thermoplastic polymer (PMMA) as bonding layer



- Versatile process:
  - Active structures (eg. by using III-V or QD in PMMA or perovskite)
  - Many degrees of freedom :
    - Materials
    - Dimensions
    - Fine tuning of both layers

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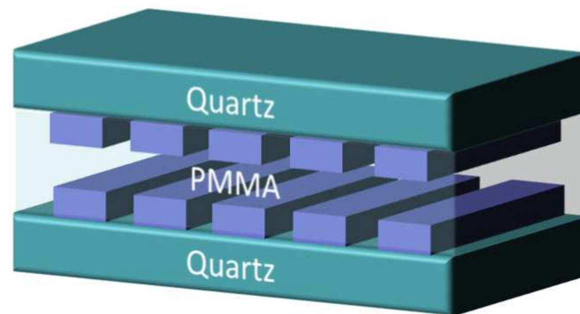

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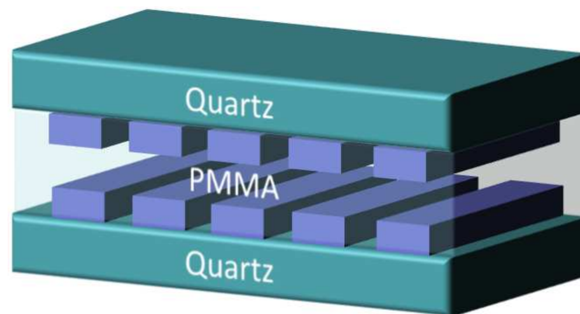
THANK YOU FOR YOUR ATTENTION

Perspectives



Passive structure

- Perspectives :
  - Active devices :
    - perovskite, doped PMMA…
    - PCM
  - Multiple layers ?
    - Fabrication of the Phc on a sacrificial layer

Nanotechnology 22 (2011) 325301 (6pp) doi:10.1088/0957-4484/22/32/325301

Single and multilayer metamaterials fabricated by nanoimprint lithography