

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

Lydie Ferrier, Maxime Gayrard, Ha My Dang, Céline Chevalier
Hai-Son Nguyen, Xavier Letartre

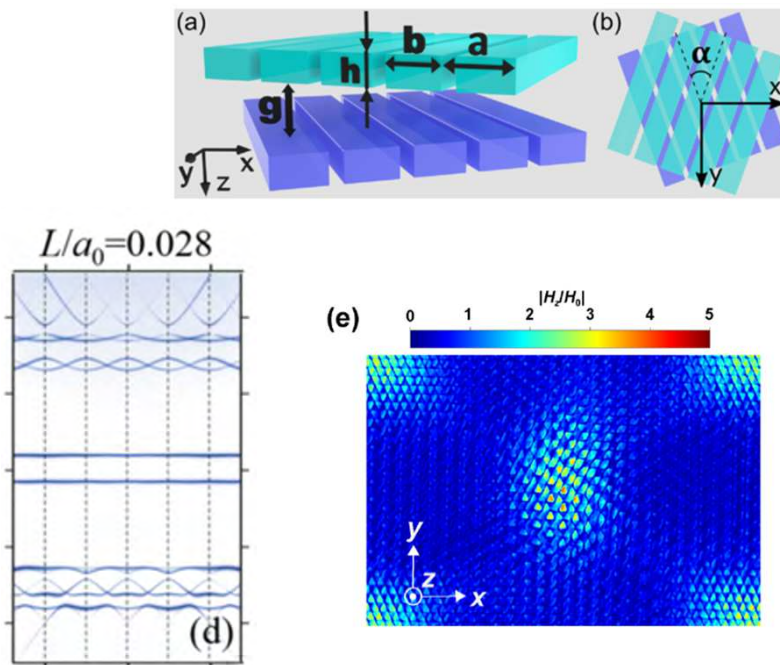
J-NIL 11/05/2023



Context (1) : twisted bilayer photonic crystals

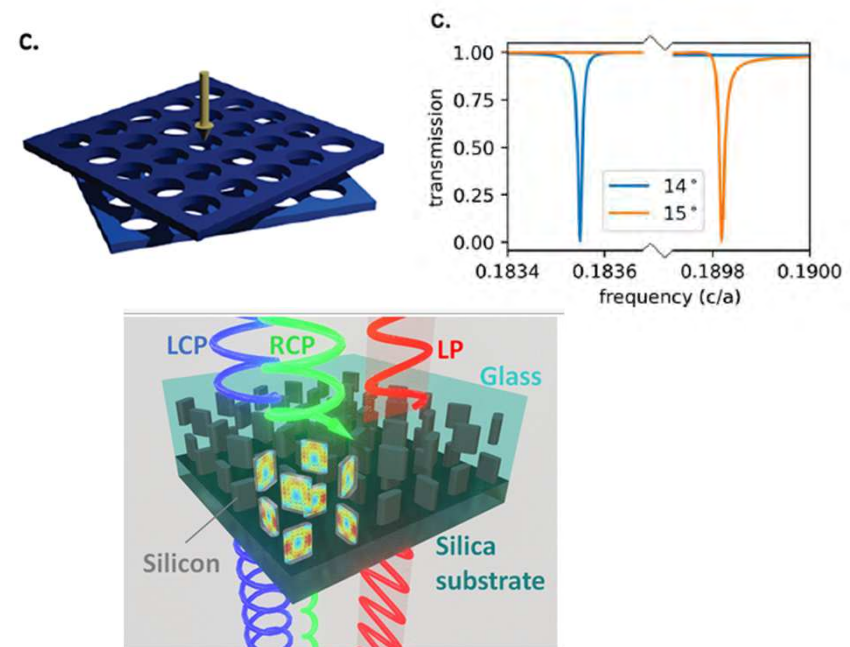
Novel photonic concepts

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



Novel photonic devices

- ▶ Filters
- ▶ Chiral devices
- ▶ Polarization control of light



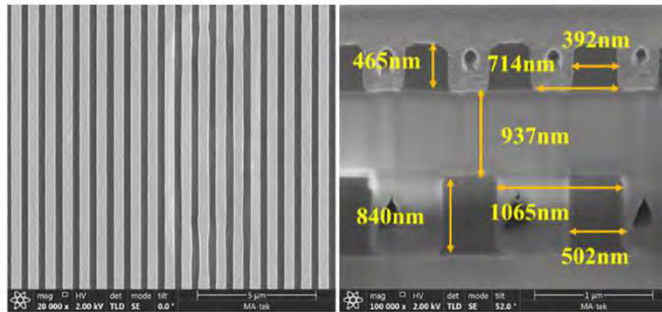
Yi, C. H., et al (2022). *Light: Science & Applications*, 11(1), 289.
 Tang, H et al. (2021). *Light: Science & Applications*, 10(1), 157.
 Nguyen, D. X., et al. (2022). *Physical Review Research*, 4(3), L032031.
 Wang, P., et al. (2020). *Nature*, 577(7788), 42-46.

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.

Context (2) : fabrication process

“Standard” fabrication process

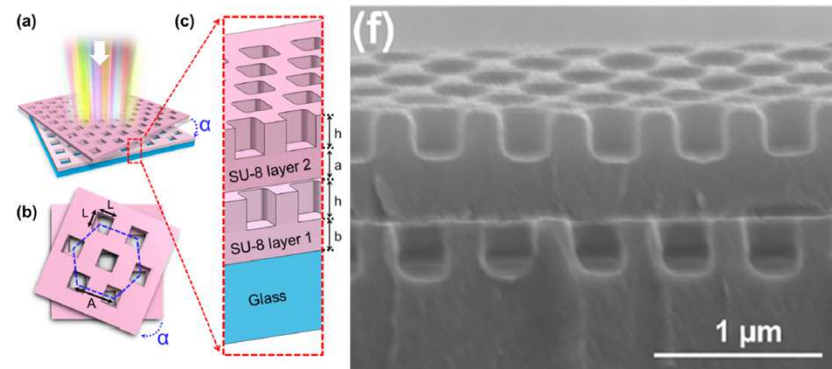
- ▶ 1st s-beam lithography, planarization, 2nd e-beam lithography (+ alignment)



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

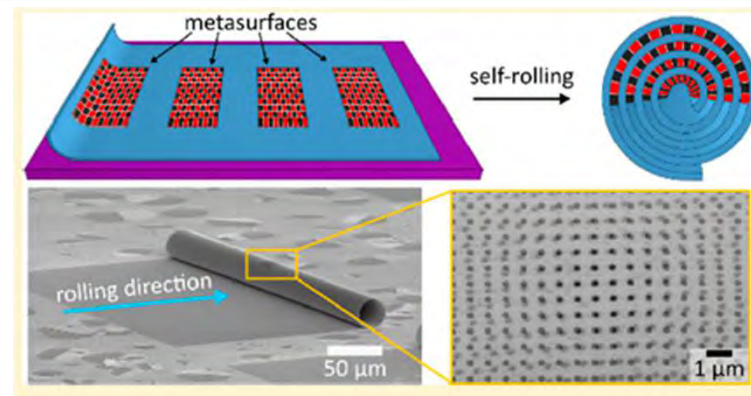
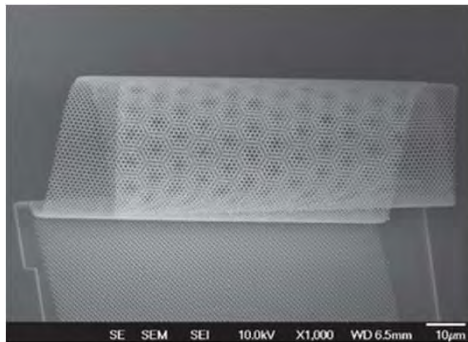
Nanoimprint

- ▶ Reversal NIL process



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

Self-rolled multilayer

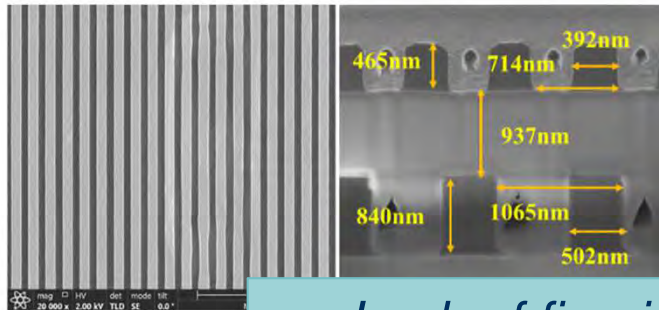


Bermúdez-Ureña, E., et al (2019) *ACS Photonics*, 6(9), 2198-2204.
Danescu, A. (2018). *Nanotechnology*, 29(28), 285301.

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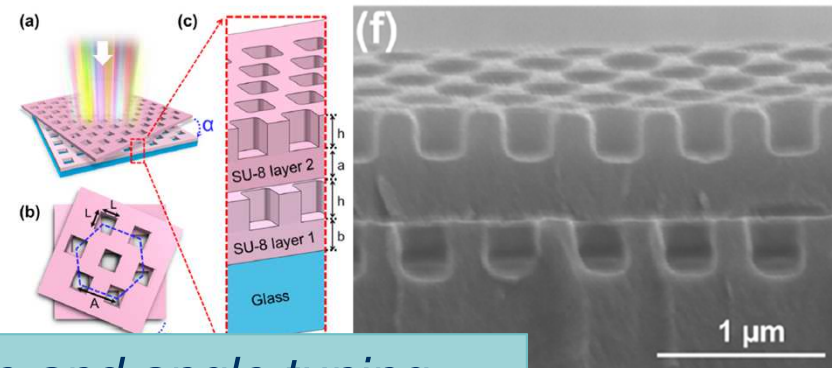
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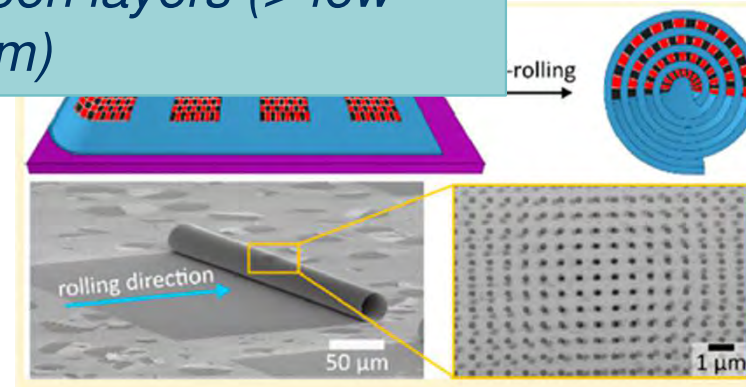
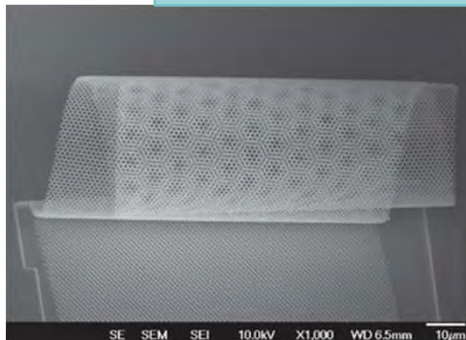
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..., 22(32), 325301.

*Lack of fine in-plane and angle tuning
between layers
High distance between layers (> few
100nm)*

Self-rolling

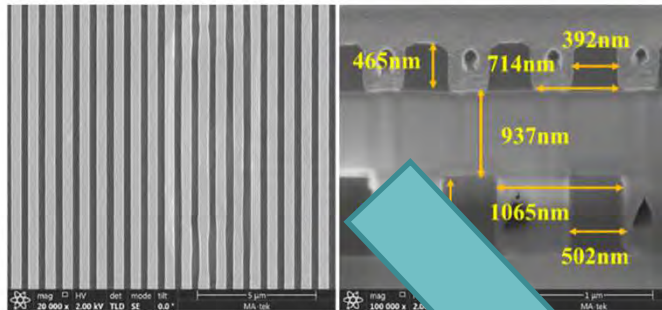


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Danescu, A. (2018). Nanotechnology, 29(28), 285301.

Objectives : twisted bilayer photonic crystals

“Standard” fabrication process

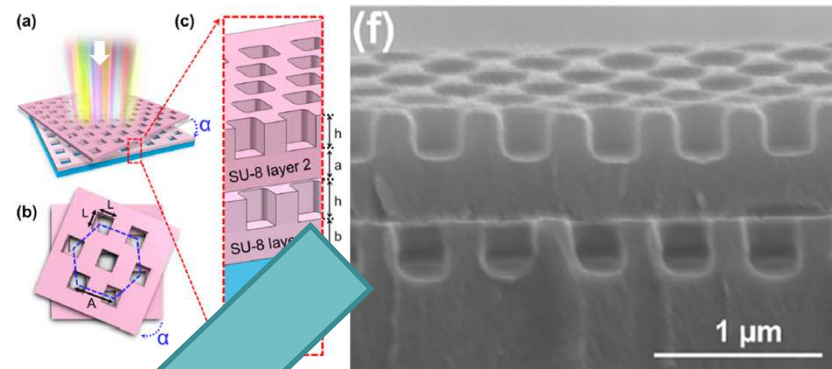
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Zhang, J., et al. (2020). *Photonics Research*, 8(1), 1-10.
and many other papers !

Nanoimprint

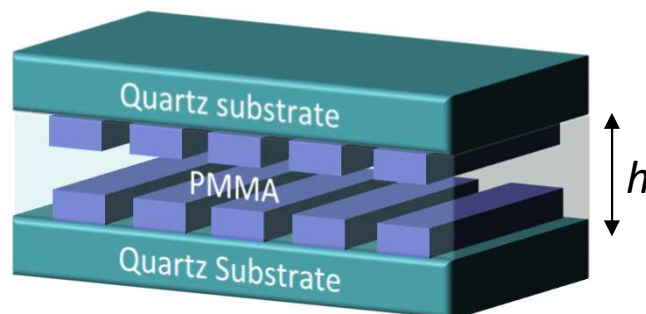
- ▶ Reversal NIL process



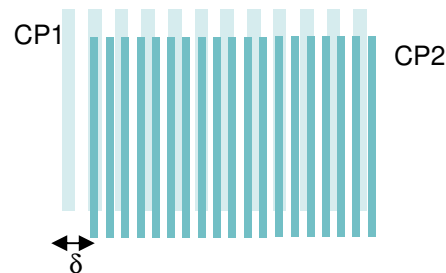
Chen, Y., et al. (2023). *Nanophotonics*.
Beck, J., et al. (2011). *Nanotechnology*, 22(32), 325301.

Standard process + Nano Printing Stepper

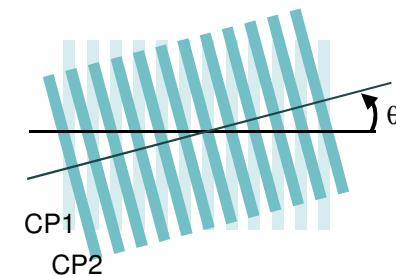
- ▶ Fine control of the distance h between both grating layers



- ▶ Accurate in-plane tuning



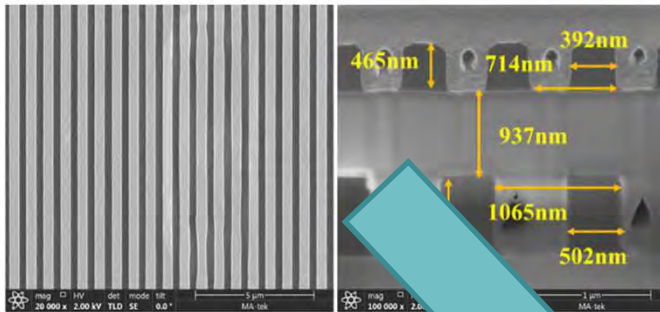
- ▶ Accurate angle tuning



Objectives : twisted bilayer photonic crystals

"Standard" fabrication process

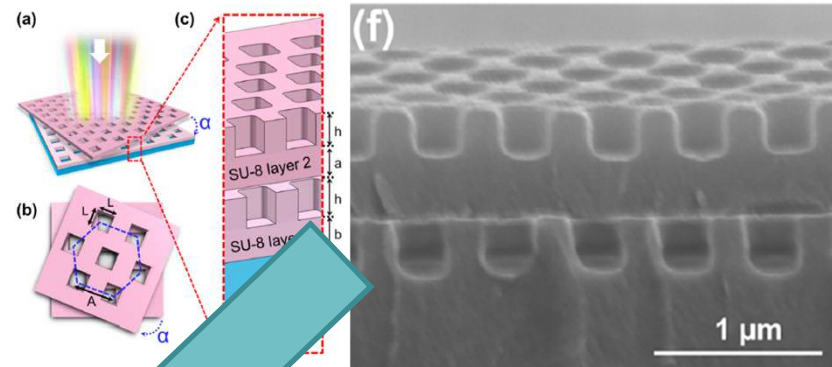
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Nanoimprint

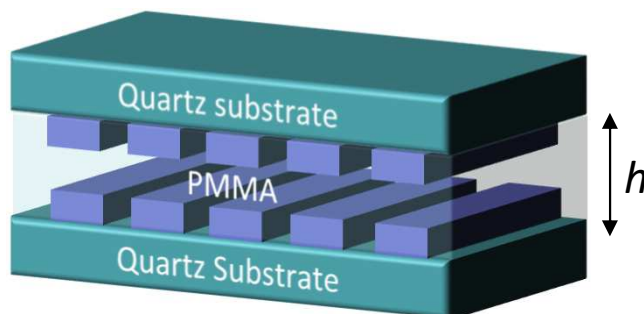
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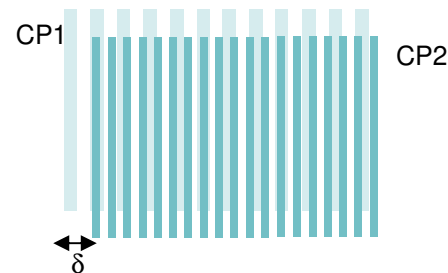
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Standard process + Nano Printing Stepper

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

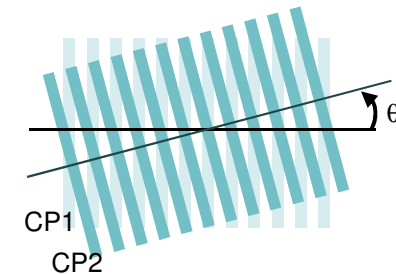


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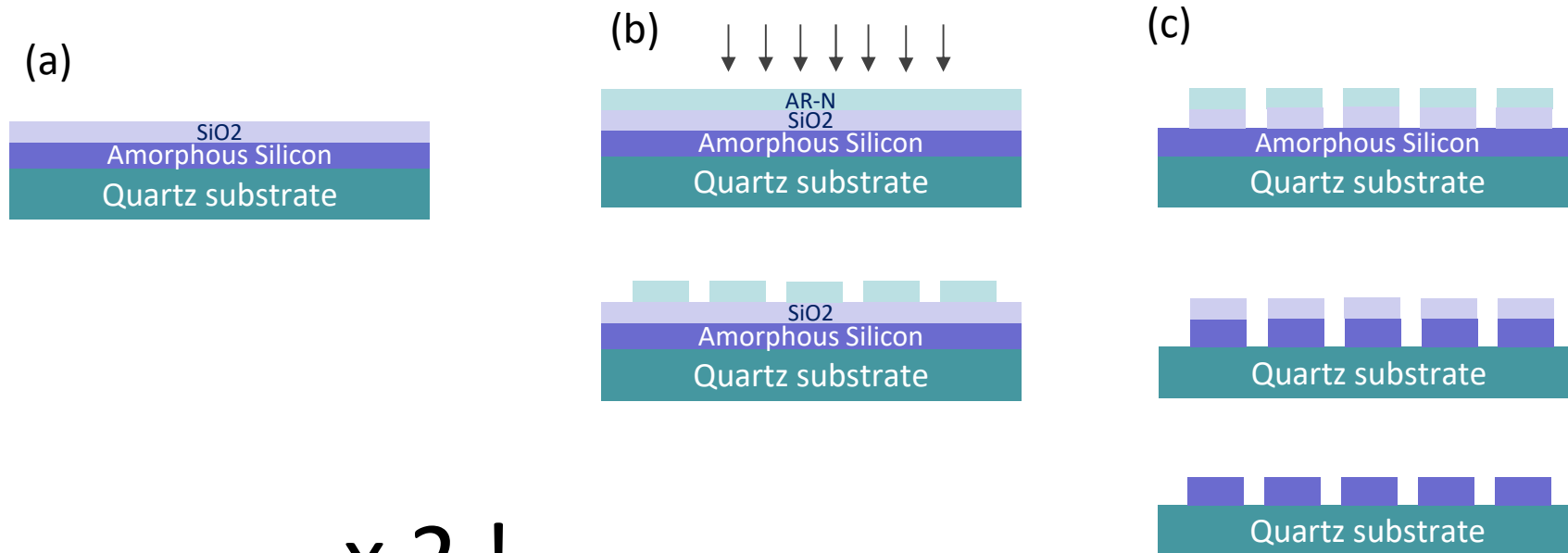
- ▶ + wafer bonding (PMMA)

- ▶ Accurate angle tuning



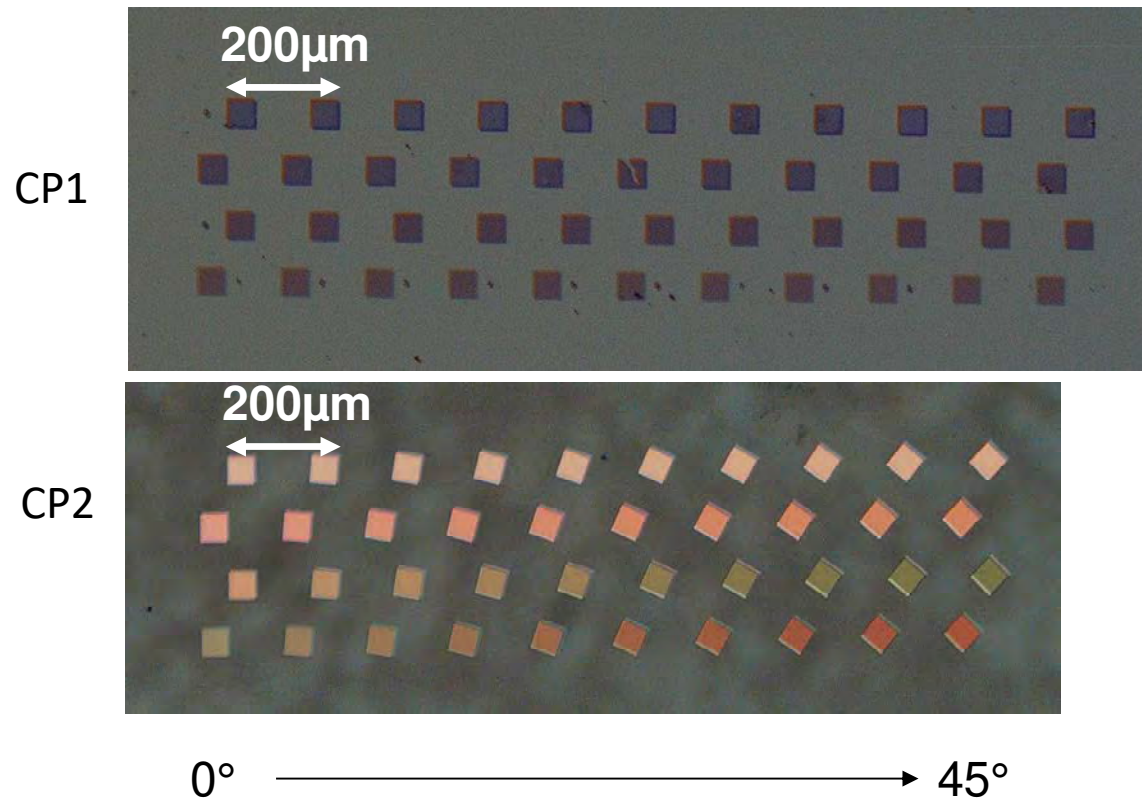
Technological steps (1)

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



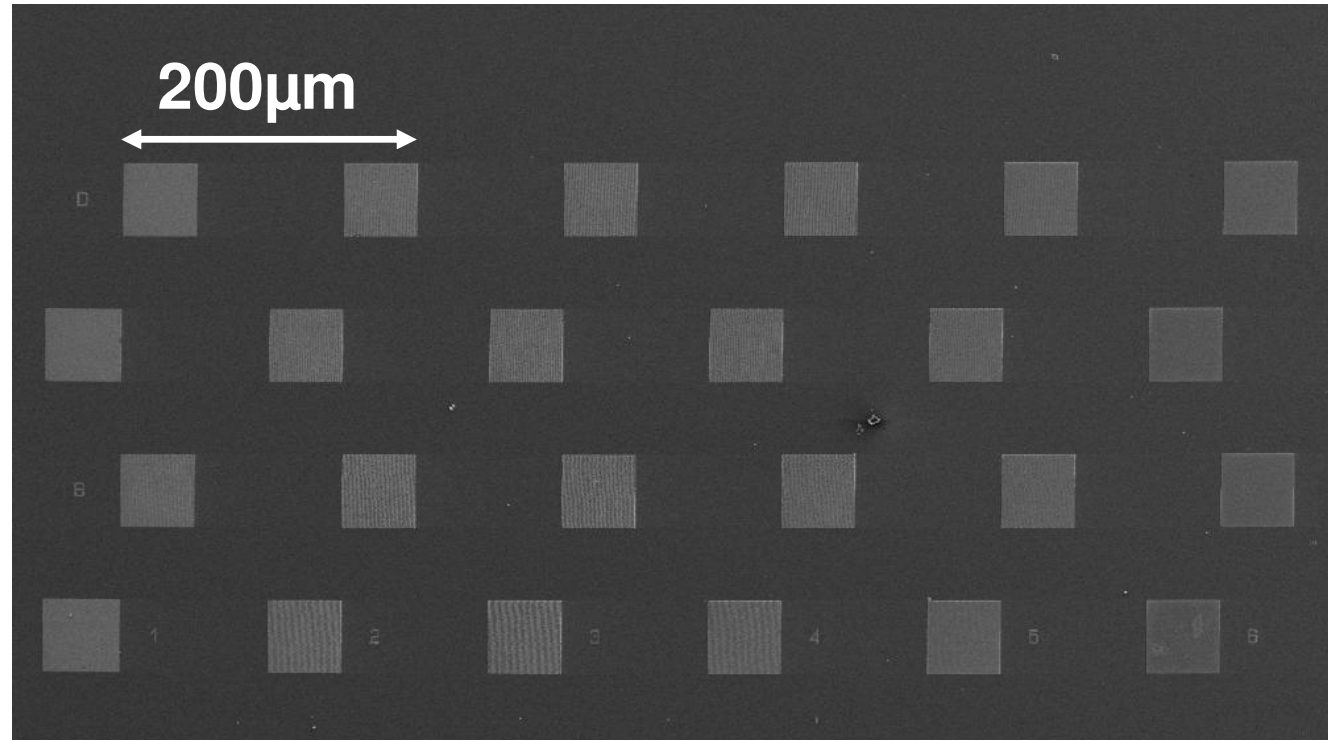
Technological steps (1)

- ▶ 1) Fabrication of each grating layer (two samples):
 - ▶ μ scope images



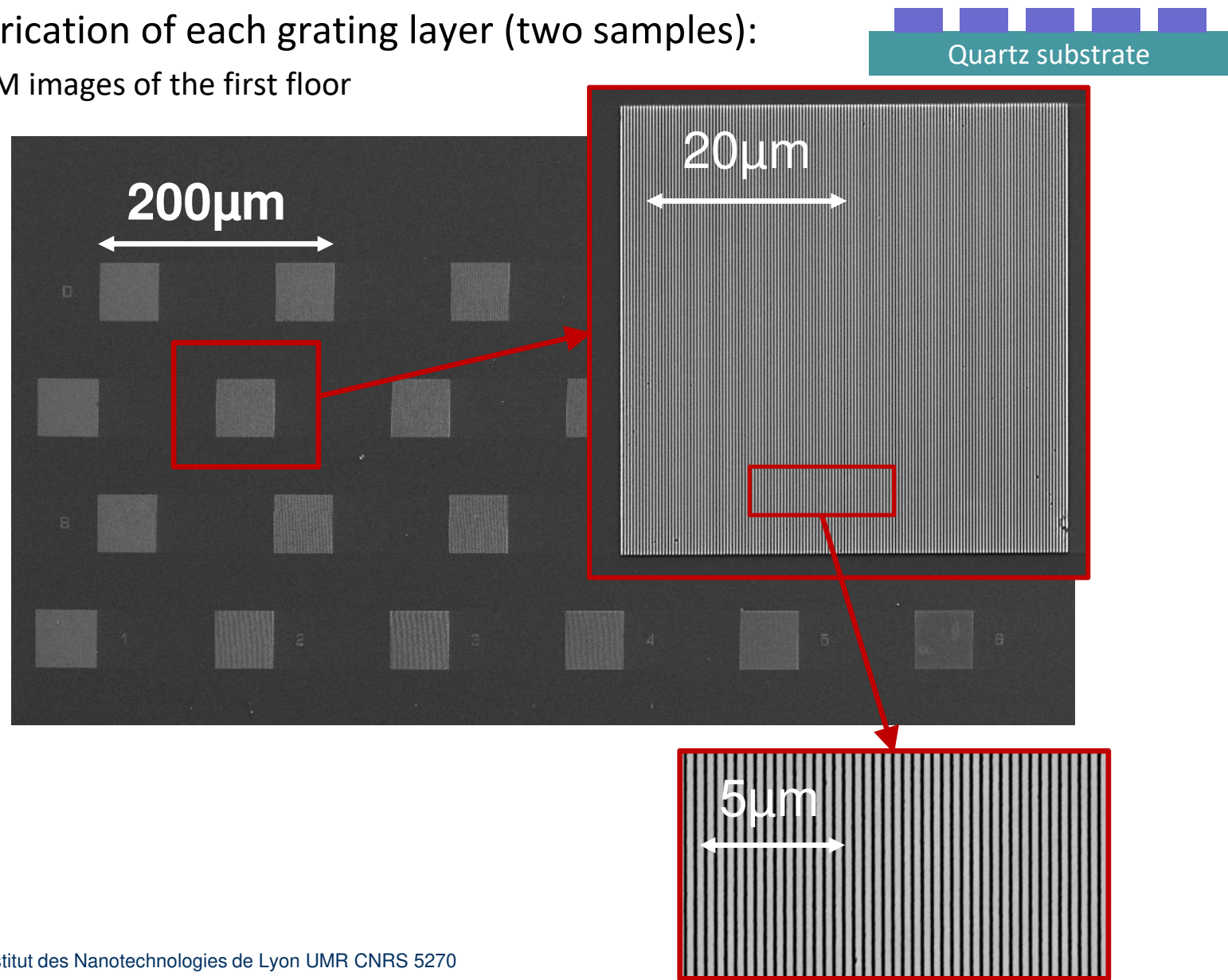
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 - ▶ SEM images of the first floor



Technological steps (1)

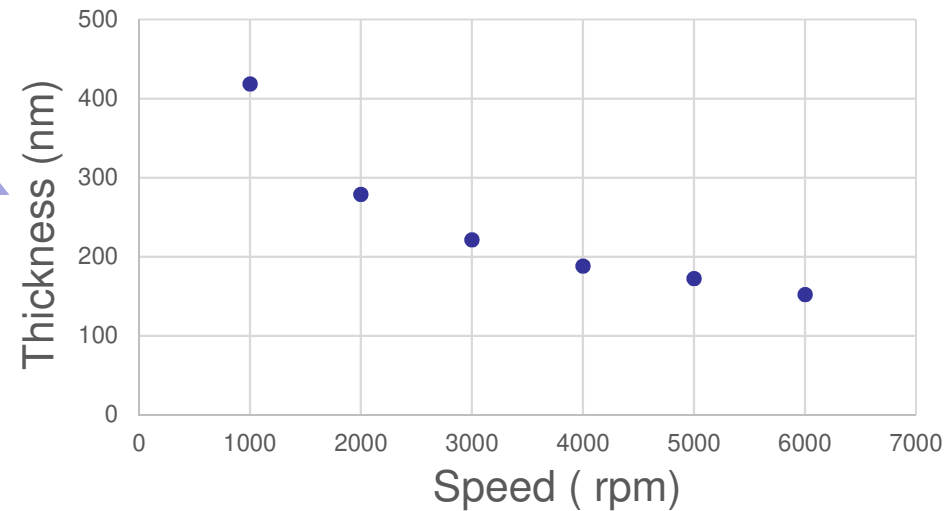
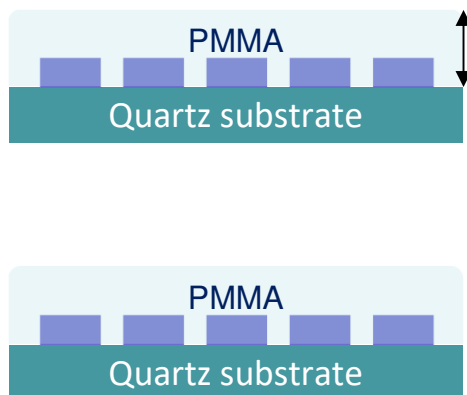
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Technological steps (2)

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

(a)

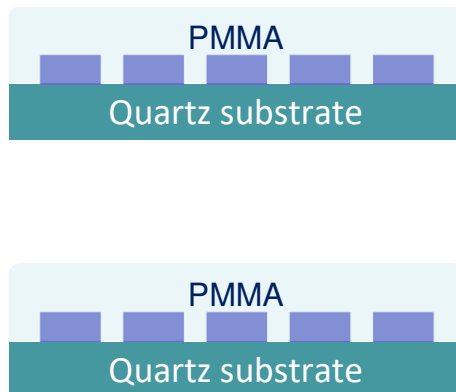


Technological steps (2)

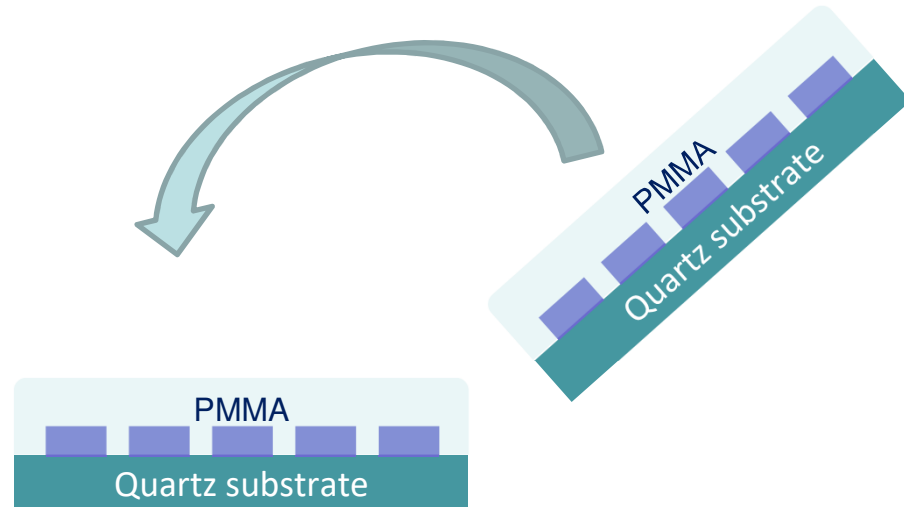
▶ 2) Bonding by using Nano Patterning Stepper :

- ▶ (a) Spin coating of PMMA
- ▶ (b) Alignment & bonding (+ Temperature, Time and Pressure optimization)
- ▶ (c) well done !

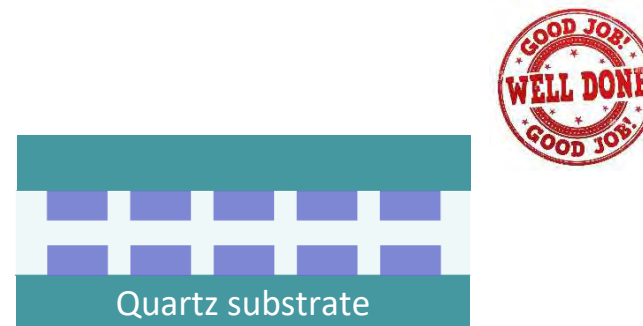
(a)



(b)

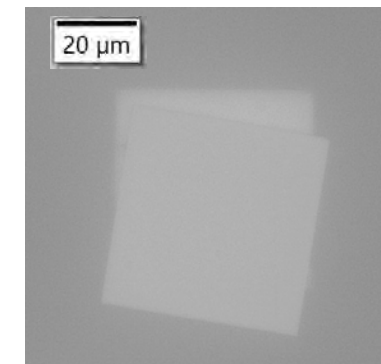


(c)



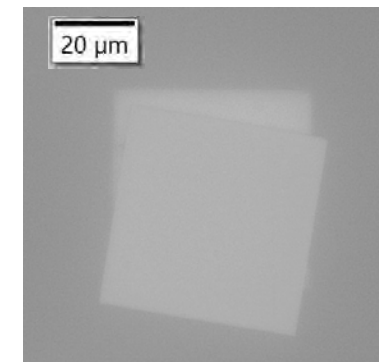
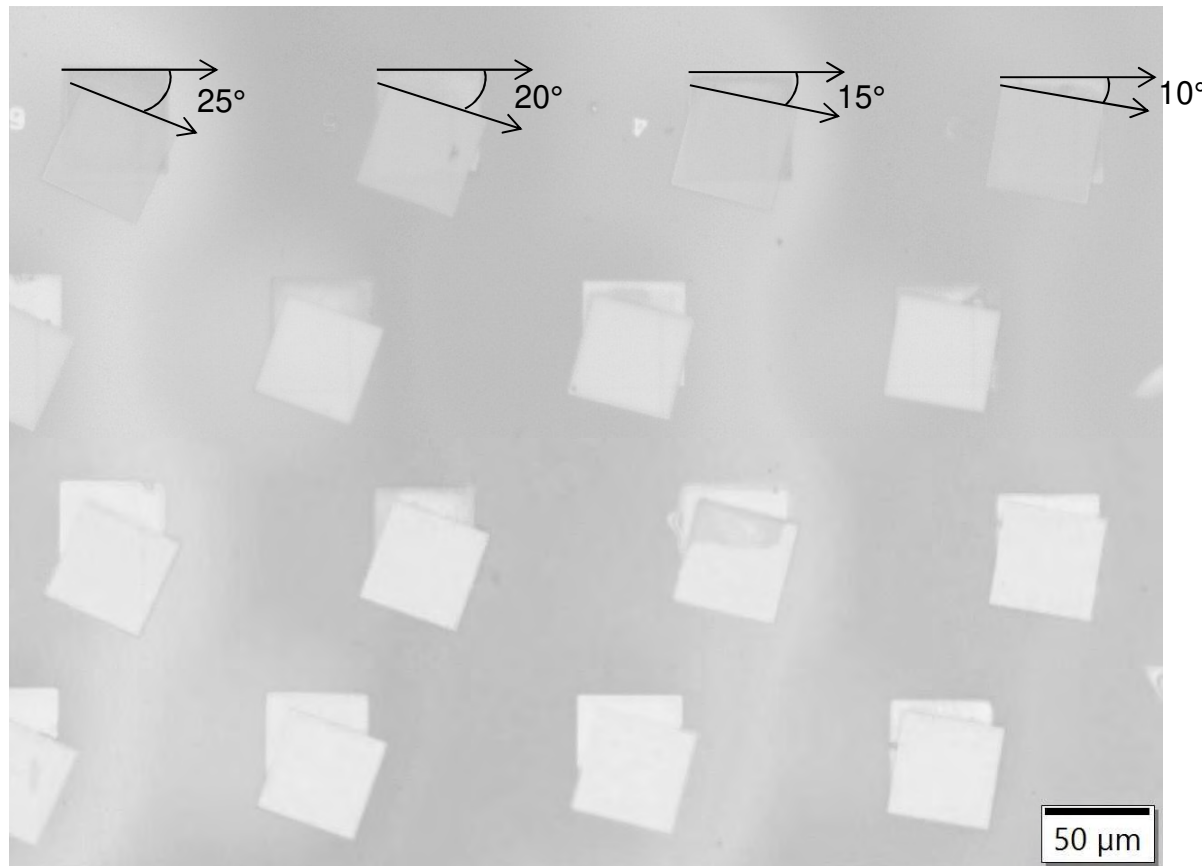
First results

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



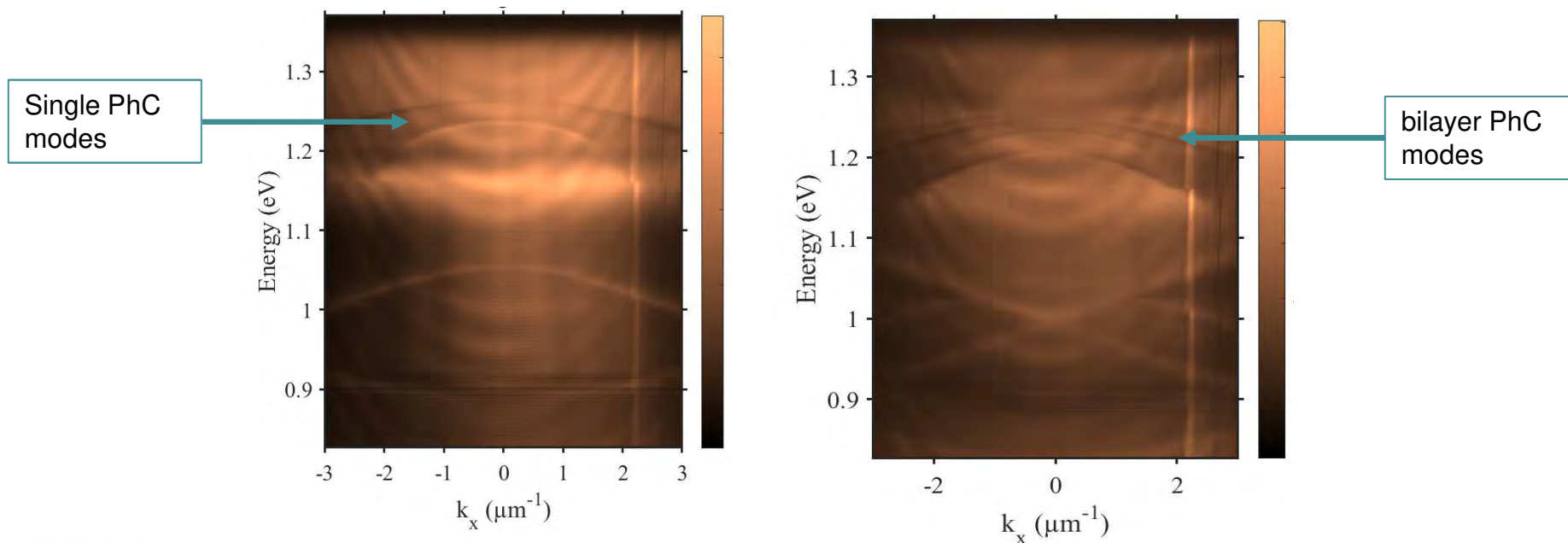
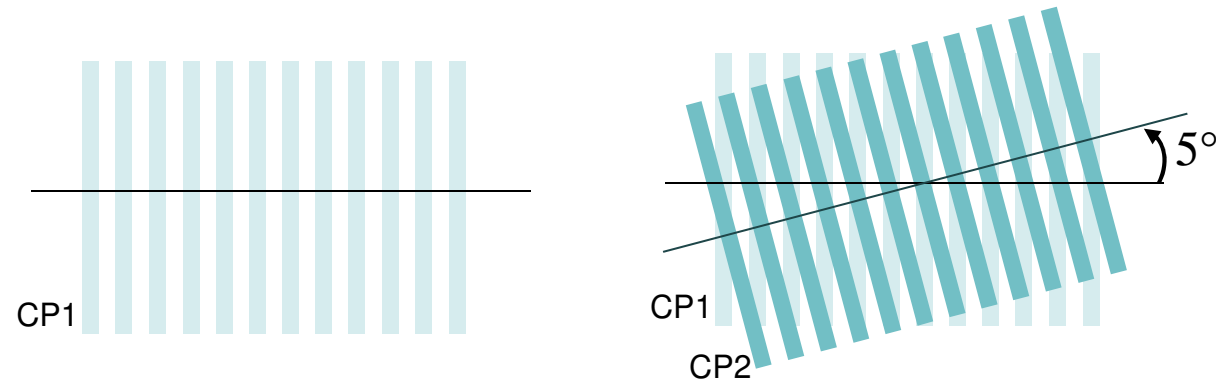
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First optical measurements

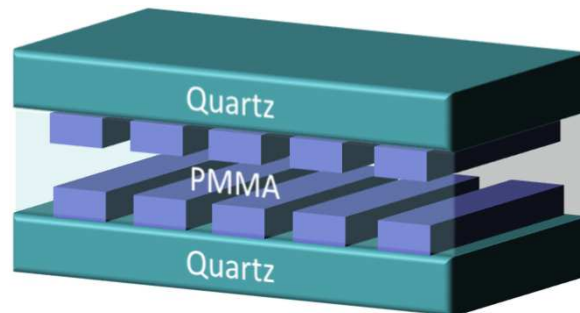
- ▶ IR Fourier space imaging of single and bilayer photonic crystals



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



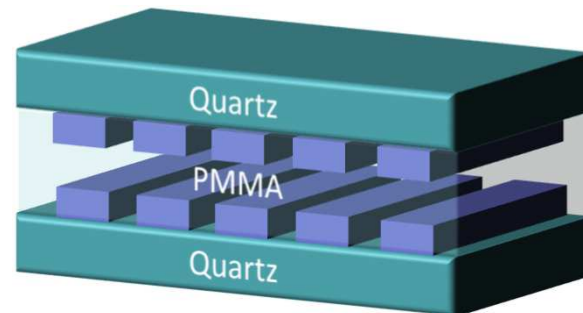
► Versatile process:

- ✓ 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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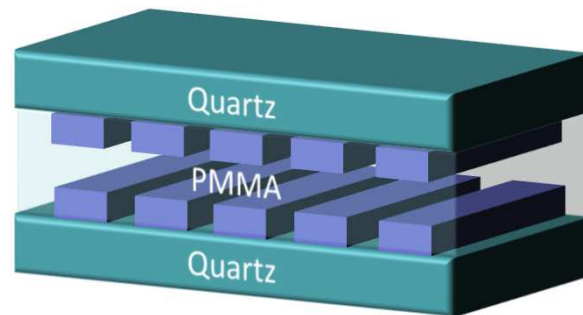
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THANK YOU FOR YOUR
ATTENTION



Perspectives



Passive structure

► Perspectives :

- Active devices :
 - perovskite, doped PMMA...
 - PCM

► Multiple layers ?

- Fabrication of the Phc on a sacrificial layer



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doi:10.1088/0957-4484/22/32/325301

Single and multilayer metamaterials fabricated by nanoimprint lithography

