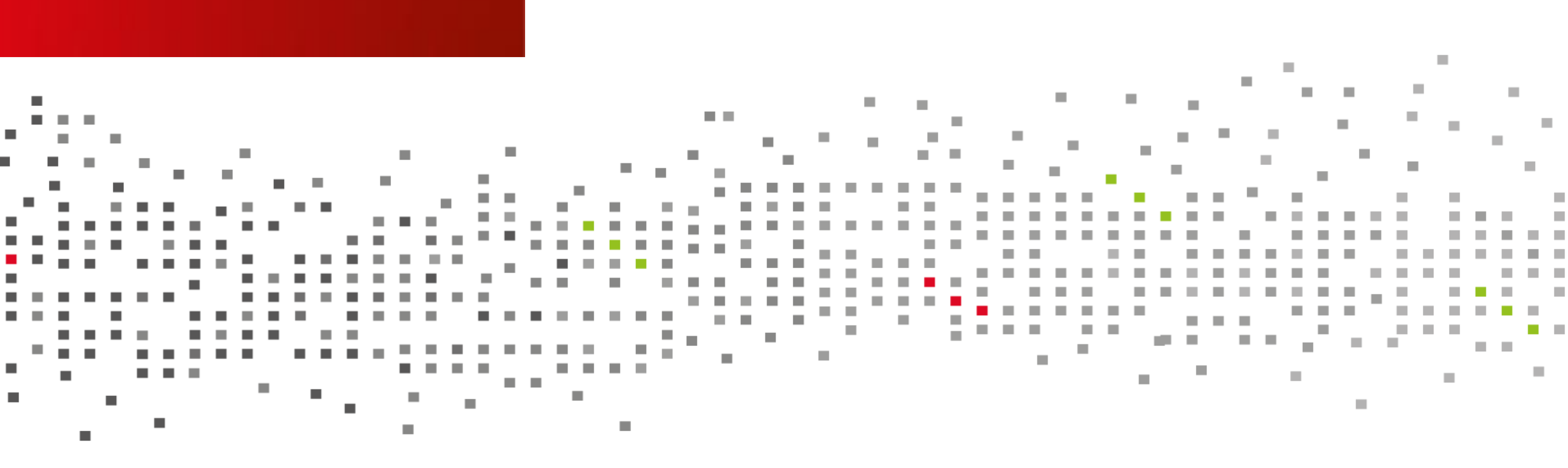
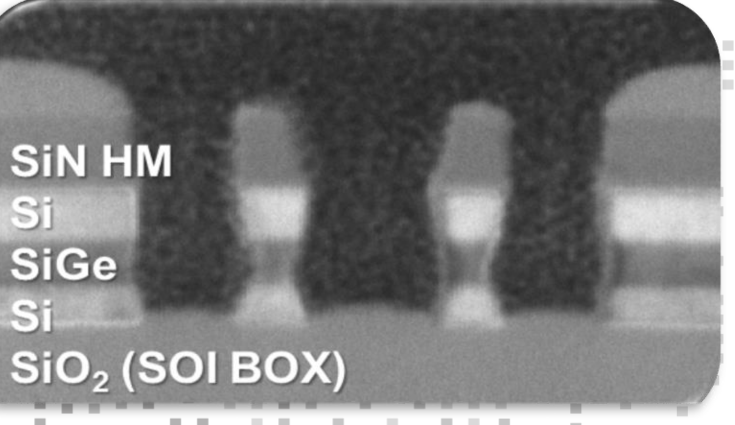


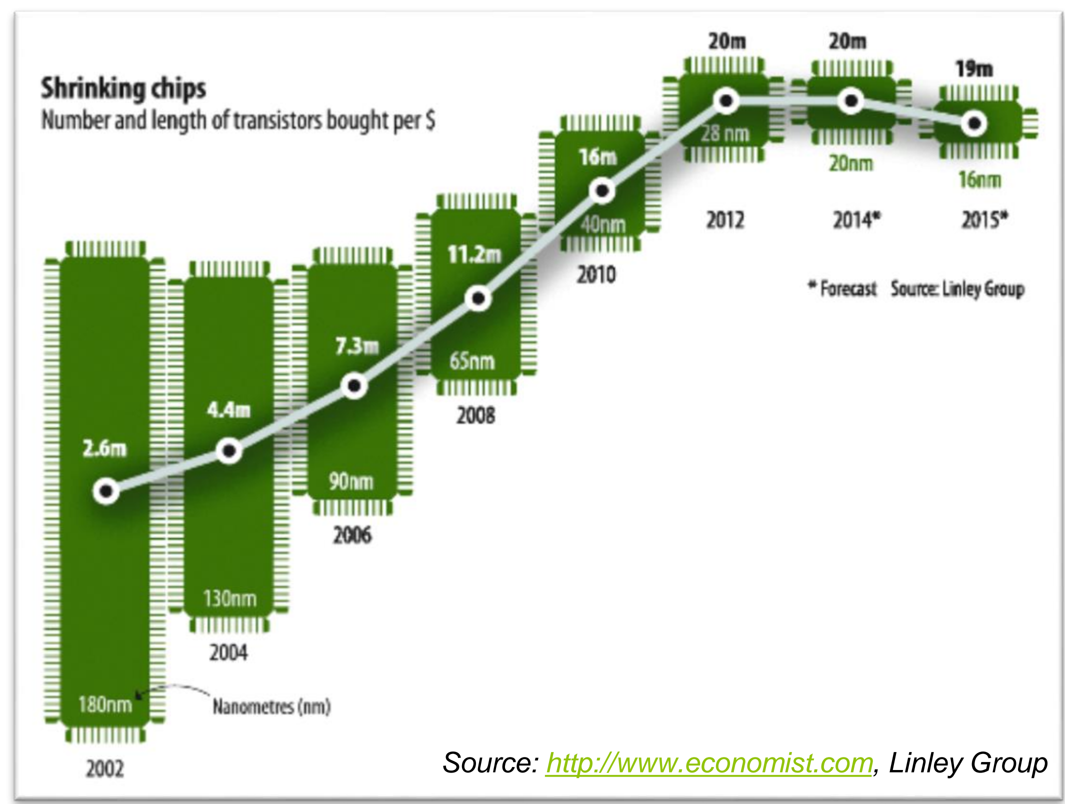


DIRECTED SELF ASSEMBLY OF BLOCK COPOLYMERS: FROM MATERIALS TO INTEGRATION

LETI Lithography Workshop | Raluca Tiron & Christophe Navarro | March 1st 2018

WHICH PROBLEMS COULD BE ADDRESSED WITH THIS TECHNOLOGY

After the 28nm node, we can continue to make transistors smaller, but not cheaper. *EETimes*



The main difficulty for IC manufacturers is the continued miniaturization of the light pattern applied to the resist.

Two **expensive** and **complex** processes

- EUV
- Multiple Patterning

DSA: a complementary lithography

Benefits

– Density multiplication (coast saving vs MP)
– Pattern rectification (for ex. for EUV)
– Good for regular arrays of lines and vias
– Improved LER (dependent on molecules sizes)

Challenges

– Difficult to ensure perfect patterning (defectivity)
– Limited patterns
– Not good for isolated features
– Design rules restrictions

ARKEMA-LETI SOLUTION: IDEAL PROGRAM

PS-*b*-PMMA

Graphoepitaxy for contact

- Shrink and doubling
- Process stability monitoring
- Integration for Via0

Graphoepitaxy for L/S

200 nm

- Benchmark materials
- Integration for NW
- Prepare metrology for high chi

Chemoepitaxy for L/S

200 nm

- Benchmark chemo vs grapho
- Prepare high chi

High - χ

High chi for L/S

Graphoepitaxy

200 nm

Chemoepitaxy

- Next generation material & processes

$22nm < L_0 < 80nm$

$L_0 < 20nm$

A large panel of materials and process flows available

THE MAIN IDEAL PROGRAM OBJECTIVES

Push material platforms to maturity

- From lab scale to industry
- Evaluate advanced copolymer platform

Develop 300mm patterning solutions

- Certify material compatibility with clean room standard
- Screen DSA material performances
- Verify transfer capabilities

Scale-up DSA processes to production level

- Compatibility with design rules
- Respect of ITRS standard : defectivity, throughput…

THE LETI ECOSYSTEM FOR IDEAL PROGRAM

Materials :

- ✓ PS-*b*-PMMA L_0 = [25:80nm]
- ✓ Neutral layer
- ✓ High resolution BCP L_0 < 20nm

DSA MATERIALS AT ARKEMA/BREWER SCIENCE

A full material set developed in collaboration between Arkema & Brewer Science :

- **block copolymers: lamellar and cylindrical**
- **Surface energy control layers: crosslinkable and standard**
- **guiding layers: PS and PMMA guiding**

1st generation

C35, L37, L22
Historical Baseline

- ✓ Good control of manufacturing
- ✓ Good control of self-assembly properties
- × Too small for C014nm design rules

2nd generation

C23 to C50,…
Improvement in molecular parameters (low hPS content,..)

- ✓ Improved manufacturing control for all the grades
- ✓ Lower BCP dispersity
- ✓ Higher Mw more adapted to C014nm requirements
- × Higher molecular weight: lower DSA kinetics

3rd generation

C23 to C50, L22 to L50…
Blends

- ✓ Precise control of periods
- ✓ Faster DSA kinetics
- ✓ Less defectivity

Under development

4th generation

Materials for beyond CMOS applications

- ✓ Very high period (C80, L80)
- ✓ Specific morphologies (inv C35)

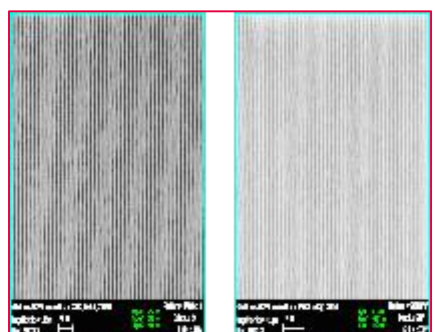
High chi materials

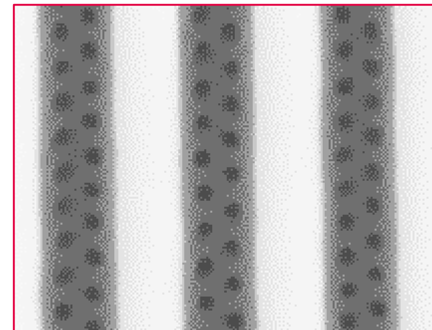
- ✓ Low period

OptiLign™ MATERIAL SYSTEMS

- Commercial-quality directed self-assembly (DSA) material set developed in collaboration between Arkema & Brewer Science

- The OptiLign™ system currently includes three materials required for self-assembly
  - block copolymers: lamellar and cylindrical
  - Surface energy control layers: crosslinkable and standard
  - guiding layers: PS and PMMA guiding





- … and more to come with materials dedicated to beyond CMOS applications and High chi full systems..

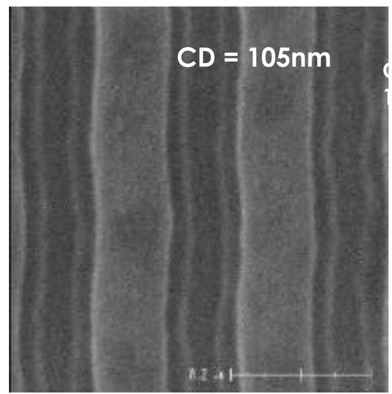
brewer science

ARKEMA

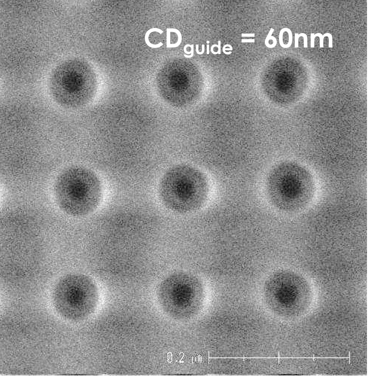
NEW GRADES UNDER DEVELOPMENT FOR BEYOND CMOS APPLICATIONS

Thanks to the changes in the process, higher Mw polymers are achievable

- C80 and L80 (under evaluation)



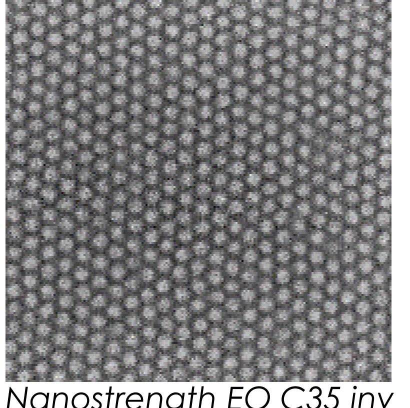
Nanostrength EO L80



Nanostrength EO C80

Inversed matrix

- C35 PMMA matrix
- Development of an adapted NL



Nanostrength EO C35 inv

ions4SET

Enlarging our portfolio opens new applications for DSA & enables demonstration for new projects

HOW TO ACHIEVE SUB-10 NM HP DSA LITHOGRAPHY FOR L/S PATTERNING ?

Keeping in mind important integration requirements:

- Fast arrangement kinetic
- Low thermal annealing temperature (<250°C)
- Etching selectivity

Block copolymer architecture

- Lamellar morphology
- Sub-20 nm period
- Block chemistry compatible with surface neutralization process

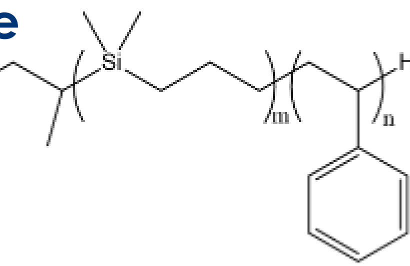
Silicon containing high-χ block copolymers

Modified PS-*b*-PMMA high-χ block copolymers

Two complementary set of materials for graphoepitaxy and toward chemoepitaxy integrations

SILICON CONTAINING HIGH-CHI BCP MATERIAL

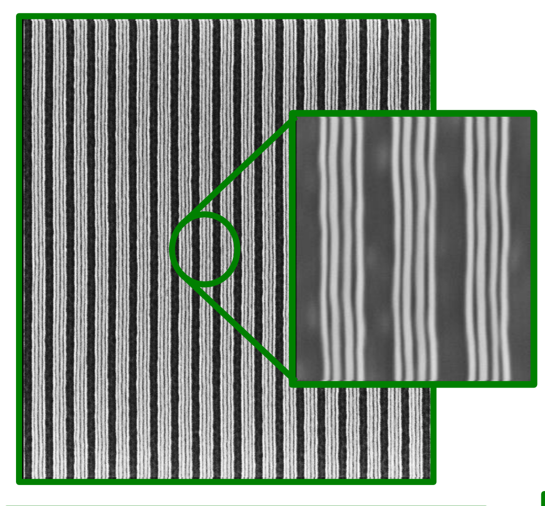
« PDMSB-*b*-PS » : Poly(1,1-dimethyl silacyclobutane)-*block*-polystyrene



- High Flory-Huggins interaction parameter PDMSB/PS
- High resistance toward dry-etch integration step due to Si block
- Specific materials required (top-coat..) for perpendicular orientation

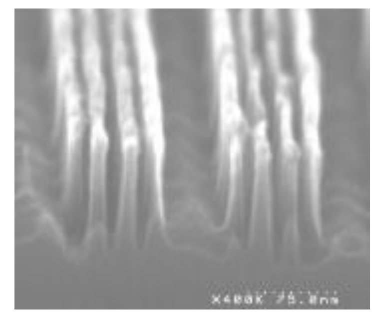
Graphoepitaxy approach

BCP of L_0= 23.5nm Thermal self-assembly during 5 mins



Defect-free x4 multiplication pattern

Plasma etch-transfer of CSS :



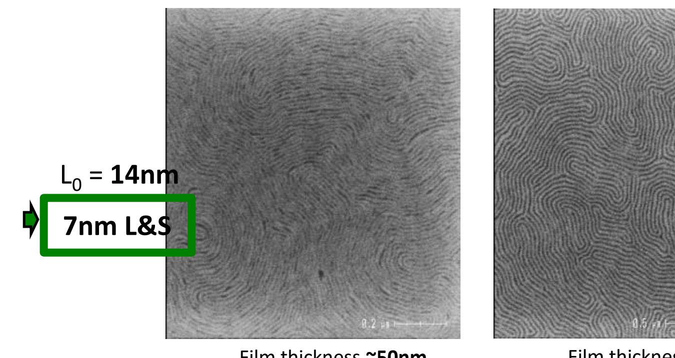
High AR features :
~20nm thick lam. → **~80nm trenches in Si**

Toward a Chemoepitaxy approach

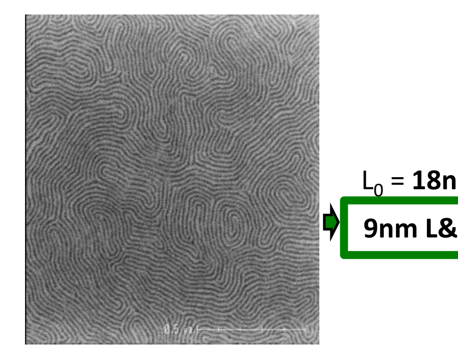
Free-surface self-assembly of CSS BCP

L_0 = **14nm**

7nm L&S



Film thickness ~**50nm**



Film thickness ~**25nm**

L_0 = **18nm**

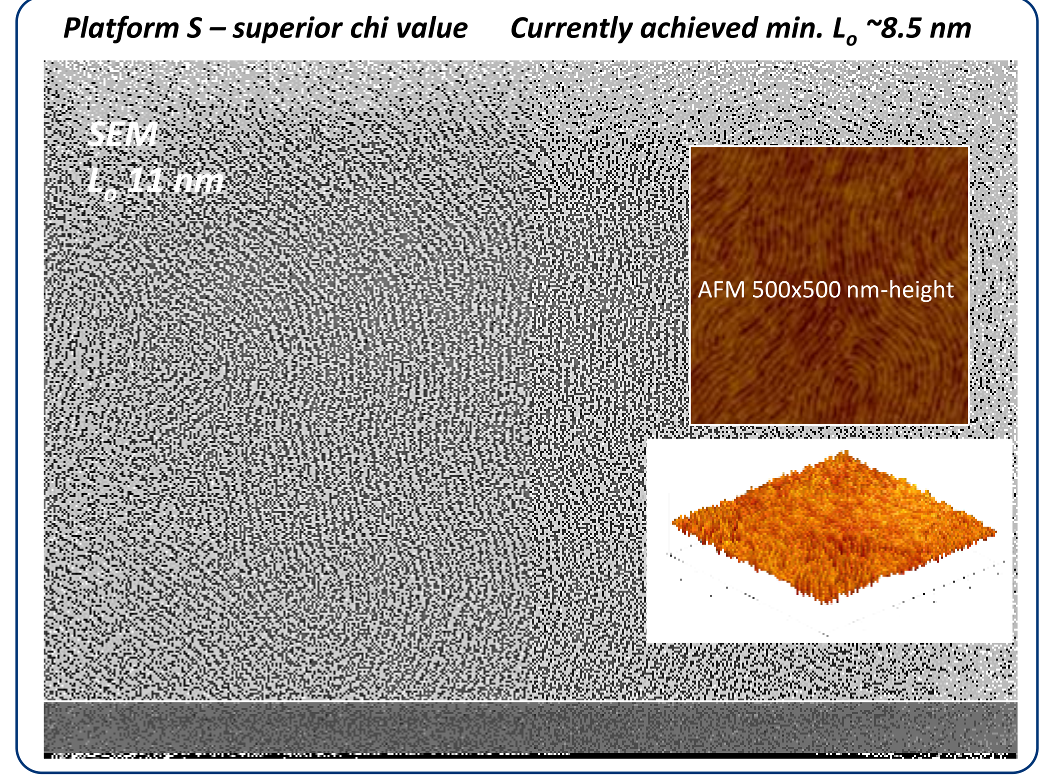
9nm L&S

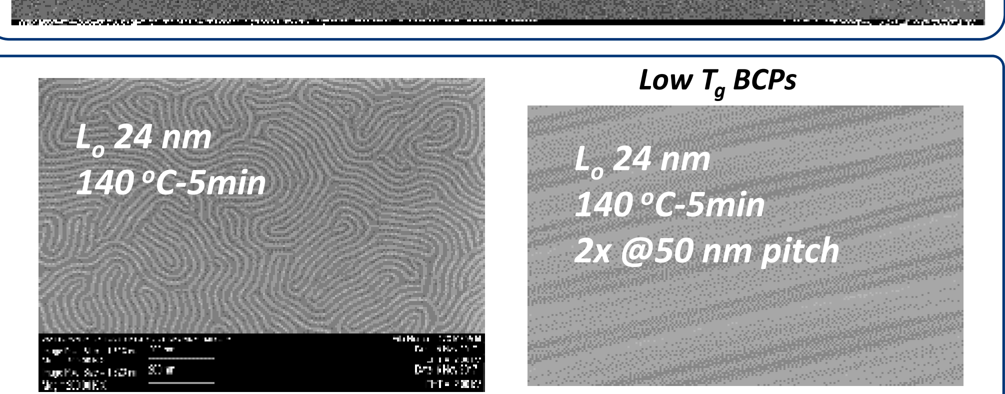
Perpendicular orientation of lam. BCP thanks to both **neutral top&bottom interfaces**

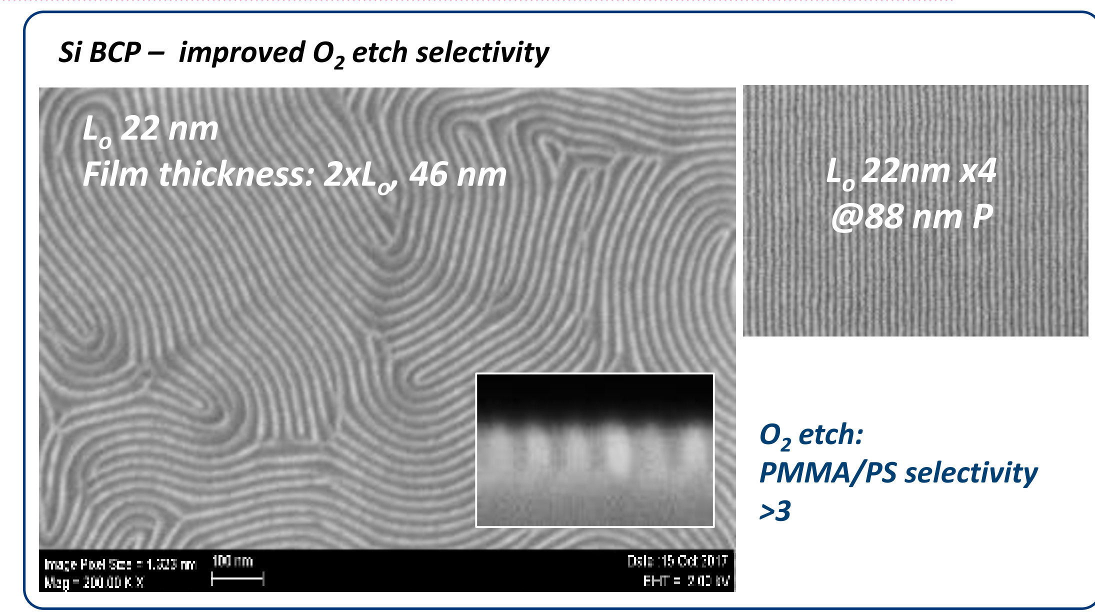
BCP film thicknesses from **~20nm to >150nm**, depending on needs of customer

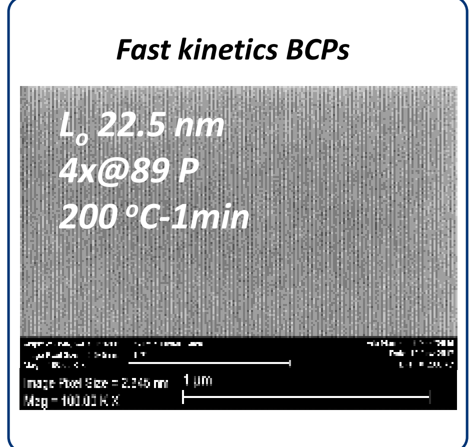
Self-assembly **process & materials entirely compatible with 300mm tracks** requirements

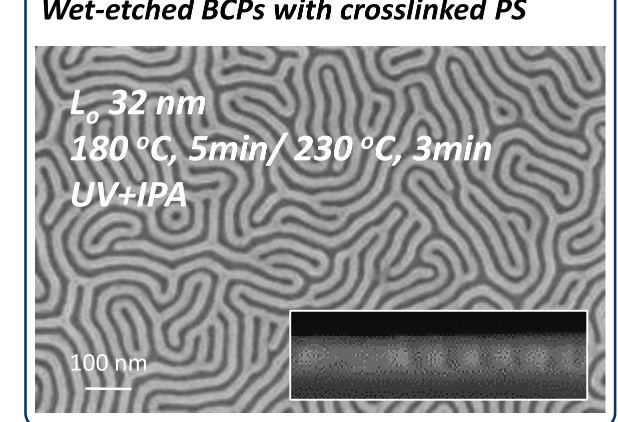
HIGH CHI MATERIALS OTHER EXAMPLES











HIGH-CHI BCP MATERIAL – CONCLUSION/ PERSPECTIVES

- **Materials with χ high enough to go down to 7nm L&S**

- **Graphoepitaxy approach :**
  - low defectivity, no need of specific layers with planarization

- **Chemoepitaxy:**
  - Neutral materials layers identified & demonstrated
  - Processes compatible with 300mm tracks

THE LETI ECOSYSTEM FOR IDEAL PROGRAM

Materials :

- ✓ PS-*b*-PMMA L_0 = [25:80nm]
- ✓ Neutral layer
- ✓ High resolution BCP L_0 < 20nm

Integration:

- ✓ Compact and physical model
- ✓ Shortloops with ST
- ✓ DSA dedicated defectivity tools

Institutional project

Technological Flow:

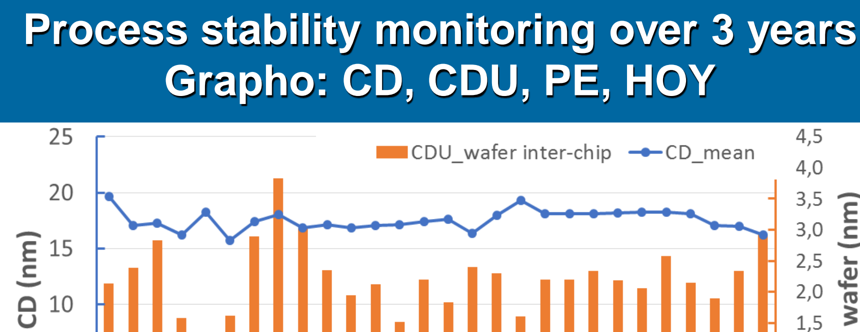
Fast evaluation at ***lab scale***
Chemo vs grapho vs fingerprint

300 mm Process Line:

- ✓ Lithography for templates
  - 193 (dry & i) or e-beam
- ✓ DSA dedicated track
  - Specific bake
  - Solvent annealing
  - PMMA removal step
- ✓ Dedicated metrology
  - CD-SEM
  - SP2
  - Scatterometry

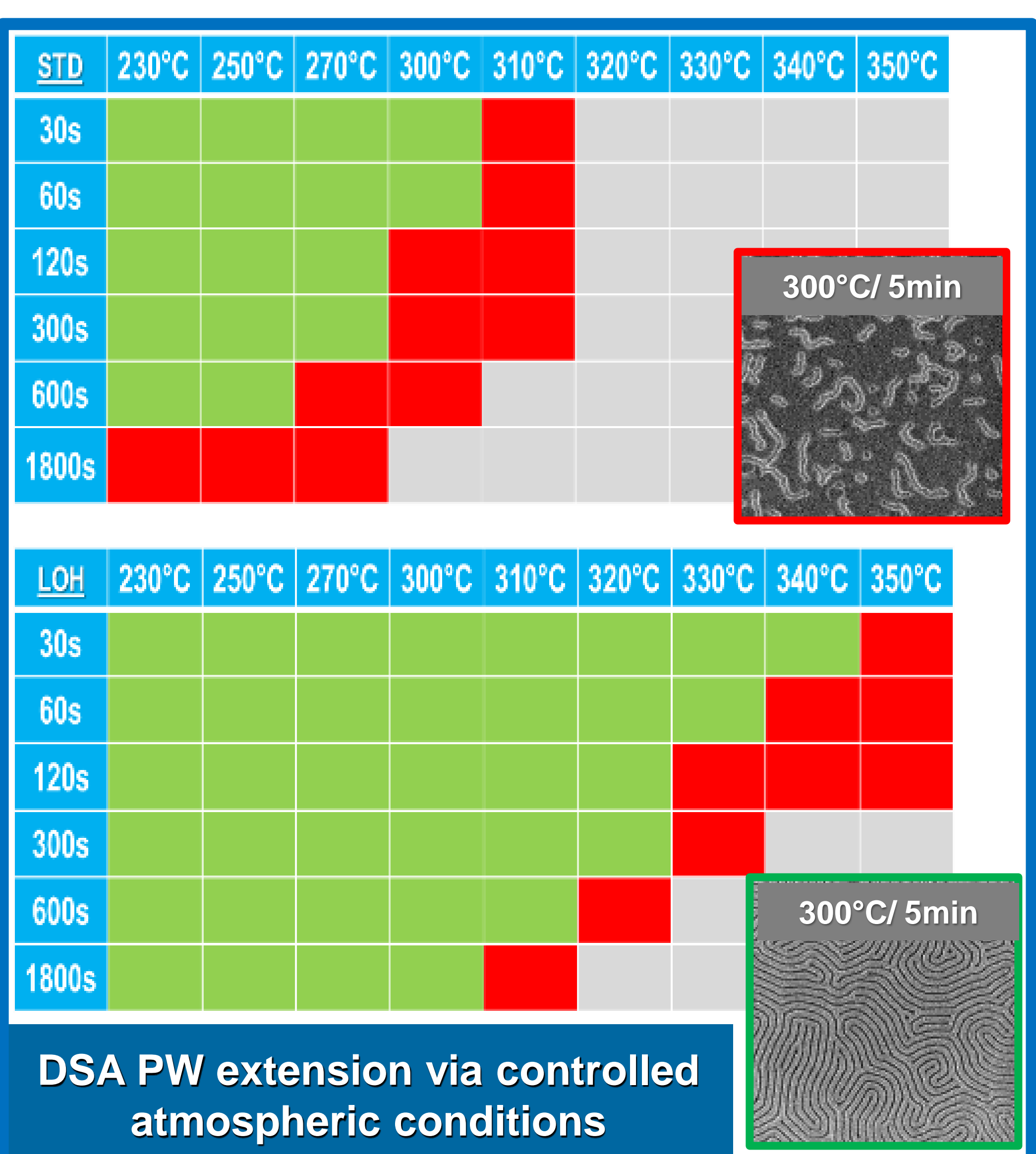
THE MAIN ACHIEVEMENTS: A DSA DEDICATED TRACK

Process stability monitoring over 3 years Grapho: CD, CDU, PE, HOY



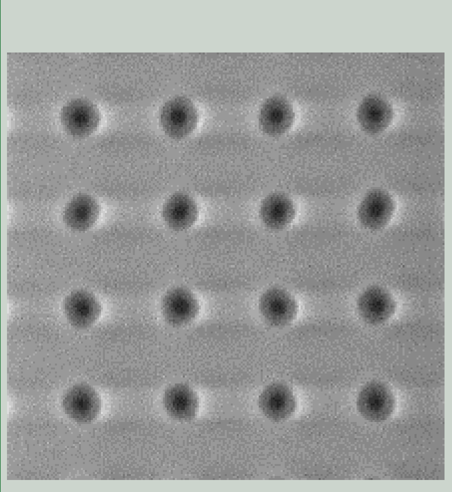
Thermal bake | *Solvent-Annealing*

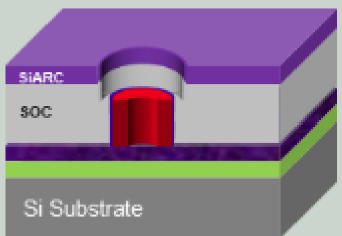
PS-b-PMMA modified, high chi L0 = 18nm

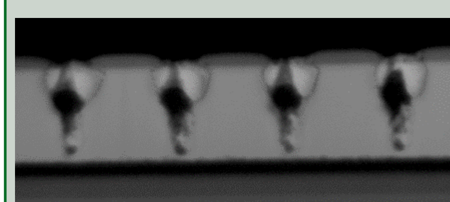


THE MAIN ACHIEVEMENTS: PS-*b*-PMMA CH DSA FOR VIA0 PATTERNING

SiARC/SOC
Organic template



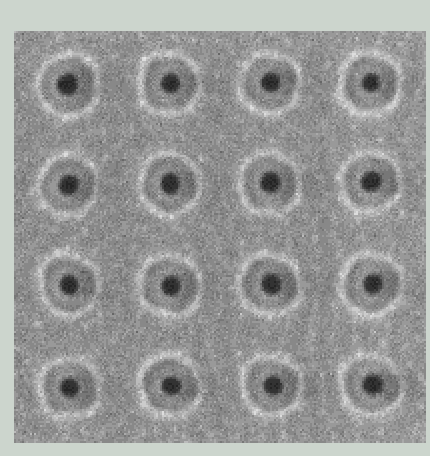


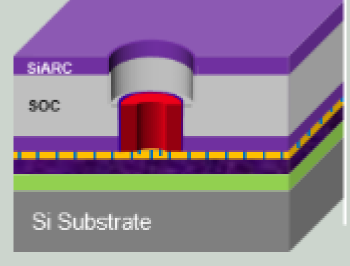


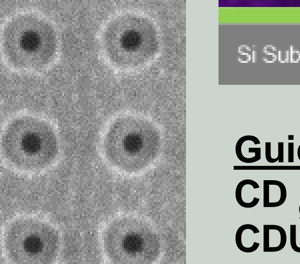
Guide template:
CD $_{guide}$ = 40.5 nm
CDU-3σ$_{guide}$ = 4.0nm

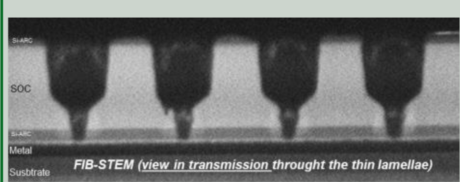
DSA:
CD = 17.2nm
CDU-3σ = 1.3nm
HOY = 100%
Planar: OK
Residue 3σ = 3.9nm
Rework : NO

SiARC/SOC
Embeded NL





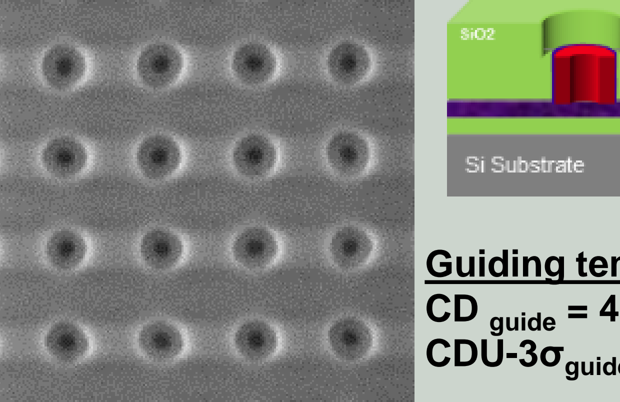


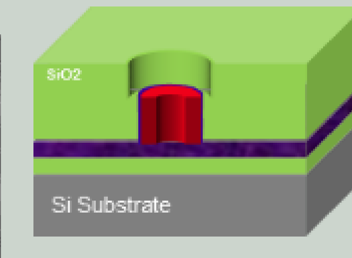


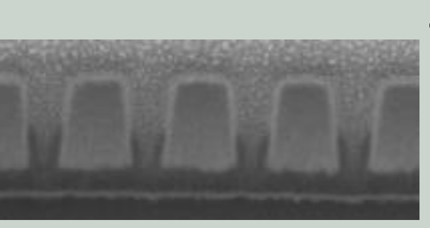
Guiding template:
CD $_{guide}$ = 50nm
CDU-3σ$_{guide}$ = 4.6nm

DSA:
CD = 22nm
CDU-3σ = 1.4nm
HOY = 100%
Planar OK
Residue 3σ = 0.6nm
Rework: NO

Silicon Oxide
Inorganic template







Guiding template:
CD $_{guide}$ = 40nm
CDU-3σ$_{guide}$ = 4.6nm

DSA:
CD = 17.6 nm
CDU-3σ = 1.4nm
HOY = 100%
Planar OK
Residue NA
Rework: OK

THE MAIN ACHIEVEMENTS: PS-*b*-PMMA CH DSA FOR VIA0 PATTERNING

Contact shrink

Fast material & process evaluation

BCP Max pitch
Lithography Resolution
Contact Min pitch

Pitch = 12
200nm

Peanuts shape

DSA Pitch modulation by 193i pattern engineering

BCP Max pitch
Contact Min pitch
Lithography Resolution

Elliptical template

Pitch density improvement by BCP natural period

Contact Min pitch
BCP Max pitch
Lithography Resolution

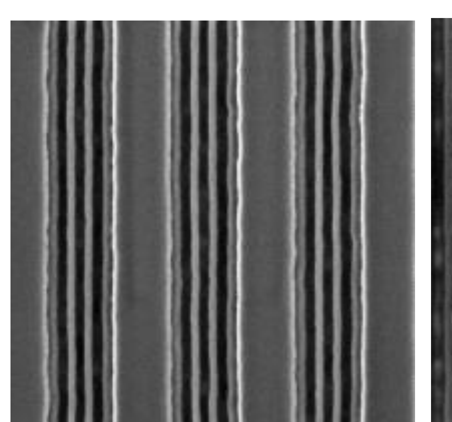
Addapted from H. Yi,et al., Nano. Letters, 2015

Full control of BCP self-assembly through pitch

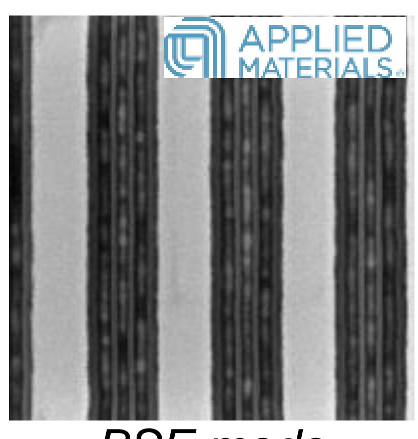
All images are taken on the same processed wafer; Templates generated by 193i

THE MAIN ACHIEVEMENTS: PS-*b*-PMMA L/S DSA FOR TRI-GATE NANOWIRES

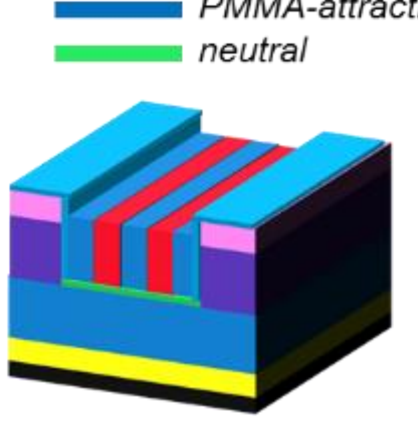
Post DSA:
CDU = 1.4nm
LWR = 2.2nm
LER = 3.8nm



SE mode



BSE mode

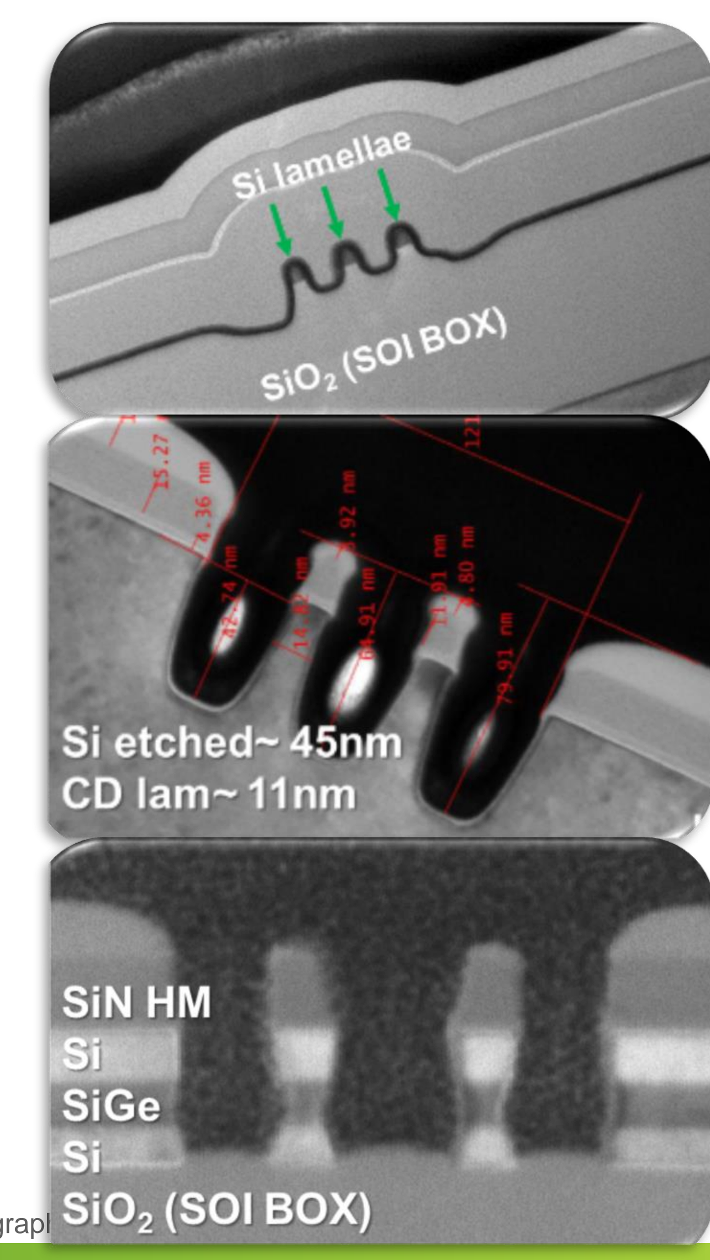


Achievements

- ✓ UV-assisted graphoepitaxy approach for a precise control of template affinity neutral bottom / PMMA sidewall affinity
- ✓ 300mm compatible DSA process (PS-*b*-PMMA, L0 = 38nm) with silicon nanowires patterning (litho, etch, cut).

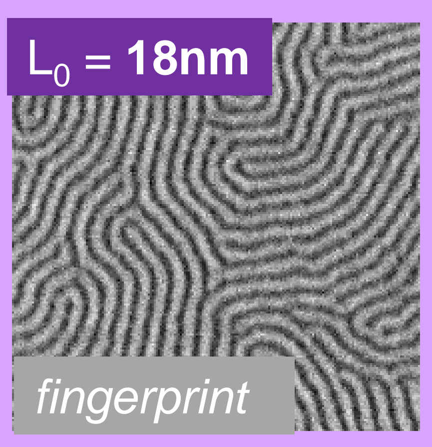
Next:

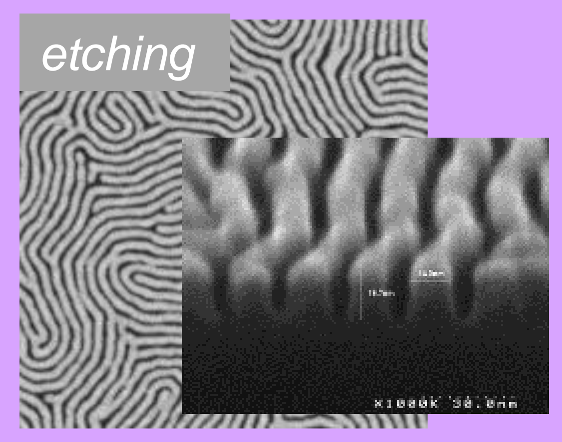
- ➢ DSA NW electrical demo and comparison to double patterning NW.
- ➢ DSA patterning for stacked nanowire devices.
- ➢ Investigation of BCPs with lower resolution.

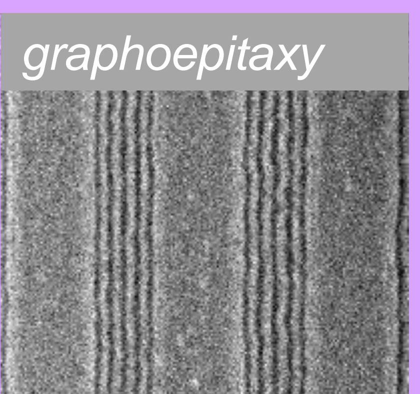


THE MAIN ACHIEVEMENTS: HIGH CHI FOR L/S APPLICATION

PS-*b*-PMMA modified BCP

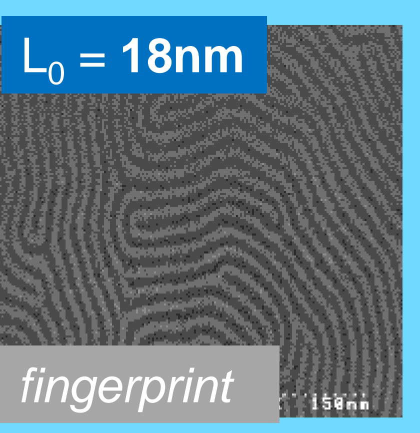


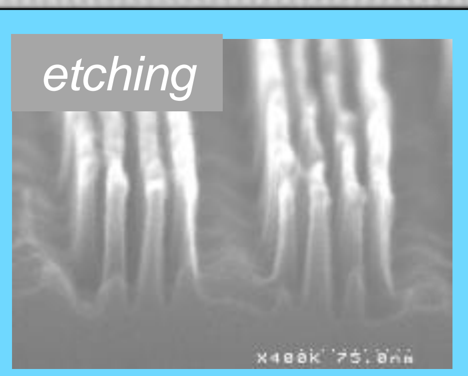


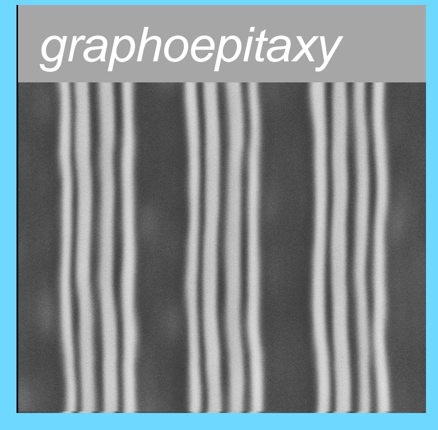


- ✓ Material implemented on 300mm Leti's pilot line
- ✓ TC free materials
- ✓ Process similar to PS-PMMA
- ✓ Etching transfer demonstrated in Si underlayer

Si containing BCP





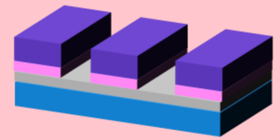


- ✓ Patterning demonstration at sample scale (LTM)
- ✓ TC & NL available
- ✓ Etching transfert demonstrated in Si underlayer

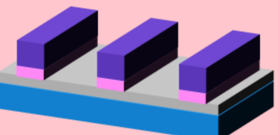
Next step: implement chemoepitaxy approach for high chi materials (L_0 = 18nm)

THE MAIN ACHIEVEMENTS: CHEMOEPITAXY WITH SPACER PATTERNING

LiNe

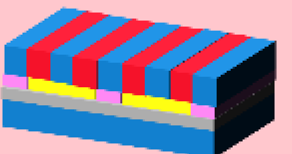


193i lithography



Pattern trimming

Lithography resist stripping & selective grafting



BCP self-assembly

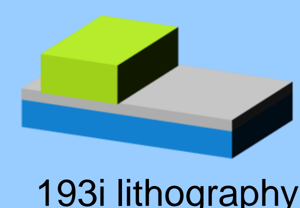
L_0=30nm CD = 15nm	guide pitch	Multip. factor
	60	2
	90	3
	120	4

L_0 = 18nm CD = 9nm	guide pitch	Multip. factor
	36	2
	54	3
	72	4

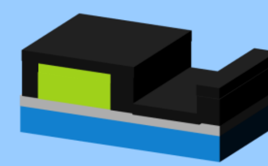
High χ BCP need of higher resolution

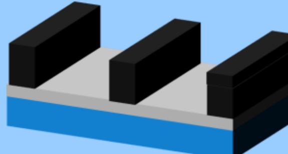
L_0 = 18nm CD = 9nm	guide pitch	Multip. factor
	72	2
	108	3
	144	4

Spacer

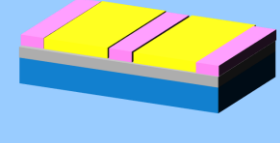


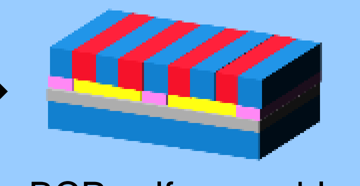
193i lithography



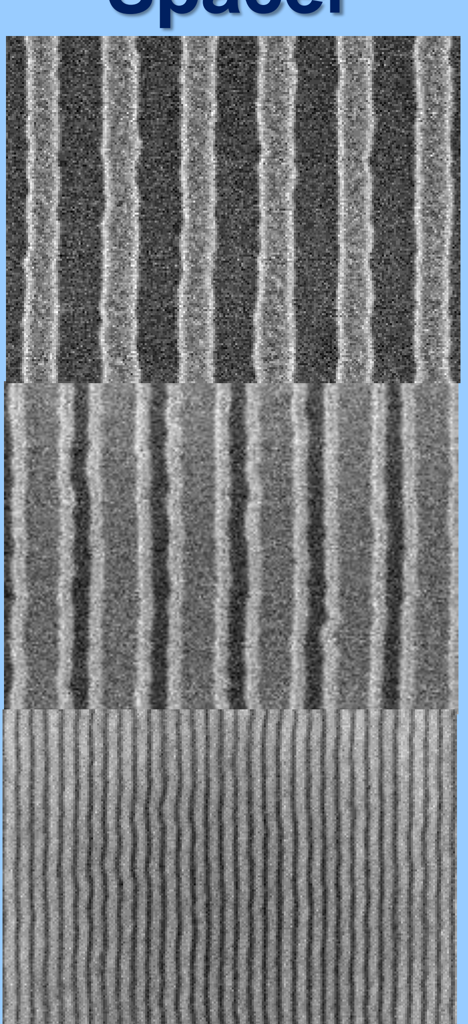


Spacer patterning

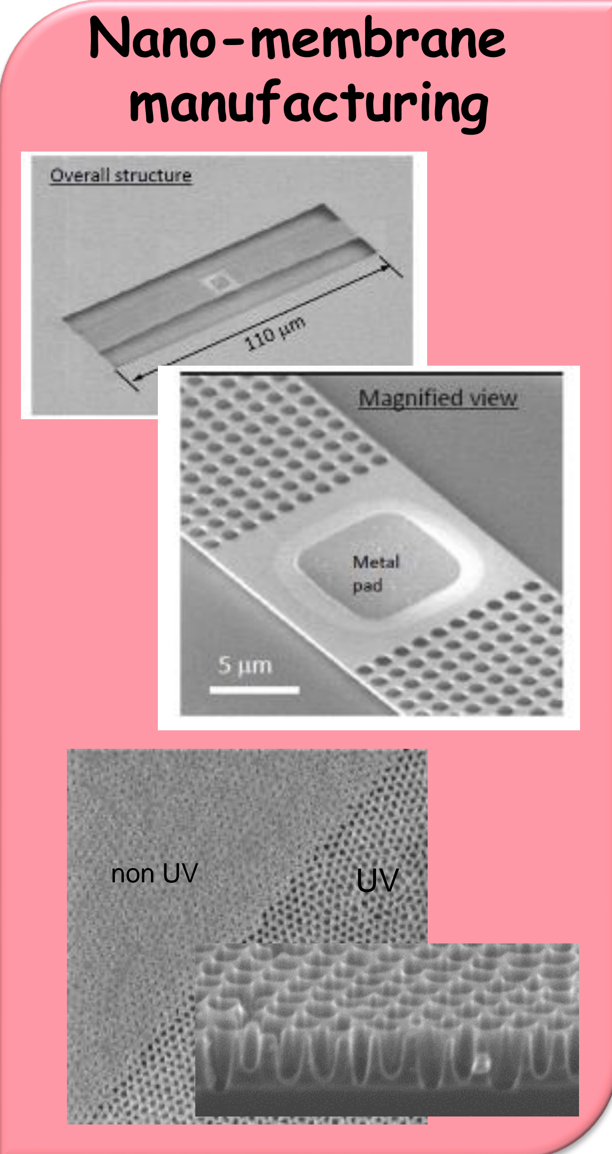


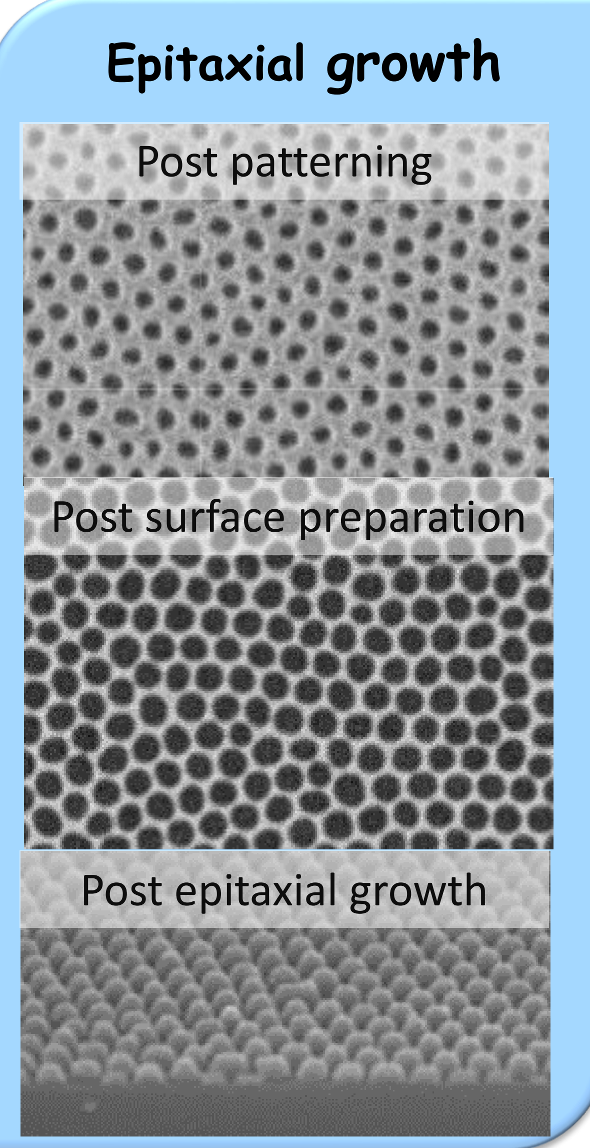


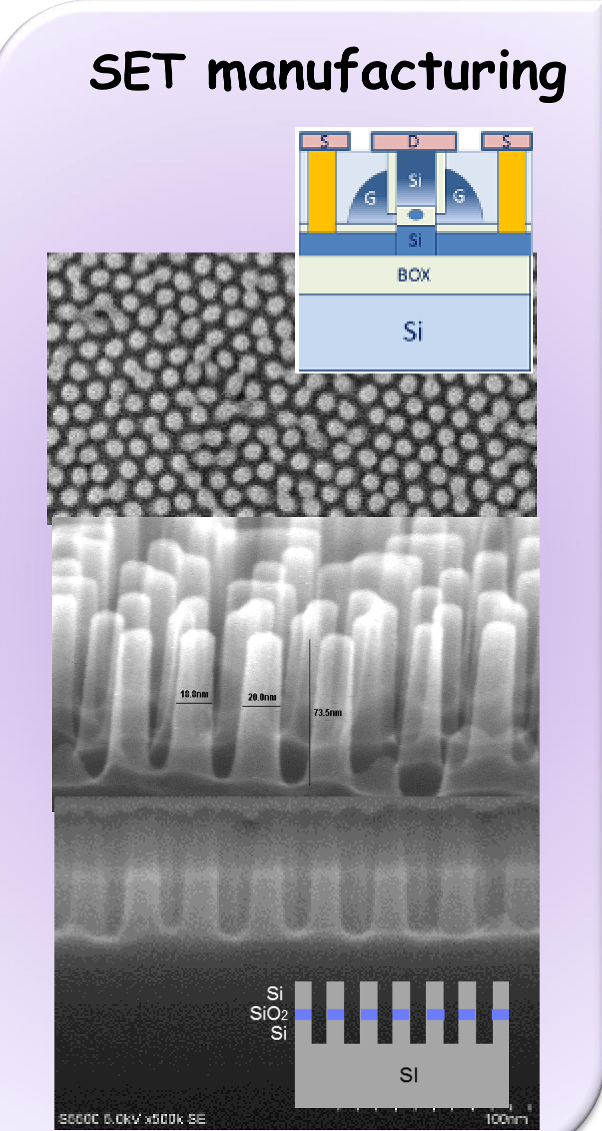
BCP self-assembly

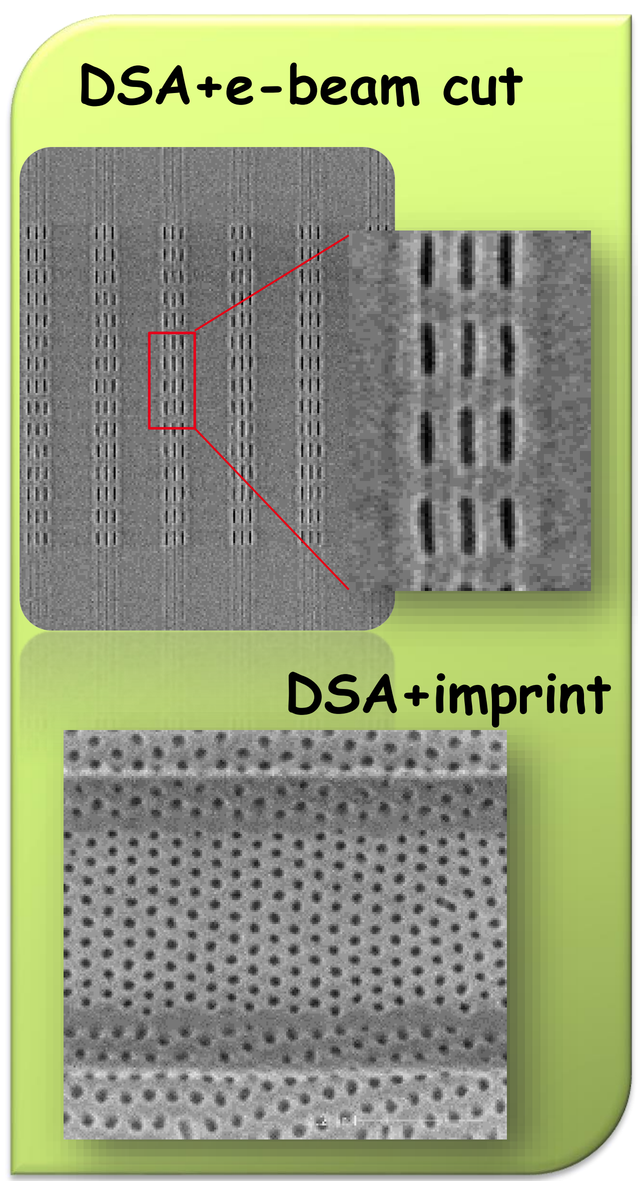


THE MAIN ACHIEVEMENTS : BEYOND CMOS APPLICATION









THE 2018 ROADMAP

	Q1	Q2	Q3	Q4
PS-*b*-PMMA				
Contact Hole & Via **CH graphoepitaxie**	Process of record monitoring (SPC)			
Nanowires **L/S grapho**	★ Si etch process			★ Electrical demonstrator
High chi L/S chemo (L0 < 20nm)				
Material evaluation	★ Si free high chi optimization	★ Si containing high chi		★ Platforms benchmark
Metrology	★ PW methodology		★ Fingerprint LER/LWR	★ Patterned LER/LWR
Chemoepitaxy	★ First process available	★ Si free high chi etching demo (fp)	★ Optimised process	★ Process monitoring implementation

THE NEXT STEPS FOR FURTHER ASSESSMENT AND VALIDATION

- *Maintain CH process baseline*
- *Perform nanowires electrical demonstration*
- *Address metrology and etching challenges*
- *Benchmark different material chemistries*
- *Implement process of record for chemoepitaxy L/S with high chi*

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