Talbot Displacement Lithography: Definition of Sub-100 nm Structures by UV-exposure

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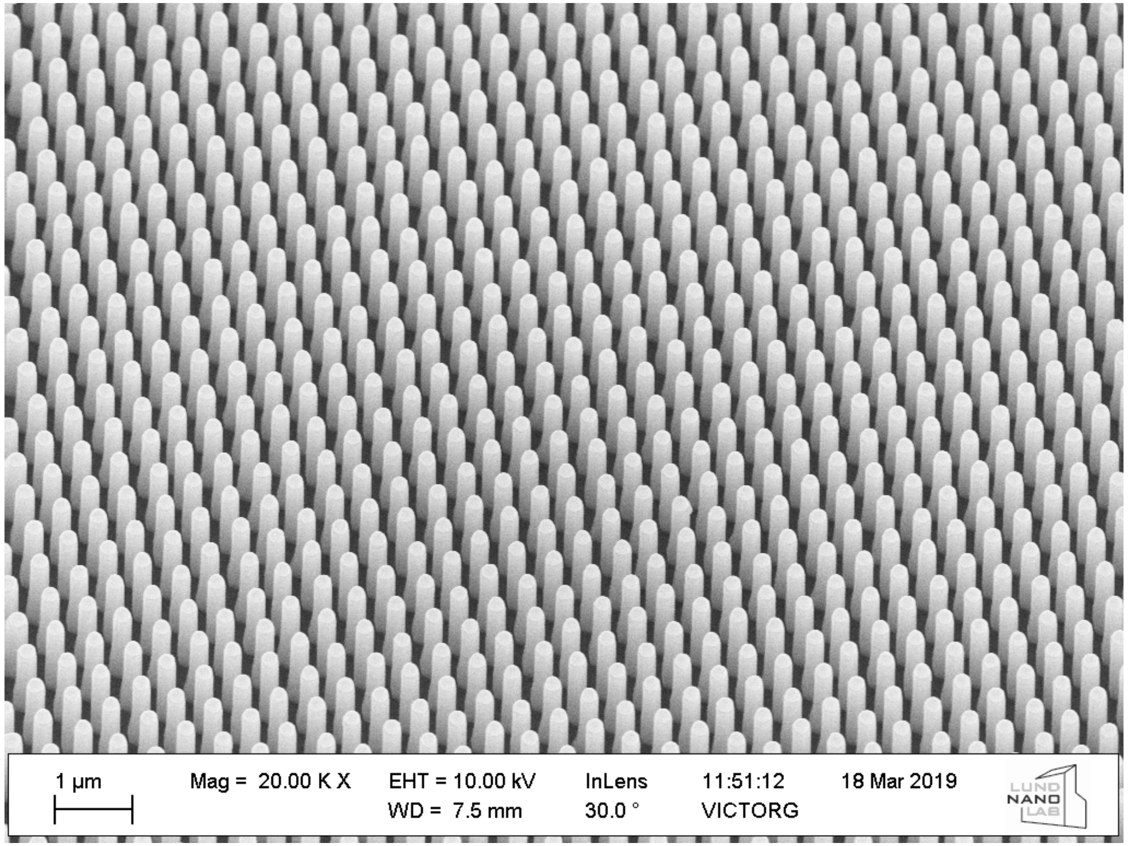
Outline of the lecture

1. Aim of lithography development
2. Overview and comparison of lithographic techniques used in Lund Nano Lab for tamplate preparation for nanowires growth
3. Basics of Talbot Displacement Lithography (TDL)
4. Technical implementation of TDL
5. Typical process flow
6. Examples of TDL processes and applications at Lund Nano Lab
7. Conclusions
8. Acknowledgements

Main aim of lithography development in LNL



GaAs nanowires growth in windows opened in SiNx mask on 2” GaAs wafer using TDL
Courtesy; Victor J.Gómez, Solid State Physics LU

In lithography, templates for nanowires growth in form of array of Au dots or holes in hard mask must be prepared.

1. Nanowires size 30-200nm
2. Pitch 500-2000nm
3. Regular pattern (array)
4. Low defects and contamination level
5. Minimum area - 2” wafers
6. Throughput (100 wafer/year)

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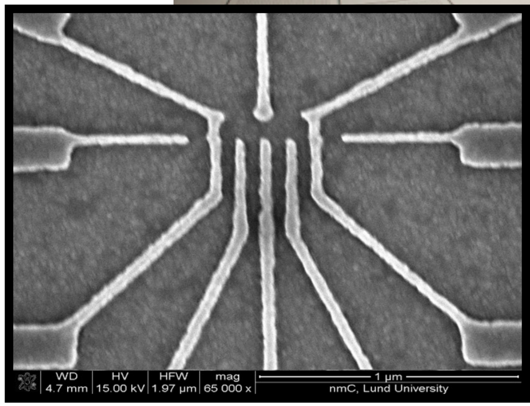
Common lithographic approaches: electron beam lithography (single beam)

Advantages:

1. High resolution (≈10 nm)
2. Flexible, suitable for research labs
3. No masks required



Drawbacks:

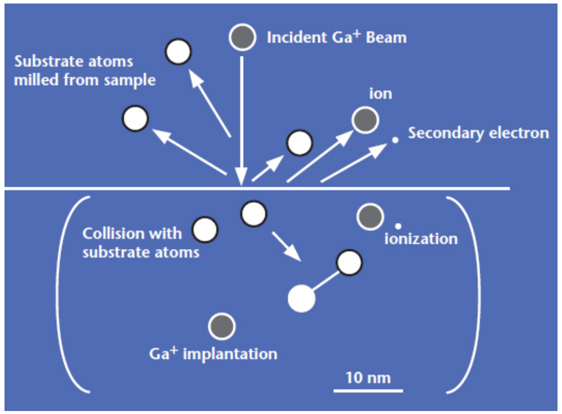
1. Very slow (sequential exposure)
2. Proximity effect
3. Requires stiching for large areas
4. Expensive

Nordic Nanolab Network

Common lithographic approaches: focused ion beam lithography (FIB)

Advantages:

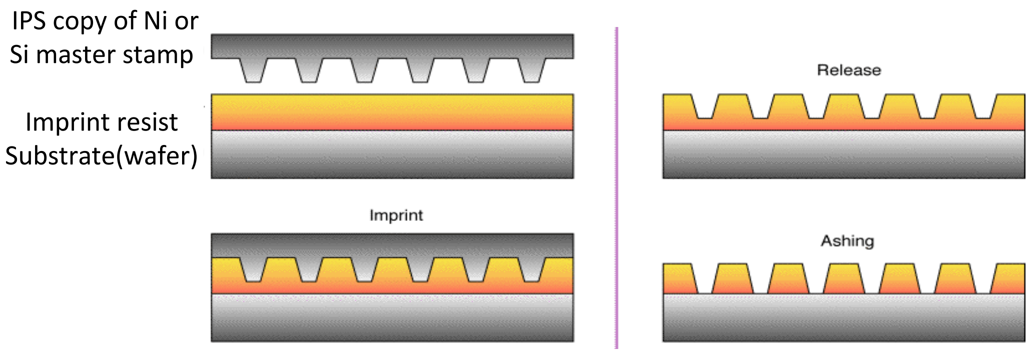
1. High resolution (≈20 nm)
2. Flexible, suitable for research labs
3. Can be used for direct patterning (sputter)
4. No masks required



Drawbacks:

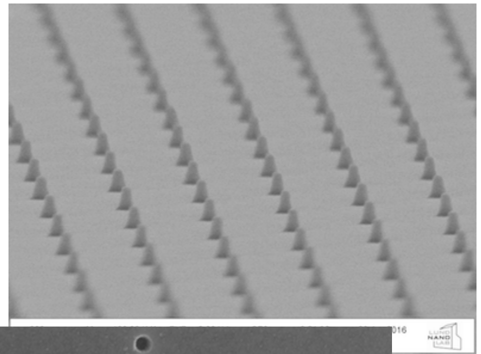
1. Very slow (sequential exposure)
2. Possible damage, re-deposition
3. Requires stiching for large areas
4. Expensive

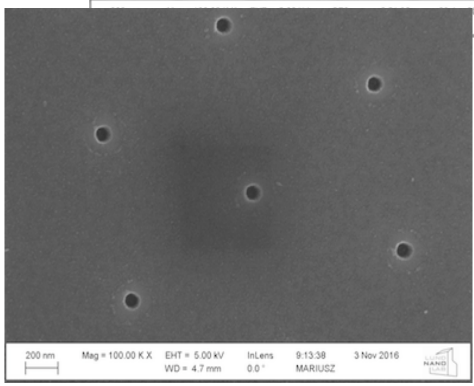
Common lithographic approaches: nanoimprint lithography



Advantages:

1. High resolution (≈few nm)
2. High throughput
3. Relatively inexpensive

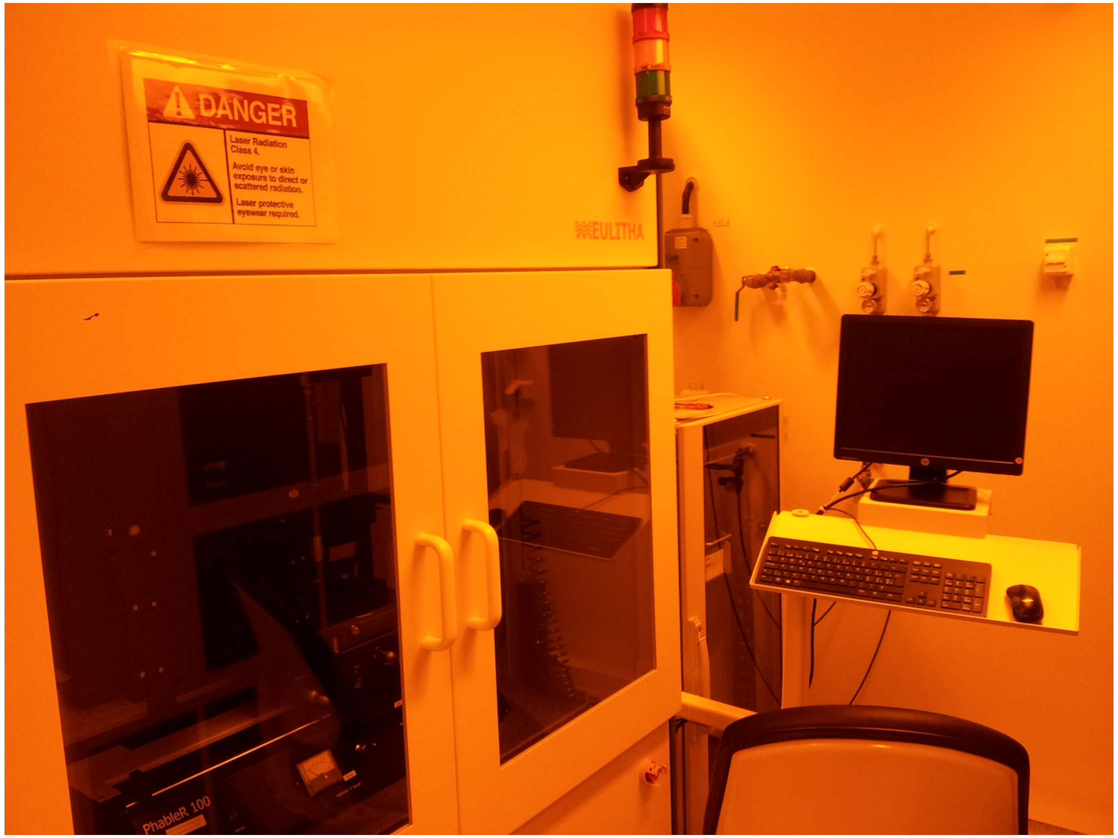




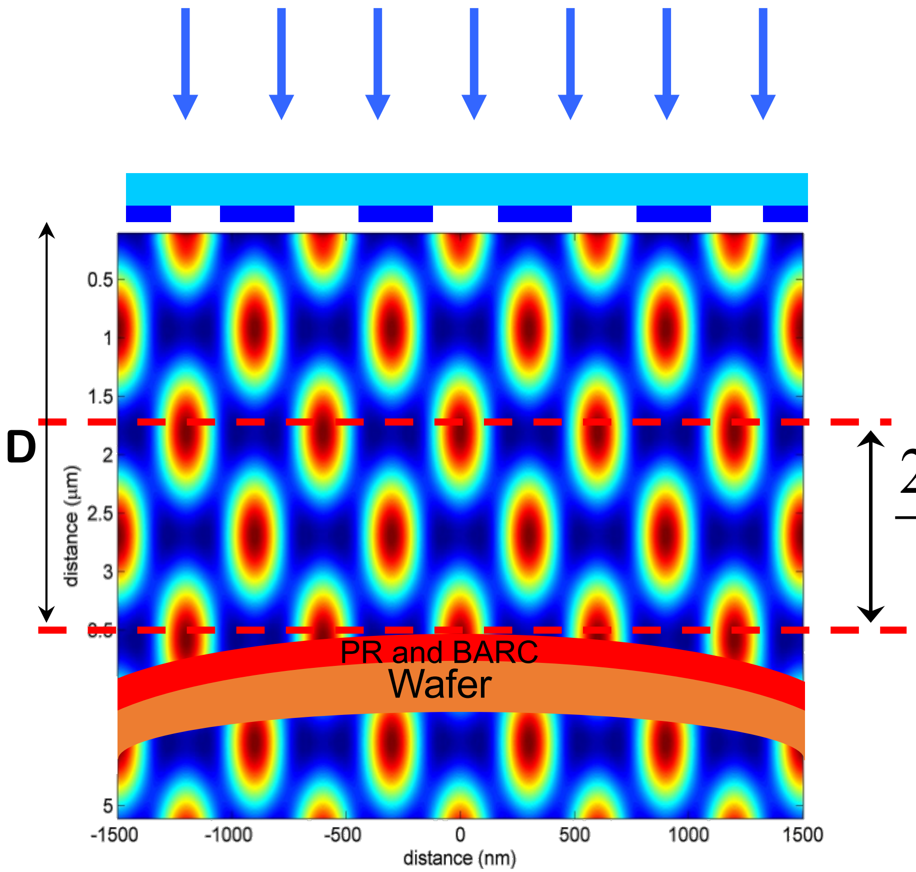
Drawbacks:

1. Mass transfer, sensitive for defects
2. Master stamp is expensive
3. Residual layer to be controled
4. Not very flexible
5. Accumulated defects

Talbot Displacement Lithography in Lund Nano Lab
PhableR 100DUV from Eulitha AG



Talbot Displacement Lithography: principles of operation



$$\frac{2p^2}{\lambda}$$

Highly collimated (0.028°) light source
193 nm wavelength excimer pulse laser

Phase shift mask
Only regular pattern is useful

3D Talbot interference pattern

Pattern repeats with characteristic Talbot period

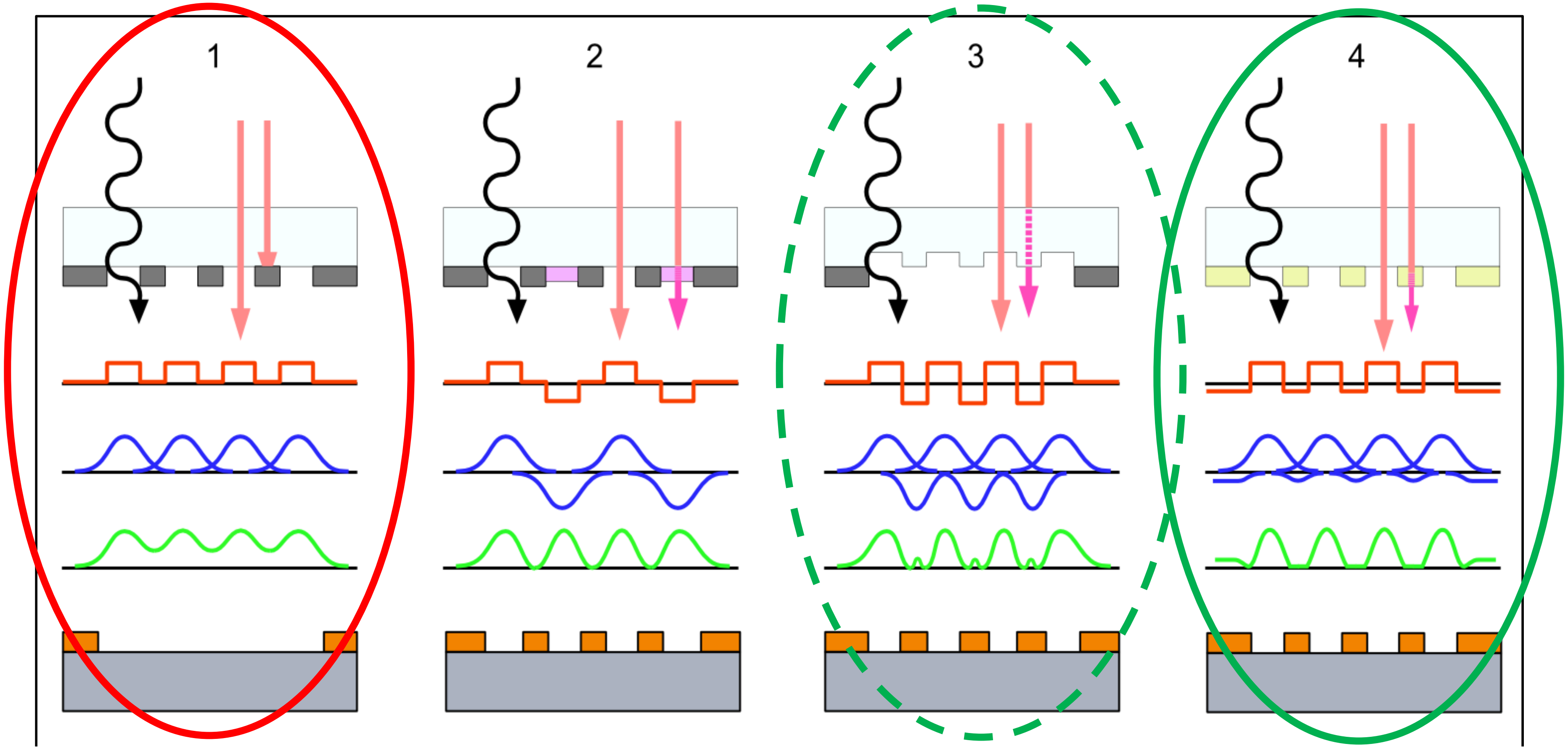
Wafer coated with BARC and DUV resist is placed in a distance D (gap) from the mask

Exposure of resist occurs during movement toward the mask by minimum Talbot period

No contact with mask, insensitive to surface imperfection, whole 4" wafer exposure

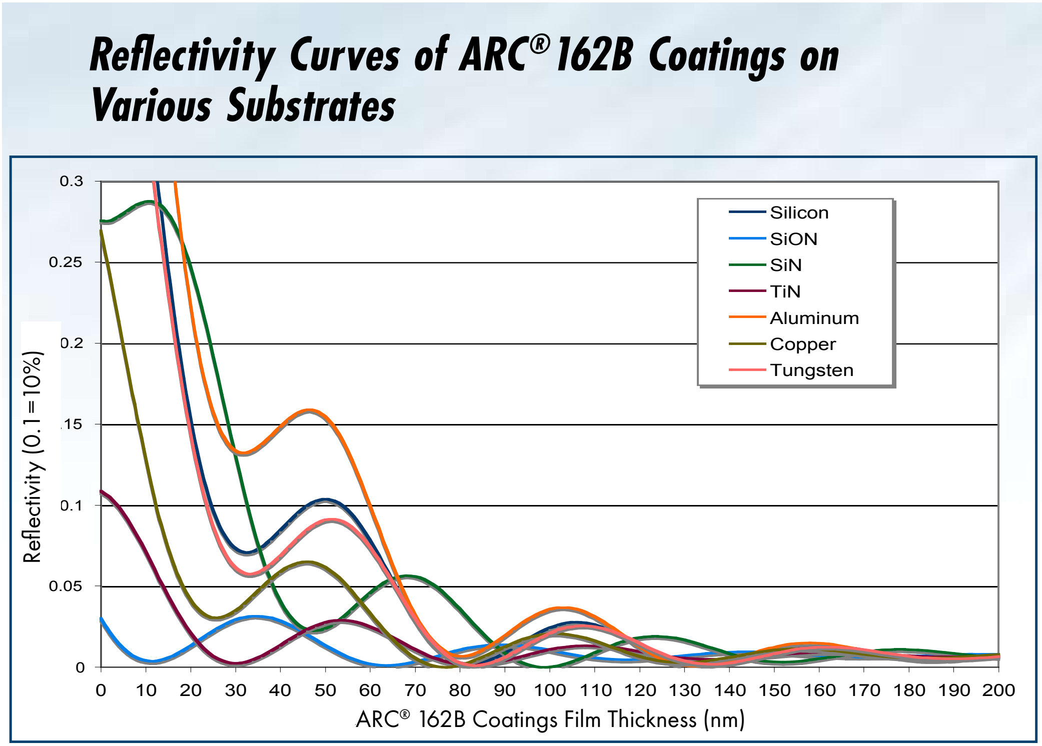
H. Solak, C. Dais, F. Clube,
Optics Express, Vol.19, No.11 (2011)

Phase shift mask necessary for high resolution
180° phase shift for specific wavelength



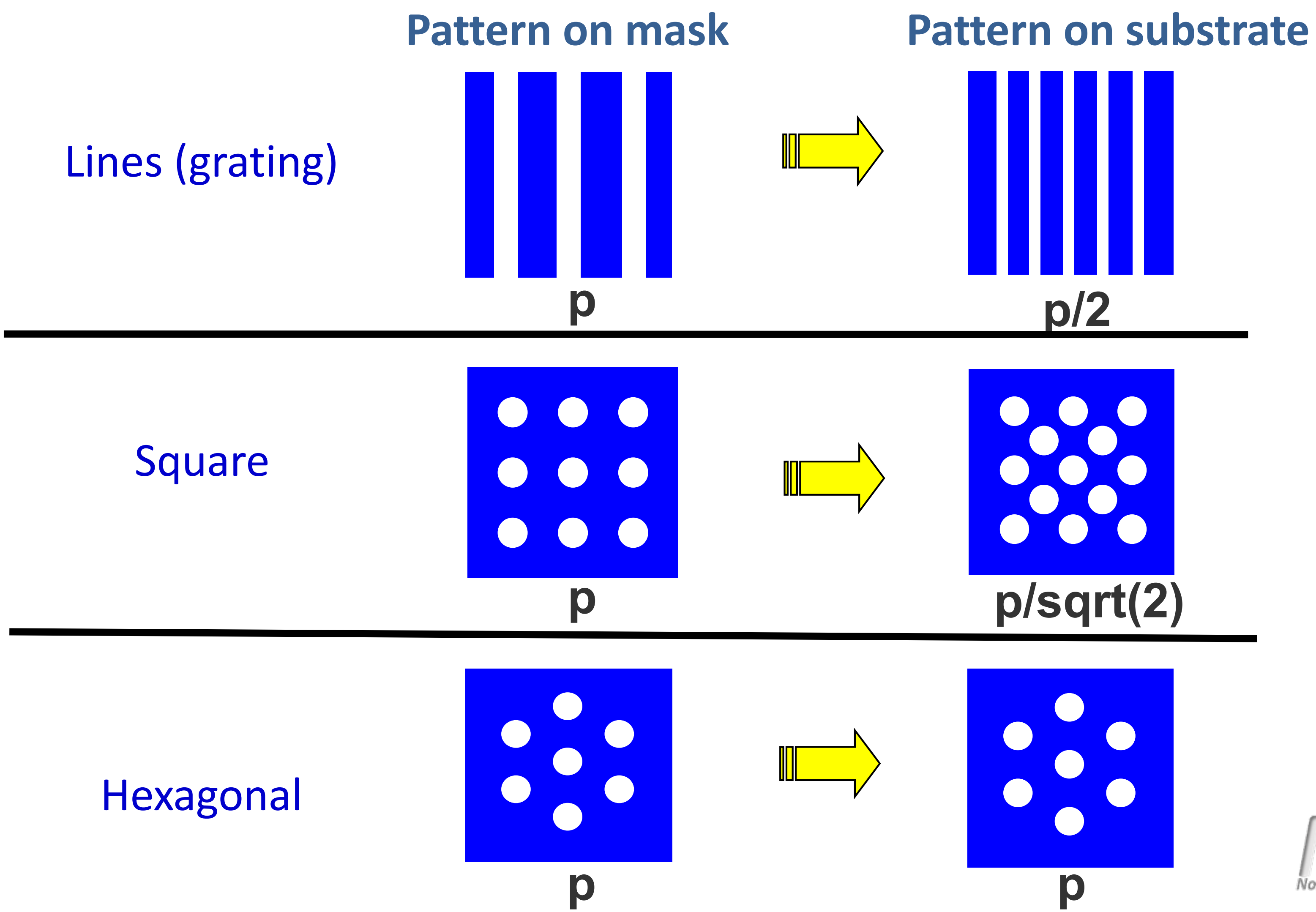
Phase-Shift Mask Types: (1) Binary mask, (2) Phase Shift mask, (3) Etched Quartz mask (Levenson mask), (4) Half-tone mask.
(Top) Mask, (Red) Light Energy/Phase on Mask, (Blue) Light Energy/Phase on Wafer, (Green) Light Power on Wafer, (Bottom) Resist on Silicon Wafer

Bottom antireflective coating BARC reduces interference between incoming and reflected beam

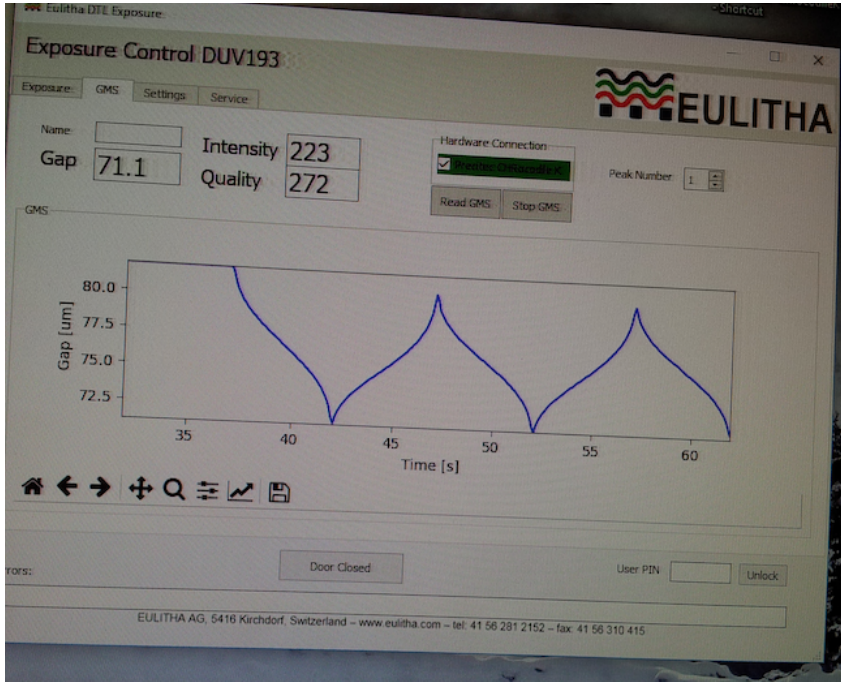


Optimum thickness for first minimum is 82nm for ARC 162B at 193nm wavelength. Both thickness and extinction coefficient for specific wavelength must be optimized for BARC.

Talbot effects for regular pattern: pitch (p) reduction for gratings and square arrays



Talbot Displacement Lithography: Piezo stage limit



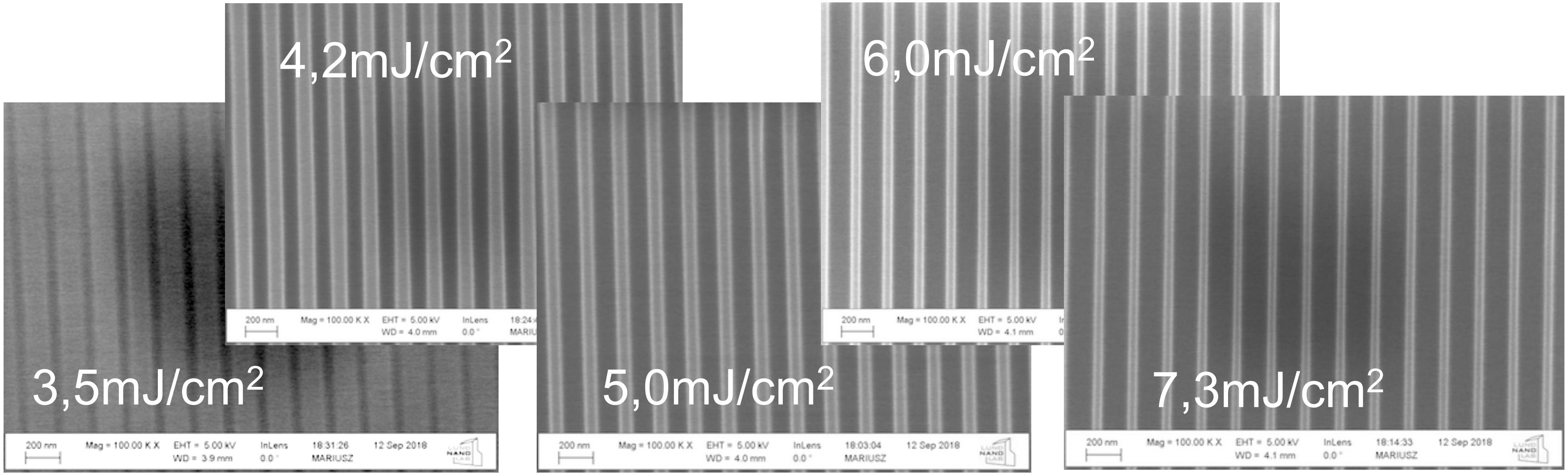
Practically wafer is transferred on the distance 3 times longer than Talbot period. Movement up and down is repeated until programmed dose is accumulated. During exposure laser generates pulses with programmed intensity from 0.5 to 3mJ and frequency from 30 to 150 Hz.

Pitch in nm	Talbot period x 3 in µm
2000	**124**
1500	70
1000	31
750	17
600	**11**
500	8
400	**5**

Exposure is possible (piezo limit)

Optical sensor integrated with hardware allows to measure gap (D) and amplitude of movement up and down. Maximum displacement in piezo stage is limited to 110µm which limits pitch to 1500nm.

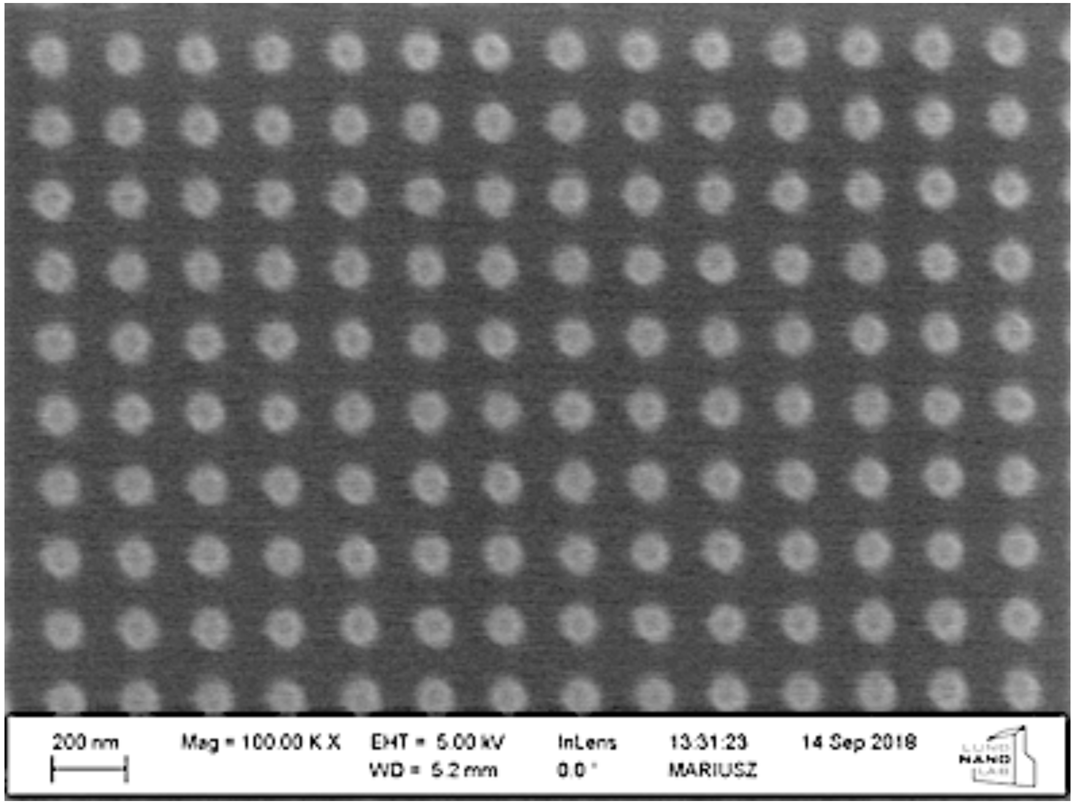
Dose test for grating – mask LIL102P400L
Linear grating with pitch 400 nm on mask.



Probably to low dose

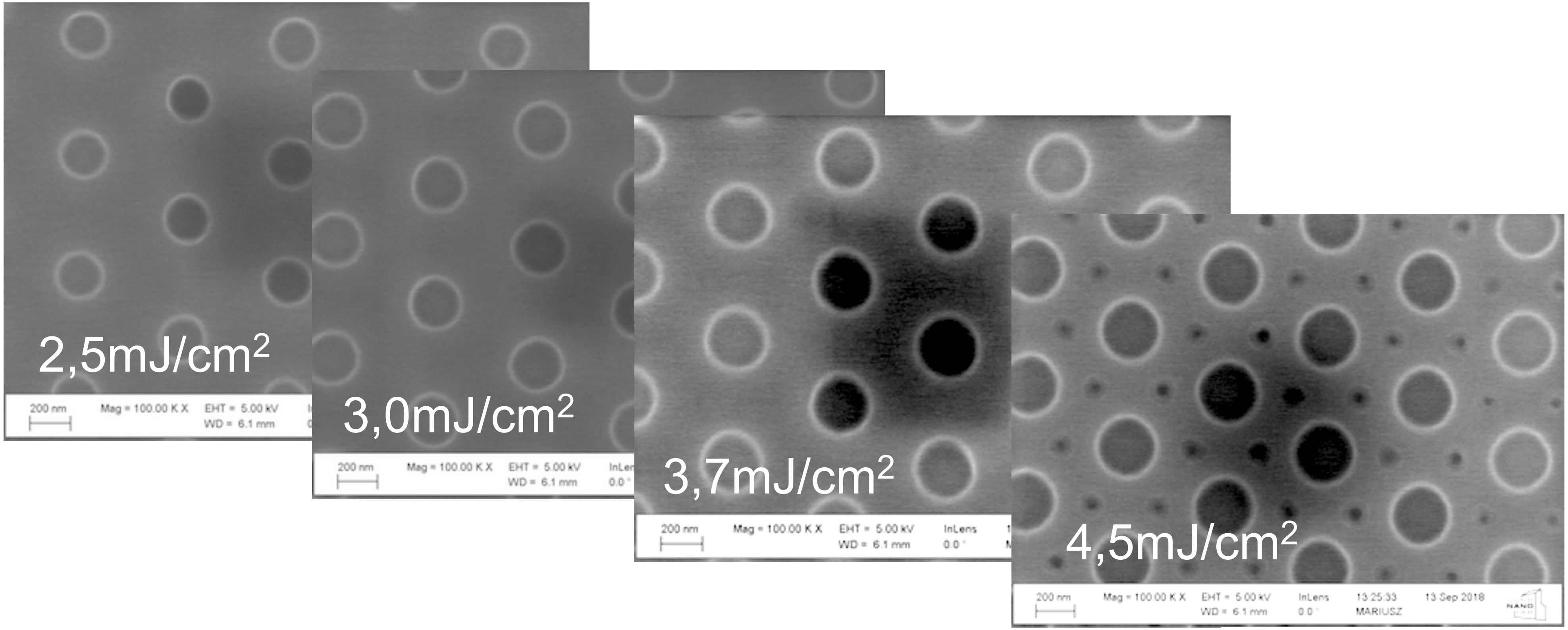
The pitch is reduced 2 times. Lines width is reduced from 136 to 45 nm with increase of dose.

Double exposure with grating – mask LIL102P400L



Wafer was exposed 2 times with dose 3 mJ/cm^2 and rotated 90^o between exposures. Pitch is reduced 2 times. Dots size 75-80 nm. Dots are arranged in a square array.

Dose test for hexagonal pattern – mask LIL120P600H (pitch 600nm)

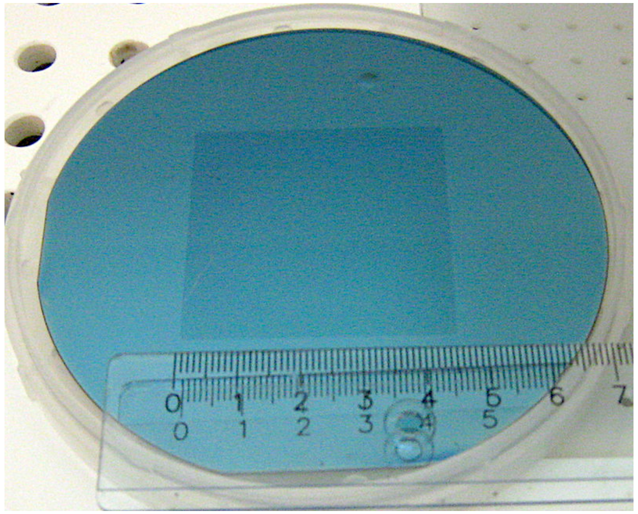


Pitch is unchanged but diameter of holes rise from 190nm to 290nm with rising dose.

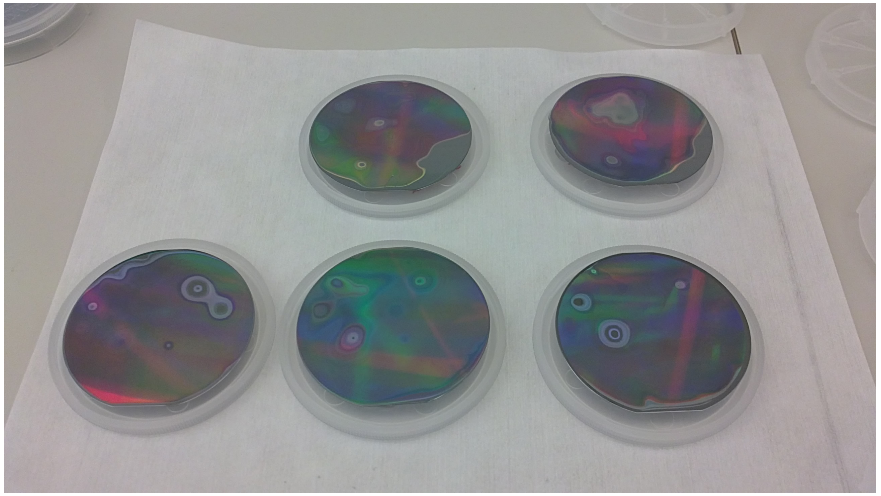
Second order diffraction effect appears

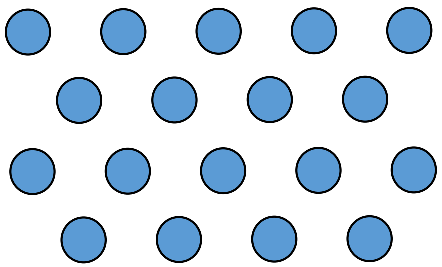
Quality of big area exposure comparing Talbot displacement and contact lithography.

PhableR 193nm



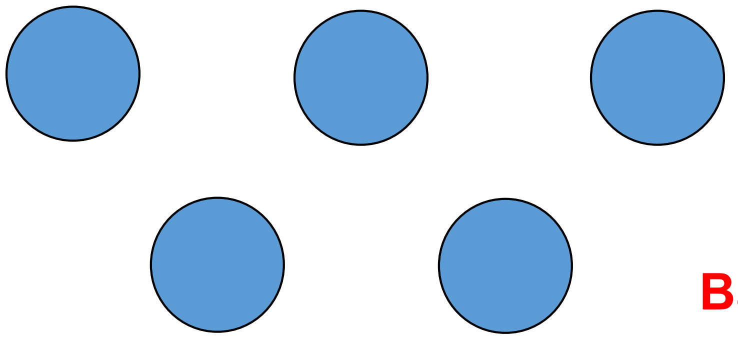
MJB4DUV





Pattern scheme

1 µm scale



Good

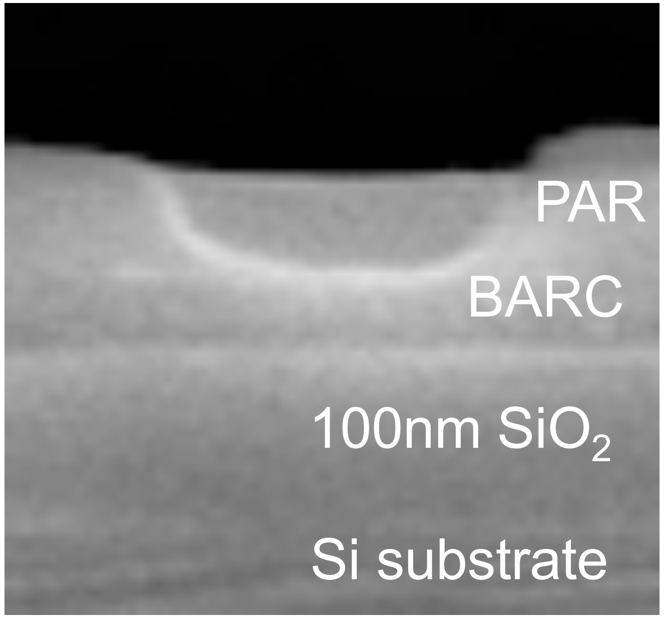
Bad

Hexagonal array of 200nm holes, pitch 600nm, 45x45mm on 4” wafer, gap 80µm

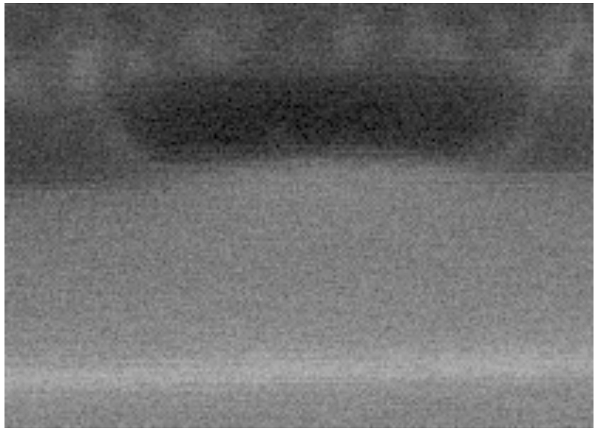
Hexagonal array of 700nm holes, pitch 1500nm, 2” wafers, vacuum contact

Steps for pattern transfer into BARC and thin SiO_2 or SiNx for nanowires growth application

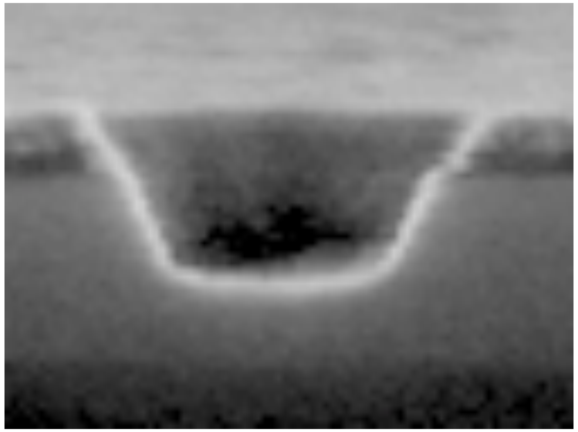
BARC is not sensitive to deep UV light and is insoluble in the developer.



After PAR resist exposure in TDL and pattern development



After BARC 4,5 min etch in O_2 plasma in Nanoetcher from Moorfield Nanotechnology Ltd



After SiO_2 5 min etching in CHF_3 plasma in RIE Sirius T2 from Trion Technology

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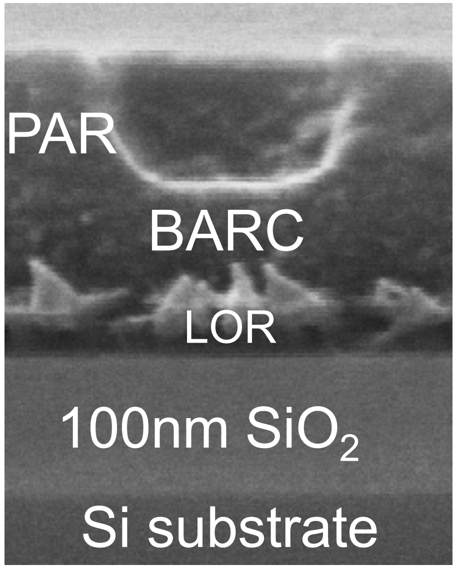
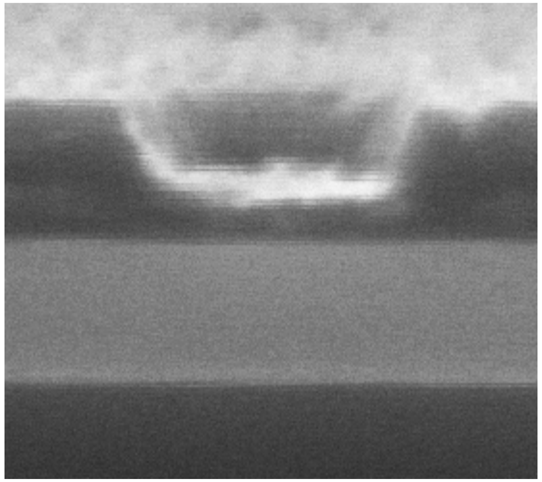
Triple resist LOR/BARC/PAR system for lift-off purpose and nanowires growth application

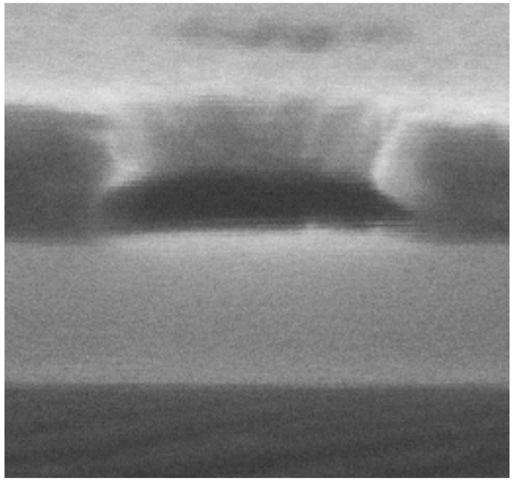
Process flow to create undercut suitable for lift-off



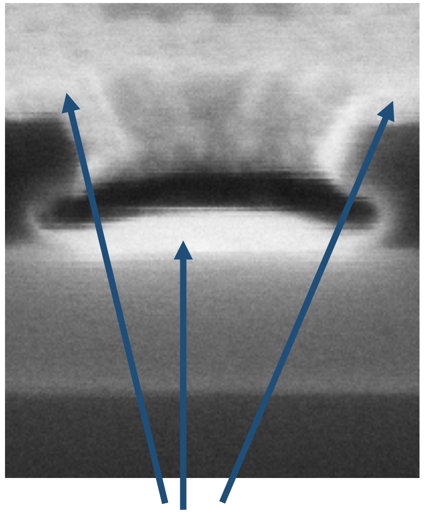
After PAR resist exposure in TDL and pattern development



After BARC 5,5 min etch in O_2 plasma in Nanoetcher

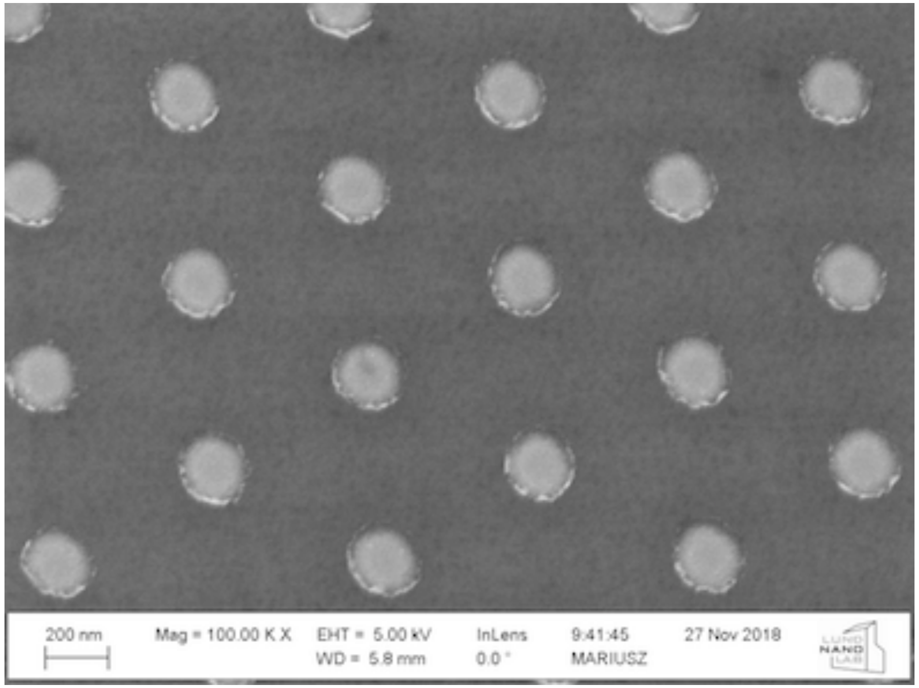


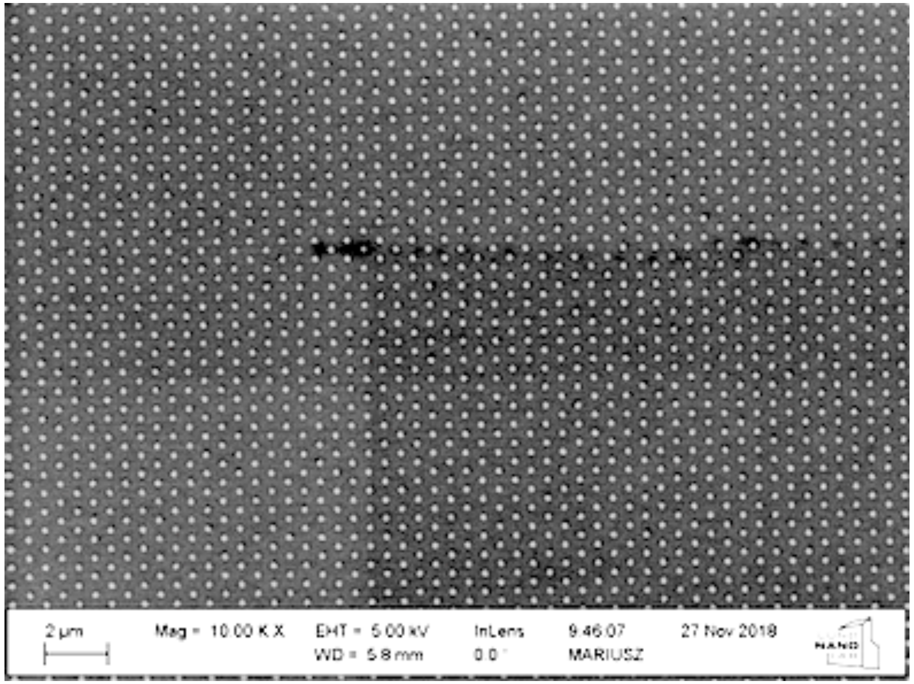
After 40sec LOR dissolving in MF319 3:1 H_2O



20nm metal After sputtering Pt80%Pd20%

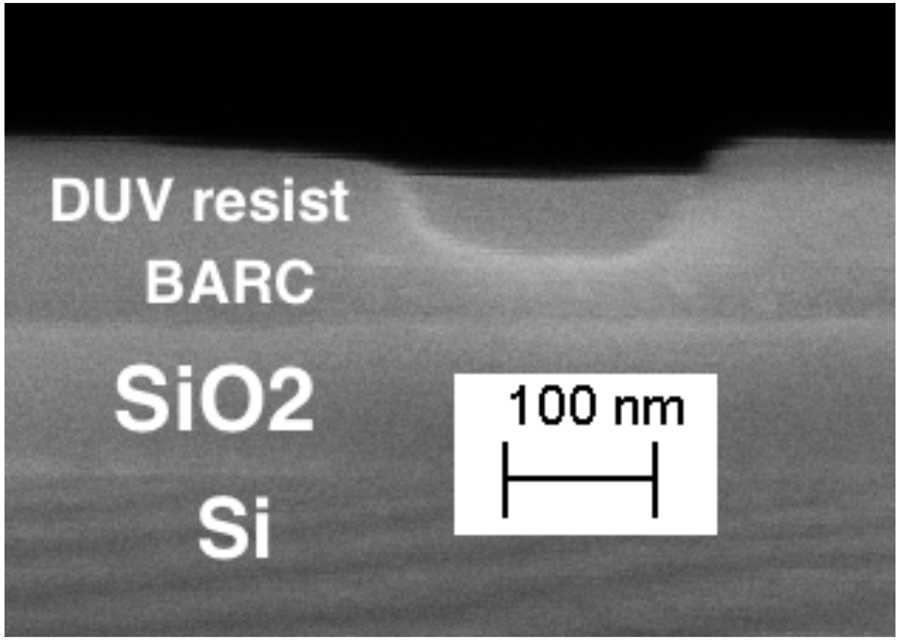
Triple resist LOR/BARC/PAR system for lift-off purpose and nanowires growth application



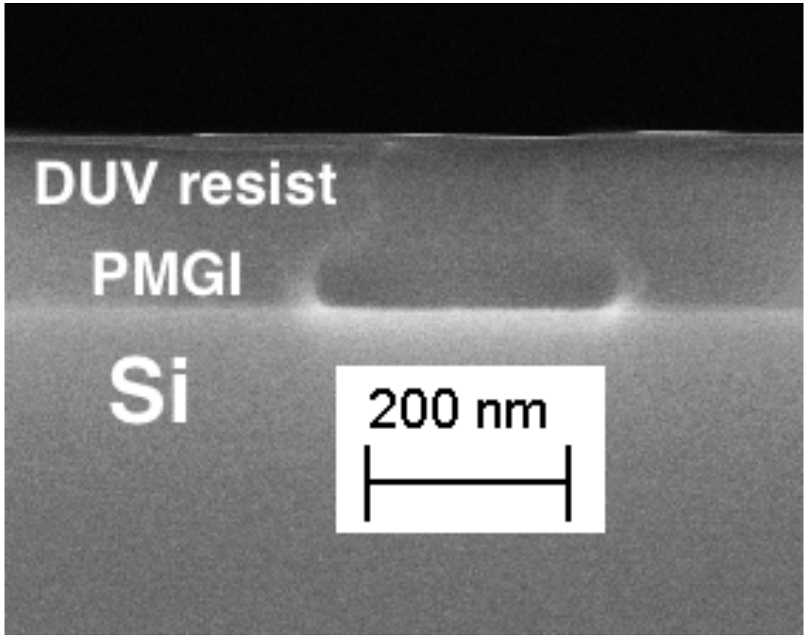


After lift-off in remover 1165
Pt/Pd dots diameter slightly over 200nm

Successful BARC replacement with PMGI resist for improved and simplified lift-off system

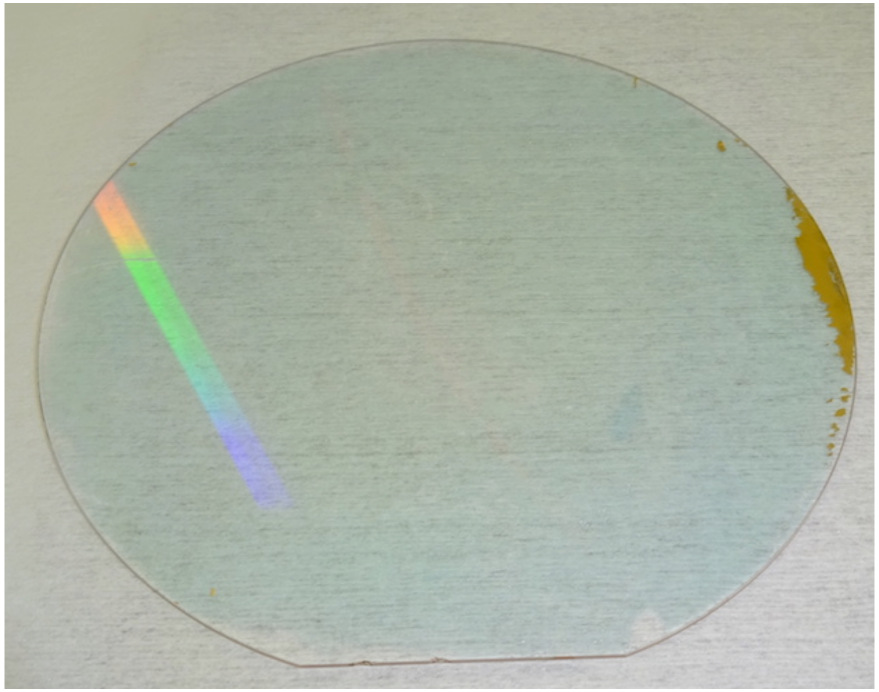


Cross section after development of PAR1077(DUV resist) / BARC. Dry etching in O_2 plasma necessary to get access to substrate surface.

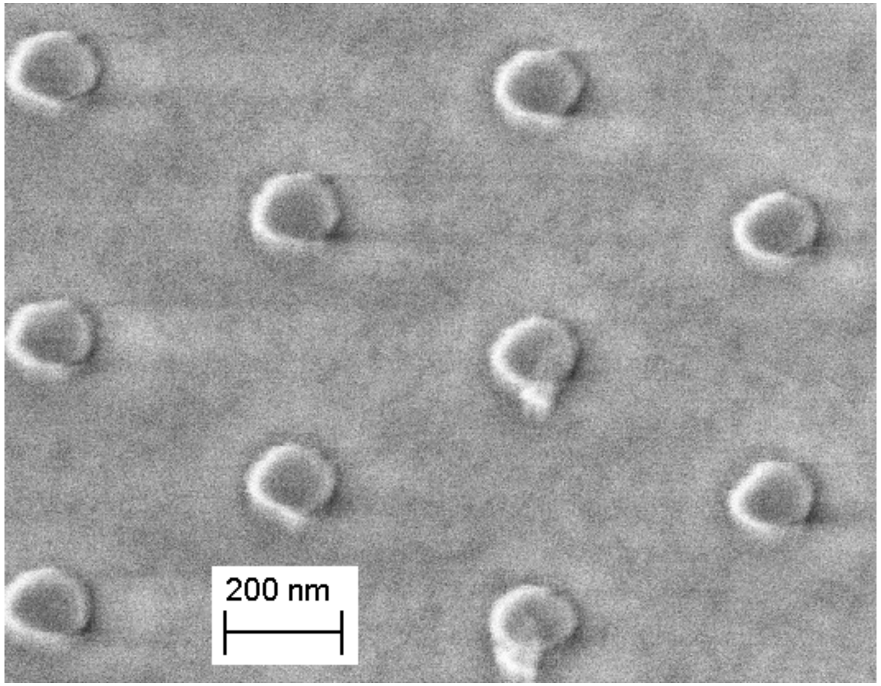


PMGI is soluble in 0.24N developer and after development resists profile is suitable for lift-off purpose. <u>No ashing necessary</u>.

Optimisation of exposure in Talbot Displacement Lithography allows to reduce dots diameter by 25%

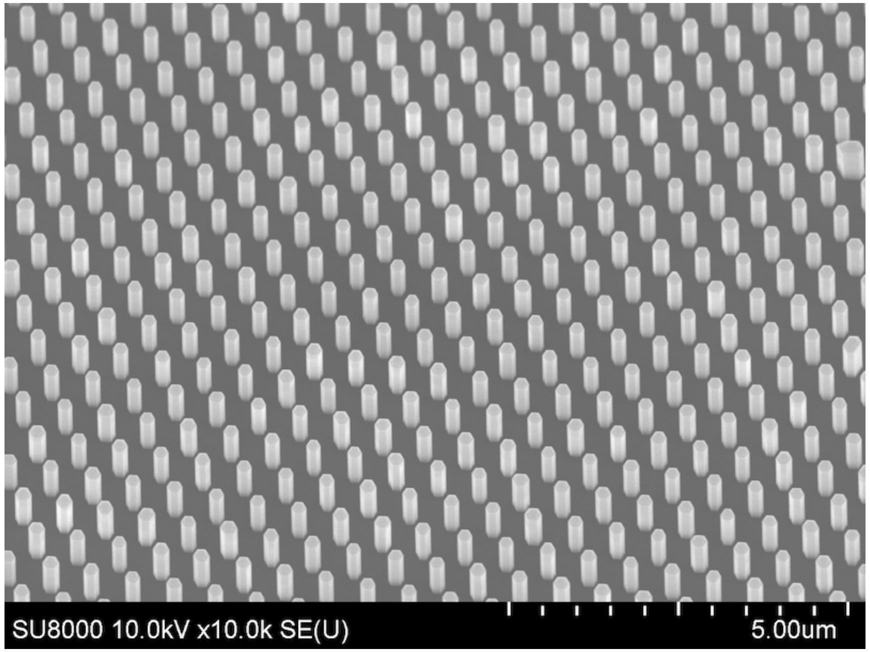


Hexagonal array of Au dots on
4” fused silica wafer. Mask
LIL171P500H

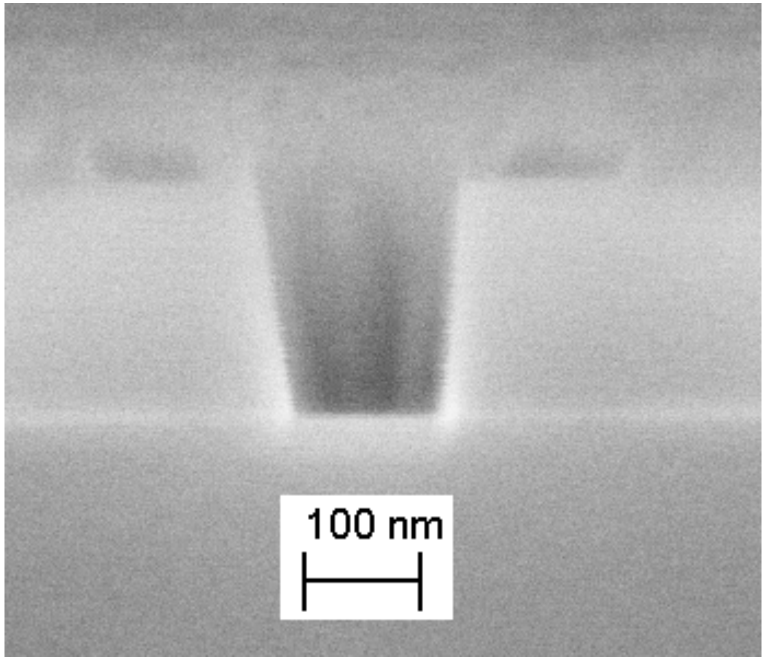


Diameter of Au dots on fused silica
is around 140 - 150nm, pitch 500nm.
PMGI residues not removed yet.

Use of proposed TDL technology for nanowire growth and SiO_2 etching for NIL stamp fabrication



GaN nanowires on sapphire substrate grown on template prepared in Talbot Displacement Lithography. Mask LIL120P600H
Courtesy; Kristian Storm, Hexagem AB



“Deep” etching of SiO_2 in CHF_3 plasma for NIL master stamp fabrication with controlled depth and profile.

Conclusions

1. Talbot Displacement Lithography is a novel technology suitable for **large area** exposures with **sub-100 nm resolution**.
2. This is **non contact lithography** system, saving expensive mask
3. This technology is **insensitive to surface curvature**.
4. Allows to **reduce size** of pattern in comparison with nominal size on the mask by proper choice of exposure parameters (lower pulse energy, higher pulse repetition frequency) to get better dose integration in space and time.
5. In comparison with Nano Imprint Lithography **amount of defects is lower**, technology **more stabile** and **ashing in O_2 plasma can be eliminated**.

Thank you!

Acknowledgements:
Financial support from NanoLund and Myfab is acknowledged.