Improving the Resolution Limit of Electron Beam Lithography

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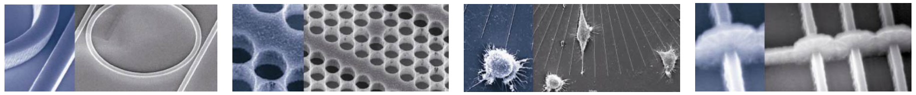

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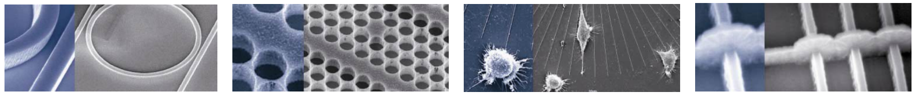
- AMO GmbH / AMICA
- Why electron beam lithography?
- Improving electron beam lithography
- Applications
- Summary & Outlook



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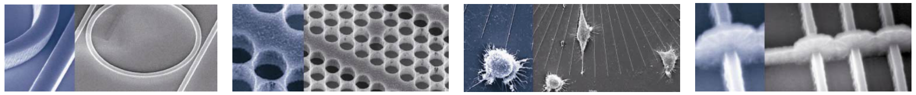
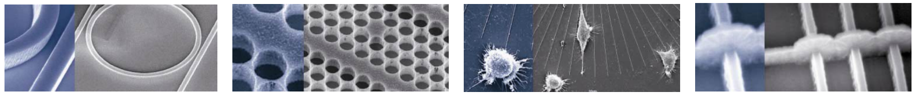
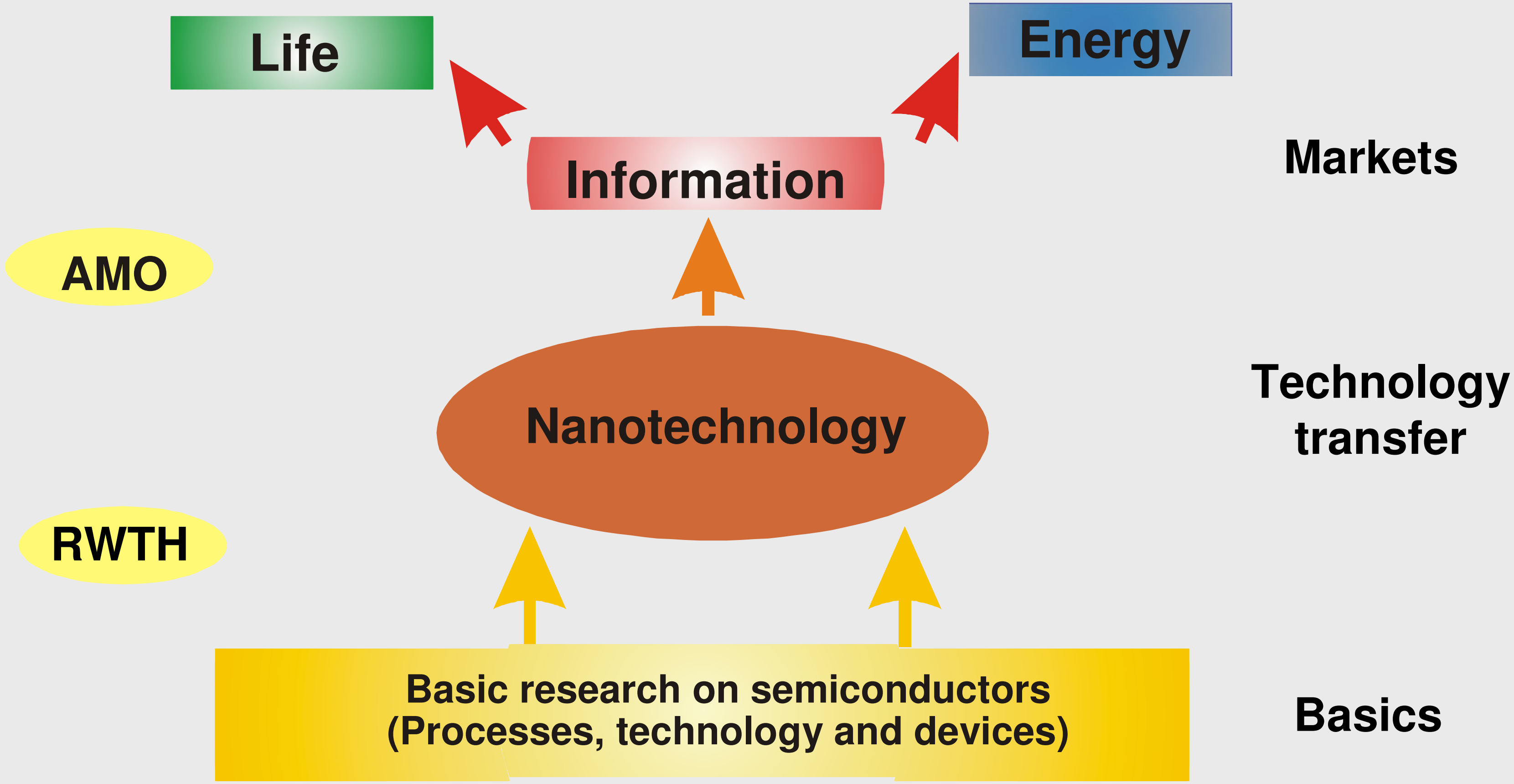


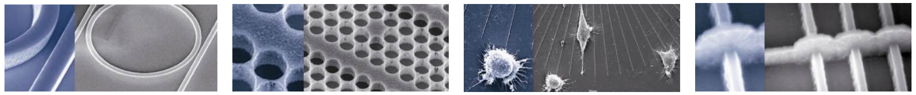
AMO GmbH / AMICA

- Spin-Off of RWTH Aachen University
- “Research foundry”
- Operational since 1997
- 43 Employees (29 Nanolab AMICA, 10 AMO Systems)
- 70% joint research, 30% sales
- 6 to 10 concurrent R&D projects
- 400 m² class 10-1000 clean room, highly flexible
- Advanced nanofabrication facilities



Mission of AMO





Research projects and collaboration

- Recent projects:
  - NaPa
  - CellPROM
  - Sinano / PullNano
  - OLAS
  - Souvenir
  - Krismos
  - …

- Partners
  - AMD
  - IBM
  - Infineon
  - Qimonda
  - Raith GmbH
  - Vistec
  - EV Group
  - RWTH Aachen
  - …

SiNANO Silicon-based Nanodevices

NaPa Emerging Nanopatterning Methods

Raith

IBM

AMD

CellPROM

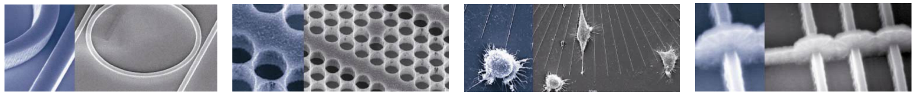
SOUVENIR SOFT UV ENHANCED NANOIMPRINT

RWTH AACHEN UNIVERSITY

Infineon technologies

Fields of research

- Novel gate stack materials
  - metal gates
  - high-k materials
- Nano transistors, e. g. triple gate MOSFETS
- Siliconizing photonics
- Fabrication of nanostructures for life science applications
- Nanoimprint lithography (NIL)
- Process development for electron beam lithography (EBL)



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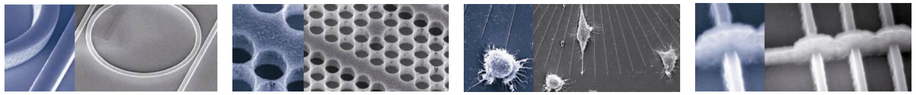
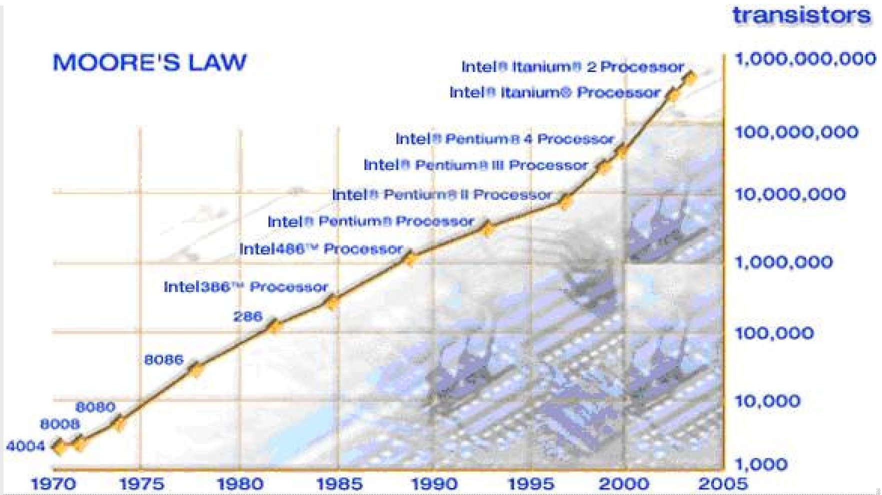


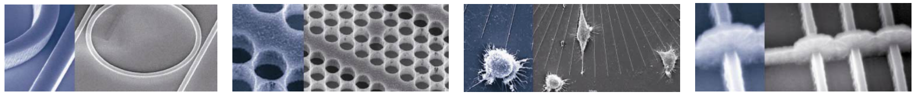
Moore’s law

- Doubling the number of transistors in IC’s every two years
- Aggressive downscaling
- Lithography process steps become more and more challenging
- Limits of conventional optical lithography already reached

→ **Next generation lithography?**



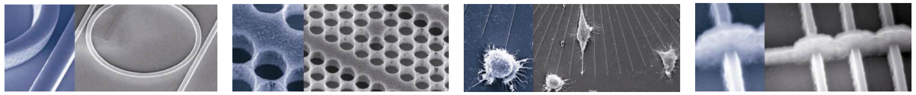
Source: www.intel.com



Next generation lithography?

- Possible candidates for next generation lithography (NGL):
  - EUV lithography (EUVL)
  - Nanoimprint lithography
- Both rely on EBL for mask (EUVL) and template (NIL) fabrication

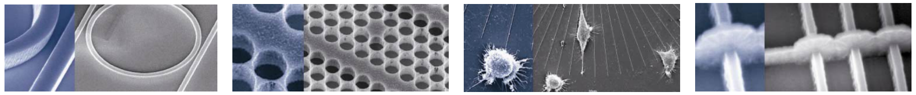
→ **Whatever technique will be chosen for NGL, EBL will be an important part of it**



Challenges for EBL

- Ultra high resolution well below 10nm needed
- Aspect ratios for such small resist structures have to be sufficient for pattern transfer
- Surface and line edge roughness of resist structures have to be kept as small as possible
- To achieve this, conventional processing might not be sufficient

→ **New processing techniques needed to further improve resolution and aspect ratio and to decrease resist roughness**



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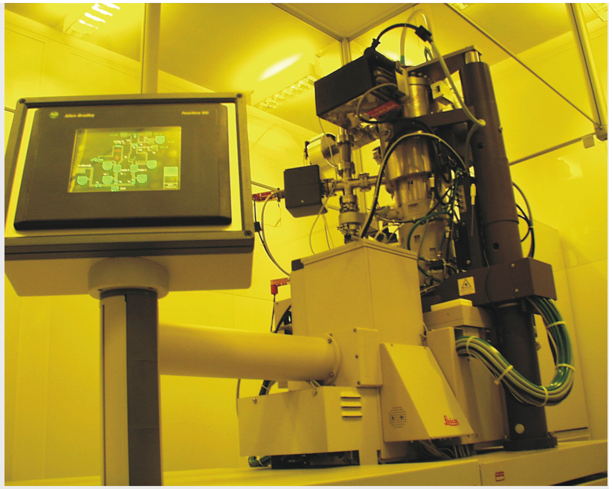
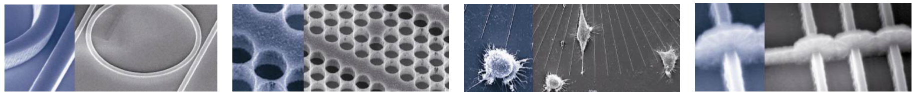
EBL process

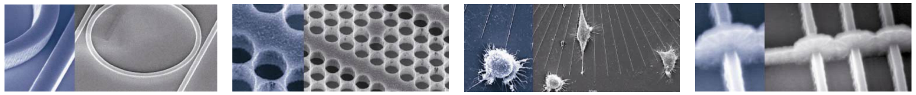


- EBL tool
  - Leica EBPG 5000 operated @ 100kV
  - Minimal beam step size: 5nm
  - Stage interferometer resolution: ~5nm
  - Margin for improvements is small
- Choice of resist material
  - Well-known resists with potential for further improvements, e.g. poly(methylmethacrylate) (PMMA)
  - Novel resist materials, e. g. hydrogen silsesquioxane (HSQ)
- Development process
  - Megasonic-assisted development (MAD)
- Drying process after development
  - Supercritical resist drying (SRD)



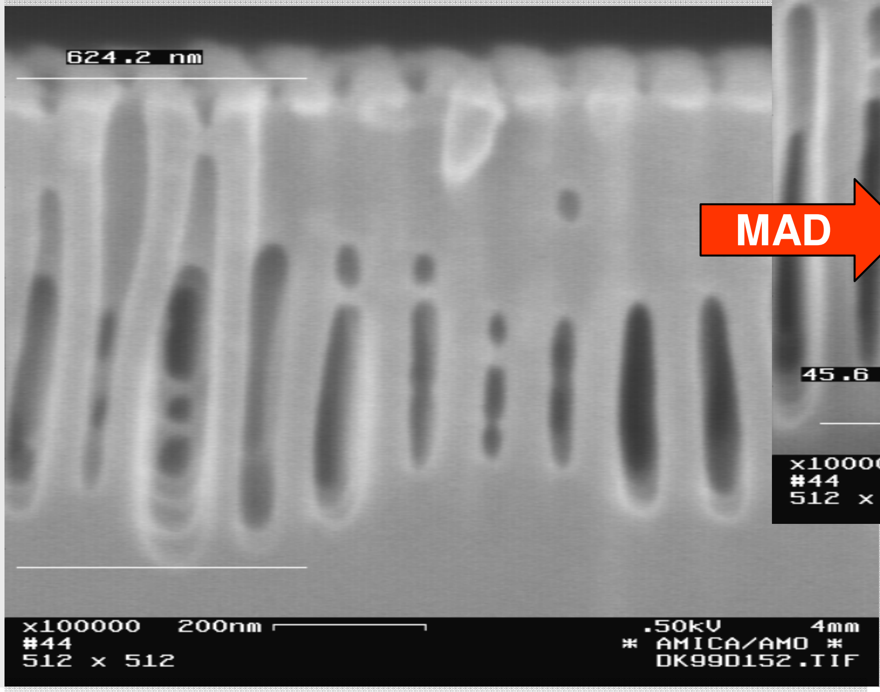
Megasonic-assisted development I

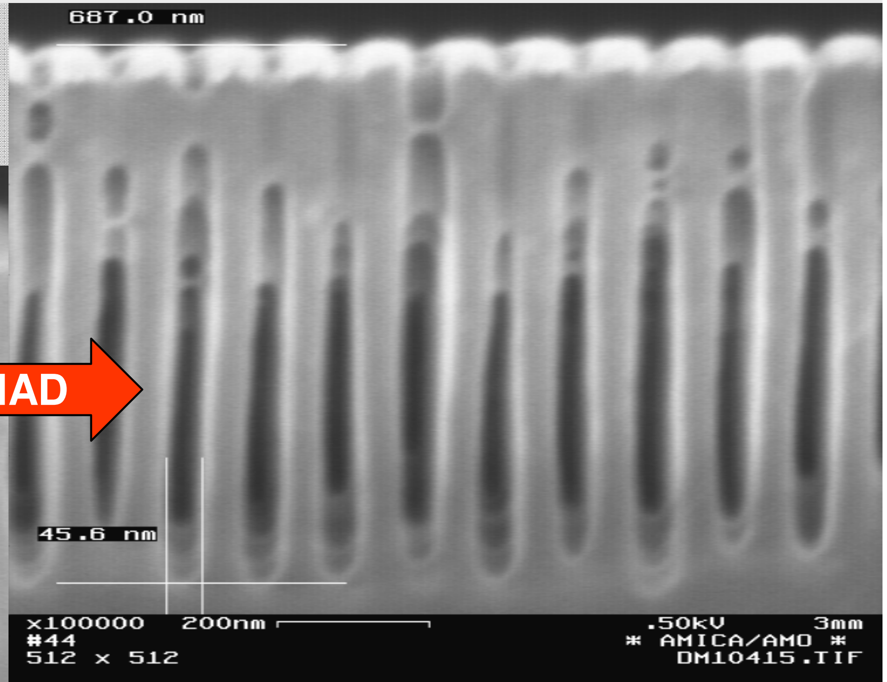
- Conventional dip development
  - Thick viscous boundary layer at resist/developer interface
  - Long development times neeeded
- Acoustic agitation during development process step
  - Reduces thickness of boundary layer
- Ultrasonic agitation (20-350 kHz)
  - Thickness of boundary layer: ~4 µm
  - Tends to damage resist structures
- Megasonic agitation (700 kHz – 1 MHz)
  - Thickness of boundary layer: <1 µm
  - Applicable for both positive and negative tone resist materials
  - Best results for positive tone resist (PMMA)



Megasonic-assisted development II

Dense holes in ~700nm PMMA resist, developed without…



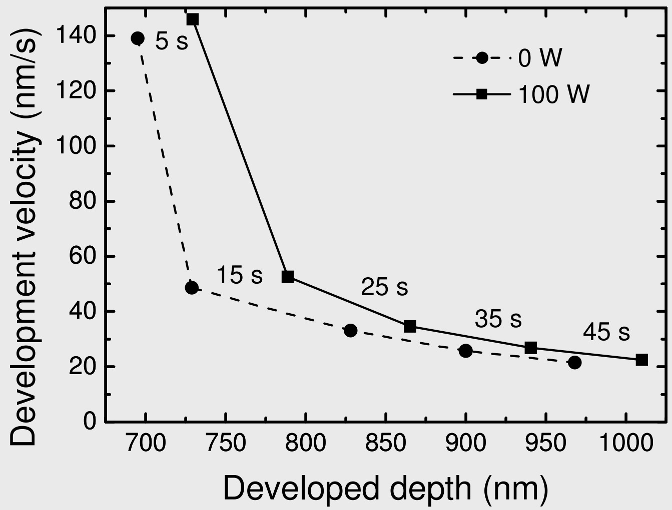


…and with megasonic agitation during development

D. Küpper et al, JVST B, to be published 2006

Megasonic-assisted development III

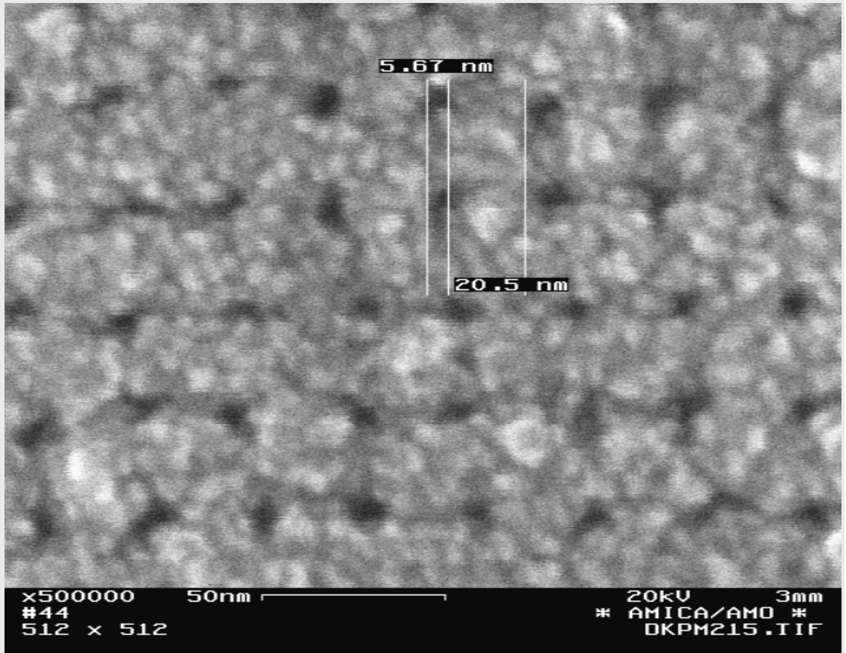
- MAD significantly increases the development velocity & depth
- Faster development leads to less resist swelling and therefore increased resolution and smoother resist surfaces



D. Küpper et al, JVST B, to be published 2006

Megasonic-assisted development IV

- MAD significantly improves:
  - Development homogeniety
  - Development depth
  - Roughness
  - Resolution

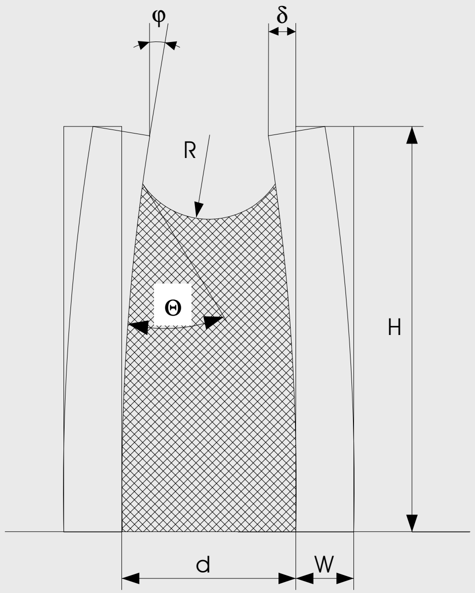


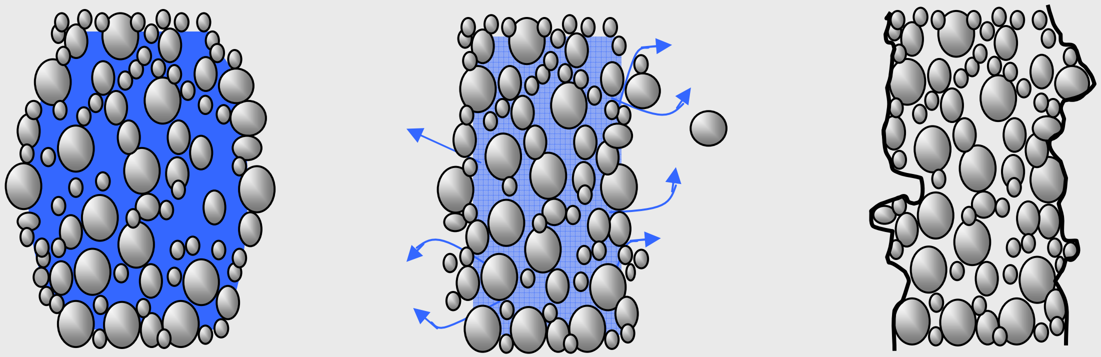
Nano holes with diameters of ~6nm, sample has been coated with Cr to avoid static during SEM inspection

D. Küpper et al, JVST B, to be published 2006

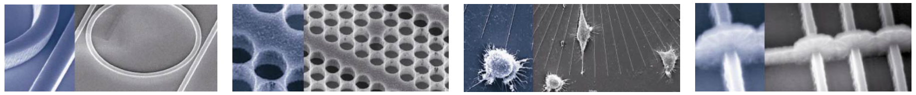
Supercritical resist drying I

- Conventional blow dry
  - Surface tension of rinsing liquid causes an attraction force and results in pattern collapse
  - Low diffusivity of rinsing liquid causes stress while flowing out of the resist structures
  - Roughness is increased during resist drying





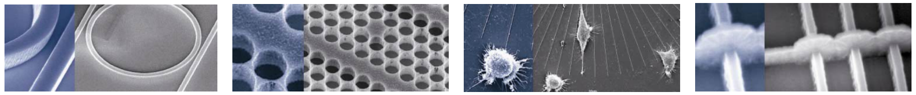
D. Küpper et al, J. Vac. Sci. Technol. B 24, (2006), 570-574



Supercritical resist drying II

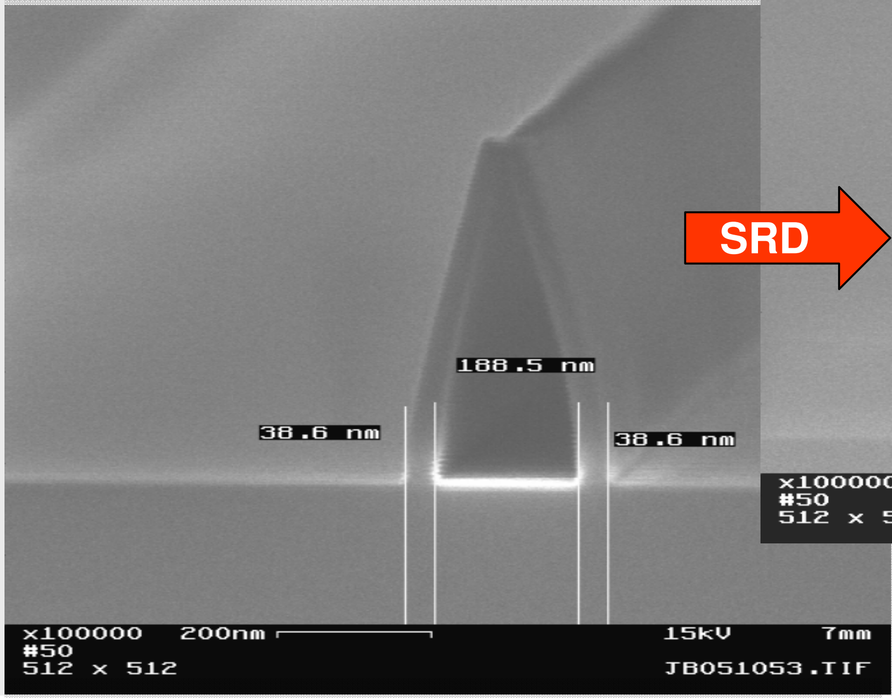
- Rinsing liquid is replaced by supercritical CO_2
- Why CO_2?
  - Chemically inert, environmental friendly
  - In supercritial state : Reduced surface tension, high diffusivity
  - Chamber pressure and temperature:
    7.38 MPa @ 35℃
- Best results for HSQ (negative tone resist)

Reduced stress for resist structures during the drying process

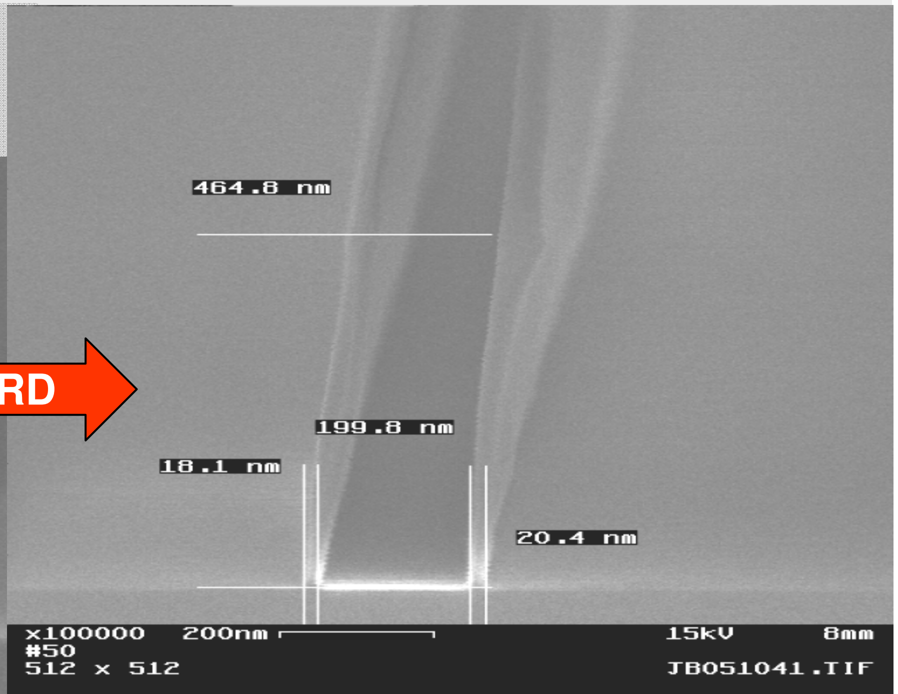


Supercritical resist drying III

HSQ lines with linewidths of ~40nm, dried without SRD …



SRD



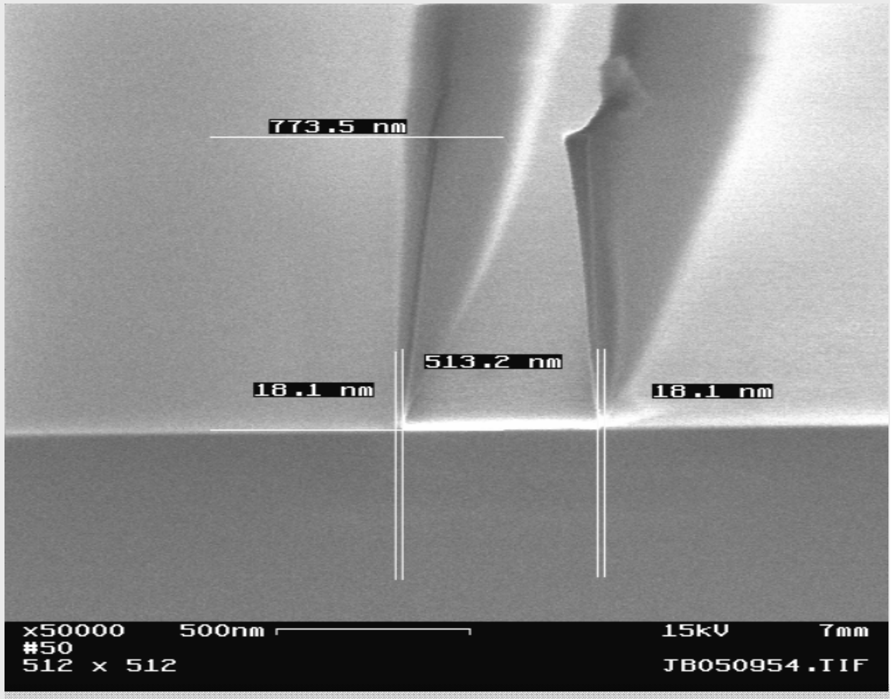
…and with linewidths of ~20nm, dried with SRD

T. Wahlbrink et al, Micro. Eng. 83 (2006), 1124-1127

AMO

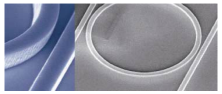
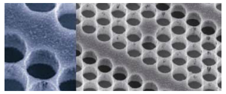
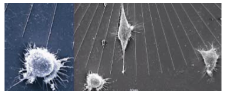
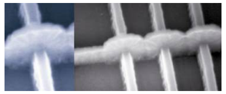
Supercritical resist drying IV

- SRD improves:
  - max. aspect ratio (AR) of resist structures
  - depending on resist thickness the AR can nearly be doubled using SRD



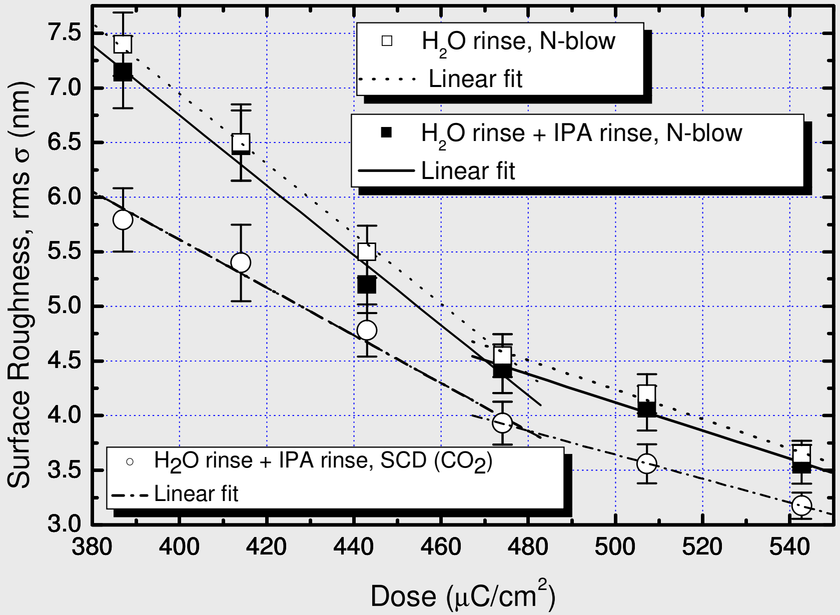
HSQ lines with linewidths of ~20nm, aspect ratio ~40

T. Wahlbrink et al, Micro. Eng. 83 (2006), 1124-1127

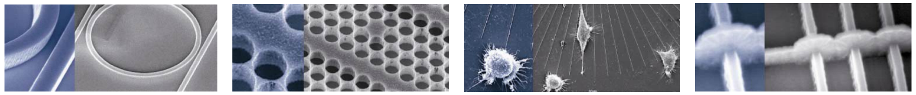
Supercritical resist drying V

- SRD improves:
  - Surface and line edge roughness by up to 20%



D. Küpper et al, J. Vac. Sci. Technol. B **24**, (2006), 570-574

Both increased ARs and decreased roughness lead to higher resolution



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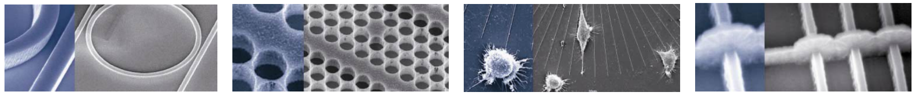
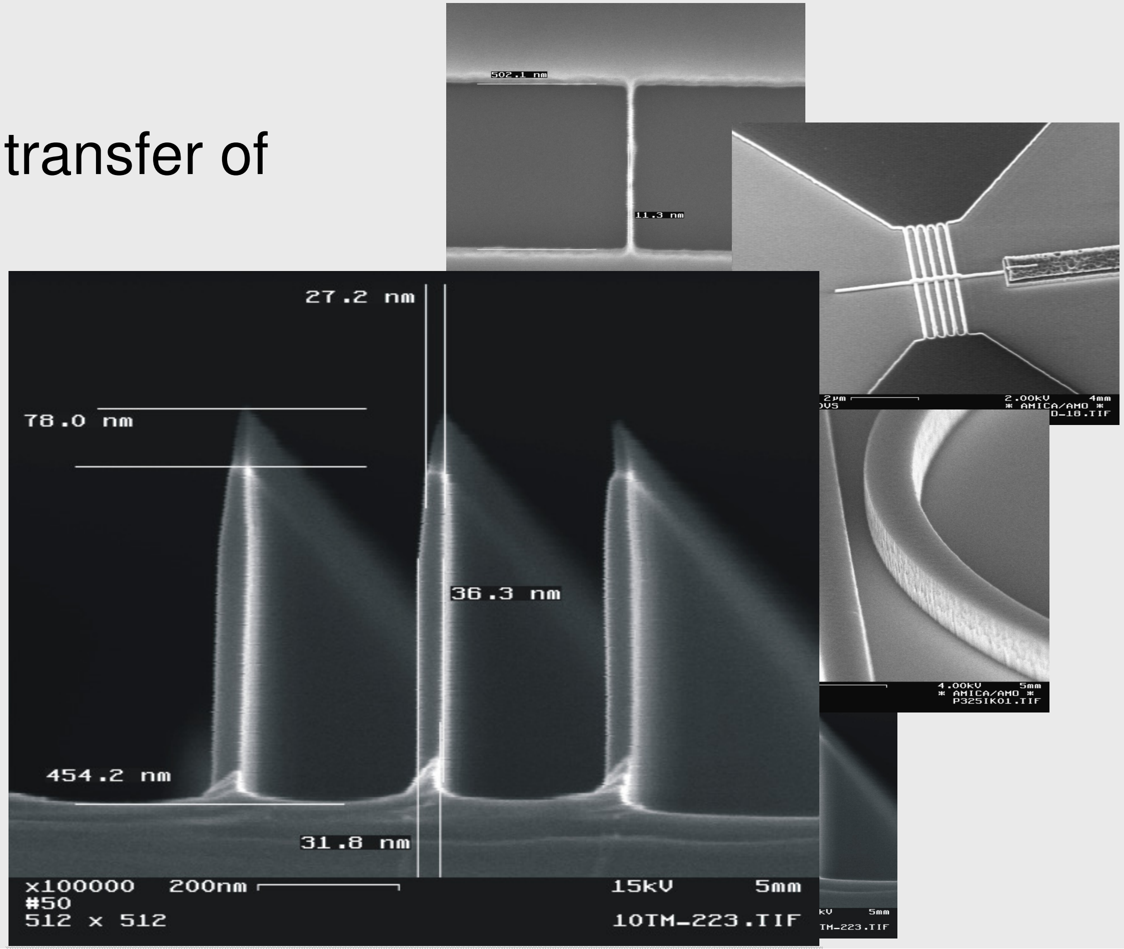
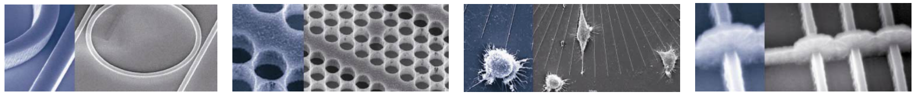


Applications

- Lithography for transfer of nano patterns

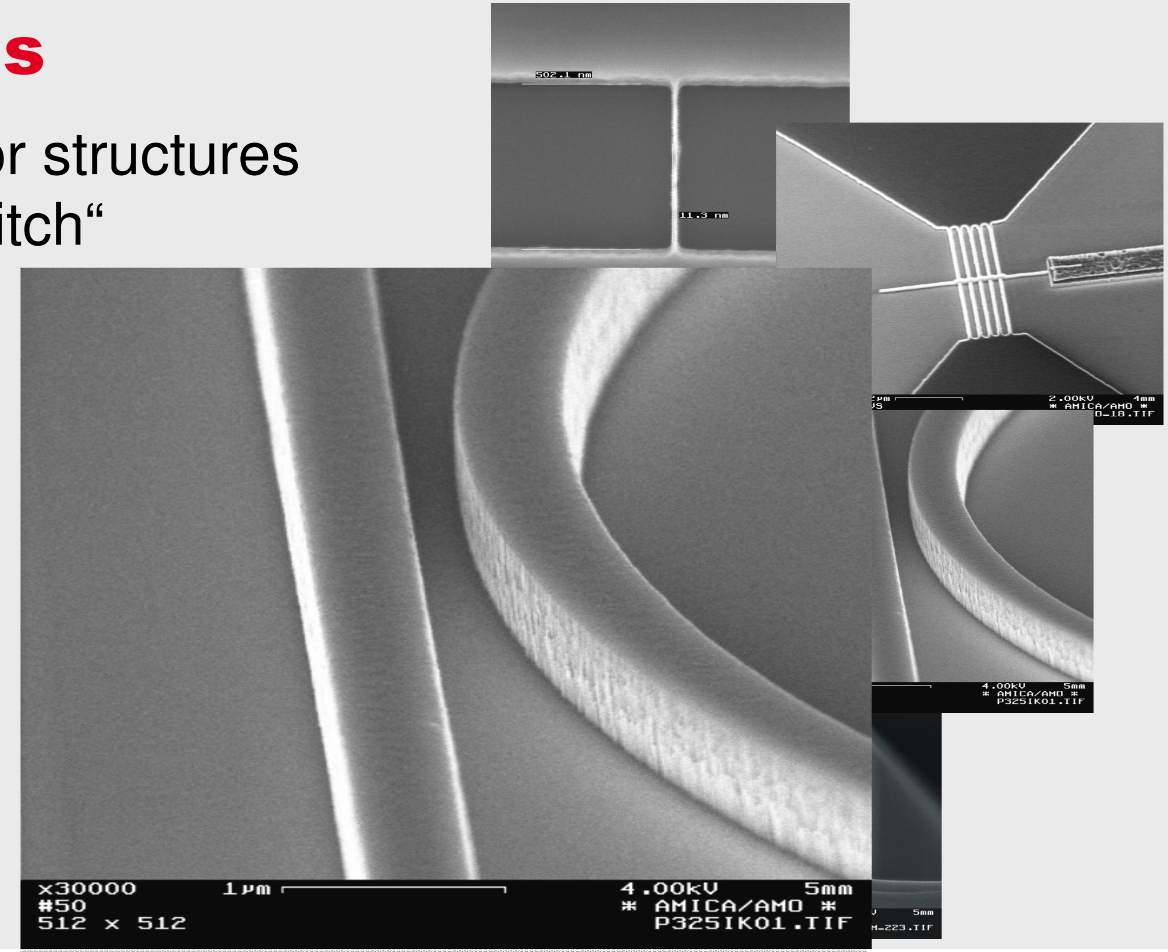


Source: AMO GmbH



Applications

- Ring resonator structures
  „all optical switch“



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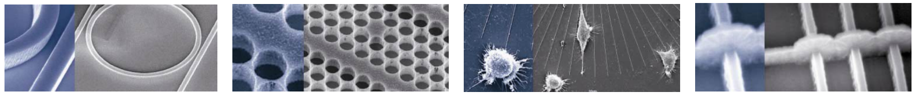
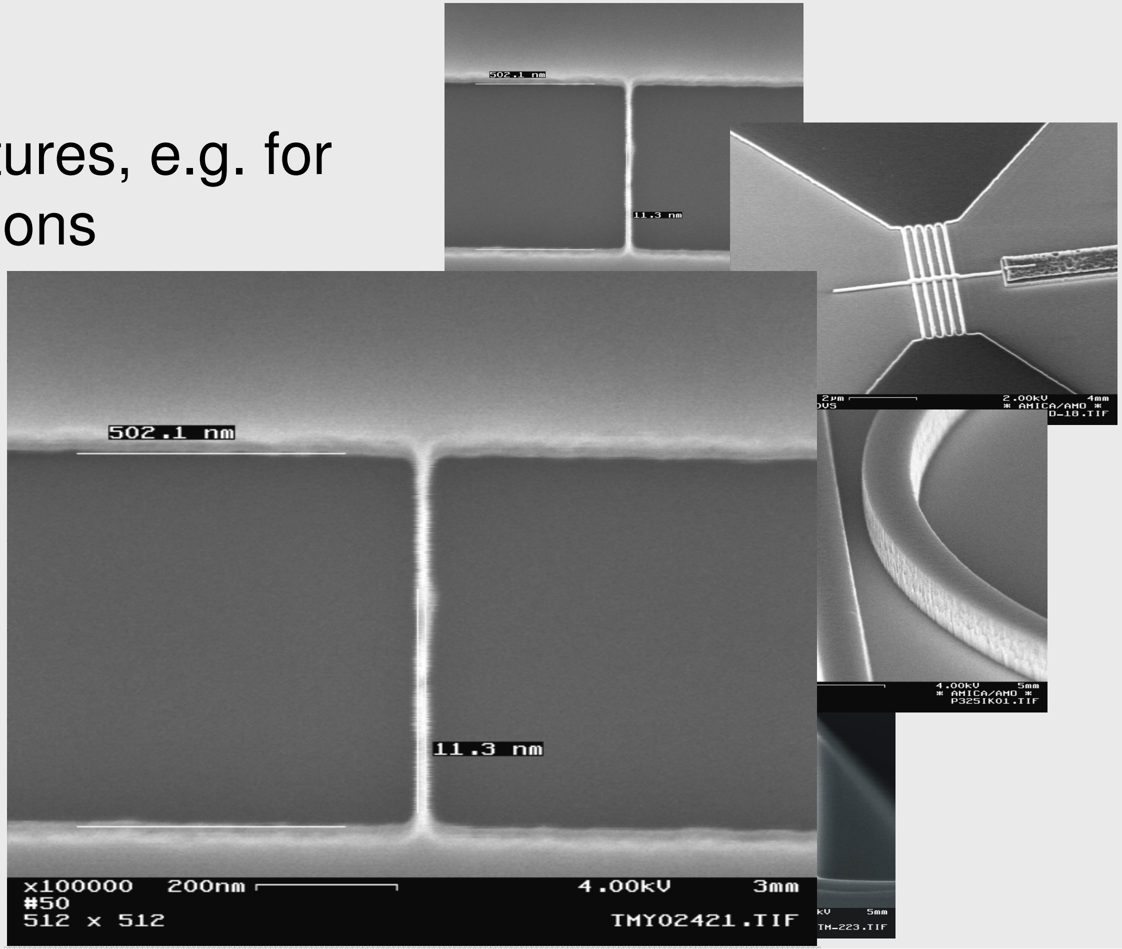


Applications

- Nanowire structures, e.g. for sensor applications



Source: AMO GmbH

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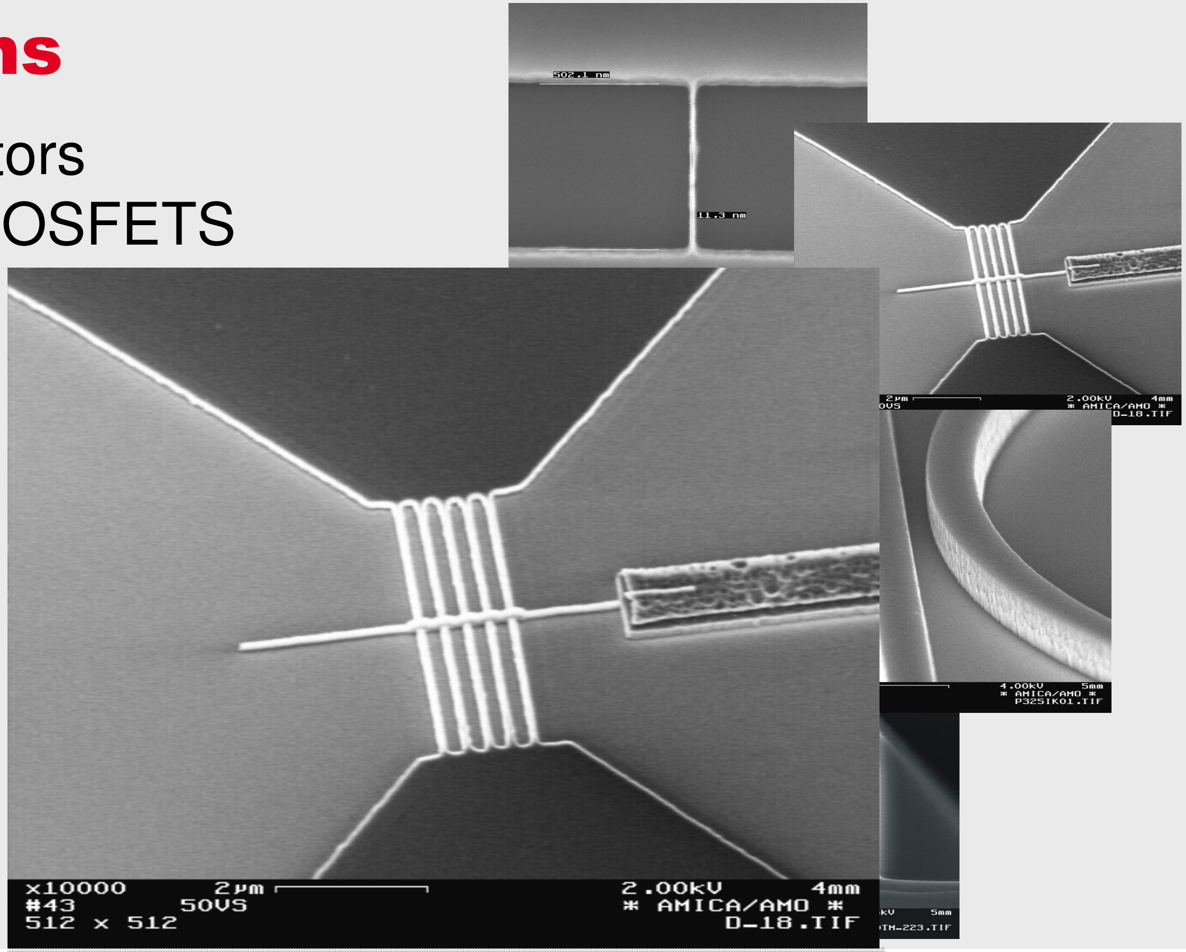
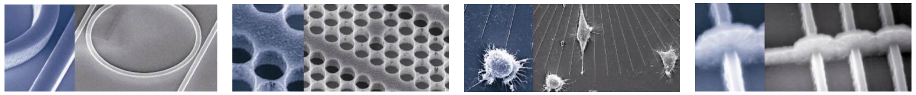
Applications

- Nano transistors
  Triple gate MOSFETS



Lemme et al., SSE, 2004



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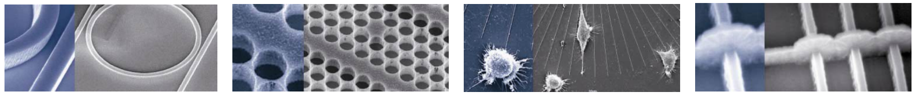


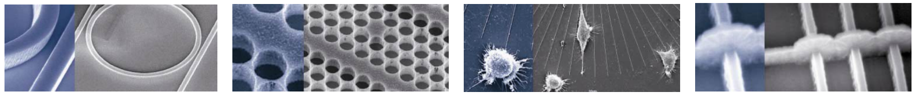
Summary & Outlook

- EBL will be an important part of NGL
- Resolution well below 10nm will be needed
- MAD and SRD have demonstrated their potential concerning resolution improvements in this regime
- Further investigations into both techniques have to be done to explore their limits
- Novel resist materials sensitive to electron beam exposure should be investigated

AMO

Acknowledgments

- European Commission
- German ministry of education and research (BMBF)
- Our partners in our research projects



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