Lithography and deposition with a sub-nanometer focused helium beam (part I)

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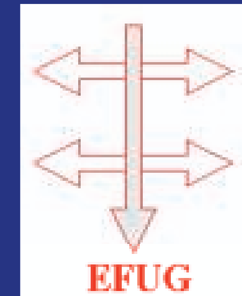
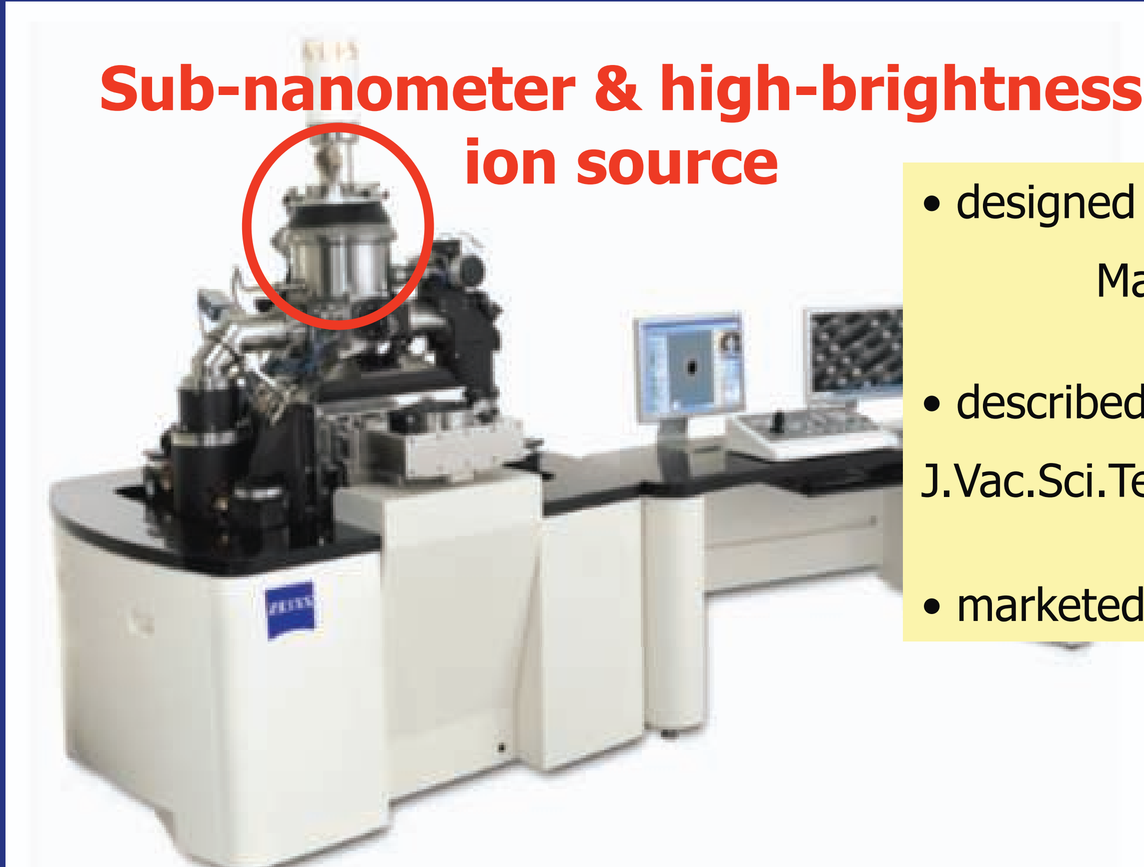


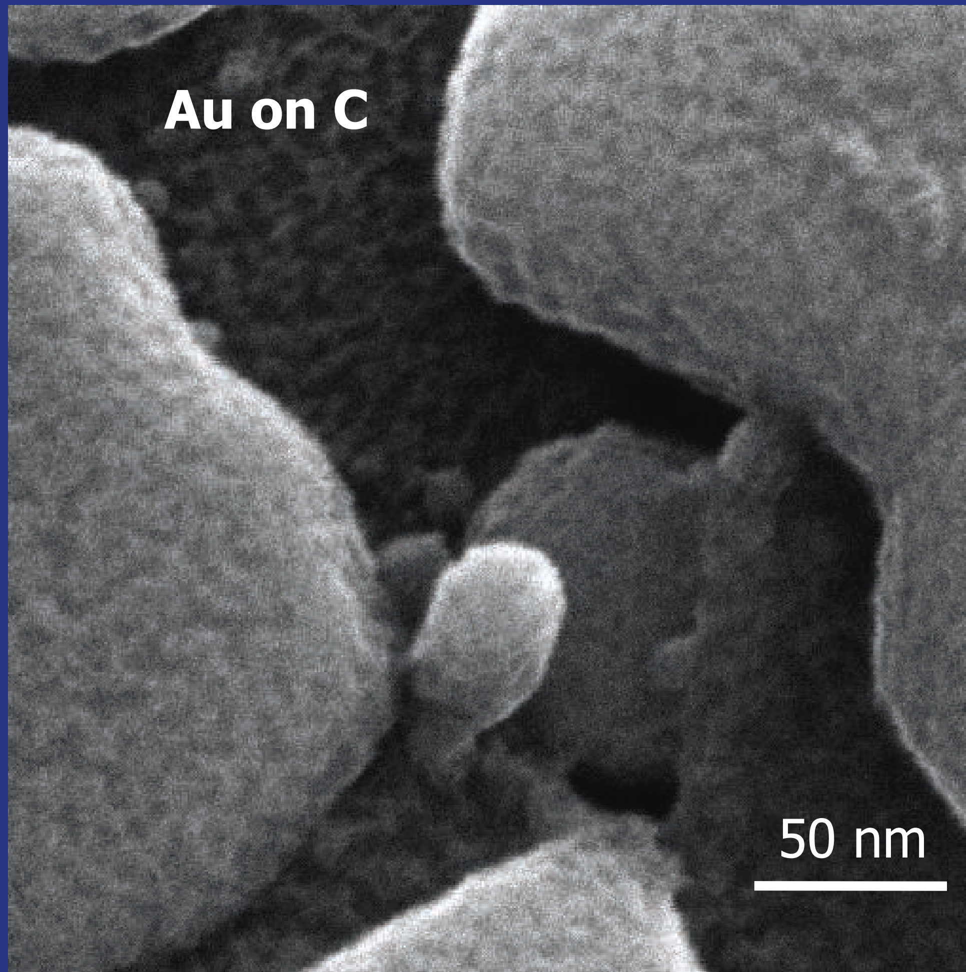
EFUG2009 : Monday 5 October 2009
Arcachon, France

Helium Ion Microscope



- designed by ALIS, Peabody,
  Massachusetts, USA
- described by B.W. Ward et al.,
  J.Vac.Sci.Technol. B **24** 2871 (2006)
- marketed by Zeiss, 2007

Helium Ion Microscope



Resolution = 0.7 nm

(25-75% edge width)

1. Helium Beam Lithography (HeBL)

- HSQ resist ('negative tone')
- PMMA resist ('positive tone')
- Sensitivity; minimal feature size; proximity / beam shape effects

Cooperation between:

- TU Delft (Kavli) Vadim Sidorkin, Anja van Langen, Raoul Mattern, Emile van der Drift and Huub Salemink
- TNO Delft Diederik Maas and Emile van Veldhoven

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2. Helium Ion Beam Induced Deposition (He-IBID)

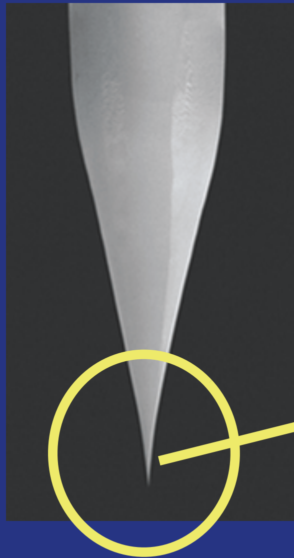
Pattern / pillar growth (compared to Ga-IBID):

- horizontal & vertical growth rates
- growth mode / growth mechanism
- proximity effect

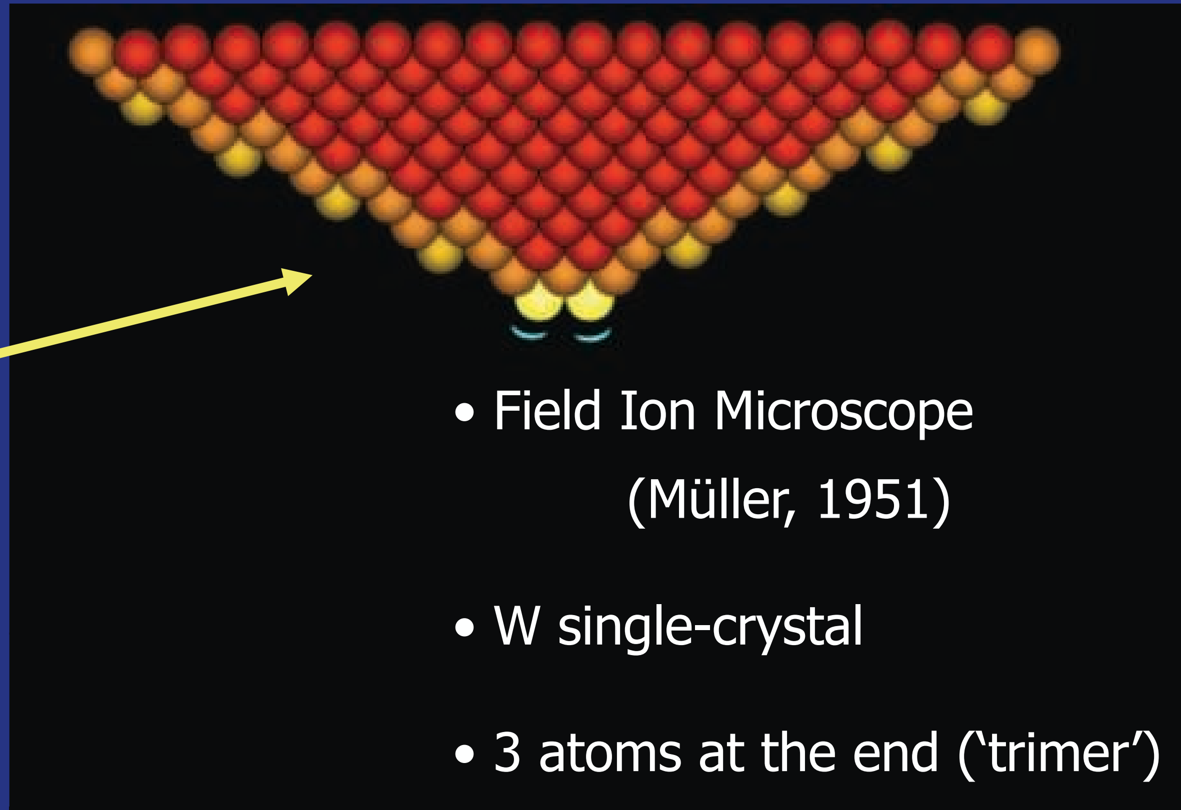
Cooperation between:

- TU Delft (Kavli) Ping Chen, Emile van der Drift, and Huub Salemink
- TNO Delft Diederik Maas and Emile van Veldhoven

Sub-nanometer high-brightness He beam

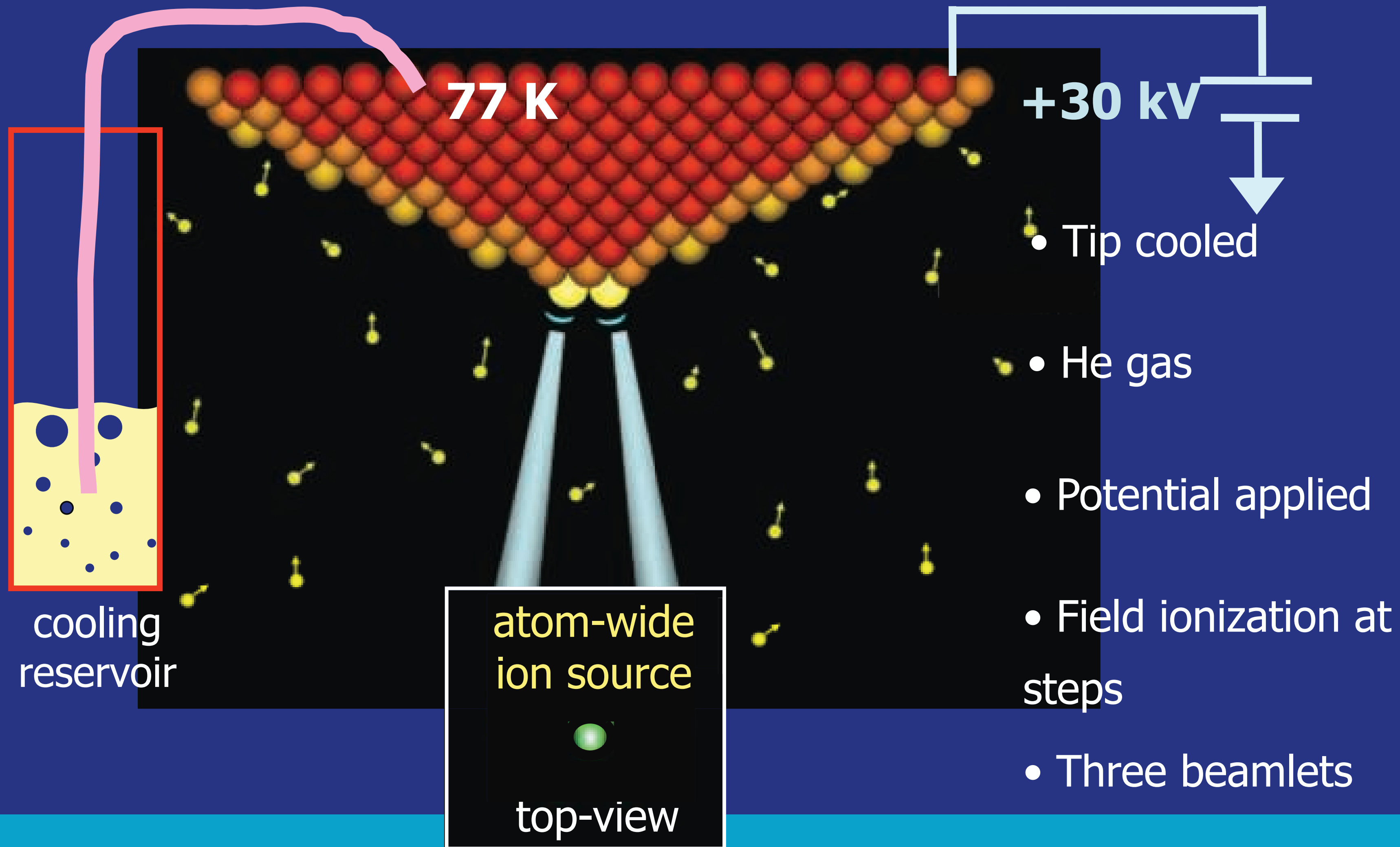


sharp tip



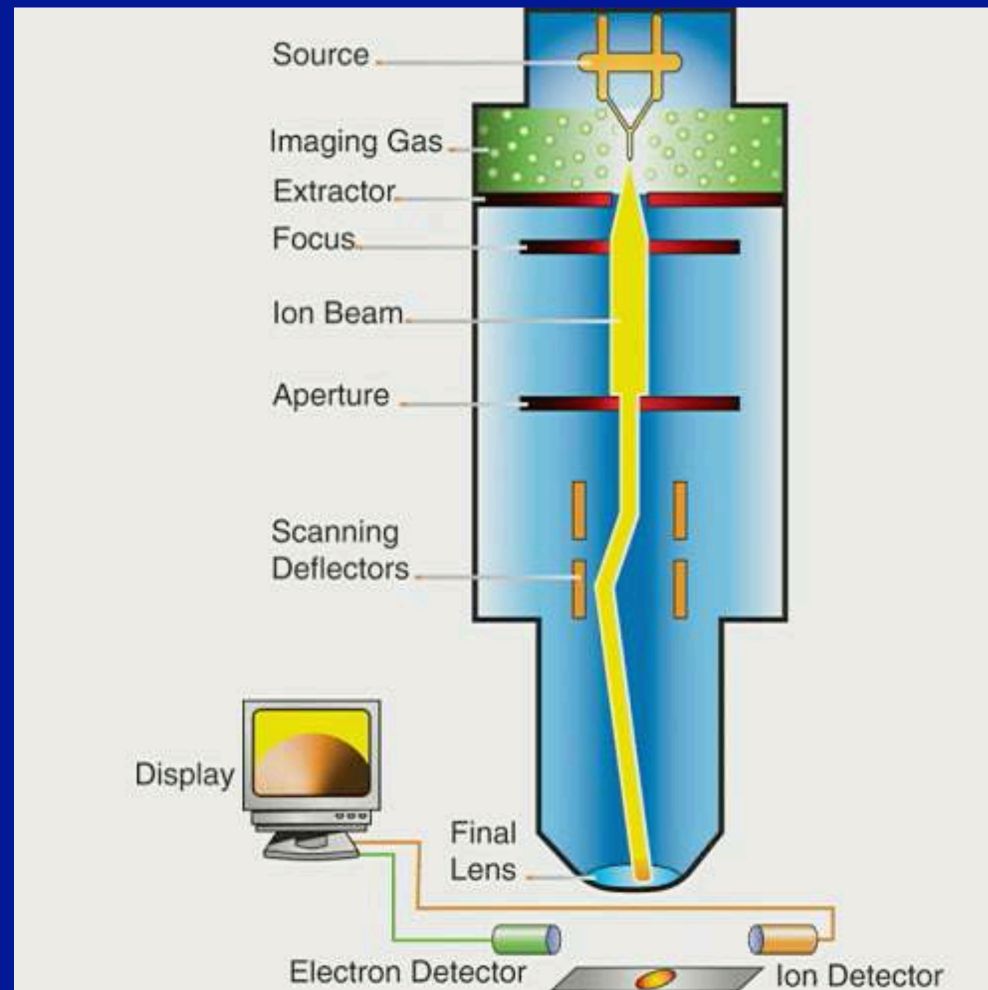
- Field Ion Microscope
  (Müller, 1951)
- W single-crystal
- 3 atoms at the end ('trimer')

Atomic-size source of ions

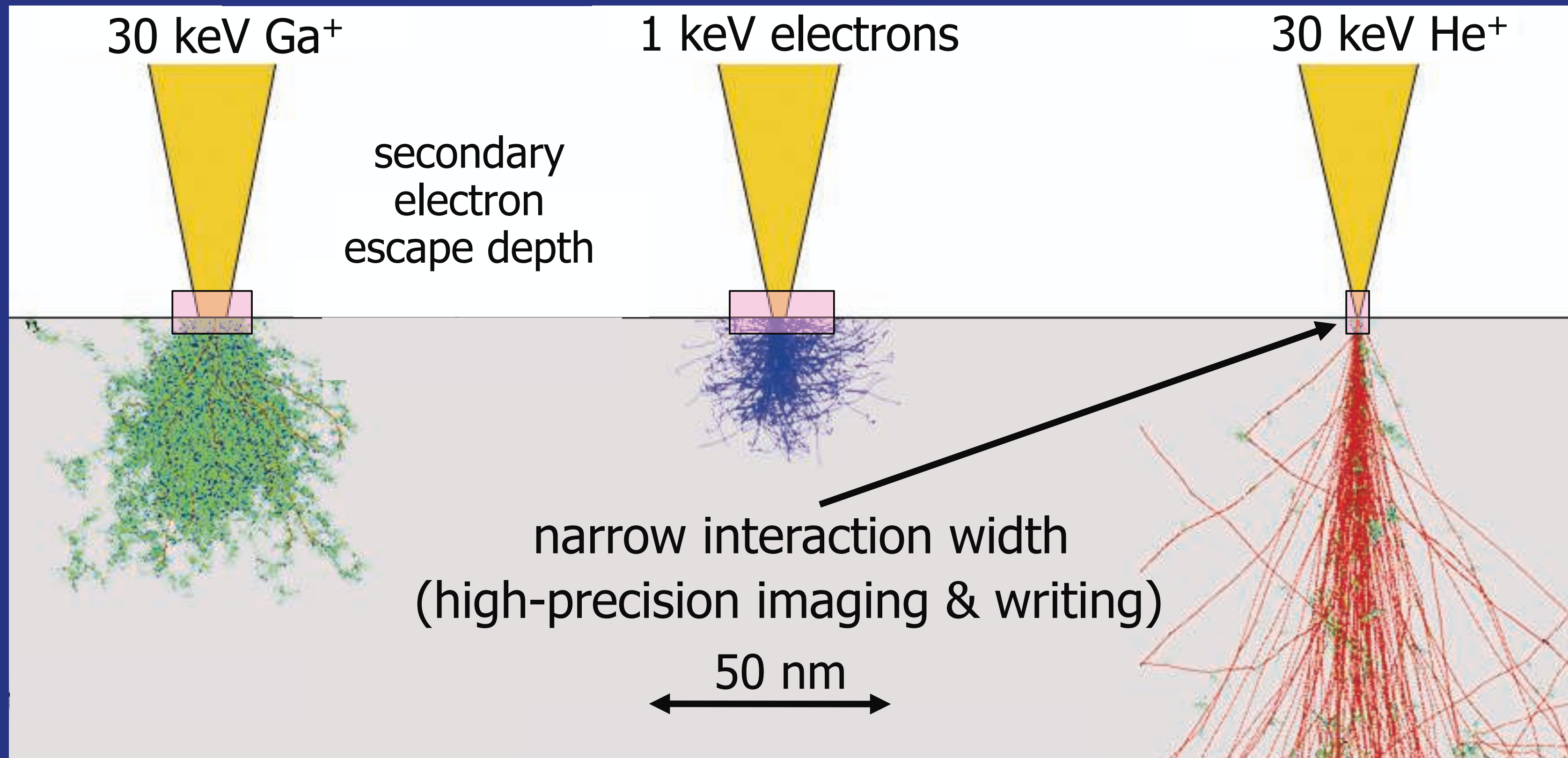


- Tip cooled
- He gas
- Potential applied
- Field ionization at steps
- Three beamlets

Beam steering and focusing



Origin of signal (=secondary electrons)



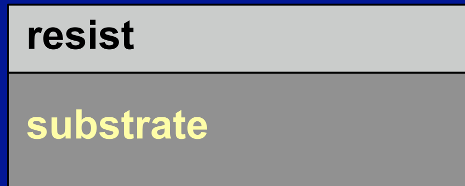
1. Lithography: exposure of a resist

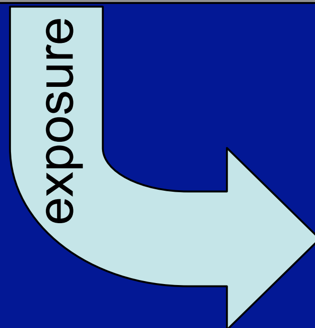
Indirect nanofabrication technique:

chemical alteration of a covering resist

Lithography: exposure of a resist (negative-tone)

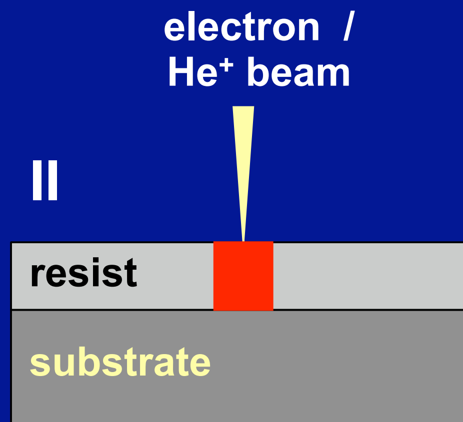
I





II

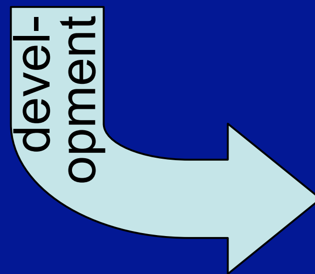
electron / He^+ beam



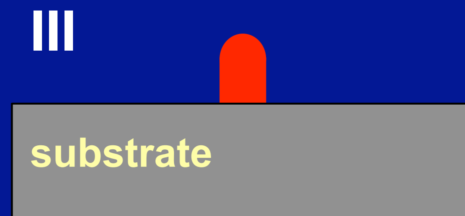
exposure induces chemical modification:

- cross linking of polymers

  => reduced solubility



III



1a. Sensitivity

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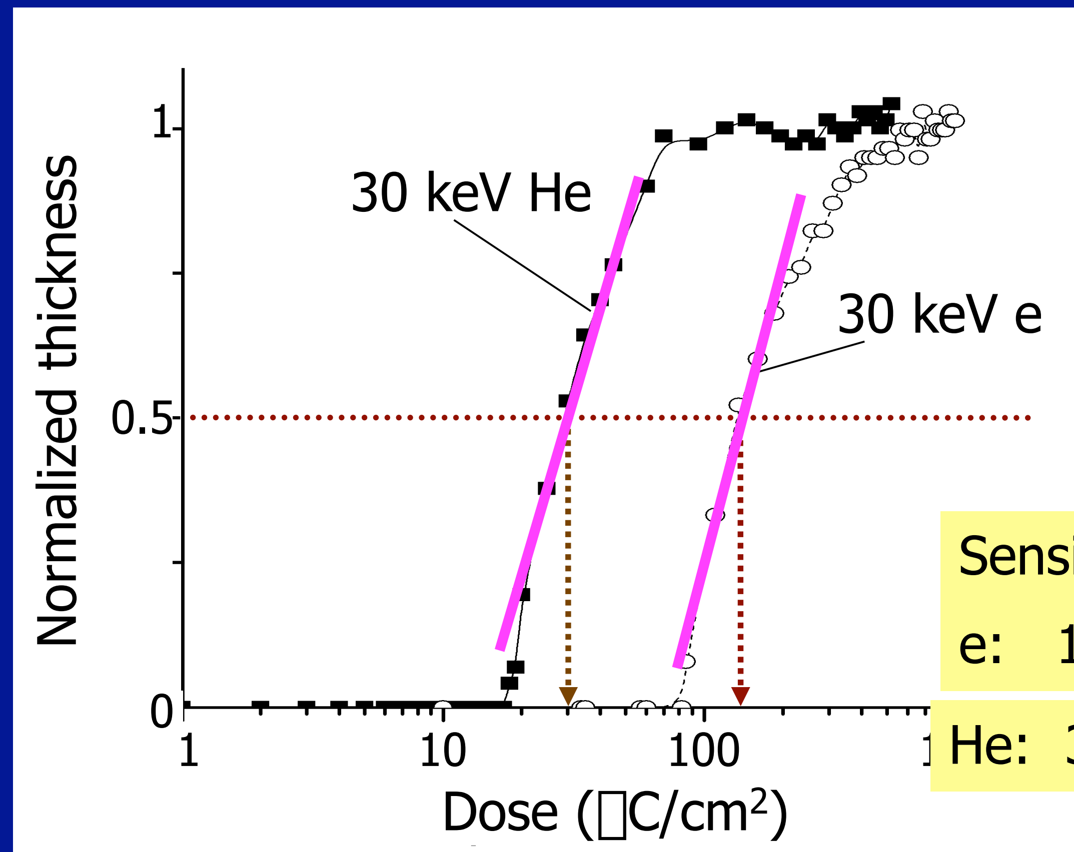
Dose-response curve for HSQ resist

Normalized thickness of exposed and develop structure in resist



Sensitivity:

e: 137 μC/cm²

He: 31 μC/cm²

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e + He sensitivities + contrasts for HSQ + PMMA resist

resist	HSQ		PMMA (pos.)		PMMA (neg.)	
beam	e^-	He^+	e^-	He^+	e^-	He^+
"sensitivity", D_{50} (µC/cm^2)	137	31	140	7.5	5500	137
	4x		17x		40x	
contrast, γ	2.1	2.1	4.8	2.8	2.0	1.9

- He is 4 - 40x more effective
- Contrasts are comparable

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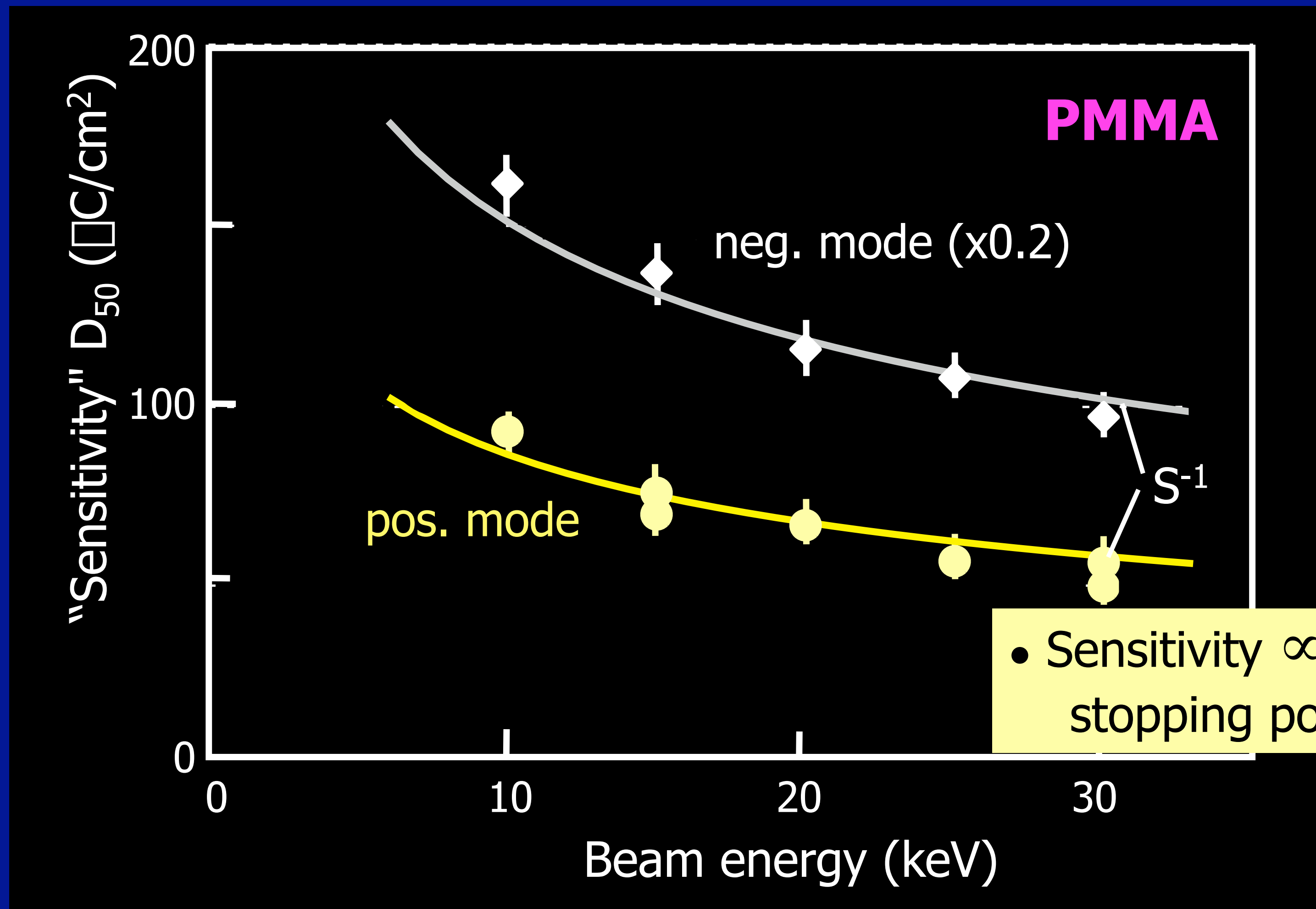
Energy dependence of sensitivity

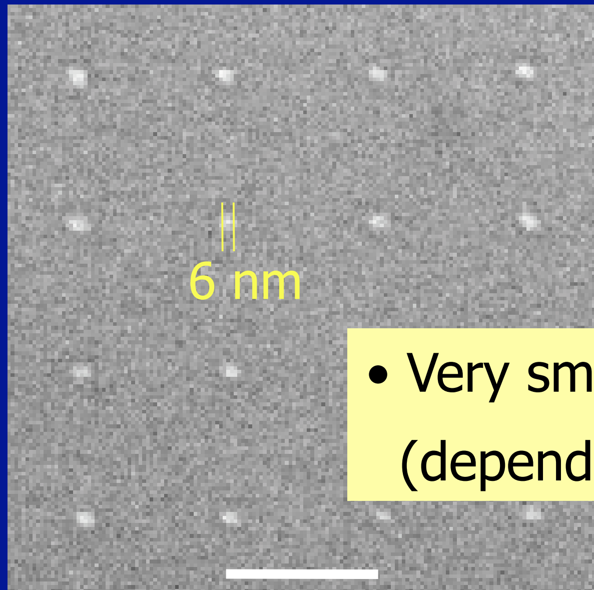


- Sensitivity ∝ stopping power (S)

1b. Minimal feature size

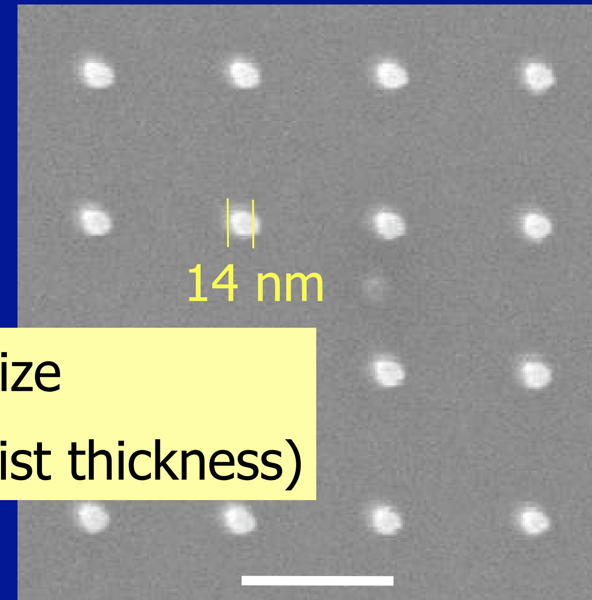
Point exposure (HSQ)

5 nm thick HSQ



100 nm

55 nm thick HSQ



100 nm

- Very small dot size
  (depends on resist thickness)

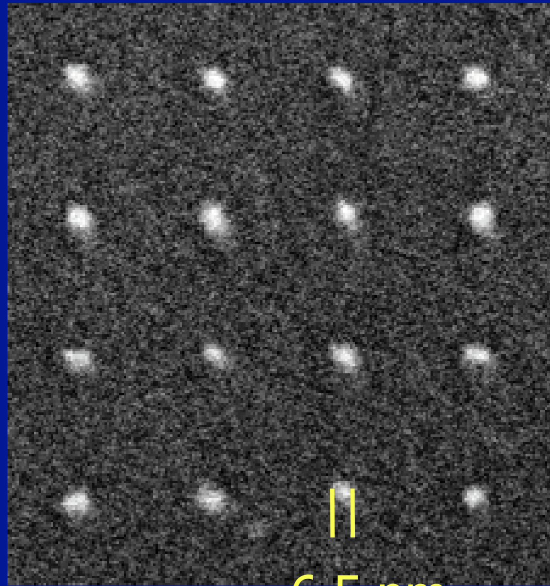
Vadim Sidorkin et al., J.Vac.Sci.Technol. B **27** L18 (2009)

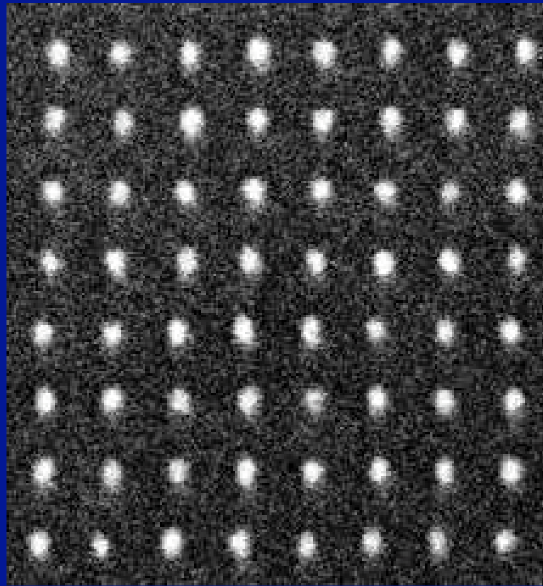
Point exposure (HSQ): various pitches

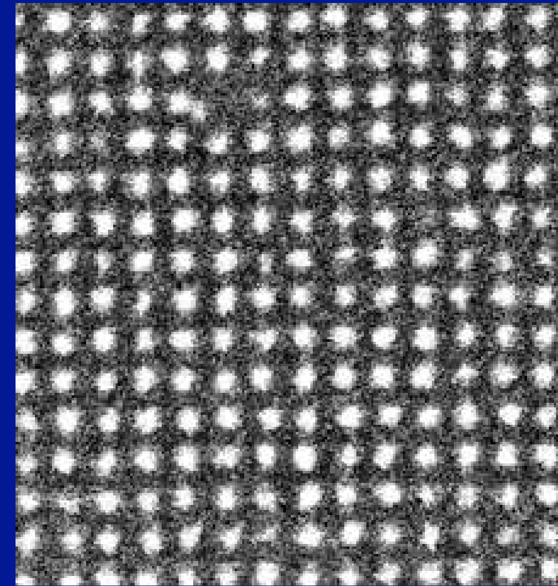
pitch = 48 nm

pitch = 24 nm

pitch = 14 nm







50 nm

Vadim Sidorkin et al., J.Vac.Sci.Technol. B **27** L18 (2009)

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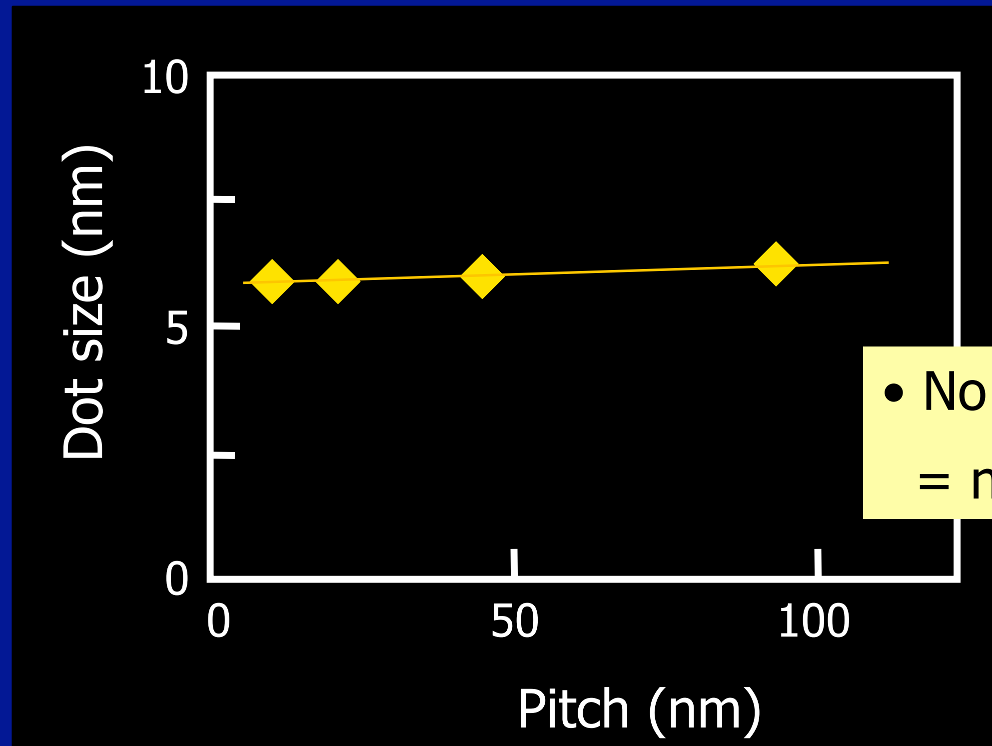
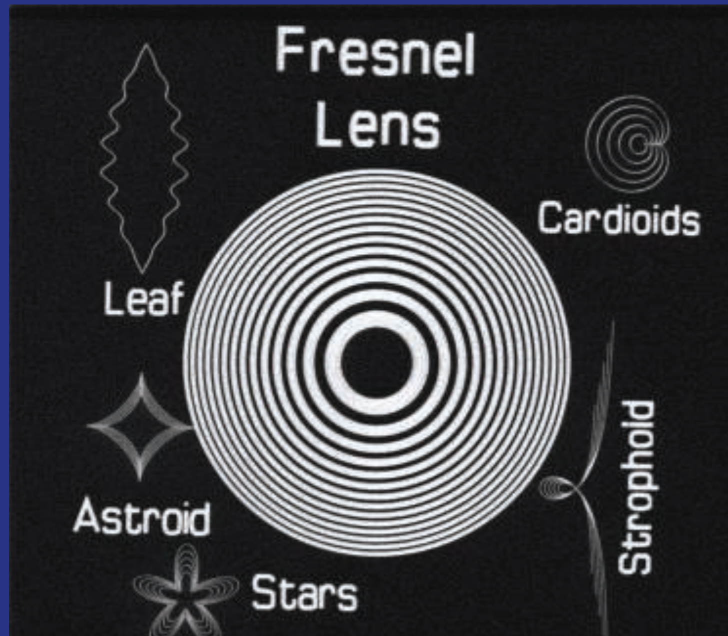
Dot size vs. pitch



- No relation :

  = no proximity effect!

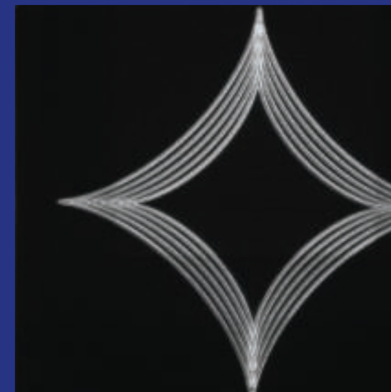
Raith pattern generator

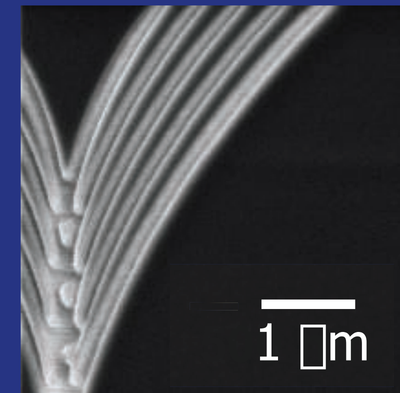


25 μm

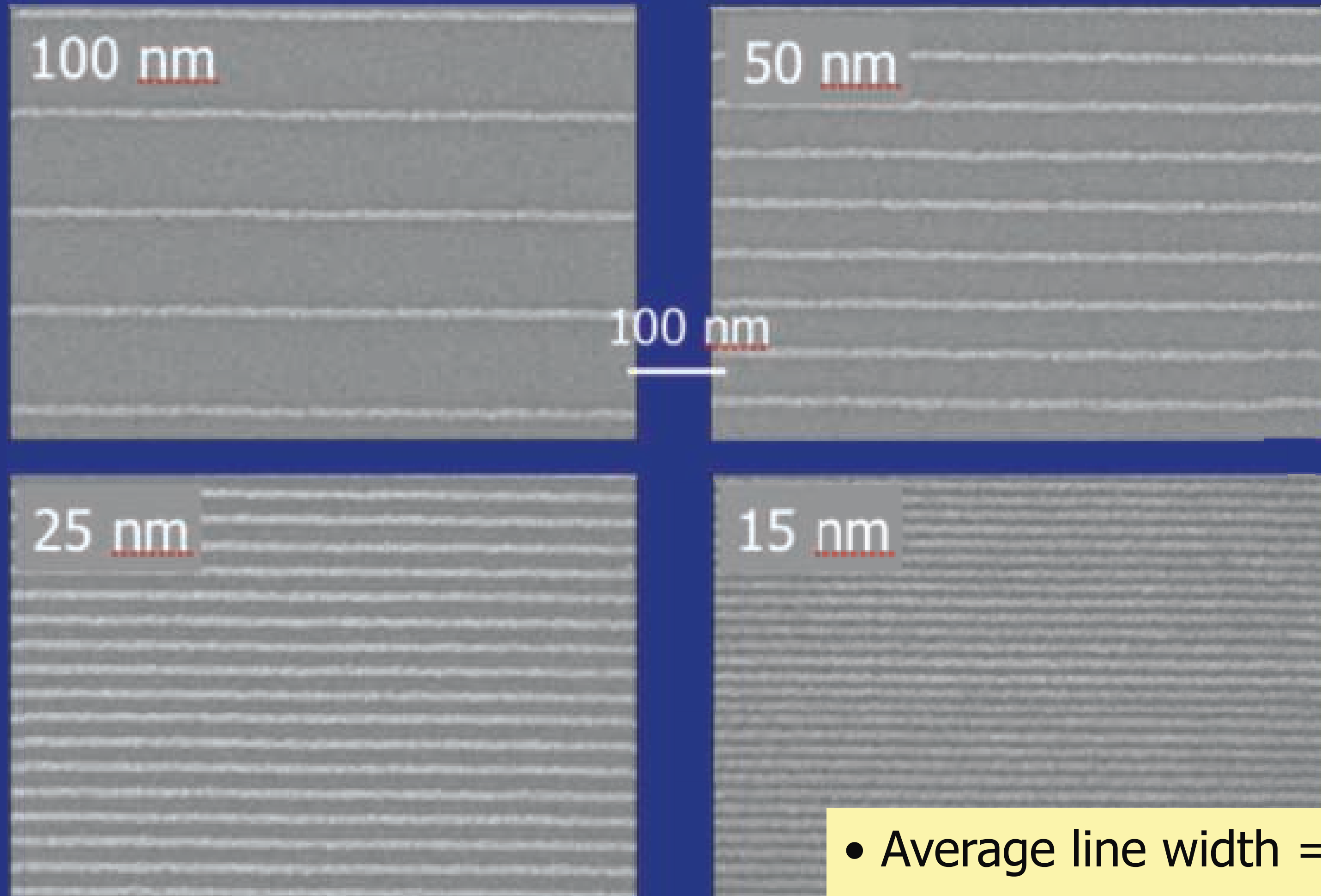
pattern made by He-IBID

imaged by SHIM





Line exposure (HSQ): various pitches



- Average line width = 7 nm (no proximity effect)