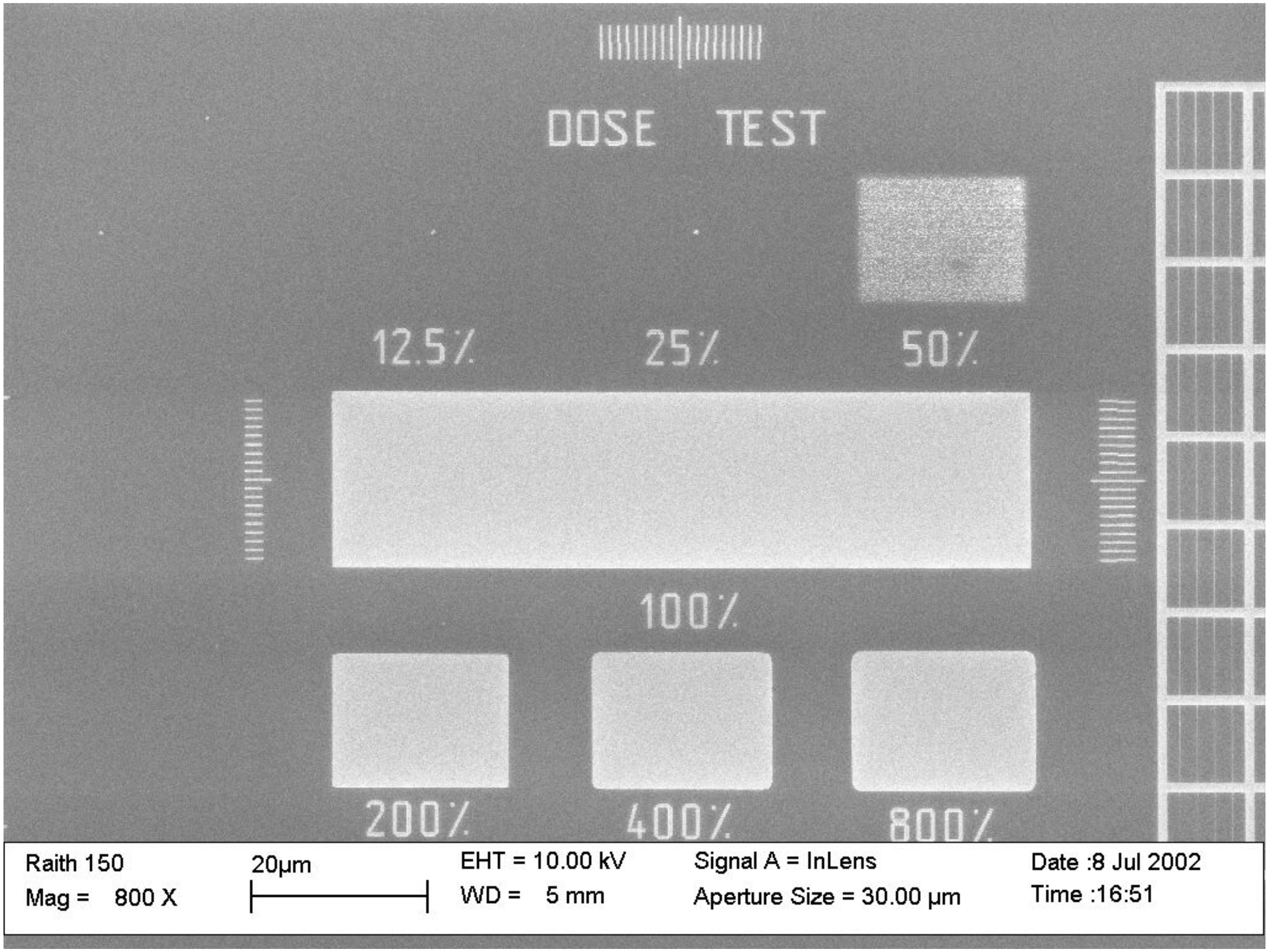
INNOVATION FROM A WORLD LEADER IN ELECTRON BEAM LITHOGRAPHY
AND SEMICONDUCTOR NAVIGATION SOLUTIONS

Basic Resist Theory

Basic Resist Theory



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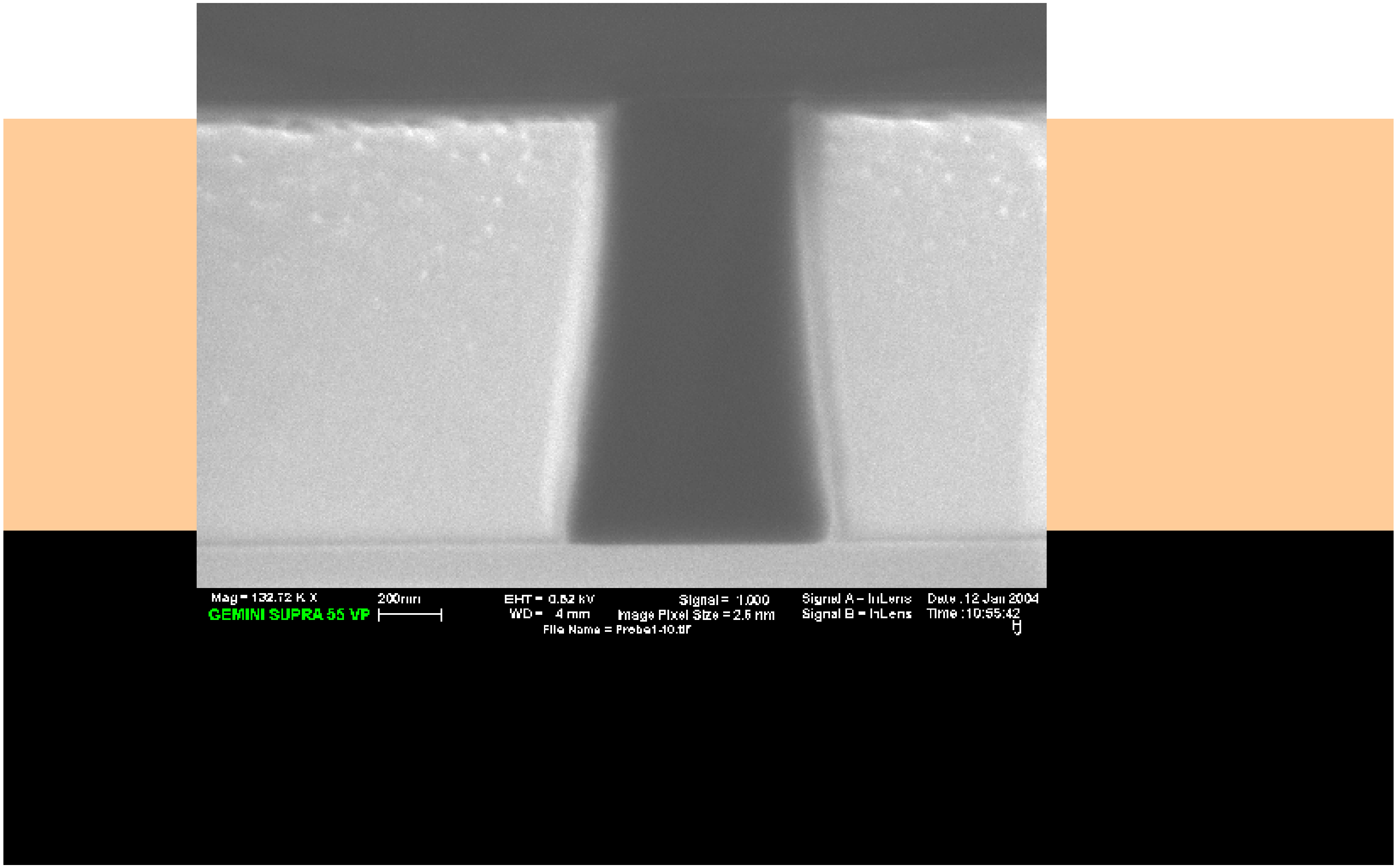
Contents

- Electron scattering in resist and substrate
- Proximity effect
- Resist interactions (positive /negative/chemically amplified resists, resist contrast)
- Dose definition
- Influence of beam energy (penetration depth)
- Resolution limits

Monte Carlo Simulations

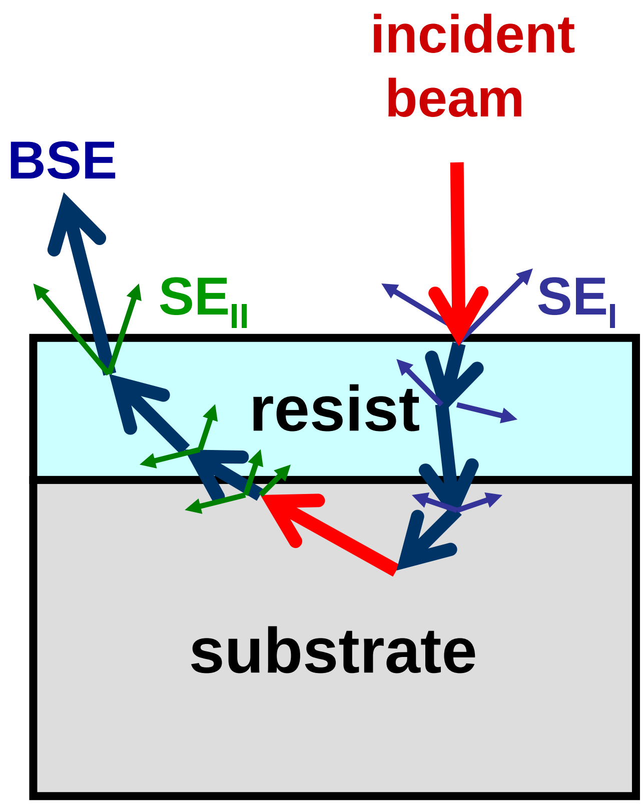
Basic Resist Theory



1.4µm PMMA on Si-substrate

Resist and Substrate Interactions of e-beam

Basic Resist Theory



Forward scattering events

- very often
- scattering under **small angles**
- small-angle hence **inelastic**
- generation of Secondary Electrons with a few eV kinetic Energy

Backward scattering events

- occasionally
- scattering under **large angles**
- large angle hence **mainly elastic**
- high kinetic energy, range of the primary electrons

electrons with typical **few eV** kinetic energy are **responsible for** most of the **resist exposure** → **exposure by secondary electrons (SE_{I} and SE_{II})**

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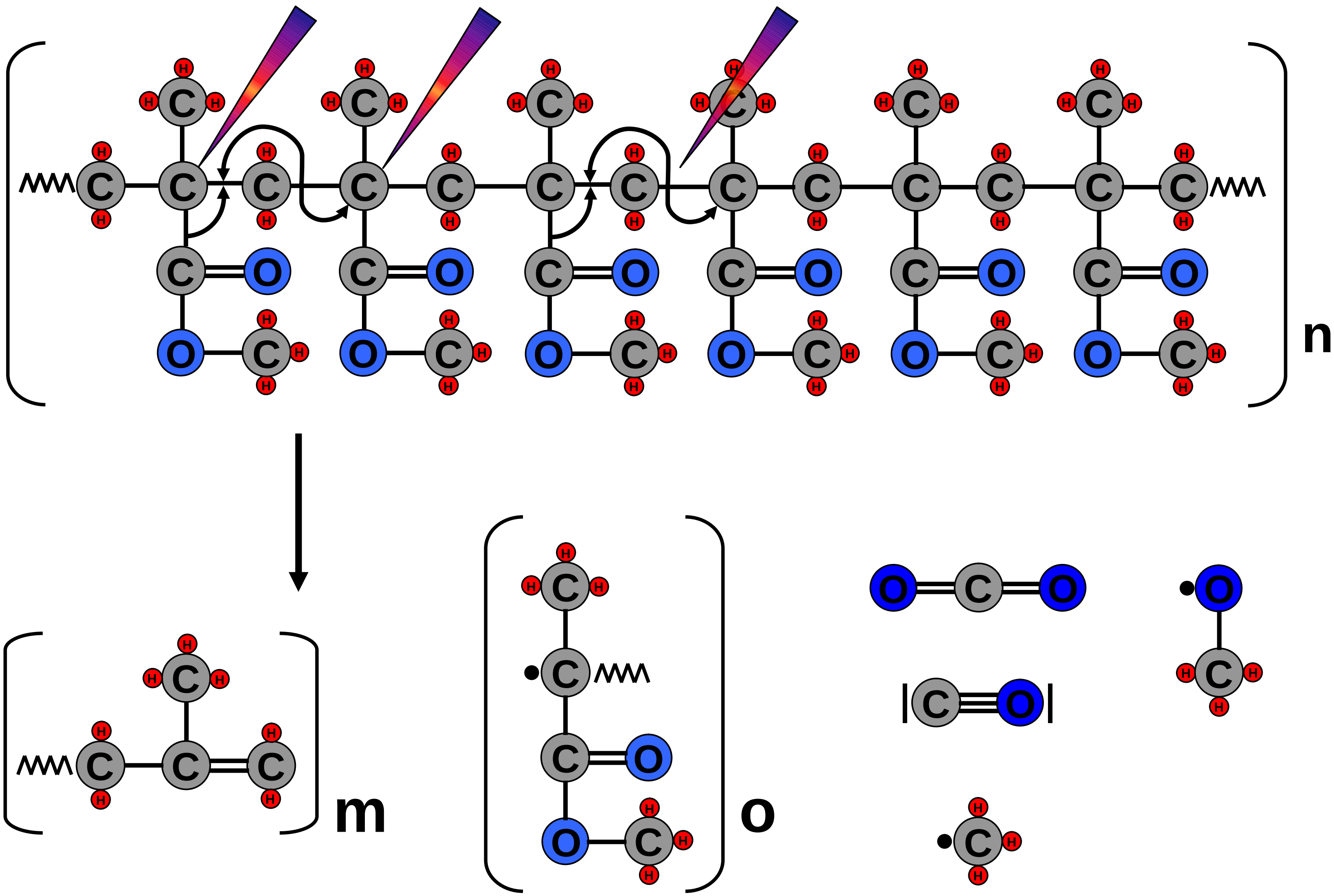
Fragmentation of PMMA

Basic Resist Theory



Positive and Negative Resist

Positive Resist:

Average molecular weight reduced by exposure

→ exposed area is solved much faster in developer and thus removed

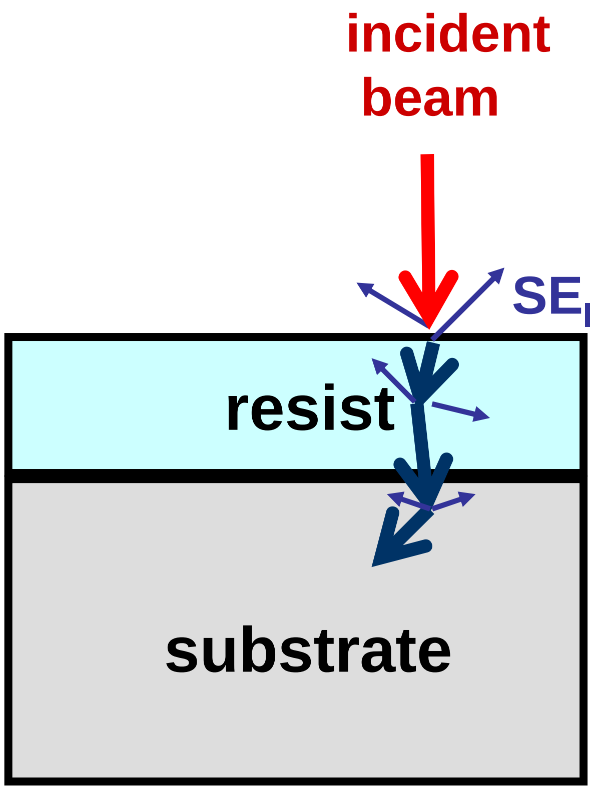
Negative Resist:

Average molecular weight increased by exposure (cross-linking of molecules)

→ <u>un</u>exposed area is removed in developer

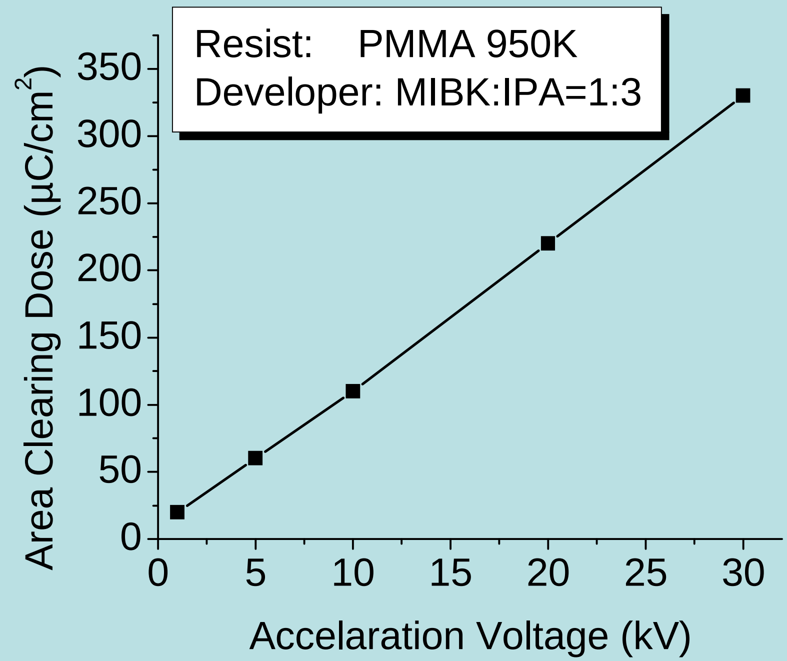
Clearing Dose

Basic Resist Theory



1. Dose independent of resist thickness

2. Dose depends on beam energy



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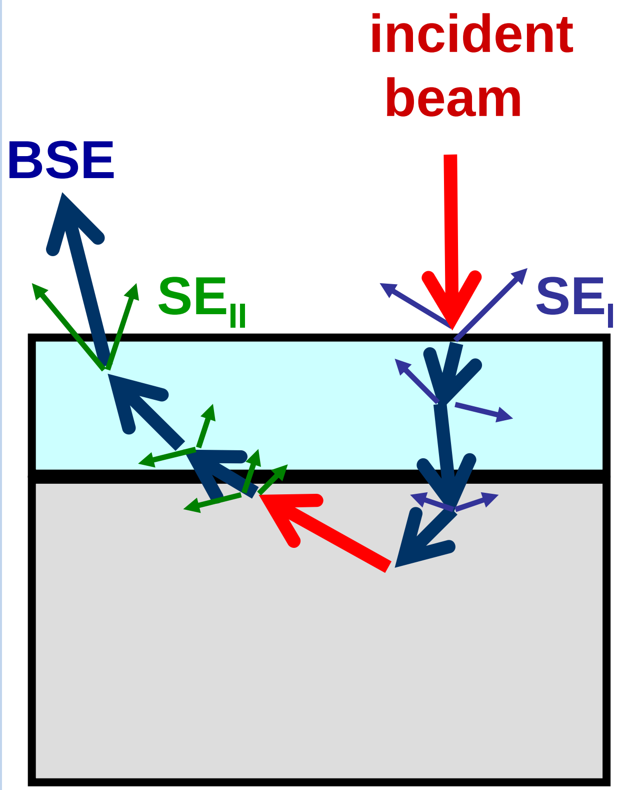
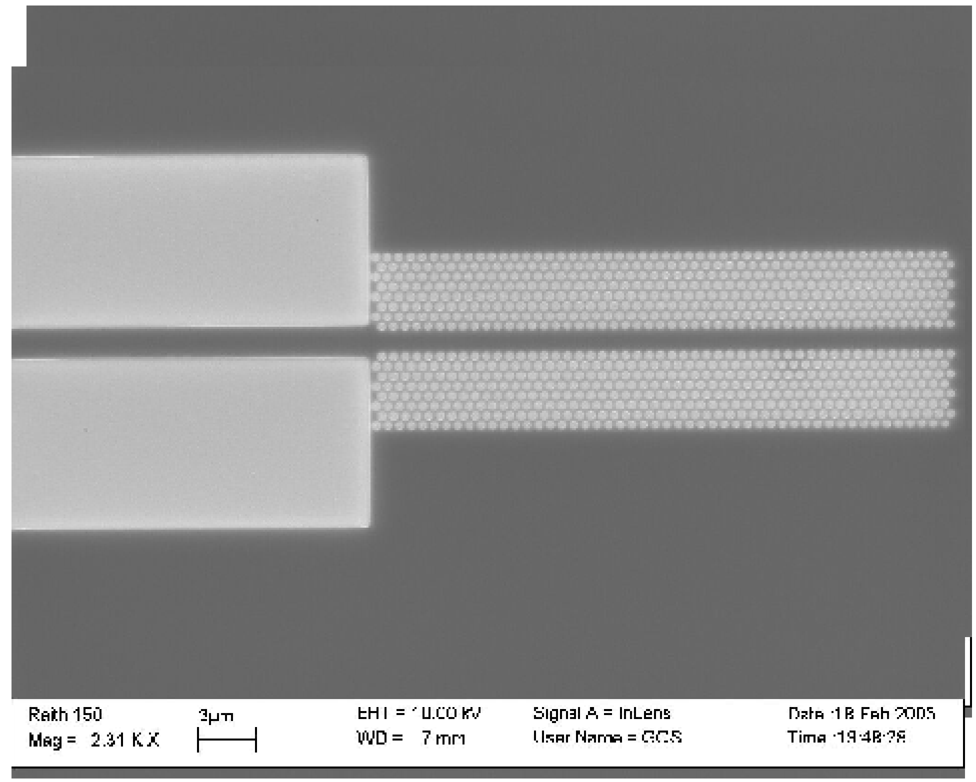
Proximity Effect



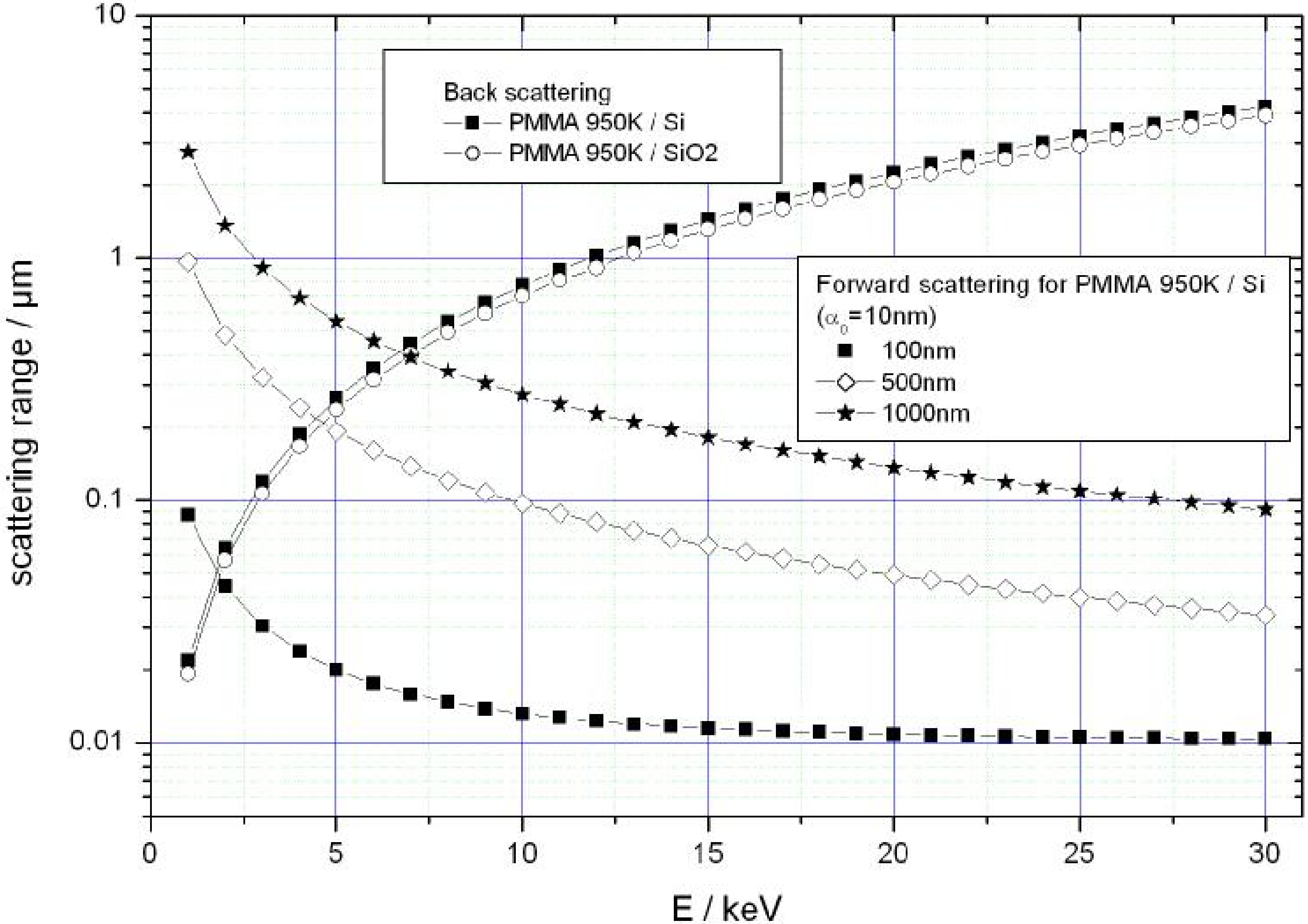


Proximity effect

- depends on beam energy, substrate, pattern
- various strategies for proximity correction, for example dose variation

Scattering Range Versus Energy

Basic Resist Theory



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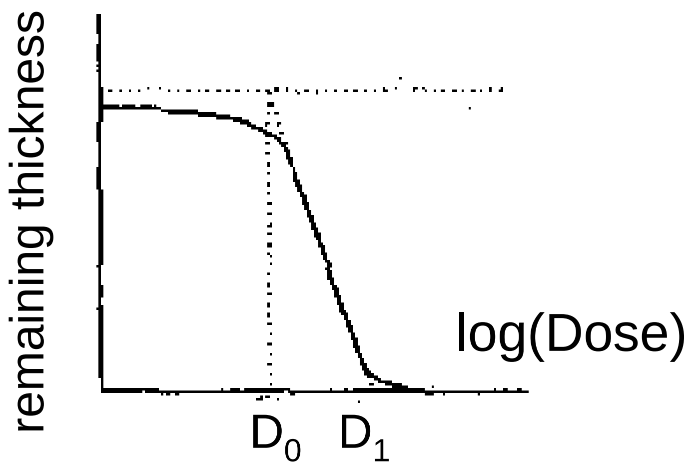
Resist Contrast

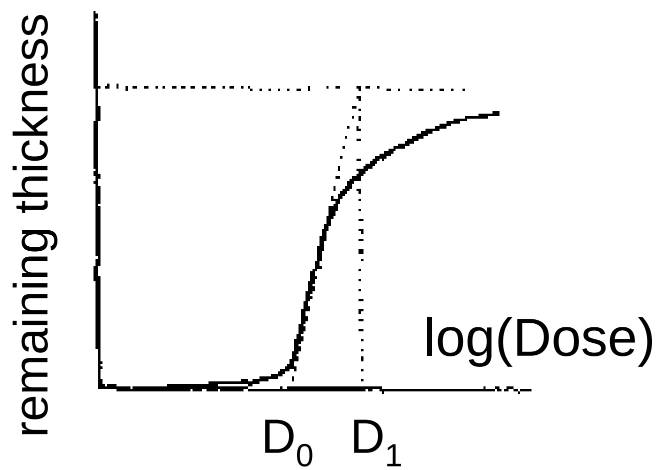
Basic Resist Theory

Resist contrast = Slope in resist

Positive



Negative



Contrast $\gamma = [\log_{10}(D_1)-\log_{10}(D_0)]^{-1}$

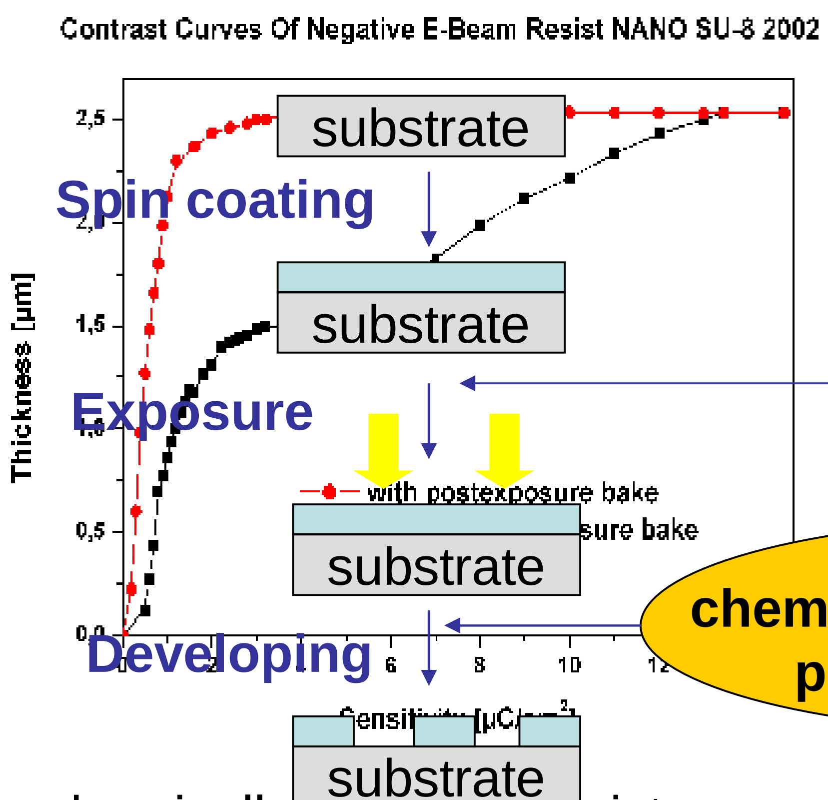
(Mark A. McCord, Introduction to Electron-Beam Lithography, Short Course Notes Microlithography, 1999, SPIE's International Symposium on Microlithography 14-19 March, 1999; p. 22)

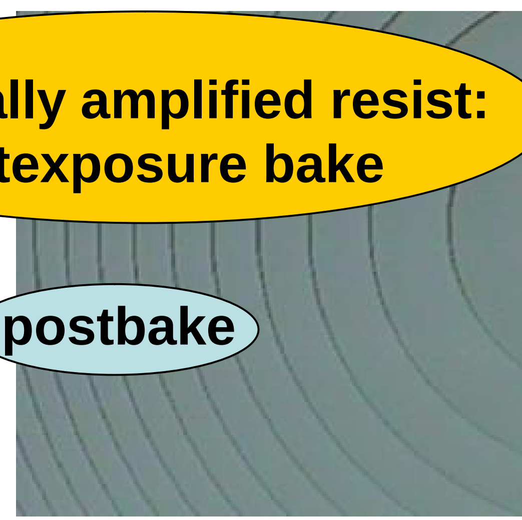
Chemically Amplified Resist

Chemically amplified resists, are modified during exposure. However the final exposure takes place during the post exposure bake, when the acids are activated.

Example: SU8

SU8 resist





- chemically amplified resist
- for 3D lithography:
  used without postexposure bake

Resist Contrast

Basic Resist Theory

Resist	Energy	Developer	Stopper	contrast
ZEP520A	**20keV**	MIBK:IPA (1:1), 30s	IPA, 30s	**1.1***
ZEP520A	**10keV**	MIBK:IPA (1:1), 30s	IPA, 30s	**2.1***
PMMA	20keV	pure MIBK, 2 min	IPA, 30s	**16*****
ma-N 2400	20keV	MIF 276, **120s**	DI-H_2O, 3-5 min	**-1.7****
ma-N 2400	20keV	MIF 276, **240s**	DI-H_2O, 3-5 min	**-2.3****
SU-8 (no post exposure bake)	20keV	SU-8 developer (MicroChem)	IPA, 60s	**-0.54***

* Raith GmbH, internal information

** http://www.nanophys.kth.se/nanophys/facilities/nfl/resists/ma-N240X-pdfs/13-MicroEngin_elsner.pdf

*** Rishton et al., JVST B **5 (1)**, 1986, pp.135-41

Resist Contrast

High contrast:

+ Steeper side walls
+ Greater process latitude
+ Better resolution
+ Less sensitivity to proximity effects

Low contrast:

+ 3d lithography

Example: 3Dimensional Lithography

Resist:

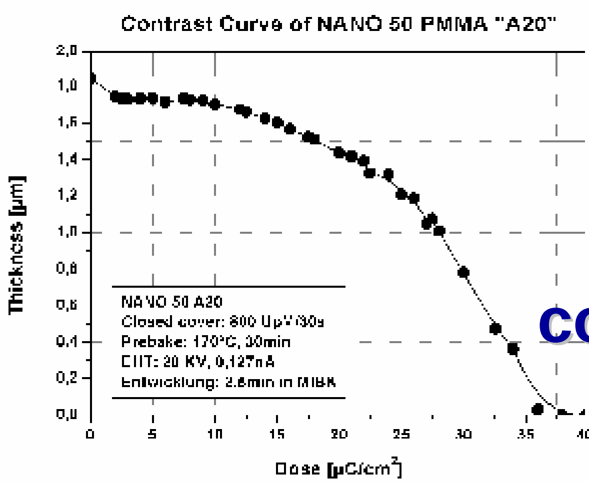
PMMA _50K

Resist thickness:

1.8µm

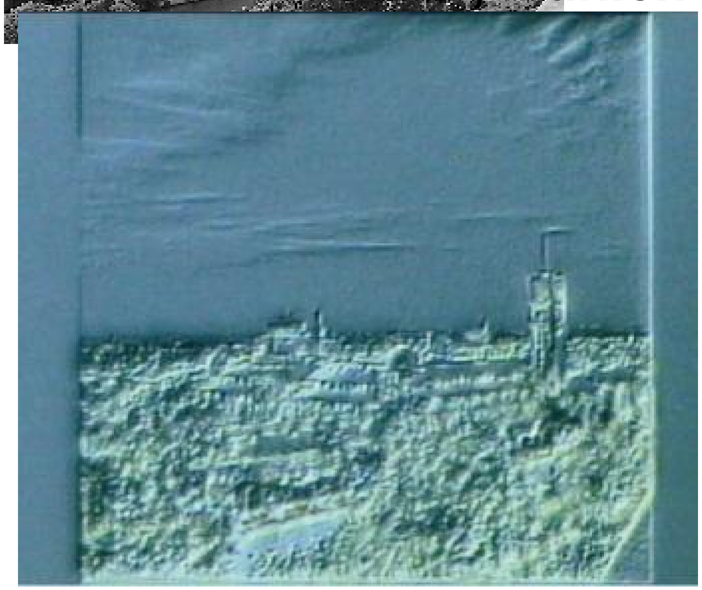
Development:

2.5min MIBK



low contrast

German Museum, Munich



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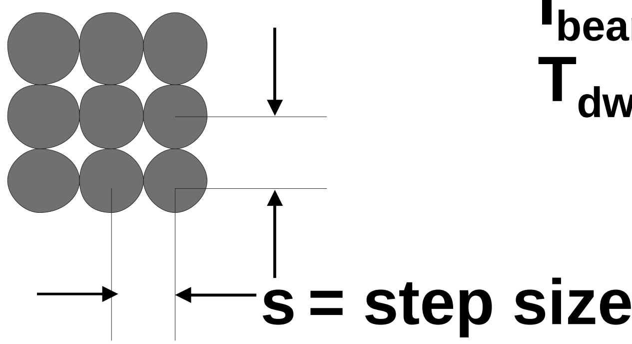
Calculation of Dose



I_{beam} = beam current
T_{dwell} = dwell time

$$\mathrm{Dose}(\mathrm{Energy}) = \frac{I_{beam} \cdot T_{dwell}}{s^2} \quad [\mu As/cm^2]$$

Dose Table for PMMA (950k)

	10 kV	20 kV	30 kV
Areas	100 µC/cm²	200 µC/cm²	300 µC/cm²
SPLs	300 pC/cm	600 pC/cm	900 pC/cm
Dots	0.1 pC	0.2 pC	0.3 pC

(developer: MIBK + IPA, 1:3)

The above values are good starting points. The best way to get optimum results is to perform a dose scaling: SPLs 0.5 – 5, Dots 0.1 – 10

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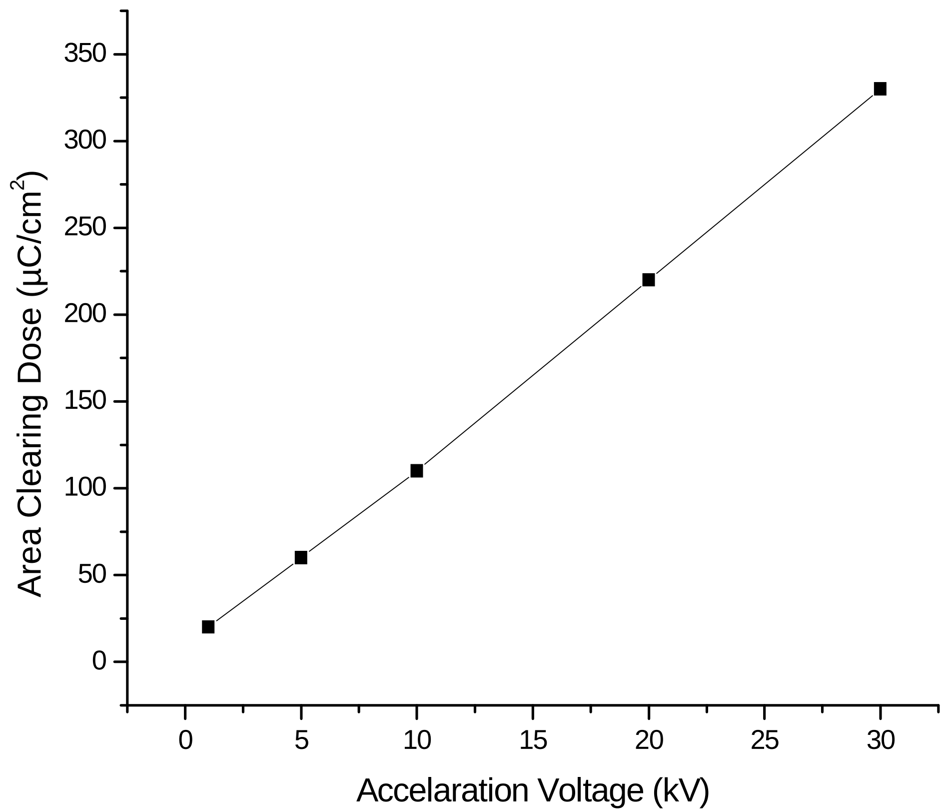
Dose Versus Voltage

Basic Resist Theory



- *Increase of dose with voltage for all resists*
- *Graph shows general behavior*

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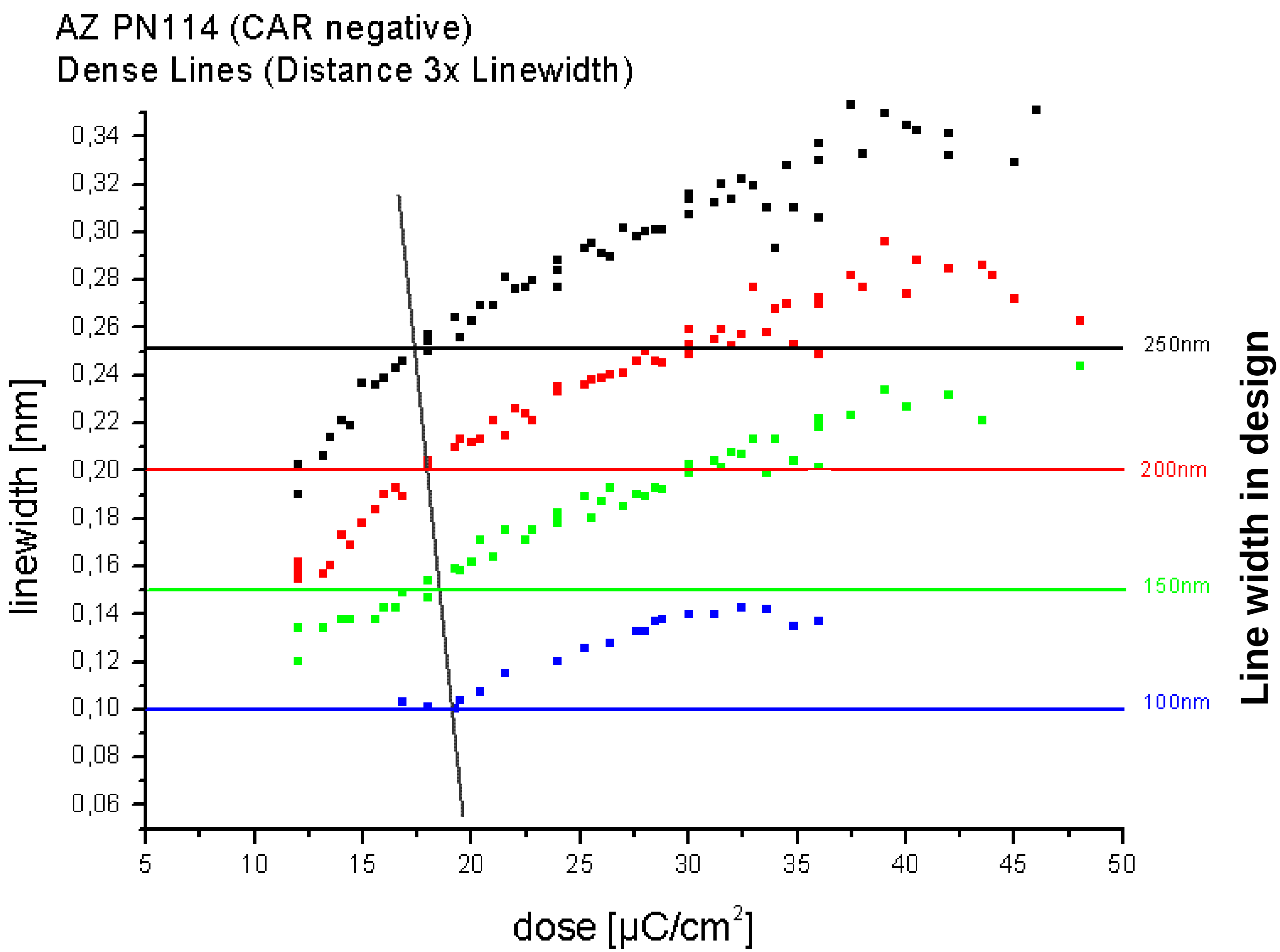
Design must be adapted to dose

Basic Resist Theory



Johannes Kretz, Infineon, Munich

Influence of Beam Energy

100 keV

+ Small scattering in resist
+ Small proximity effect

– High beam damage
– strong sample heating

20 keV

+ Small beam damage
+ Small sample heating
+ Best electron-optical performance (classical columns)

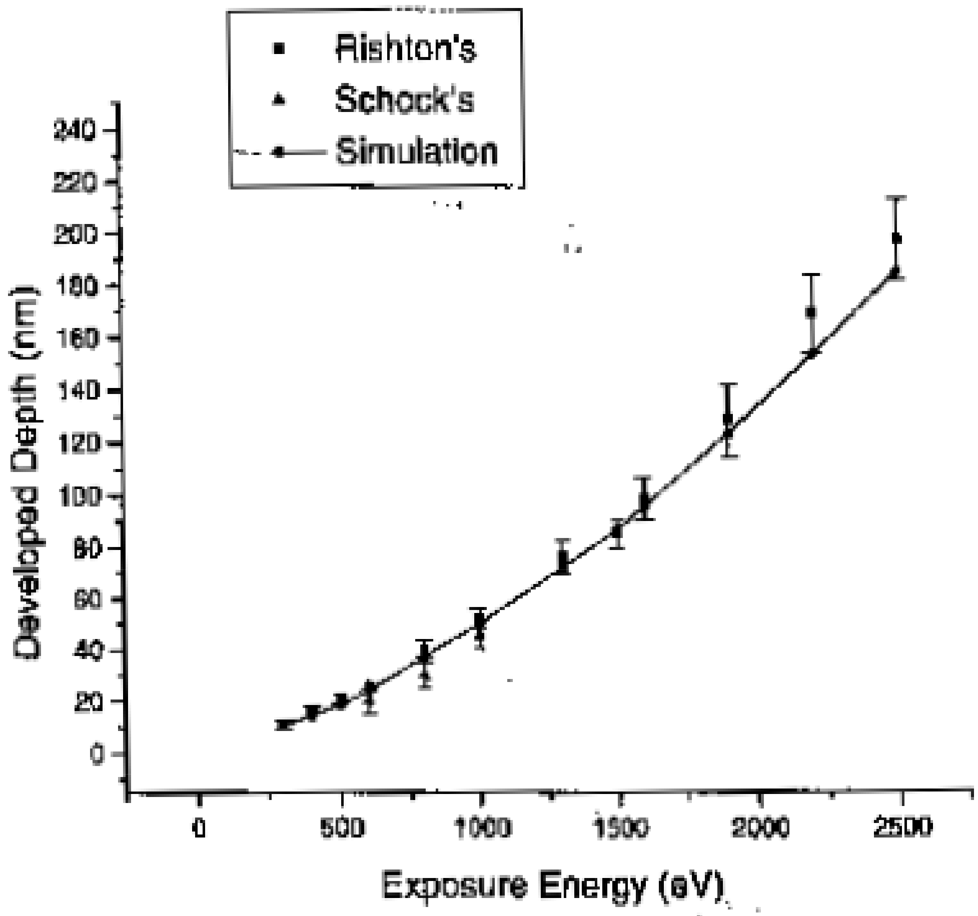
– Scattering in thick resist
– Strong proximity effect

2 keV

+ No beam damage
+ No proximity effect
+ High throughput (high resist sensitivity)

– High scattering in resist
– Needs very thin resists

Penetration Depth Versus Energy



Y. Lee, W. Lee, and K. Chun 1998/9, <u>A new 3 D simulator for low energy (~1keV) Electron-Beam Systems</u>

Resolution Limits

Beam resolution

- Thick resists (forward scattering)
- Thin resists (~0.5nm by diffraction, de Brogli wavelength)

Resist limits

- Polymer size (~5-10nm)
- Chemically amplified resists (acid diffusion ~50nm)

(Mark A. McCord, Introduction to Electron-Beam Lithography, Short Course Notes Microlithography, 1999, SPIE's International Symposium on Microlithography 14-19 March, 1999; p.63)

Resolution Limits

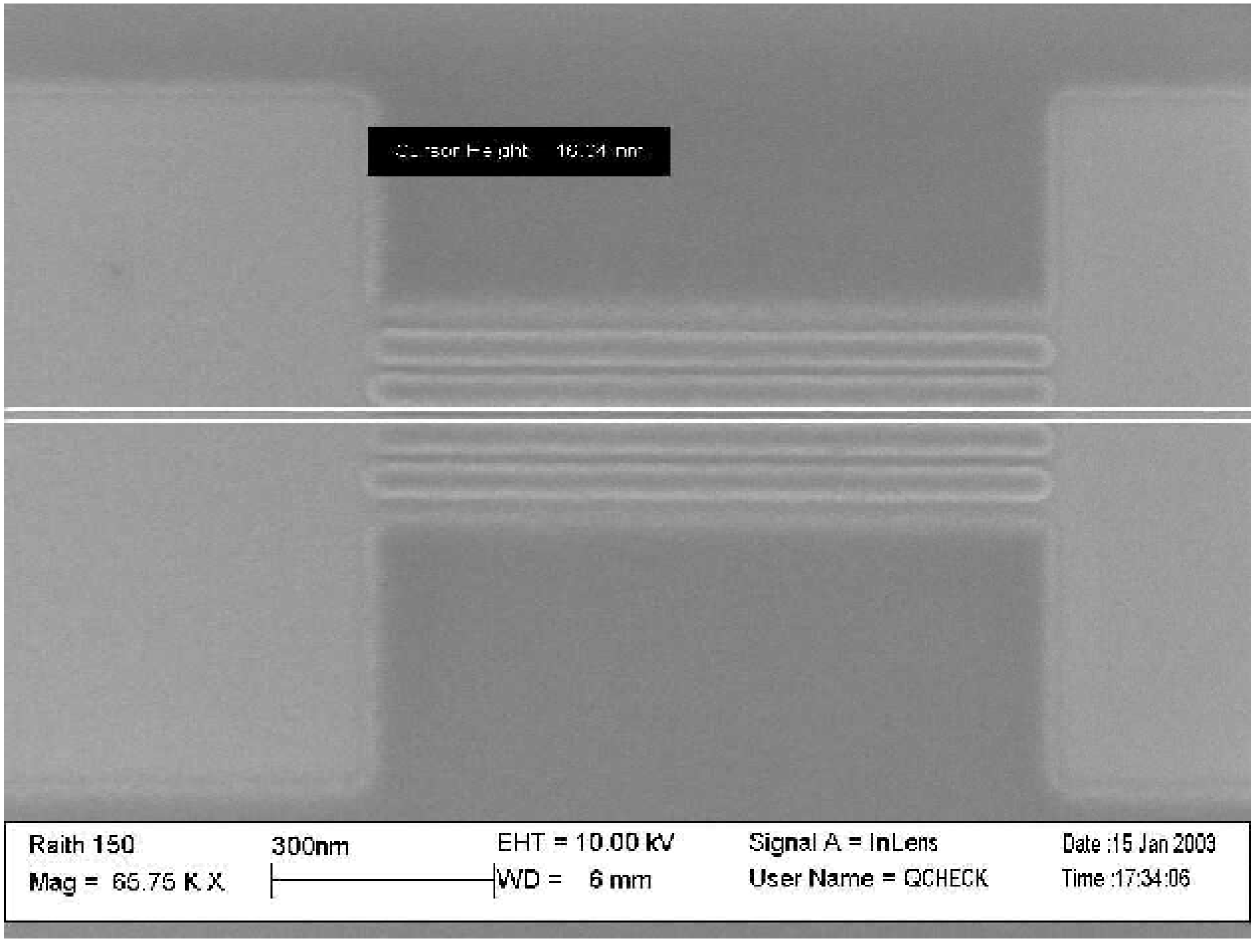
Secondary electron range (~5-10nm)

In practice, the best achievable resolution in polymer resists is about 20nm, with inorganic resists (currently impractical for most applications) 5nm.

(Mark A. McCord, Introduction to Electron-Beam Lithography, Short Course Notes Microlithography, 1999, SPIE's International Symposium on Microlithography 14-19 March, 1999; p.63)

What is Possible ?

Basic Resist Theory



Ultra high resolution in PMMA (45nm thickness):
16nm line width in resist