Electron-Beam Lithography

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ECE 730-10

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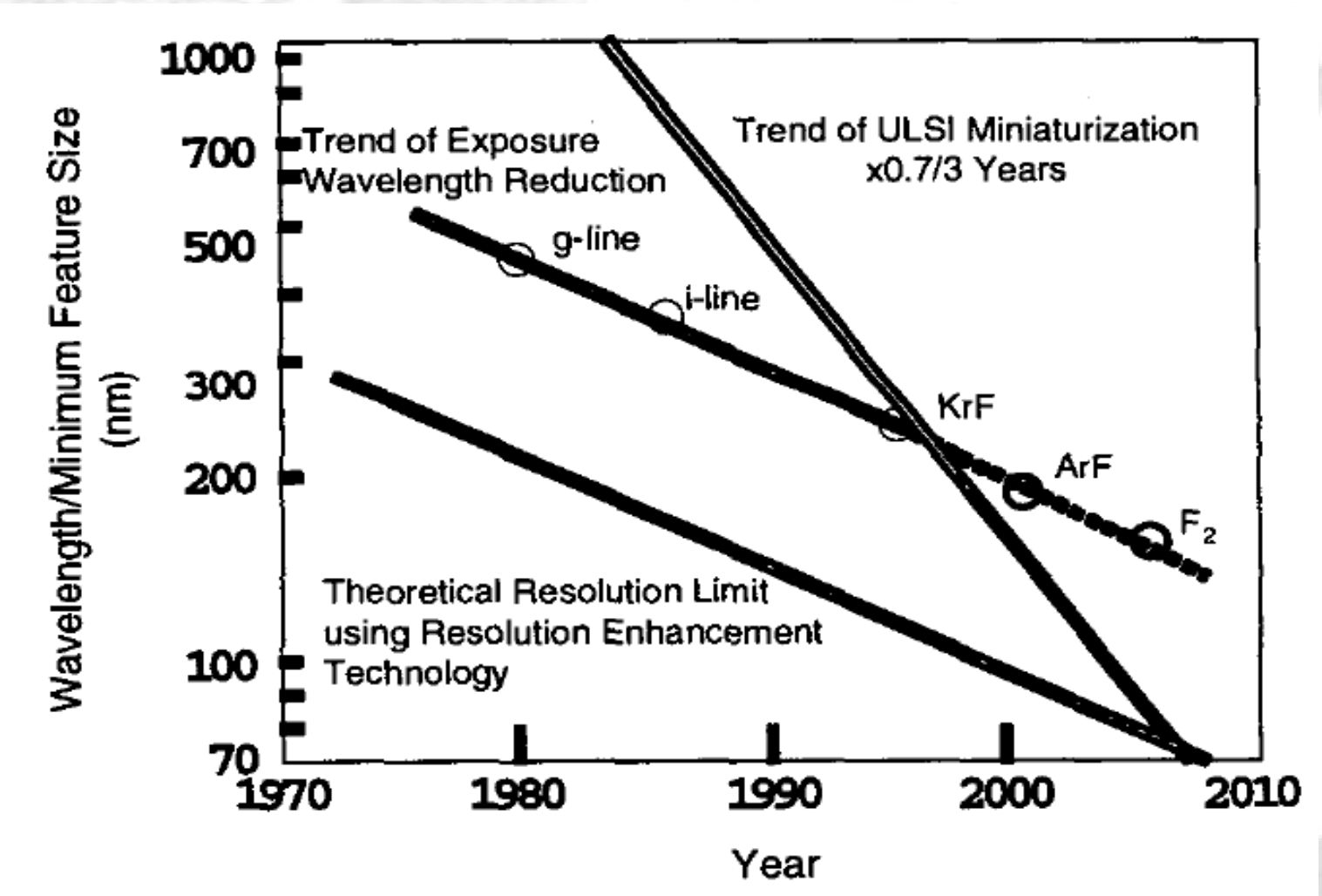
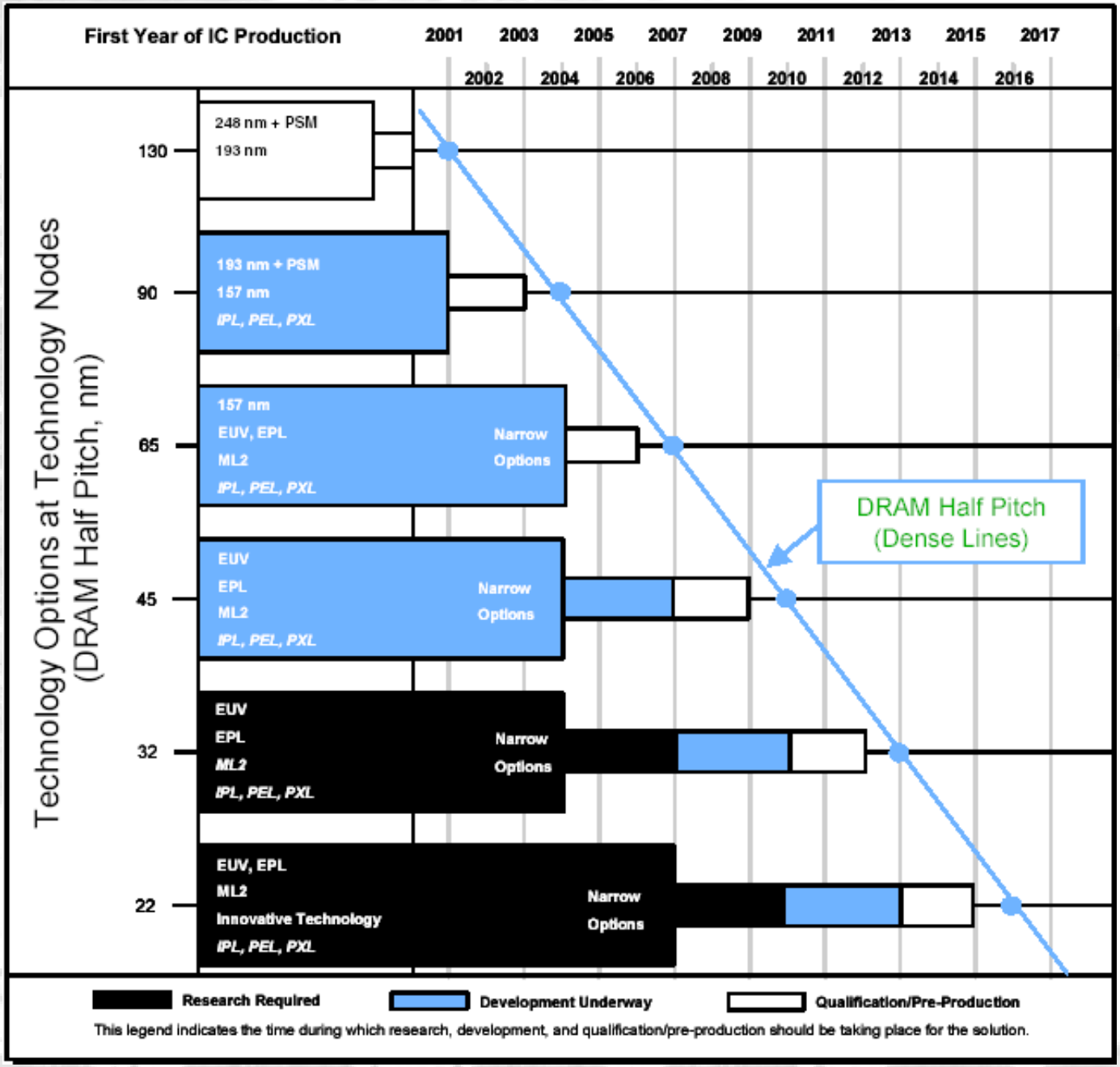
Outline

- Motivation
- Electron Optics
- Electron Interactions
- Resists for EBL
- Systems:
  - Old
  - New

Motivation

- UV Lithography reaching its limit
- NGL (next-generation lithography) will be needed beyond < 65 nm node after 2007




First Year of IC Production
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Technology Options at Technology Nodes
(DRAM Half Pitch, nm)
130
248 nm + PSM
193 nm
90
193 nm + PSM
157 nm
IPL, PEL, PXL
65
157 nm
EUV, EPL
ML2
IPL, PEL, PXL
Narrow
Options
45
EUV
EPL
ML2
IPL, PEL, PXL
Narrow
Options
32
EUV
EPL
ML2
IPL, PEL, PXL
Narrow
Options
22
EUV, EPL
ML2
Innovative Technology
IPL, PEL, PXL
Narrow
Options
DRAM Half Pitch
(Dense Lines)
Research Required
Development Underway
Qualification/Pre-Production
This legend indicates the time during which research, development, and qualification/pre-production should be taking place for the solution.

Advantages of EBL

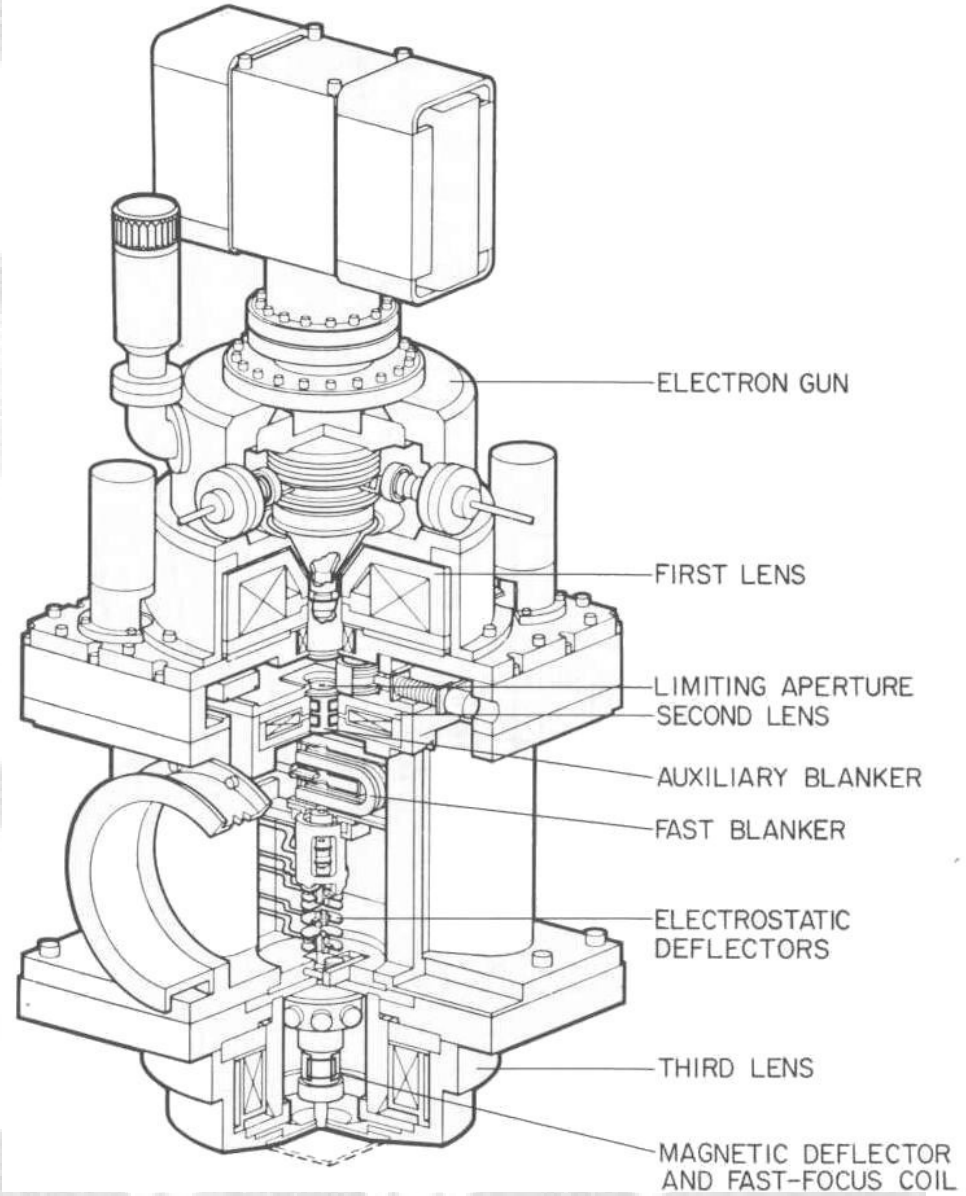
- Not diffraction-limited, limited by resist, scattering, and throughput trade-off
- Can be mask-less (direct-writing)
- Resolution down to at least 50 nm easily, and even less in the future
- Cost is similar to optical lithography systems

Disadvantages of EBL

- Low throughput (maximum is currently 40 200mm wafers/hour but only on modern systems)

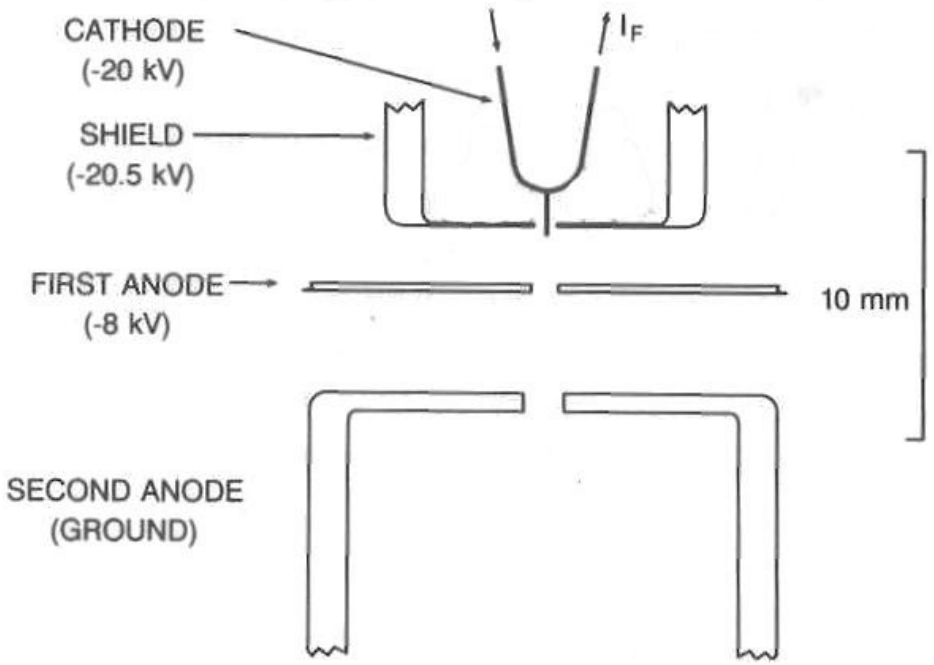
Basic EBL Column

- Many different styles
- SEM columns can also be used
- Basic columns use mature technology



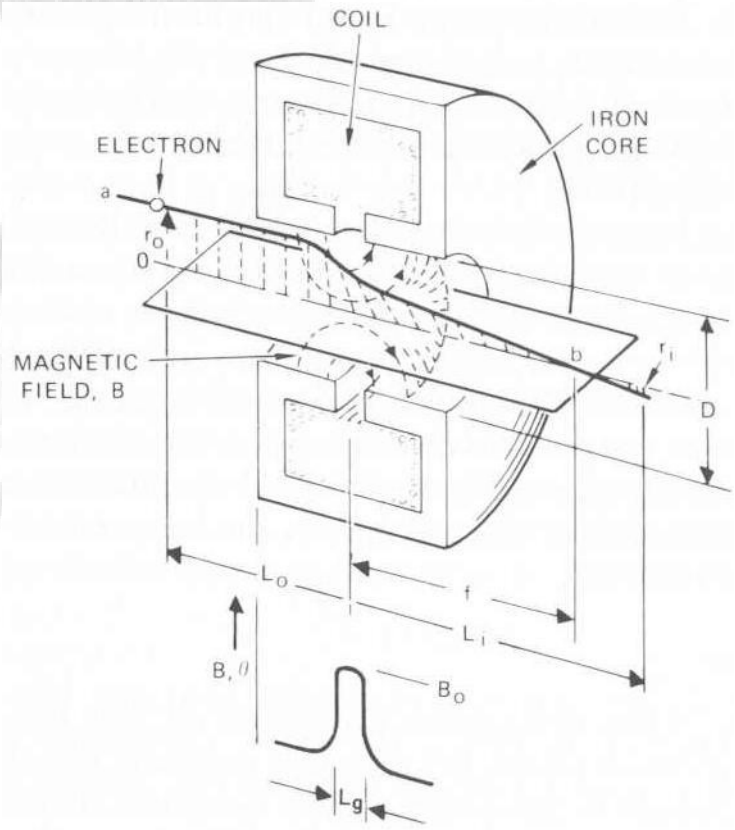
Electron Sources

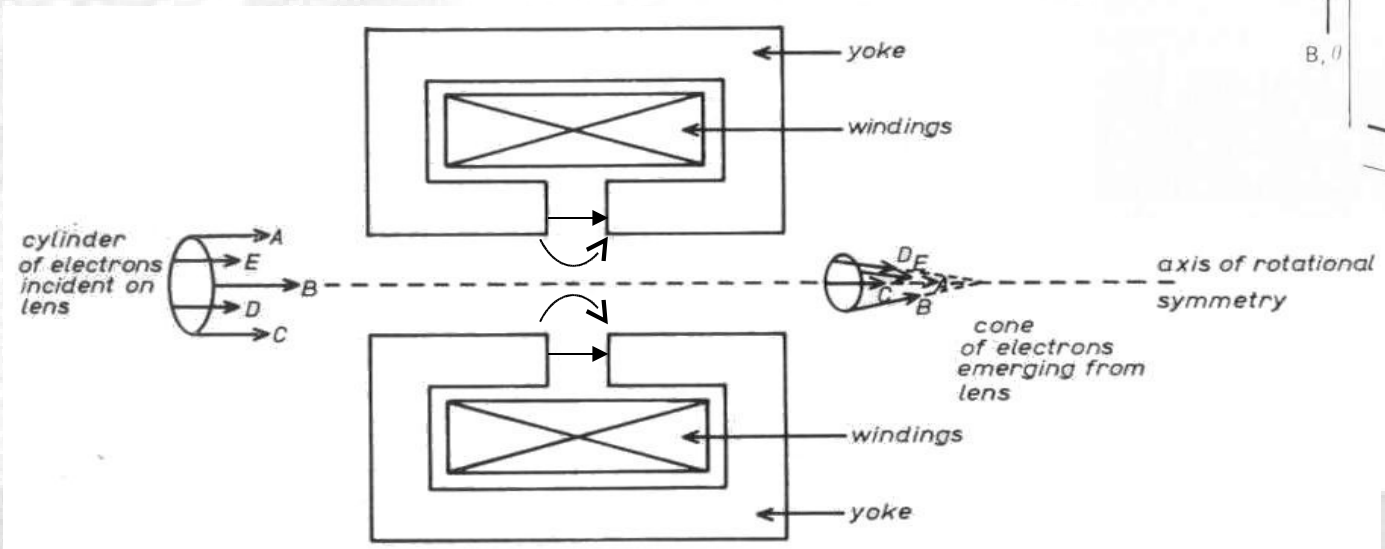
- Thermionic
  - Tungsten (2700 K)
  - LaB_6 (1800 K)
  - Large source-size, high energy spread
- Cold field-emission
  - Excellent performance
  - Re-adsorption on the tip causes noise
- TFE (Thermal field-emission)
  - High brightness
  - Small source-size
  - Low energy spread



Magnetic Lens

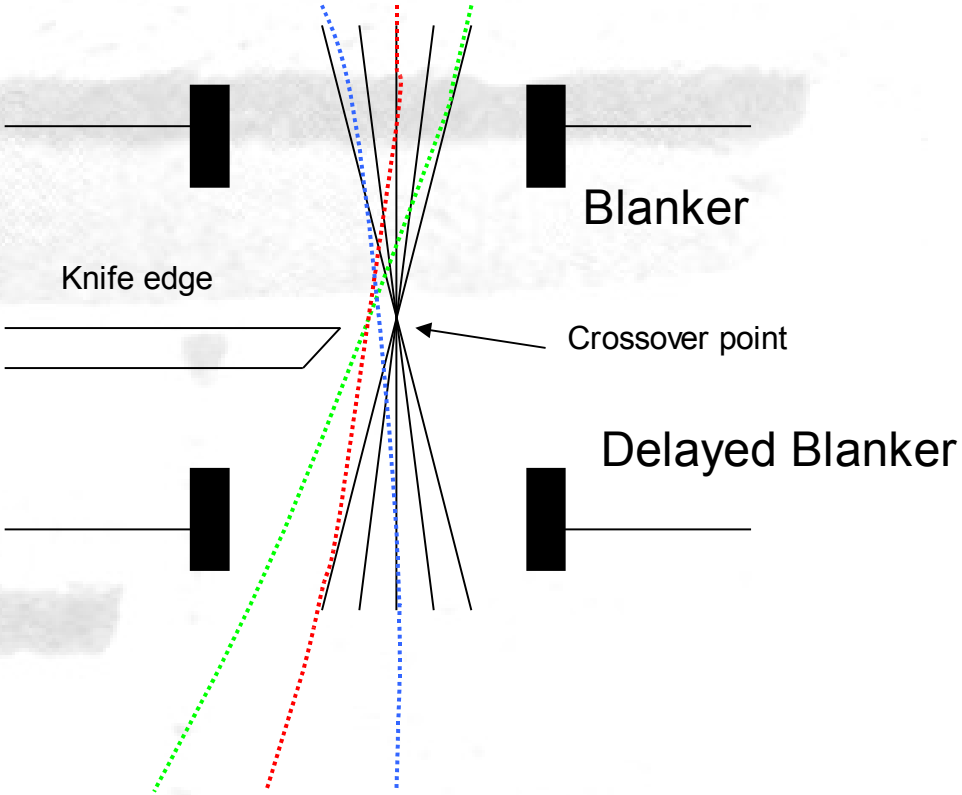
- Axial electron motion + radial B field rotates electrons
- Tangential electron motion + axial B field pulls electrons closer to axis
- Less aberrations than electrostatic lenses





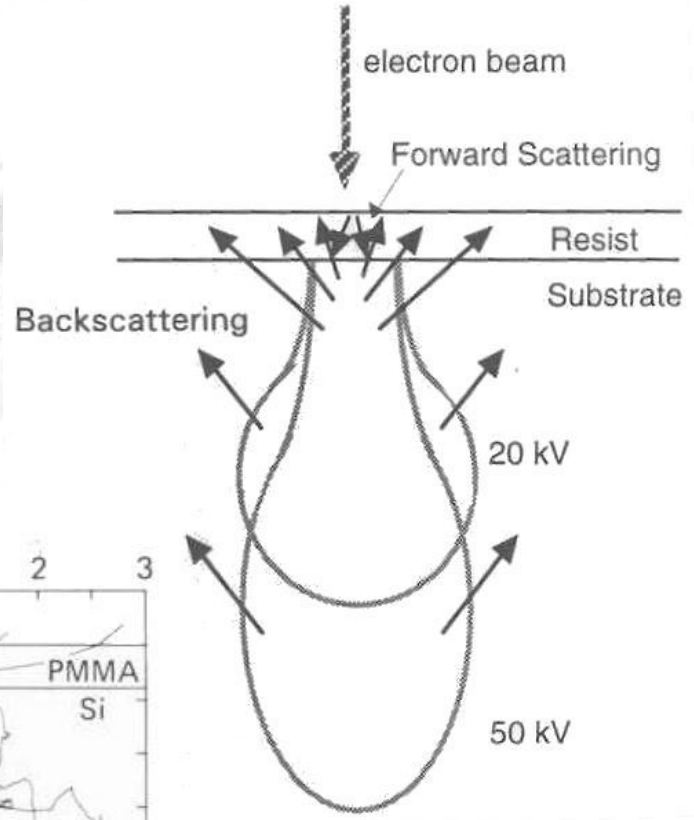
Other Electron Optics Components

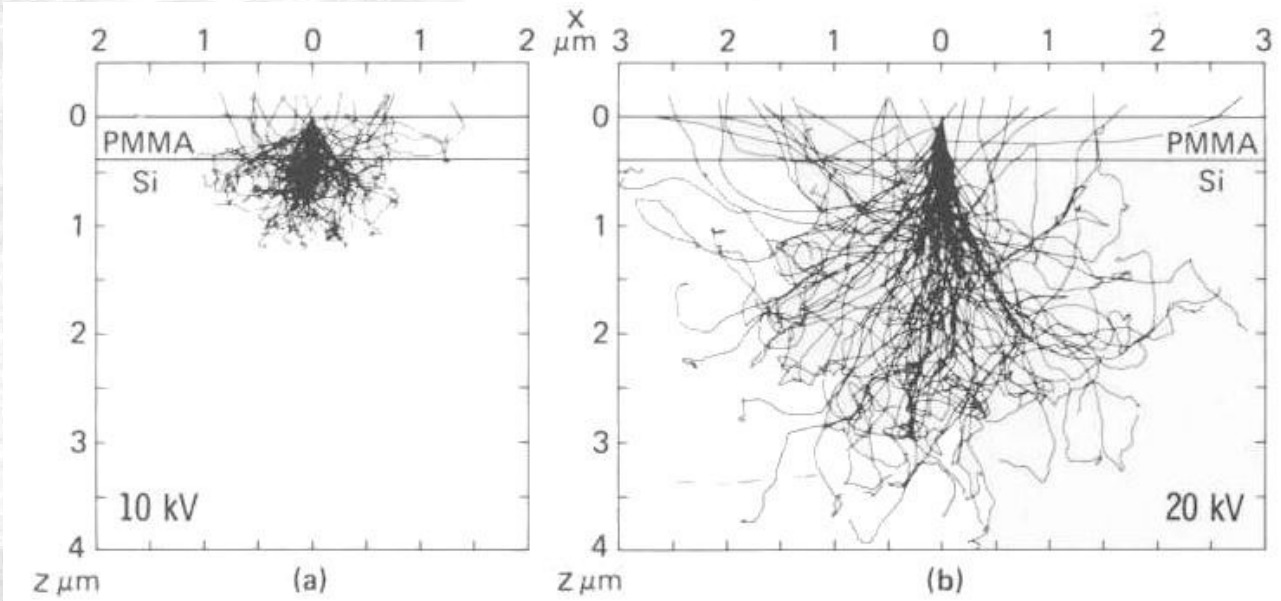
- Apertures
- Beam Blanker
  - Knife-edge system
- Stigmator
  - Corrects for astigmatism
- Beam Deflector
  - Magnetic



Electron Interactions

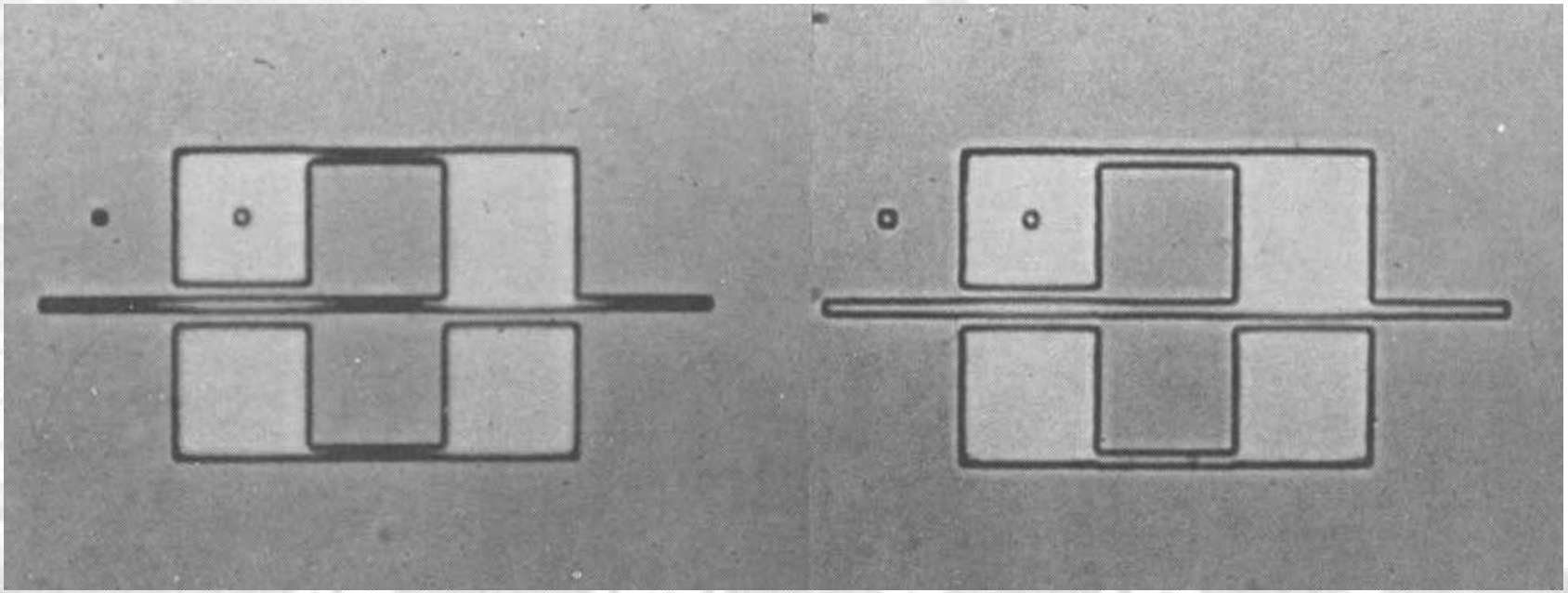
- Forward Scattering
  - Resolution limiting
- Backscattering
  - Proximity effect
- Secondary Electrons
  - Expose the resist
  - Resolution limiting





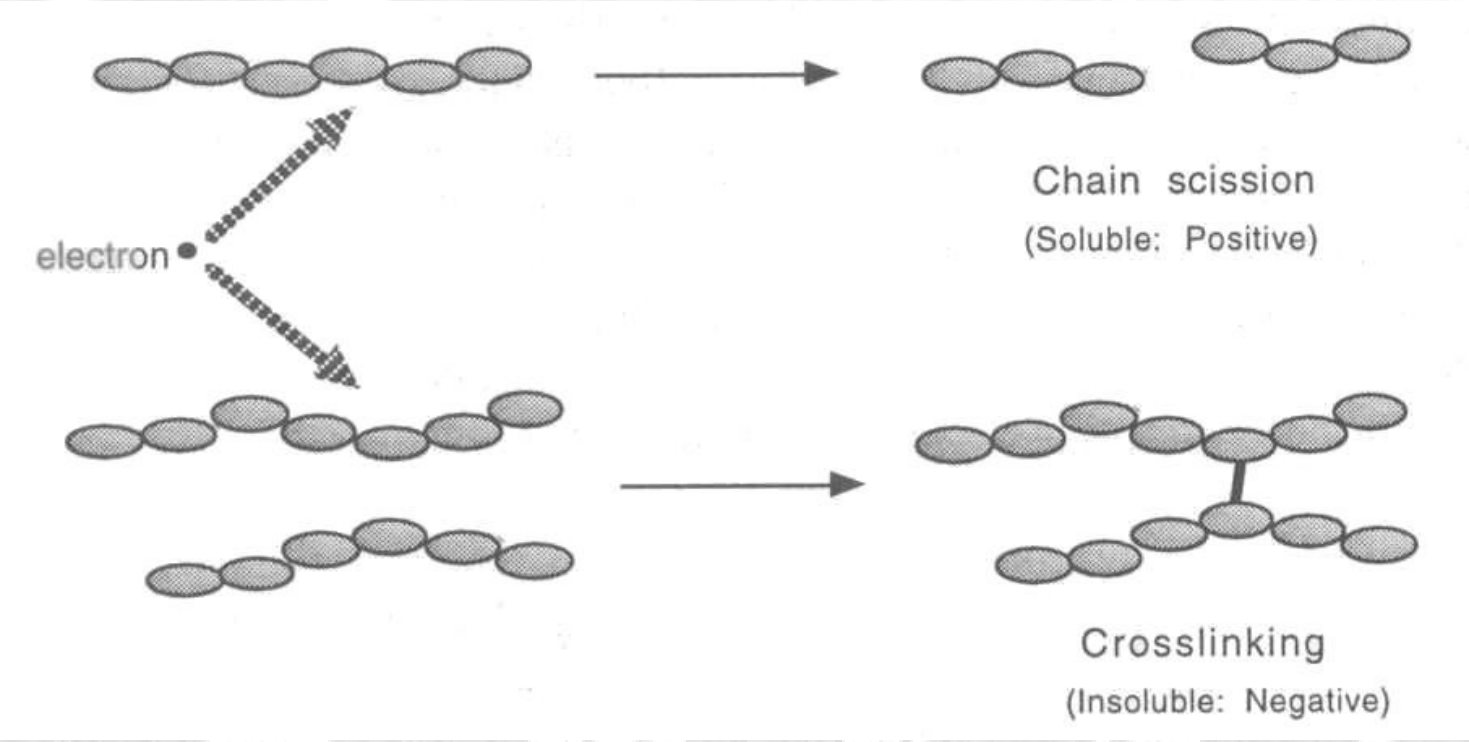
Proximity Effect

- Total exposure depends on a feature's "proximity" to other features
- Change processing to correct for it (lower beam energy, tweak dose)
- Many numerical techniques to correct for the proximity effect

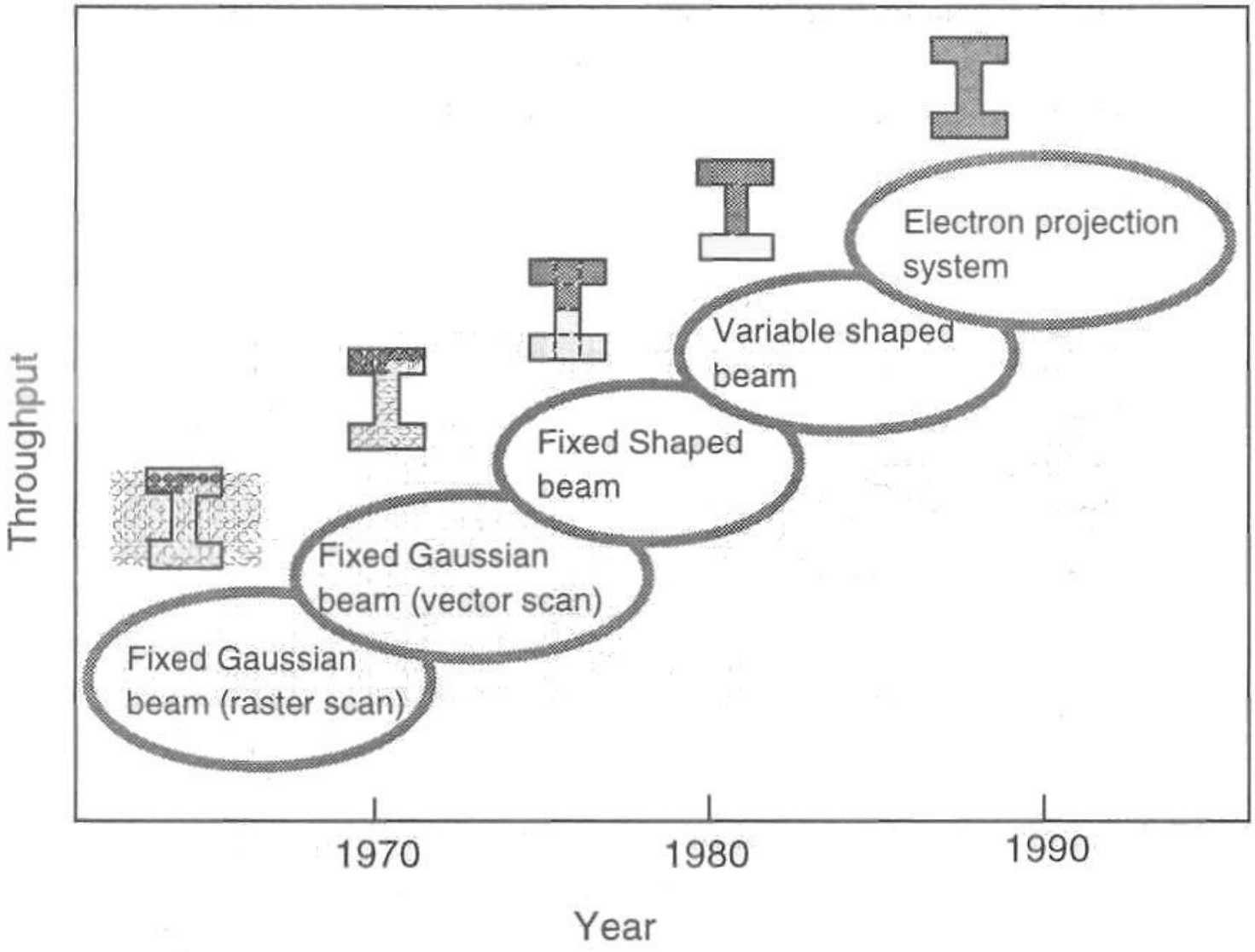


Resists

- Positive:
  - PMMA (10 nm resolution)
  - ZEP (10 nm resolution, 3 times more sensitive than PMMA)
- Negative
  - In general, worse resolution than positive resist

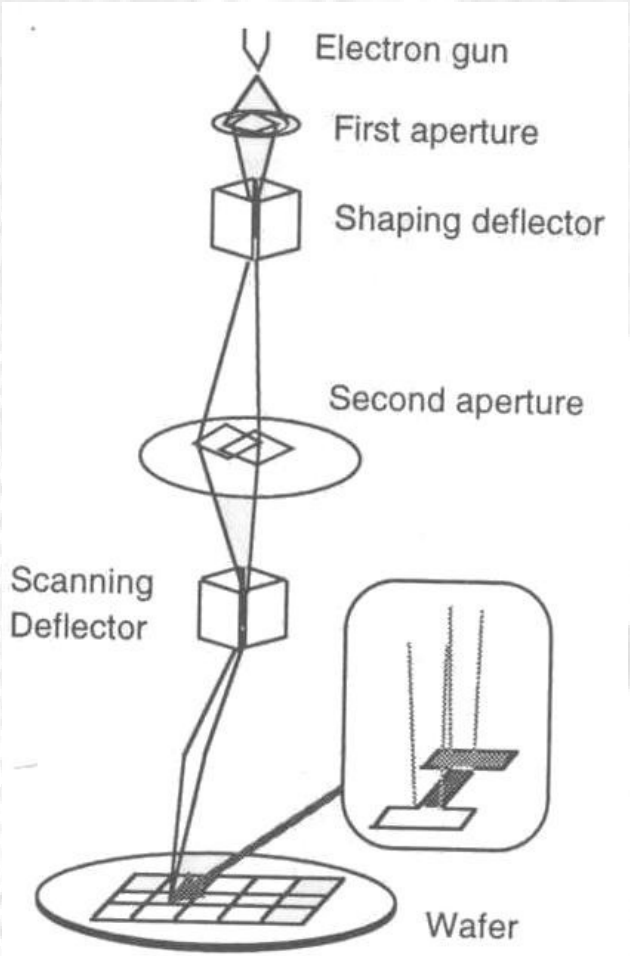


Systems

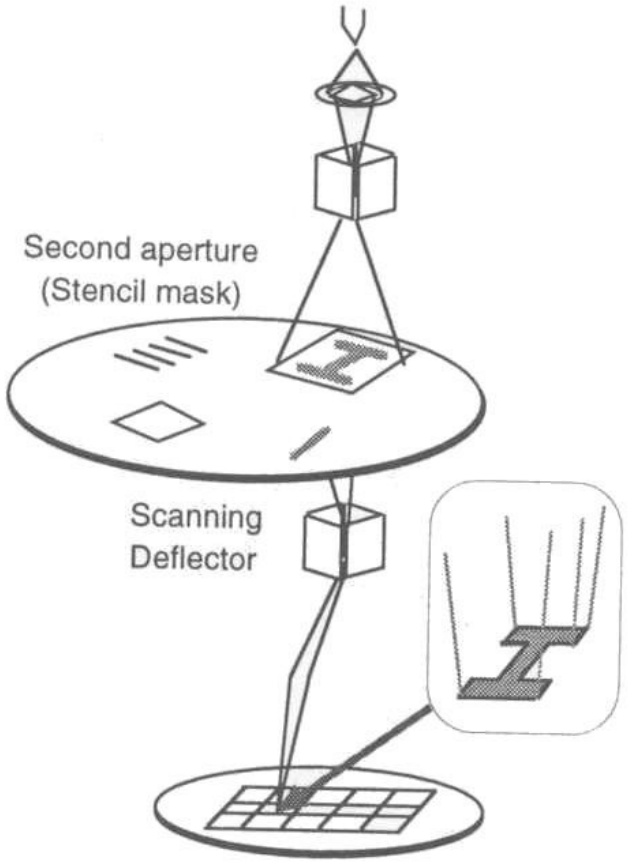

Throughput
Fixed Gaussian beam (raster scan)
Fixed Gaussian beam (vector scan)
Fixed Shaped beam
Variable shaped beam
Electron projection system
1970
1980
1990
Year

Systems

- Shaped Beam

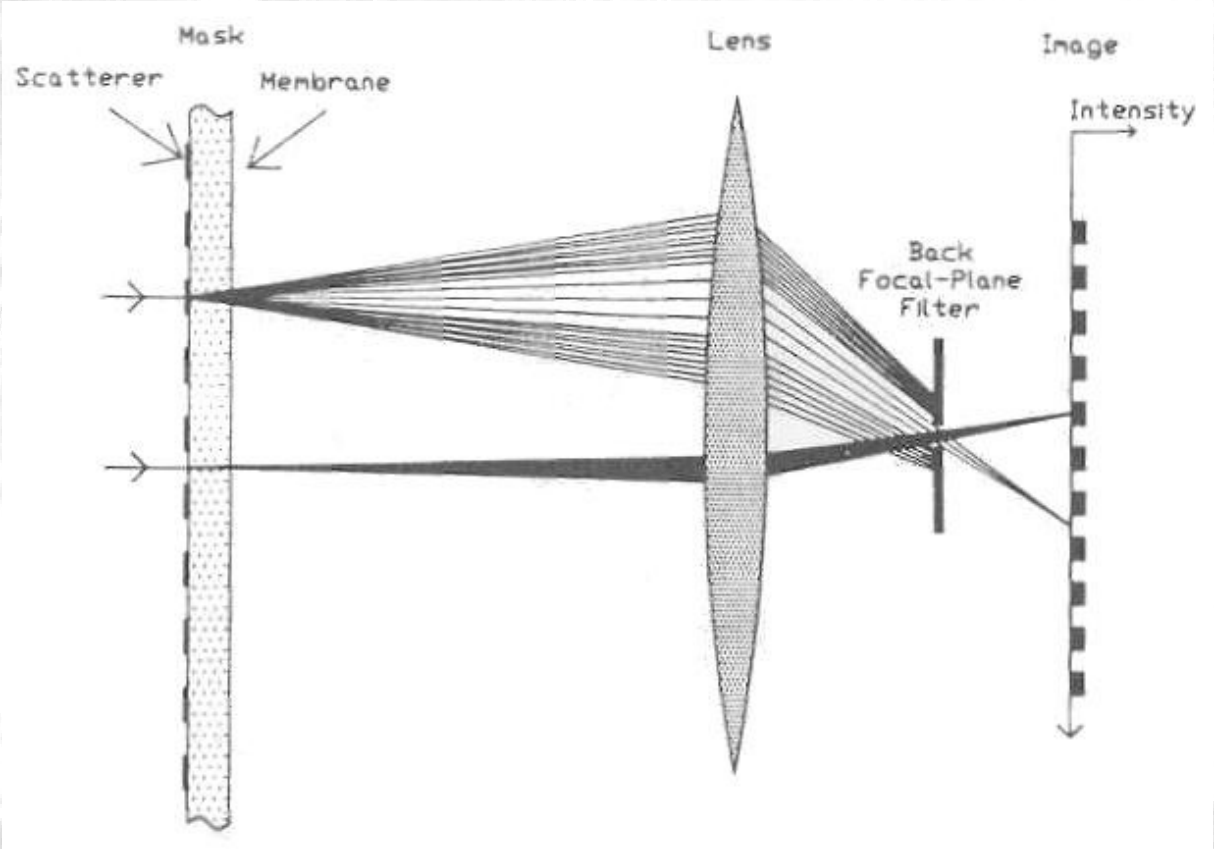


- Projection



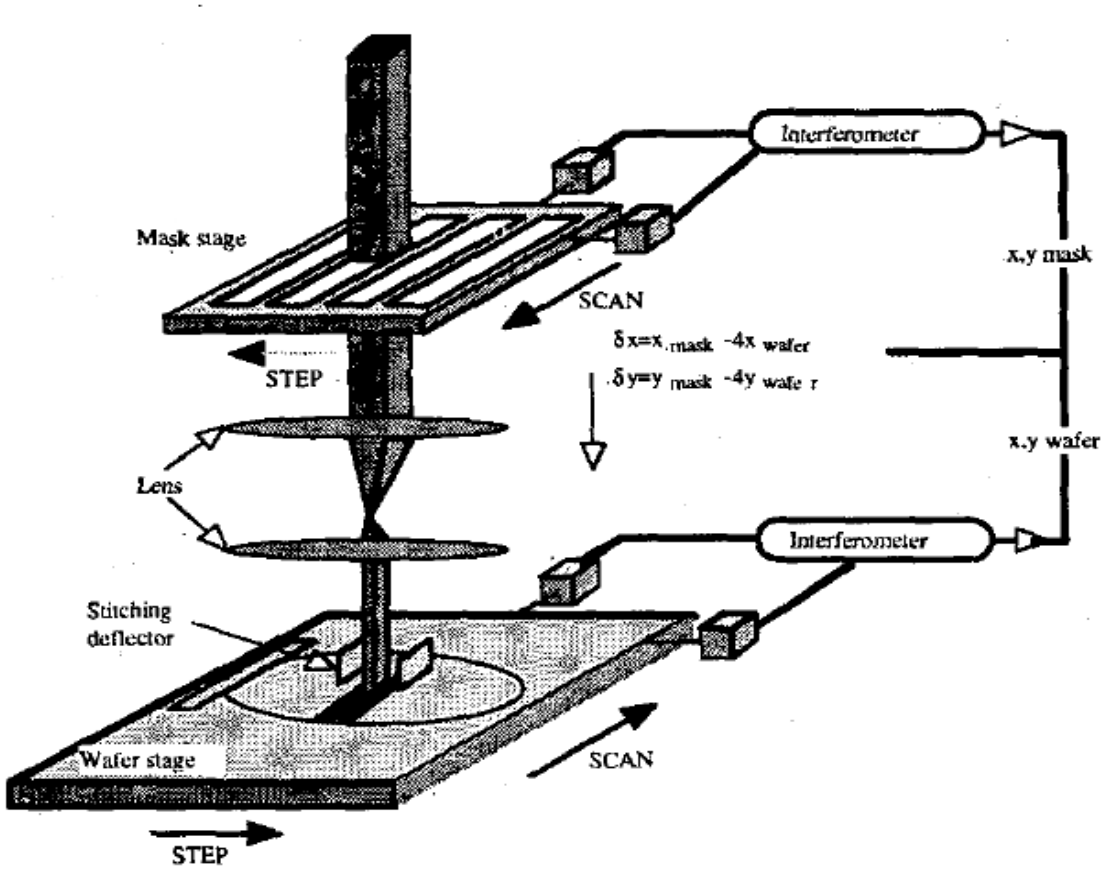
SCALPEL

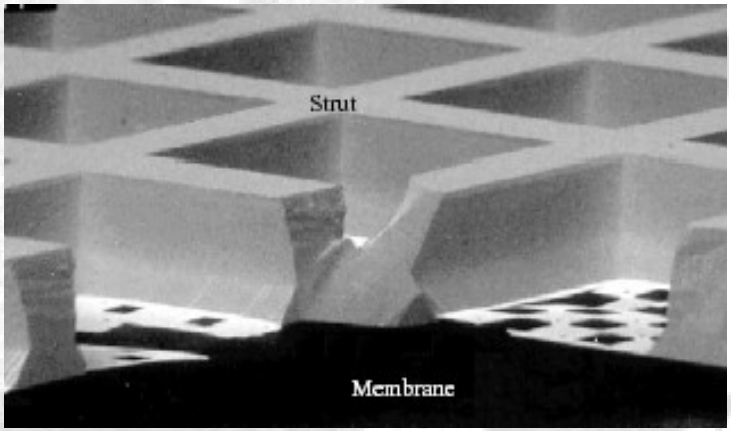
- An absorbing mask requires *20 μm* thick layer of silicon to absorb beam, so this limits the resolution of the mask.
- SCALPEL separates contrast generation and energy absorption between the mask and the aperture
- Thinner masks, higher resolution, no thermal effects
- Currently *80 nm* line widths, approx. *40 200 mm* wafers/hour



SCALPEL

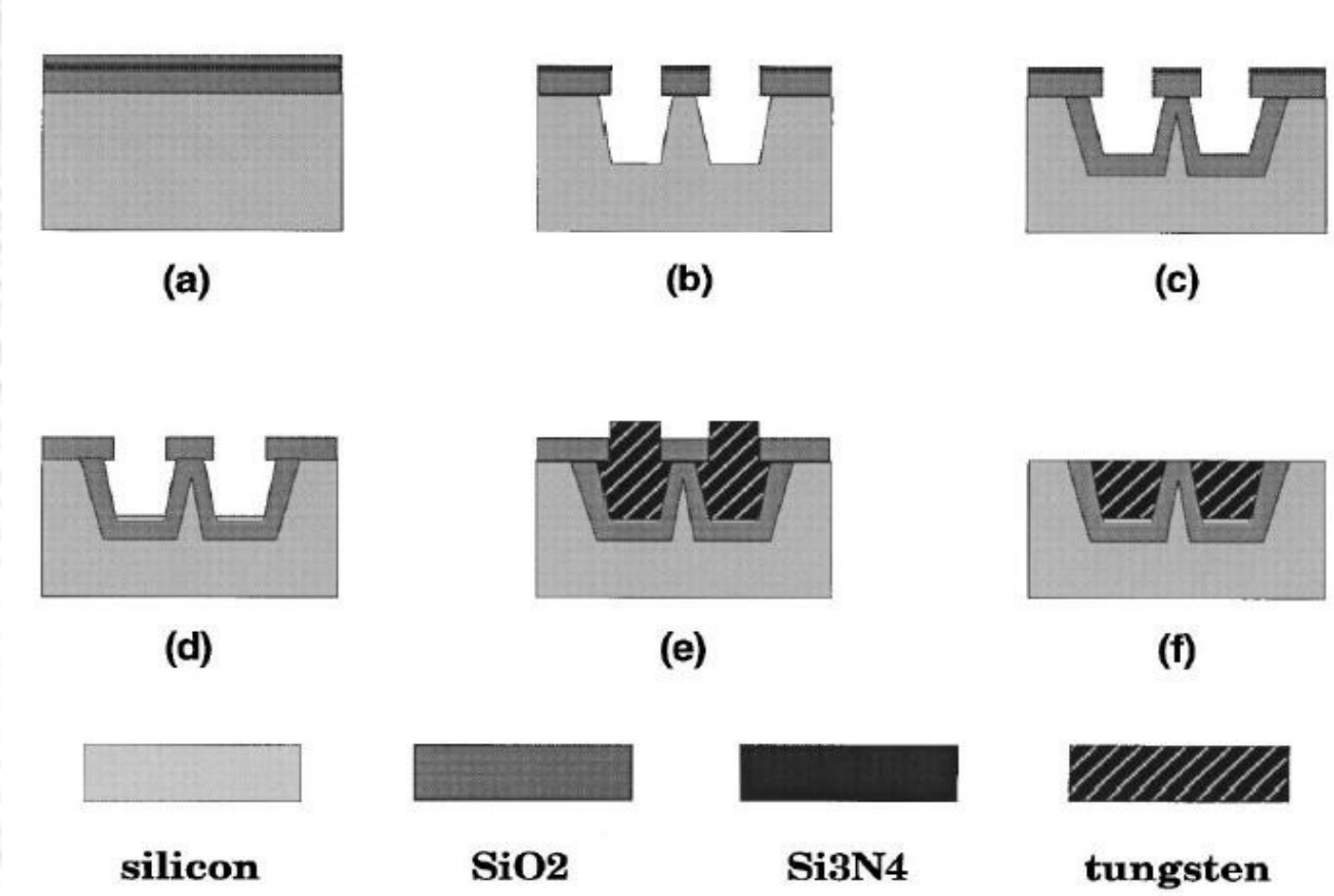
- Large parallel beam
- 4:1 reduction
- Table and wafer are scanned
- Thin mask supported by struts
- Final pattern is stitched together



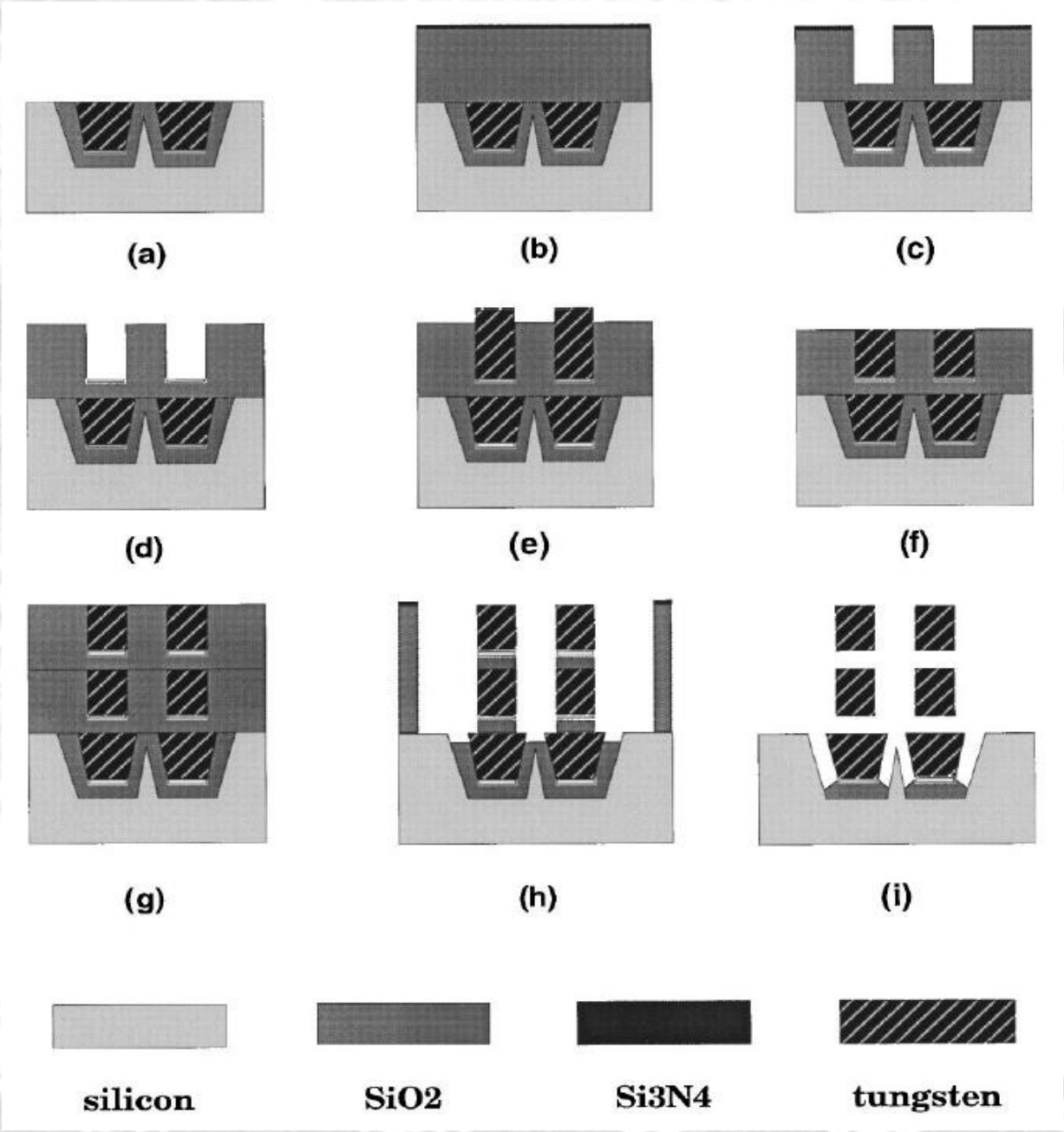


MEGA – Micro-machined Electron Gun Array

- Tip formation with self-aligned electrodes

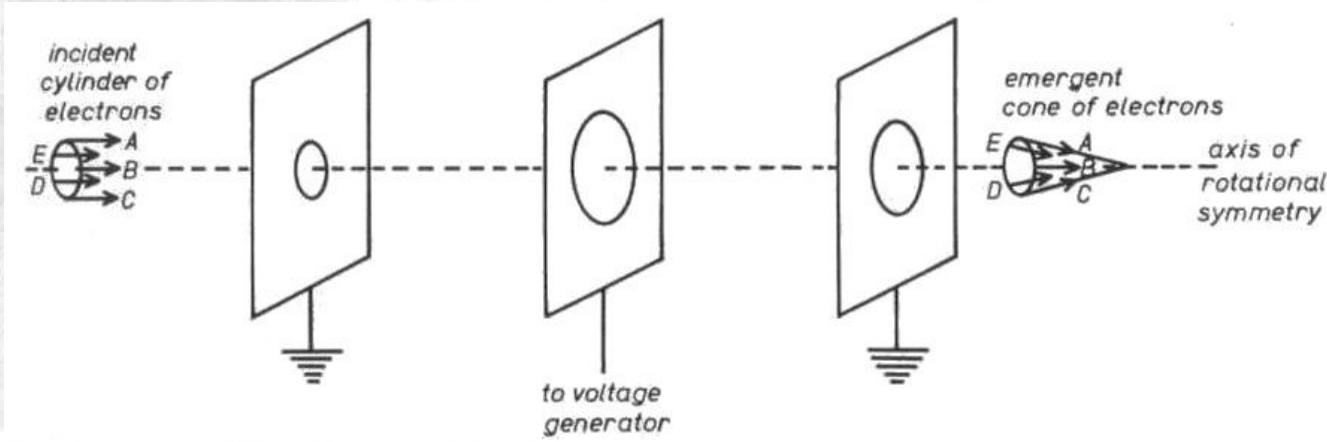


- Micro-lens formation

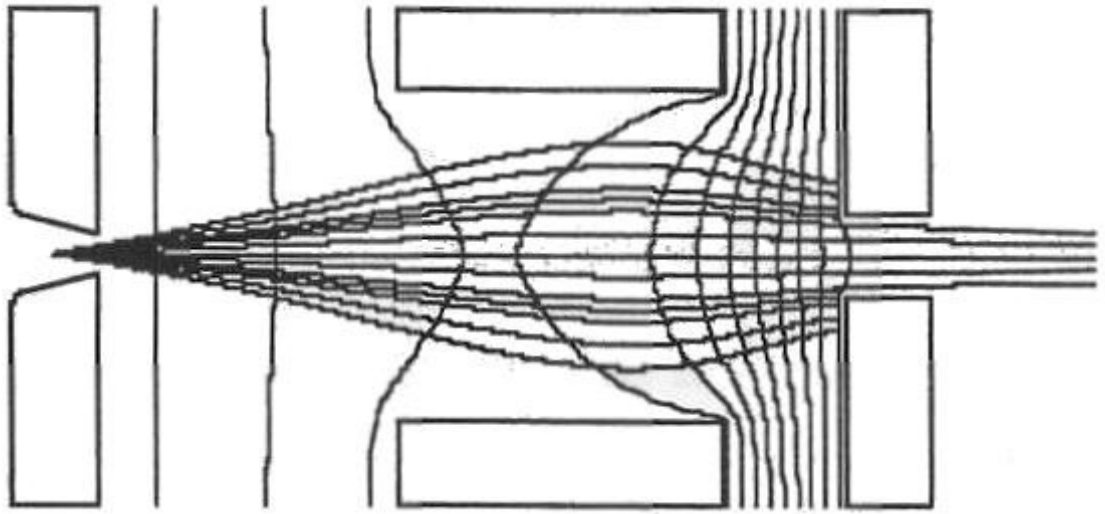


MEGA electrostatic micro-lens

- Circa 1965



- Not individually addressed
- 8.7 nm spot size
- Throughput of a similar system (SAFE) estimated to be 60 wafers/hour



Conclusion

- EBL will continue to be used for mask-making
- Useful for many applications where throughput is not an issue.
- EBL has a bright future, lots of new ideas for achieving higher throughput and better resolution (SCALPEL (Lucent), PREVAIL (IBM), MEMS arrays, etc.)
- Should be a strong candidate for lithography beyond 65 nm node.