Performance Issues in E-Beam Nanolithography

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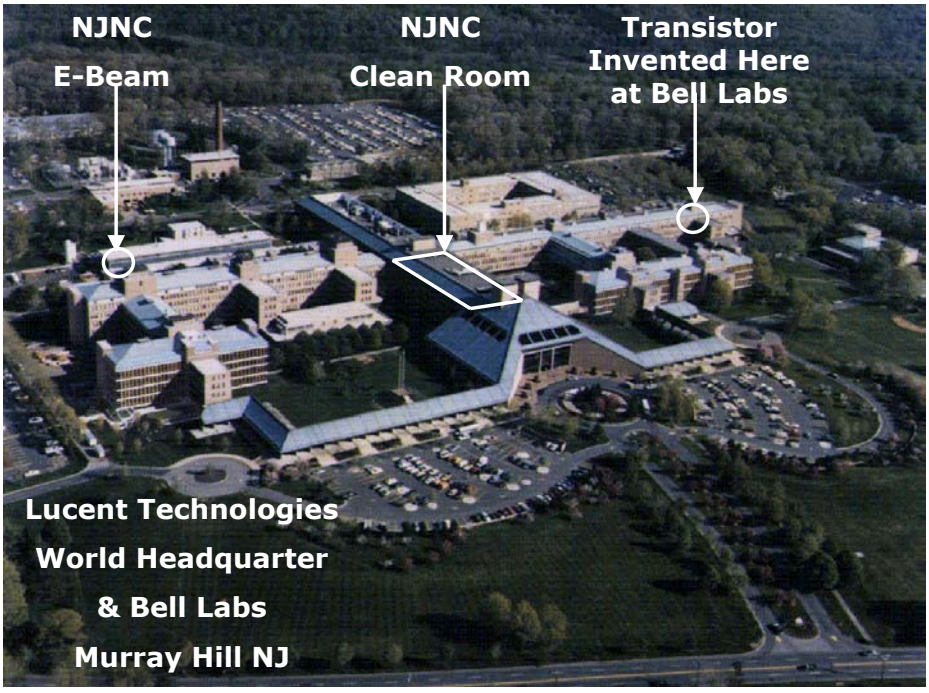

Performance Issues in E-Beam Nanolithography

Tool Performance: Want Resolution, Precision, Uniformity, Throughput

- Machine
  - Beam size, Stitching, Overlay, Deflection Speed , Current Density , etc.
- Physics
  - short range and long range effects

Resists:
- Pattern Collapse (especially CARs)
- Sources of granularity

Pattern Transfer:
- high aspect ratio pattern transfer
- Electroplating

Applications:
- X-ray optics (resolution, plating, high aspect etch)
- gratings for DWDM (precision)
  - ~ppm chirp in gratings?
- silicon MOSFETs subthreshold leakage (CD control)

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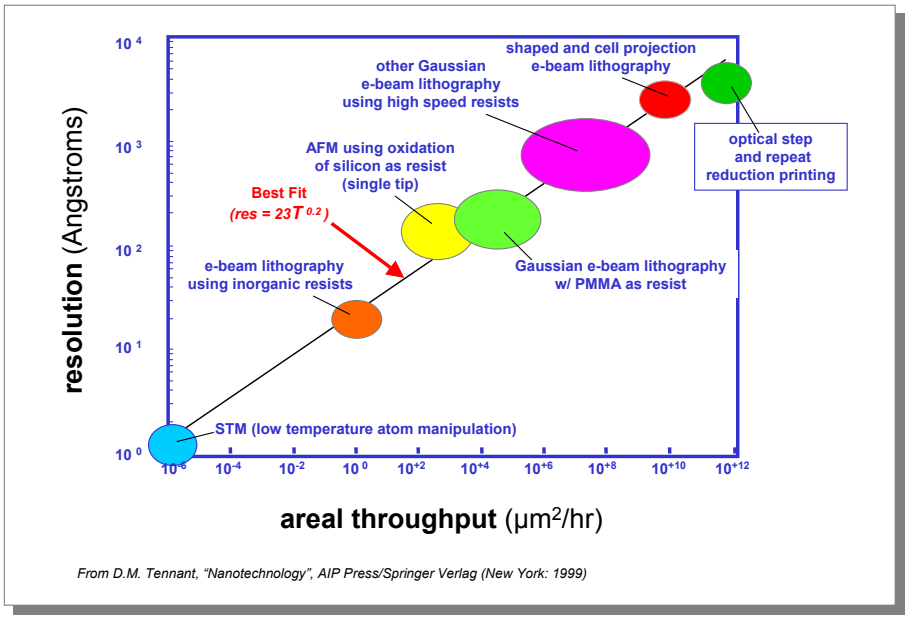
Overview of Lithography: Resolution and Throughput



From D.M. Tennant, "Nanotechnology", AIP Press/Springer Verlag (New York: 1999)

JBX 9300FS Electron Beam Lithography Facility

- ***100kV operating voltage***
- ***25 MHz Deflection Rate***
  (50 MHz, 2Q '03)
- ***1 nm address grid***
- ***4 nm minimum spot***
- ***Multiple substrate capability***
  - *Wafers: 2",3",4",5",6",8"*
  - *Mask plates: 4",5",6"*
  - *Small piece holder*
  - *300mm Upgradeable*

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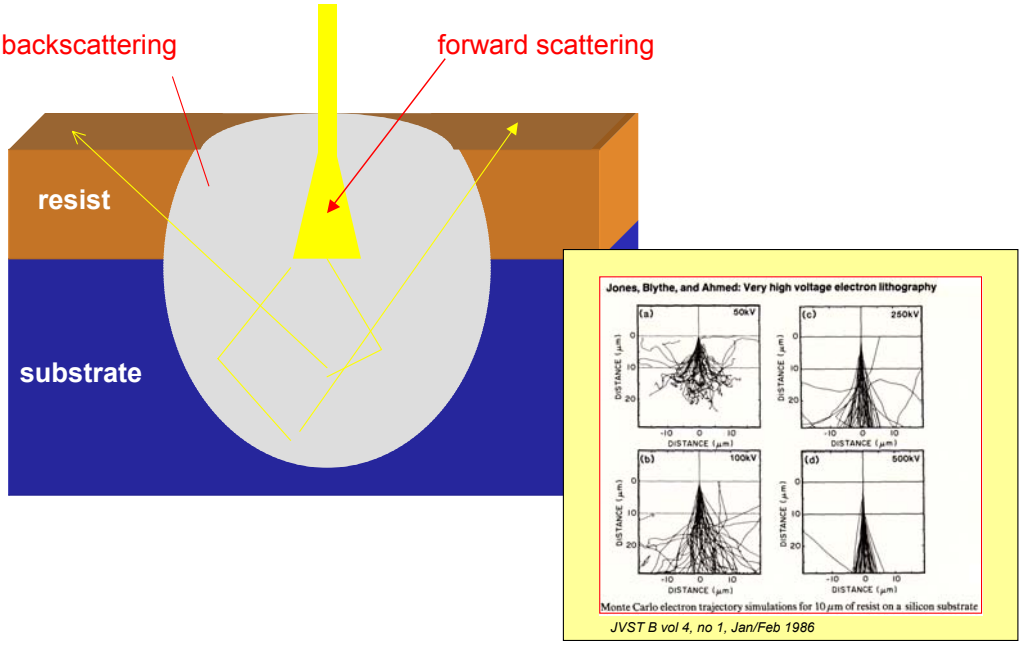
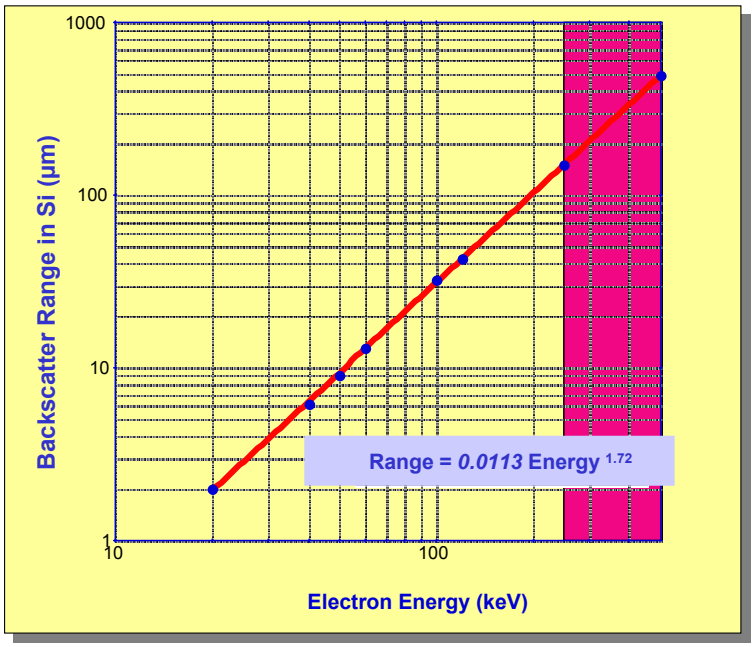
limits of e-beam lithography: scattering effects



JVST B vol 4, no 1, Jan/Feb 1986

limits of e-beam lithography: Backscatter Range in Silicon



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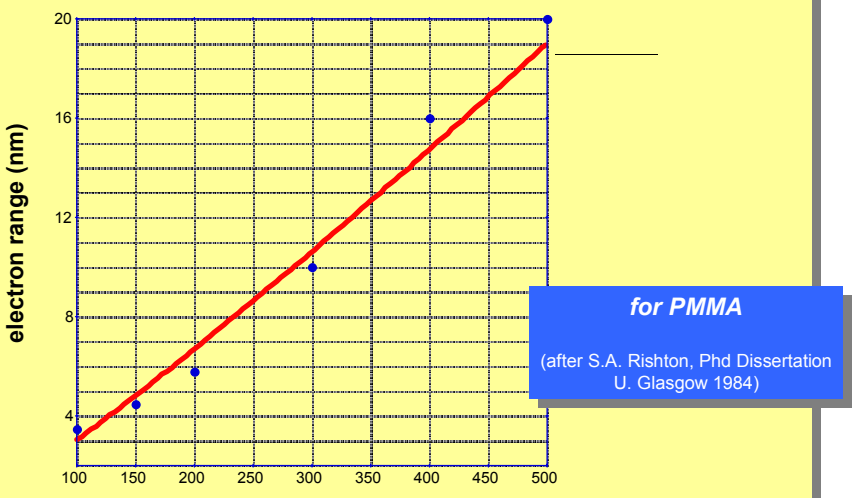
Secondary Electron Range in Resist (experimental)



High Voltage e-Beam Lithography

TABLE I. Linewidths of latent image from equienergy density contours.

500 Å Film

E′ (eV/coul-cm²)	W (Å) 25 keV	50 keV	75 keV	100 keV
1 x 10^{31}	80	40	40	40
1 x 10^{30}	300	200	100	80
5 x 10^{29}	500	300	250	200
2 x 10^{29}	900	600	550	500

1000 Å Film

E′ (eV/coul-cm²)	W (Å) 25 keV	50 keV	75 keV	100 keV
1 x 10^{31}	200	40	40	40
1 x 10^{30}	400	300	150	100
5 x 10^{29}	700	400	300	250
2 x 10^{29}	1200	800	600	550

Kyser

J. Vac. Sci. Technol. B, Vol. 1, No. 4, Oct.–Dec. 1983

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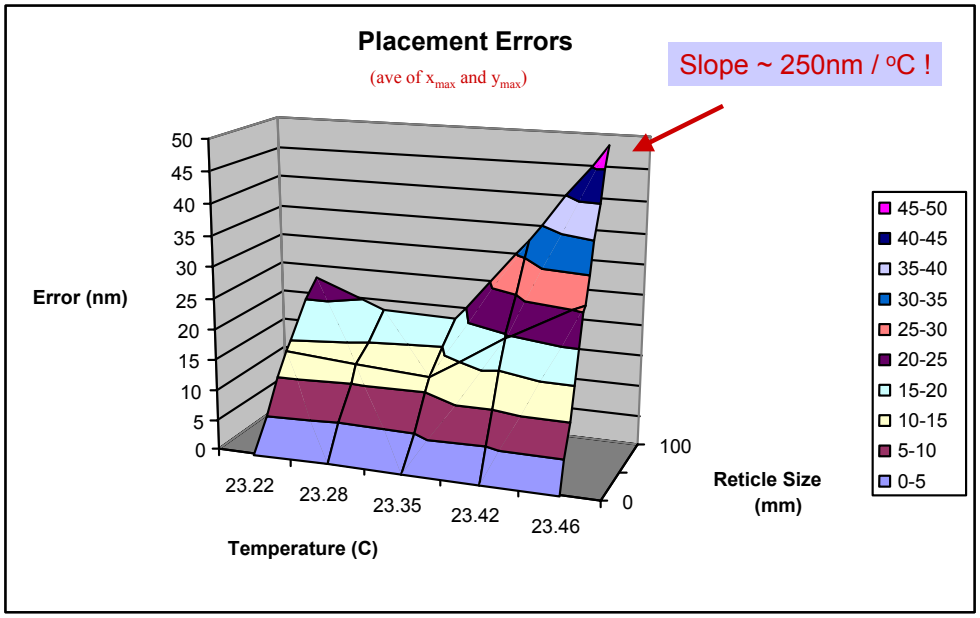
Performance Summary

Acc Voltage	100 kV +/- 2ppm
Minimum Beam Size	4.0 nm
Linewidth Uniformity (in 1 field)	Xmin = 100 nm; Xmax = 106 nm Ymin = 104 nm; Ymax = 110 nm
Position Accuracy within Field	-0.007µm, +0.006µm
Mask Write: Field Stiching Accuracy	-0.010µm, +0.013µm
Direct Write: Field Stitching Accuracy	-0.021µm, +0.024µm
Overlay Alignment Accuracy	-0.013µm, +0.012µm
Placement Accuracy: 50 mm Mask Area	-0.011µm, +0.016µm
Placement Accuracy: 100 mm Mask Area	-0.030µm, +0.026µm

Temperature Optimization of Pattern Placement



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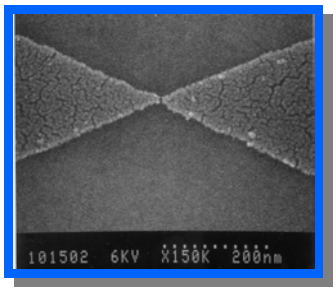
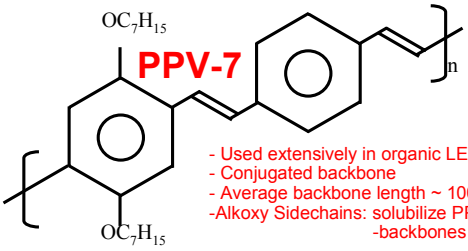
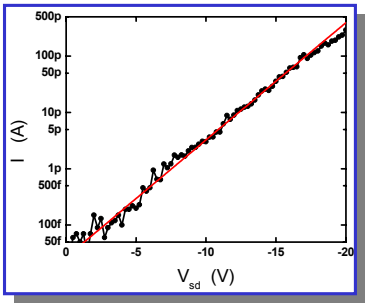
Molecular Scale Metal Probes: **Tools for Transport Measurements 0f Organic Conductors**





- Used extensively in organic LEDs
- Conjugated backbone
- Average backbone length ~ 100nm (50 – 130 nm)
-Alkoxy Sidechains: solubilize PPV and Insulate -backbones and prevent stacking



Studied

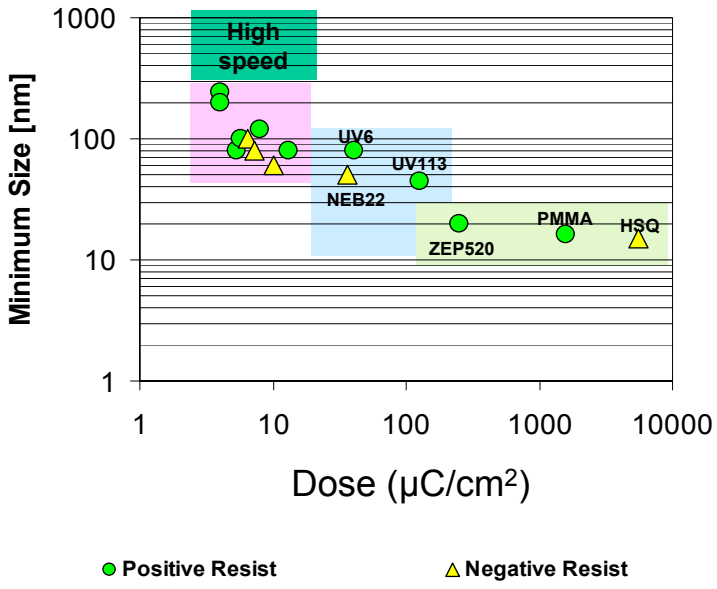
- **Fabricated transistor structure with electrode spacing from 50 nm to 2 um**
- **Explored both rectangular(for well defined E field) and triangular (for spatial confinement) electrode geometry**

Results

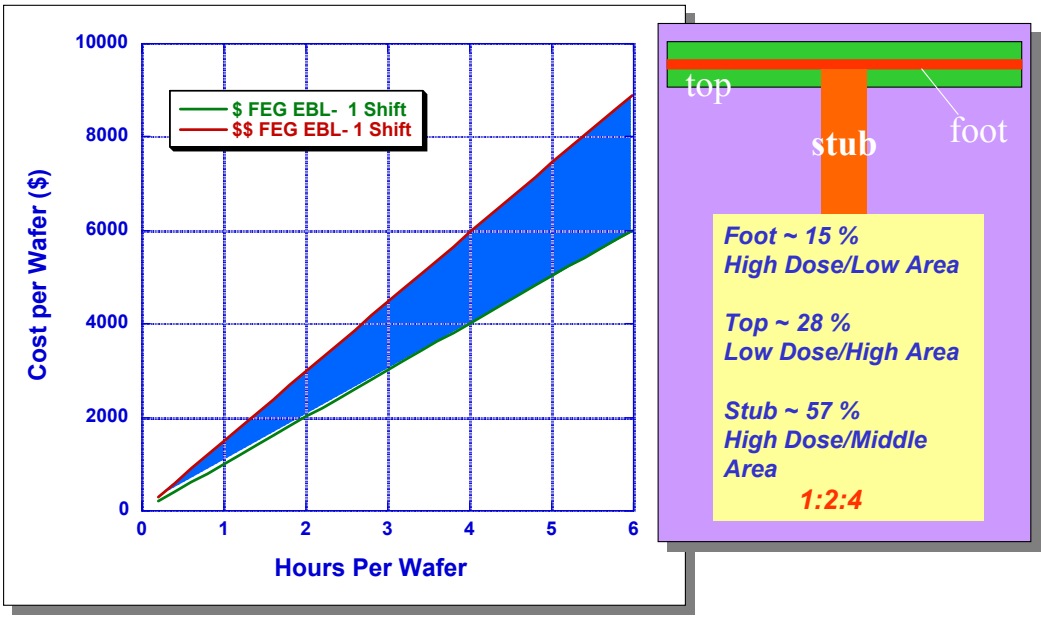
- **In rectangular geometry PPV-7 found to have current exponential in electric field (see I-V at left)**
- **Current likely through series of barriers**
- **Unconventional FET has mobility exponential in field**
- **May indicate current dominated by intrachain transport**
- **Some triangular electrodes show large currents->Transport may be dominated by small number of chains of polymer**

D. Abusch-Magder, D.Tennant, T. Someya, J. Wang, E. Laskowski, A. Dodabalapur, Z. Bao, Lucent Technologies

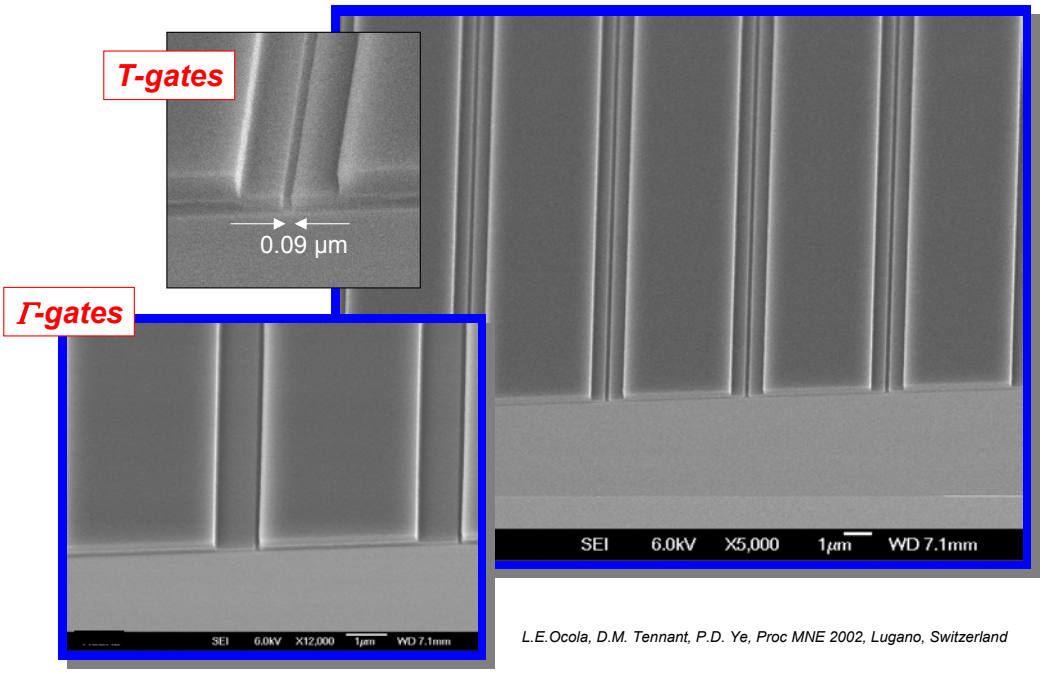
E-beam resist sensitivity vs. resolution (100 kV)



T-gate Cost Depends on E-beam Throughput

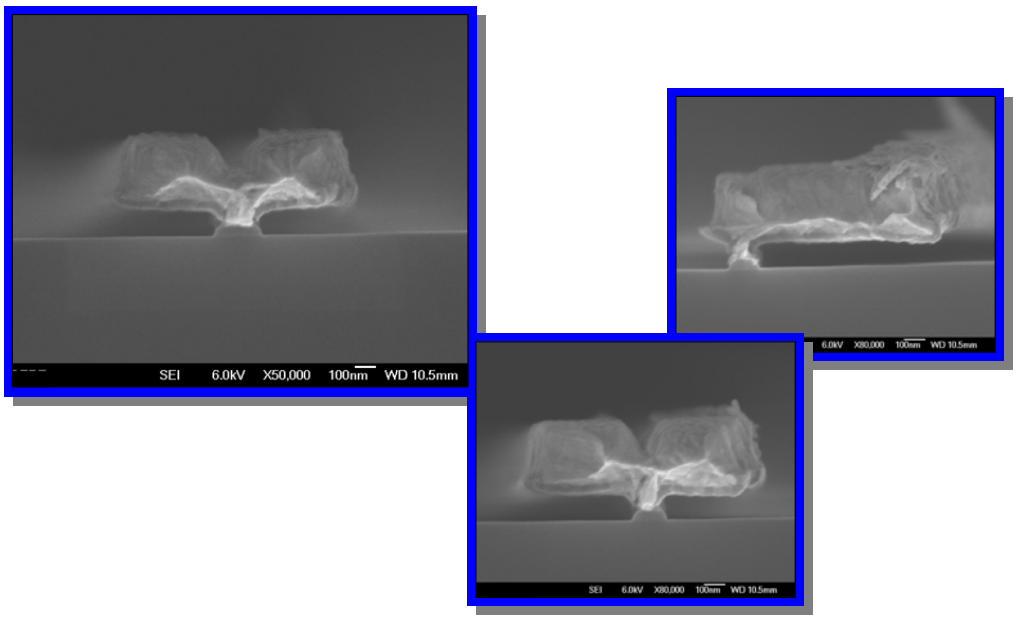


BiLayer : O_2 Plasma Step Added



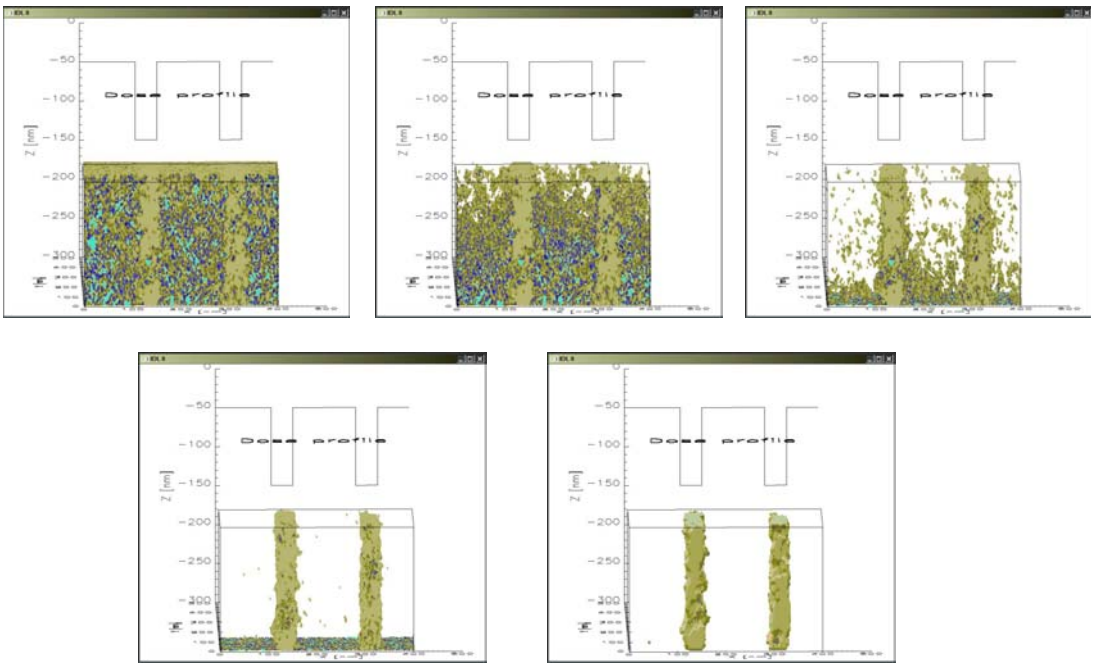
L.E.Ocola, D.M. Tennant, P.D. Ye, Proc MNE 2002, Lugano, Switzerland

Metallization and liftoff : T-gates

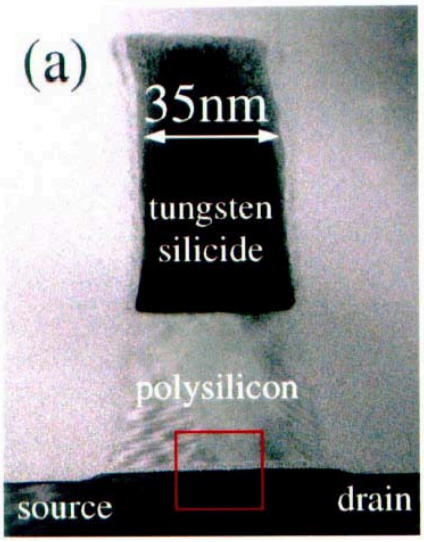


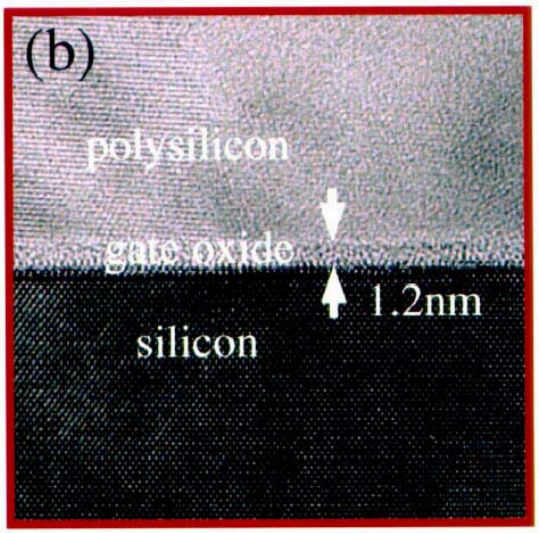
L.E.Ocola, D.M. Tennant, P.D. Ye, Proc MNE 2002, Lugano, Switzerland

Image formation model: 45 nm isolated lines
(negative resist)



The Ballistic Nano-transistor

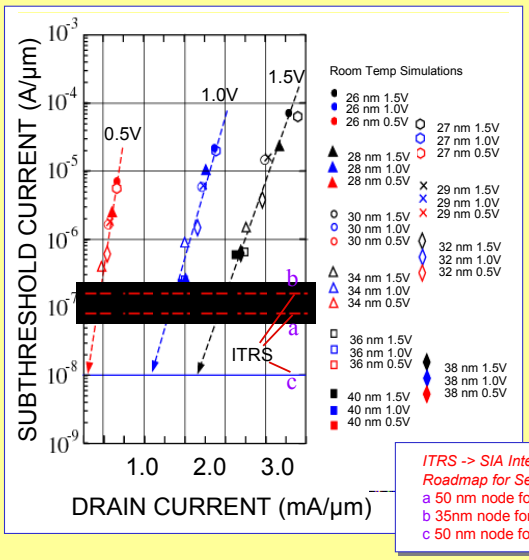




G. Timp et al, IEDM 1999

Subthreshold Leakage for nMOS , Lg= 40 - 26nm

(calculated w/ PADRE)



ITRS -> SIA International Technology Roadmap for Semiconductors
a 50 nm node for microprocessors
b 35nm node for microprocessors
c 50 nm node for memory

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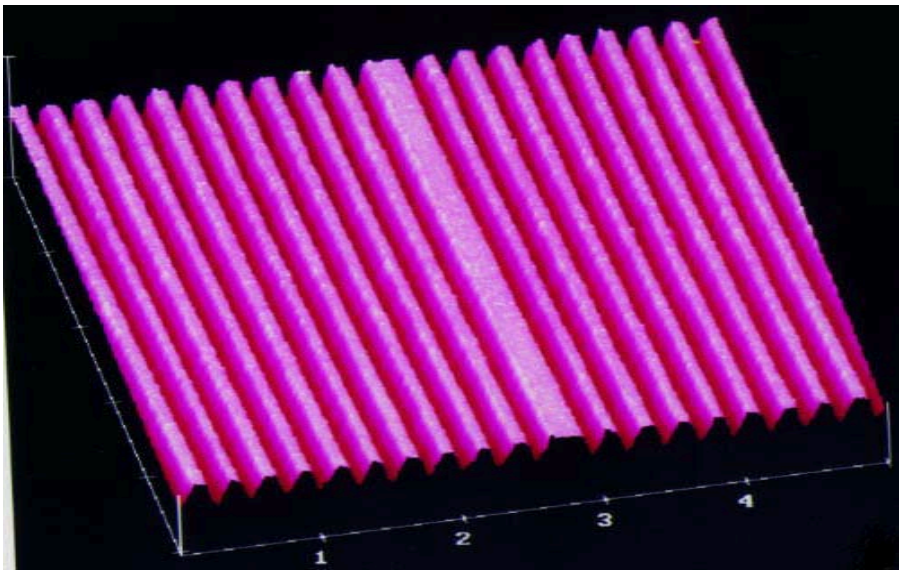
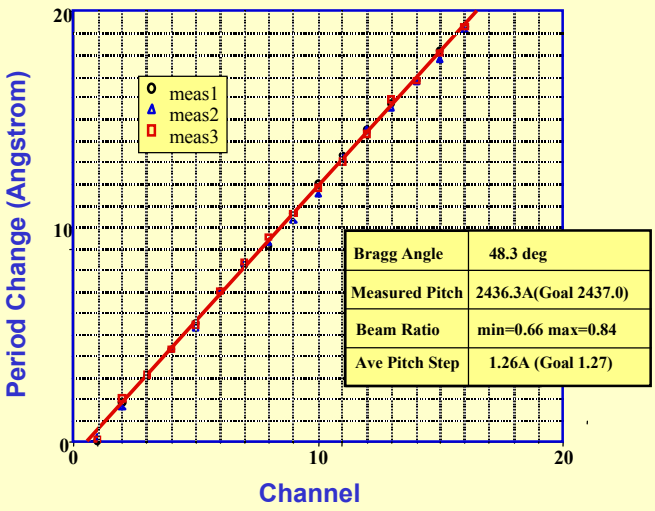
Precision Photonic Gratings
For Communications Lasers and Filter Components

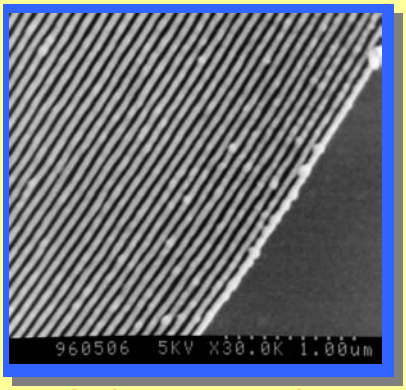


DWDM: 16 Period Phase Grating Mask



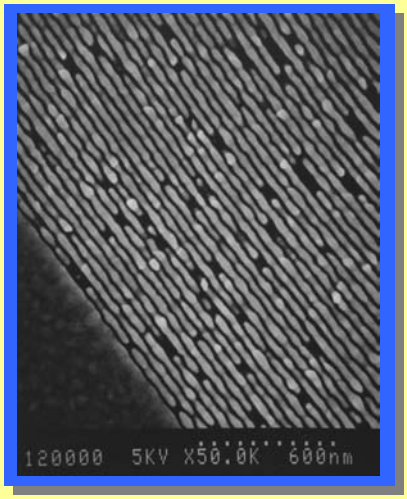
Nickel STXM zone plates

40 nm zones in 110 nm Ni



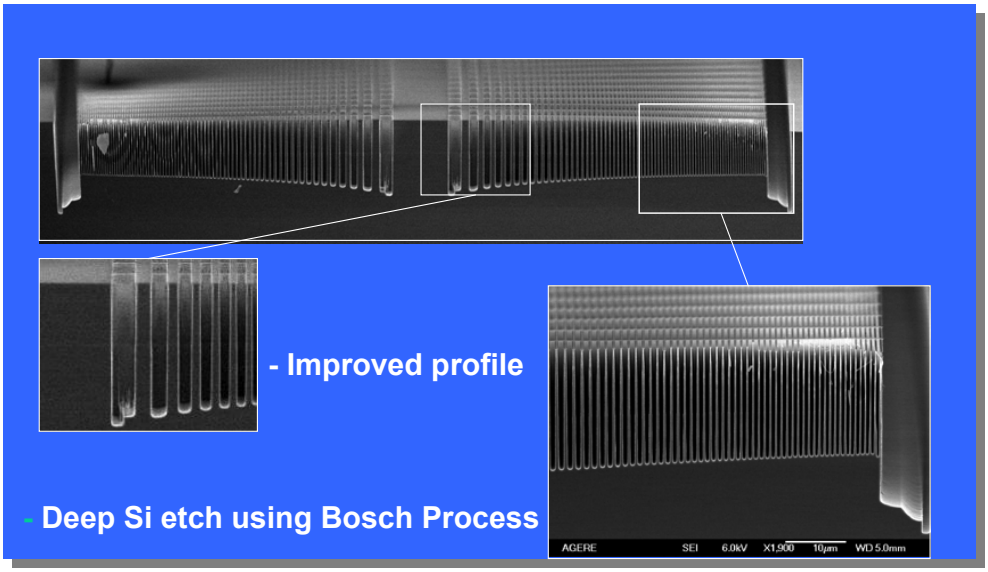
(Calixarene resist)

20 nm zones in 60 nm Ni



Diffraction efficiencies measured at *400 eV*:
30 nm wide, 110 nm thick zones: 10%
45 nm wide, 180 nm thick zones: 18%

Bragg Fresnel Zone plate for Hard X-rays (7- 16 keV)



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Challenges for Nanolithograpy

Litho tools:
- o ***Vendors***: -> improve throughput
  less environment sensitivity
- o ***Fabrication***: alignment methods for organic layers

Resists:
- o ***Pattern Collapse*** (especially CARs)
- o ***Finer granularity*** to reduce LER

Pattern Transfer:
- o Control/ engineer ***stress*** in films
- o Broaden range of materials accessible to ***high aspect ratio etching***
- o ***Electroplating*** in high aspect ratio trenches below 20 nm

Applications:
- o ***ppm chirp*** in optoelectronic gratings (vendors and researchers)
- o in silicon mosfets determine the relative role of ler vs. doping for subthreshold leakage