Semiconductor Processing: Lithography Part I

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Planar Processing with Semiconductors (Silicon): Course Map







- Crystal growth (semiconductors)
- Wafer doping (in situ)
- Wafer characteristics
- SiO₂ growth*
- Defects and impurities

- SiO₂ growth*
- LITHOGRAPHY
- Masked diffusion doping
- Vacuum Systems
- Thin Films: CVD, MBE, PVD, ALD
- Implantation
- Wet and Dry Etching
- Integration

Lithography

How do we make the n doped regions in channel?







(Gatan, 2003)

How do we generate masked areas and doping windows for diffusion doping?

How do we generate patterned oxides, wires, contact pads, waveguides, mechanical resonators, microfluidic channels of a micro- or nanodevice?

Transfer pattern using a stencil or a mask



(Banksy, West Bank)

Transfer pattern using a stencil or a mask



Use light and patterned semitransparent mask to transfer patterns to radiation sensitive material





An example that uses negative and positive resists

Negative









An example that uses negative and positive resists



Shadow Printing: Diffraction through a single slit



Shadow printing resolution determined by gap L and wavelength λ

Mask Aligner



Projecting Steppers

Non-reducing

Reducing (5:1-10:1) $10 \ \mu m \rightarrow 1 \ \mu m$





Single Wafer Stepper



(UCSB)

Cassette Stepper



(UCSB)

Cleanrooms are important for lithography





Diffraction affects pattern transfer

Diffraction through a single slit



$$W = \frac{2L\lambda}{b}$$

Diffraction through a rectangular slit





(b)





Diffraction through a circular slit (Airy Disk)



Rayleigh's Criterion



Resolution and Depth-of-focus of an optical system



DOF is a measure of distance over which image formed by lens will remain in focus

Sources of light: Spectrum of Tungsten-Halogen Lamp



Figure 2-11 Spectral irradiance from a 100-W quartz halogen lamp, providing continuous radiation from 0.3 to 2.5 μ m. (Oriel Corp., General Catalogue, Stratford, Conn.)

Sources of light: Spectrum of Mercury-Xenon Lamp



Figure 2-14 Spectral emission for Hg-Xe arc lamp. (Canrad-Hanovia, Inc.)

SEMs have μm DOF and nm resolution



Large part of image in focus. Large DOF and small l_m

The challenges of registration illustrated by the 7 nm transistor







An example of registration in e-beam lithography



An example of registration in e-beam lithography





Phase Shifting



Optical Proximity Correction (OPC)

Mask



Wafer



Electron-beam lithography



An example of electron-beam lithography

500	450	400	350	300	280	260	240	220	200	180	160	140	120
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Simulating proximity effect with CASINO

monte CArlo SImulation of electroN trajectory in sOlids

300 nm PMMA, Si Substrate 10 nm beam diameter

10 keV

100 keV



The proximity effect limits e-beam resolution



Extrem UV (100 eV) lithography



Double Patterning



Roadmap

180 nm	130 nm	90 nm	86 nm	45 nm	32 nm	22 nm	15 nm		
KiF + OPC	KrF + OPC + RET	ArF + OPC + RET	ArF + emmersion + OPC + RET	ArF + immersion + OPC + strong RET	45 nm + DP	45 nm + DP + restricted layout	45 nm + MP		
KIF + OPC	KrF + OPC + RET	Increasing cost barrier							
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wikipedia

Photoresist Materials

Exposure-Response Curves of Photoresist

Sensitivity
$$\propto \frac{1}{D_0}$$
 $\gamma = \frac{1}{\log \frac{D_{100}}{D_0}}$

An example of calculating γ



Exposure-Response Curves of Photoresist: Sensitivity and Contrast

Sensitivity

Contrast

Resist contrast determines resolution, sidewall angle and line width (minimum feature size)



SU-8 is a negative tone resist with high contrast





10 um features, 50 um SU-8 2000 coating

Critical resist Modulation Transfer Function (CMTF) and the Modulation Transfer Function (MTF)

$$CMTF = \frac{D_{100} - D_0}{D_{100} + D_0} = \frac{10^{1/\gamma} - 1}{10^{1/\gamma} + 1}$$

$$MTF = \frac{M_{image}}{M_{mask}} \longrightarrow M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

$$MTF = M_{image} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

No image is formed if CMTF > MTF.

Modulation Transfer Function



Mask

Image

SU-8 Thickness vs. spin-speed curve



Microchem