CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

Lecture 61
Electron Beam Lithography, part 1

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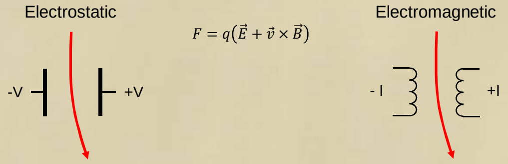
de Broglie Wavelength

- Particles have a wavelength (1924 PhD thesis)
  - $\lambda = h/p$, p = momentum, $h = 6.62607 \times 10^{-34}$ m^2 kg/s
- In 1927 at Bell Labs, Davisson and Germer demonstrated a diffraction pattern from electrons
- Some electron wavelengths:
  - E = 100 keV, λ = 0.037 Å
  - E = 10 keV, λ = 0.122 Å
  - E = 1 keV, λ = 0.387 Å
  - E = 100 eV, λ = 1.23 Å

E-Beam Deflection and Focus



$F = q(\vec{E} + \vec{v} \times \vec{B})$

- By varying the electric or magnetic field as a function of radial position, a lens can be made
- Correcting aberrations in the lens is very difficult (spherical and chromatic), so NAs are low

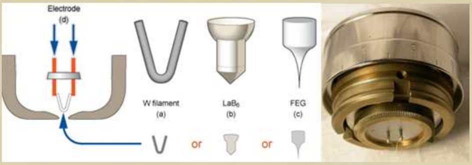
Electron-Beam Lithography

- Developed in 1960s based on scanning electron microscope (SEM) technology
- Direct write – no mask necessary
  - Computer controlled beam blanking
  - Often used to make masks
- Three possible limits to resolution
  - Spot size due to electron wavelength and lens NA
  - Electron scattering in the resist/substrate
  - Electron-electron repulsion if current is too high

Electron-Beam Tools

- Electron gun (source) supplies the electrons
- Electron column shapes and focuses the electron beam, including beam blanker
- Mechanical stage positions the wafer under the electron beam
- Wafer handling system
- Computer system that controls the equipment and provides the data to be written

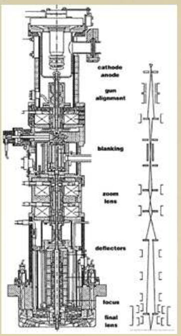
Electron Gun (Source)



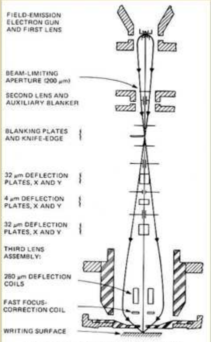
http://www.ammrf.org.au/myscope/sem/practice/principles/gun.php

- Thermionic emitters
  - Electrons “boiled” off the surface by giving them thermal energy to overcome the barrier (work function)
  - Tungsten in low vacuum, LaB_6 in high vacuum
- Field Emitter Gun (FEG)
  - Apply a large electric field to a solid (e.g., Tungsten, carbon nanotubes)
  - Electrons tunnel out when the surface barrier becomes very narrow

E-Beam System



Leica Lithography Systems Ltd



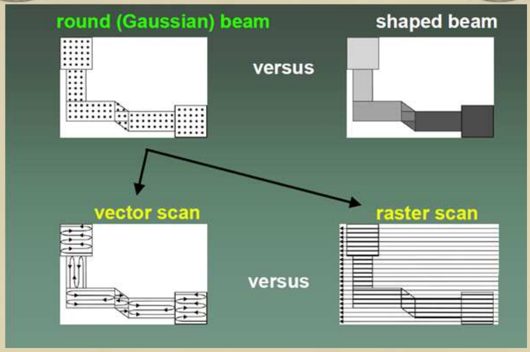
The optical components of the EBES-4 column.

J. Vac. Sci. Technol. B **5**, 53 (1987)

Writing Strategies

- Raster Scan: scan back and forth, blank beam where you don't want to write
  - Easy, slow, spot size can be adjusted
  - Spot size gives direct trade-off between resolution and throughput
- Vector Scan: move the beam to only those areas that are to be exposed
  - Can be much faster, especially for sparse patterns
- Variable-Shaped Beam
  - A rectangle is projected at one time

Writing Strategies



From: *Marco Salerno*, http://www.lira.dist.unige.it/

Commercial Systems

- JEOL JBX-3200MV: variable-shaped beam, 50 kV for mask making to 20 nm node
- JEOL JBX-9500FS: Gaussian raster scan, 100 kV for R&D
- Raith 150: R&D tool, 100 eV – 30 keV

Throughput vs. Resolution

- To get higher throughput:
  - Larger spot size (Gaussian systems)
  - Larger address grid (shaped beam systems)
  - Higher current (can result in electron-electron repulsion)
  - Faster stage (harder to control)
- Higher throughput always results in lower resolution
  - Higher resolution results in lower throughput

Lecture 61: What have we Learned?

- How can electrons be used to form an image?
- Name two common ways to generate electrons for an e-beam lithography system?
- What are the main writing strategies?
- Explain the resolution-throughput trade-off