Electron-beam Lithography

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Group seminar 04.05.07

Outline

- Equipment
- Principle of standard EBL
- Resists
- Challenges
- Direct-writing techniques

Definition

Electron-beam lithography (EBL) is a technique used for the fabrication of micro- and nanostructures, based on the chemical modification of polymer resist films caused by electron irradiation.

EBL Equipment

- Electron writer/ electron microscope

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- Step motors for stage positioning

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- ▪ Control and read-out of connected hardware (position of sample stage, e-beam deflection unit)

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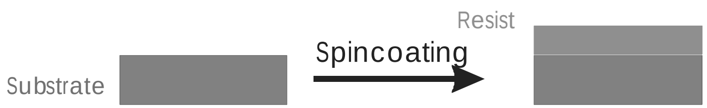
- Step motors for stage positioning
- Picoamperemeter
- EBL software
  - Design
  - Calculation of exposure parameters
  - Control and read-out of connected hardware (position of sample stage, e-beam deflection unit)
- E-beam resist and chemicals for developing

Process steps

- Spincoating of resist solution onto the sample surface



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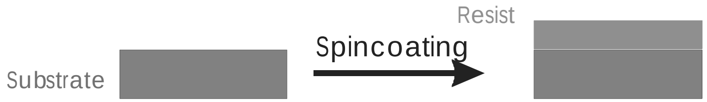
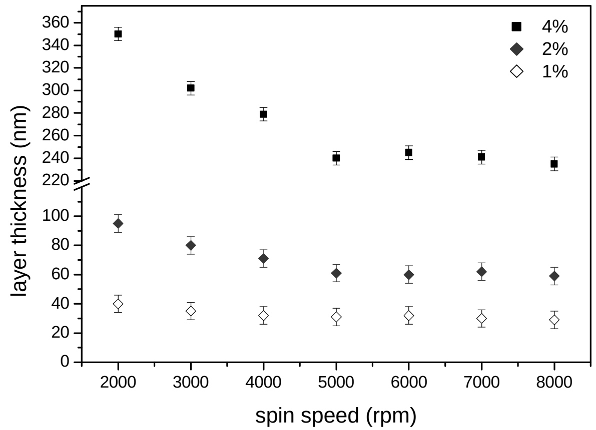
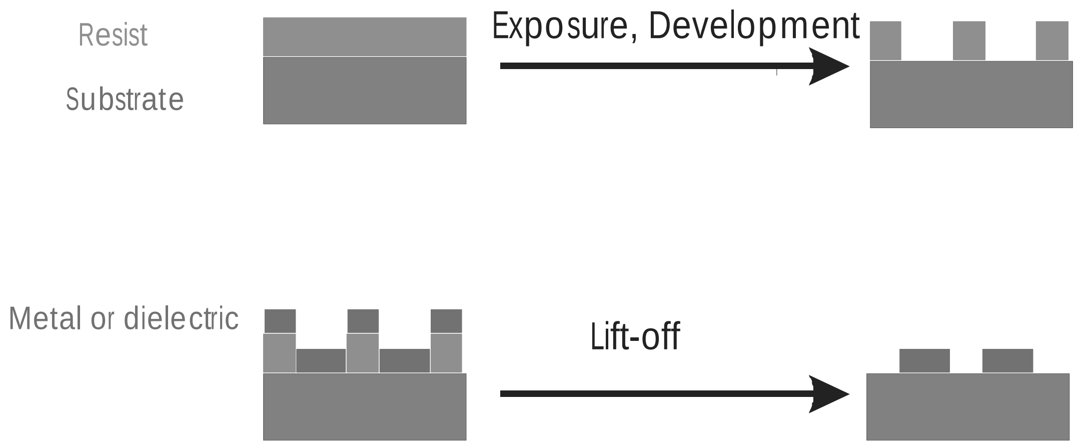




• Resist layer thickness depends on concentration and spin velocity

Process steps



Resist film

Two different types:

- Negative resist: After development, the exposed structure is higher than the surrounding due to crosslinking of polymer chains.

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- Negative resist: After development, the exposed structure is higher than the surrounding due to crosslinking of polymer chains.

- Positive resist: After development, the exposed structure is deeper than the surrounding due to chopping of polymer chains.

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Characteristical features of resist films

- *Resolution*

Resist film

<u>Characteristical features of resist films</u>

- *Resolution:* smallest structure size obtainable

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  - Also dependent on accelerating voltage and developer
  - Independent of resist thickness

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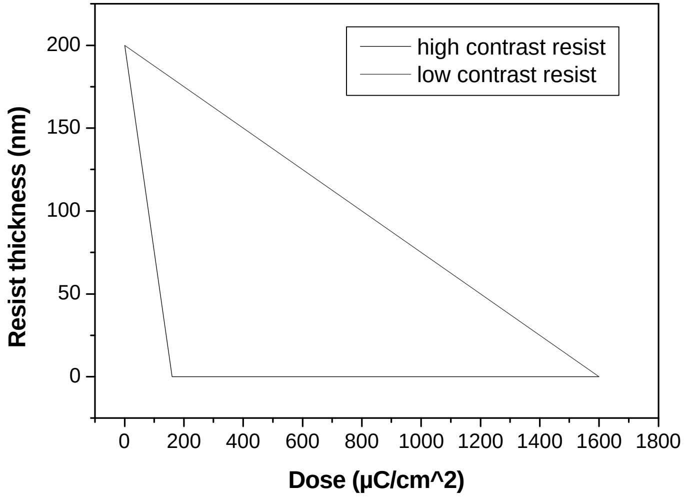
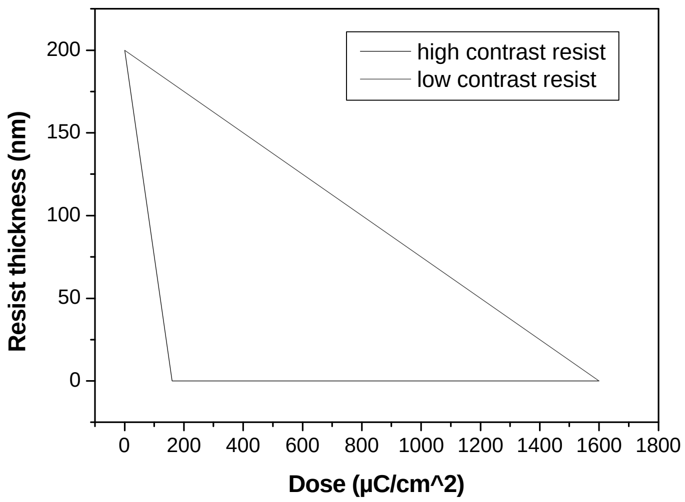


Resist film

Characteristical features of resist films

➢ *Contrast*



▪ Low contrast resists usuable for „greyscale lithography"/ 3D-lithography

Resist film

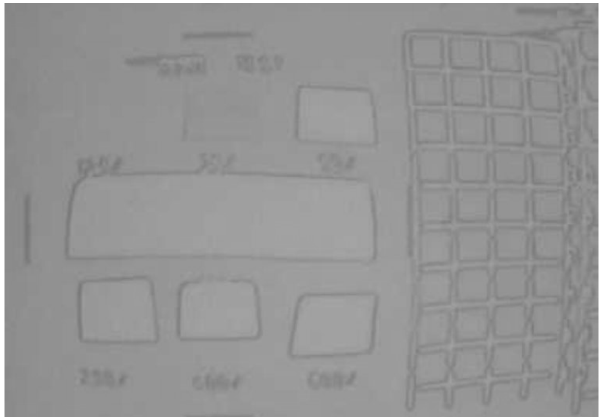
Example: Polymethyle-metacrylate (PMMA)

- One of the first e-beam resists (developped in 1968)
- Standard positive resist
- Resolution < 10nm
- Medium sensitivity (150-300 $\mu C/cm^2$)
- Available with high (950k) and low (50k) molecular weight
- Contrast: high for 950k-resist, low for 50k-resist

Challenges

Charging effects

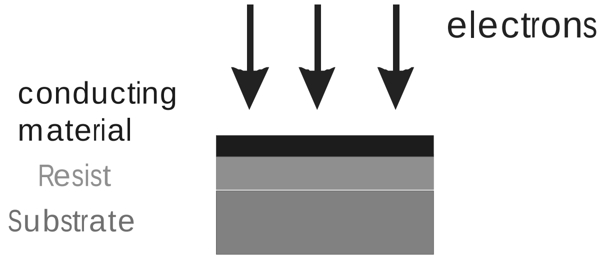
- Complicate exact focusing of electron-beam
- Yield displacement and distortion of exposed structures



Challenges

Charging effects- Avoidance

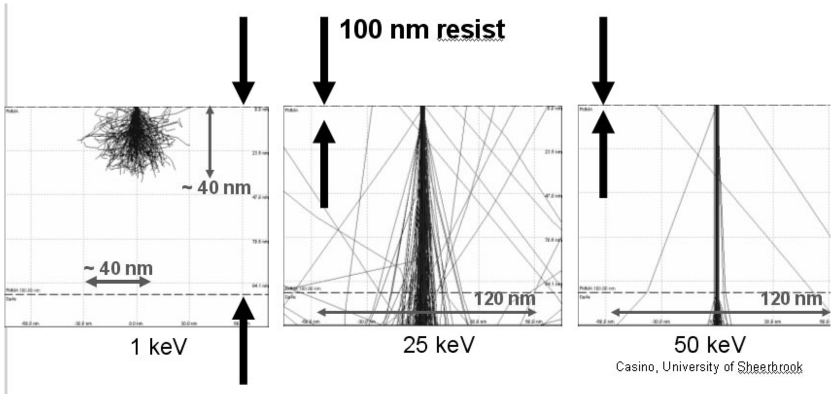
- Spincoat conducting polymer on top of resist
- Sputter or evaporate thin layer (~5nm) of Aluminium on top of resist



Challenges

Proximity effect

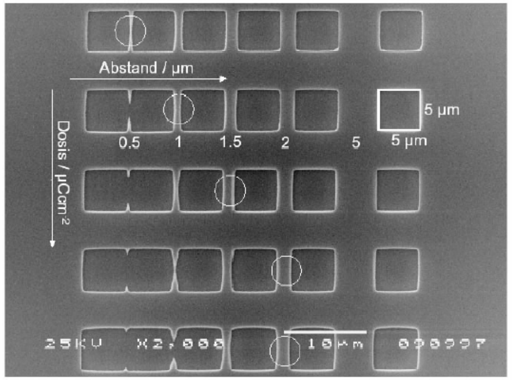
- Scattering of electrons in resist film (forward scattering) and substrate (back scattering)
- Dependent on the electron energy, substrate and structural pattern



Challenges

Proximity effect

- ➢ Yields unwanted additional exposure
- ➢ Can be described as the sum of two Gaussian distributions



$$P(r) = \frac{1}{p(1+h)}\left[\frac{1}{a^2}\exp\left(-\frac{r^2}{a^2}\right) + \frac{h}{b^2}\exp\left(-\frac{r^2}{b^2}\right)\right]$$

r: Radius of a point exposure

α: Forward scattering

β: Backward scattering

η: ~ Number of forward to number of back scattered electrons

Challenges

Proximity effect- avoidance

- Low acceleration voltage (< 5keV)

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Proximity effect- avoidance

- Low acceleration voltage (< 5keV)
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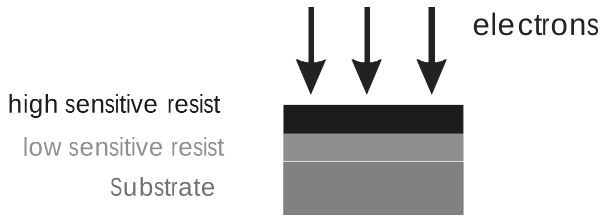
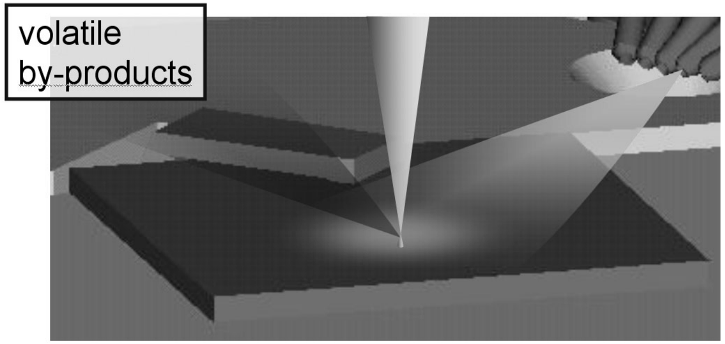
- Double-layer technique



Direct-writing techniques

- Electron-beam induced deposition (EBID) technique/ contamination lithography
- Electron-beam induced etching (EBIE)

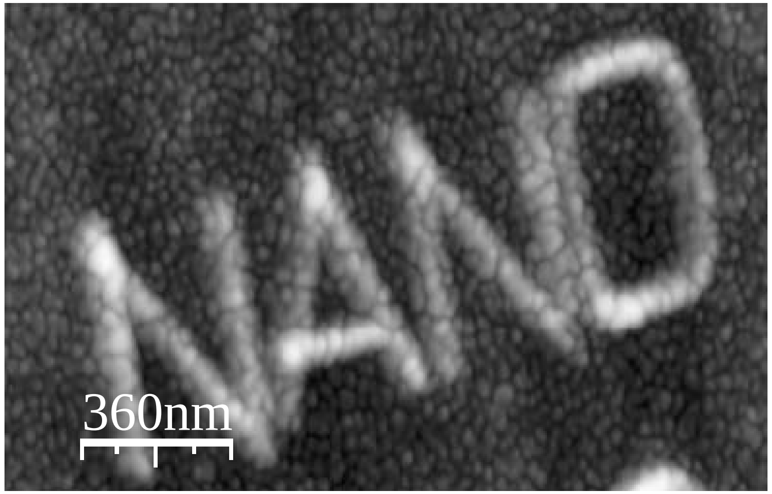


Direct-writing techniques

- Different precursor molecules for different purposes:
  EBID: Hydrocarbons, metal-organic compounds
  EBIE: Fluorine, water
- Commercial EBID/ EBIE systems available

Direct-writing techniques

Example: E-beam induced carbon deposition



Carbon deposition on
5nm thick gold film.
30keV, 10 C/cm^2

Structural width: 70nm, height: 3nm

Summary

- EBL Equipment
- Different lithographic techniques
- Resist properties
- Challenges

Thank you for your attention!!