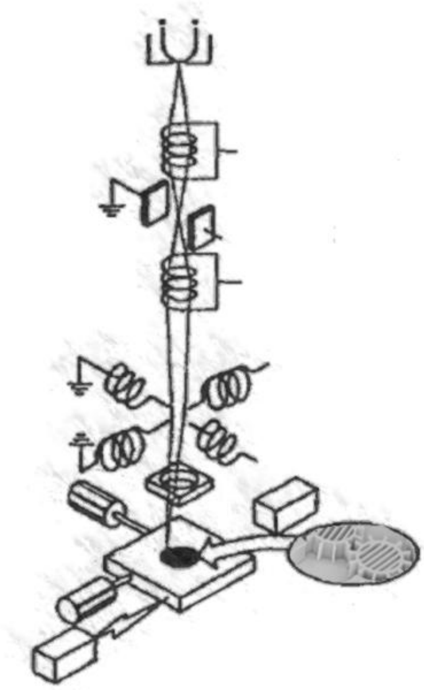
MICROSYSTEMS TECHNOLOGY FOR MOLECULAR BIOENGINEERING

LAB COURSE - ELECTRON BEAM LITHOGRAPHY



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1. Introduction

Electron beam lithography (EBL) is an emphasized technique for fabricating extremely fine patterns required by the modern electronics industry for integrated circuits. Derived from the early scanning electron microscopes, the technique in brief consists of scanning a beam of electrons across a surface covered with a resist film sensitive to those electrons, thus depositing energy in the desired pattern in the resist film.

The main attributes of the technology are:

1) it is capable of very high resolution (~20 nm);
2) it is a flexible technique that can work with a variety of materials;
3) it is slow, being one or more orders of magnitude slower than optical lithography;
4) it is expensive and complicated (due to proximity effect).

2. Process schemed for positive-tone resist (see section 4)

a) Surface treatment: cleaning, dehydration, priming or plasma etching

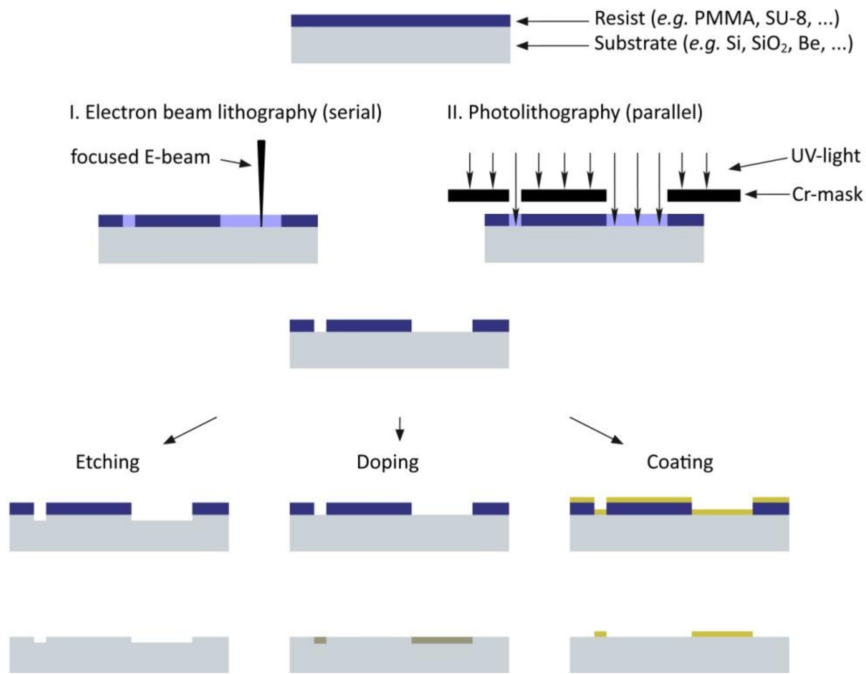
b) Spincoating:

c) Exposure:

d) Development:

e) Pattern transfer:

f) Stripping (removing of resist):



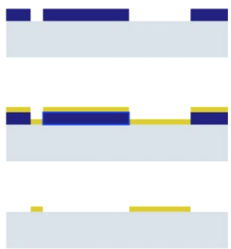
The fundamental idea of EBL is identical to optical lithography. A thin layer of resist is spin-coated onto a substrate and chemically modified during exposure to the electron beam. The exposed (non-exposed) areas are soluble in a specific solvent and can be removed (development). After the removal of the exposed resist the pattern may be transferred to the substrate by e.g. etching, doping or coating.

3. Lift-off process

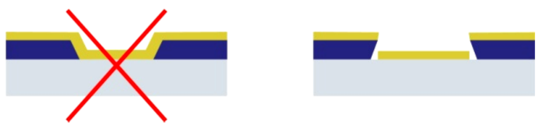
a) Patterned resist:

b) Metal coating:

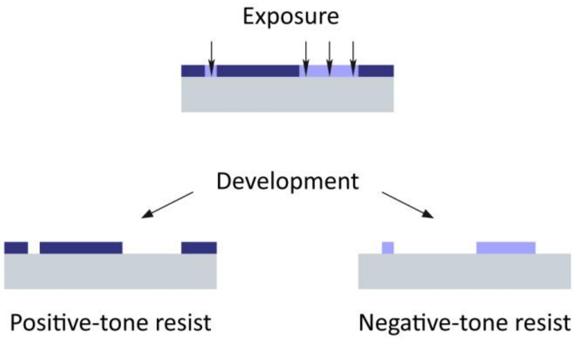
c) Lift-off:



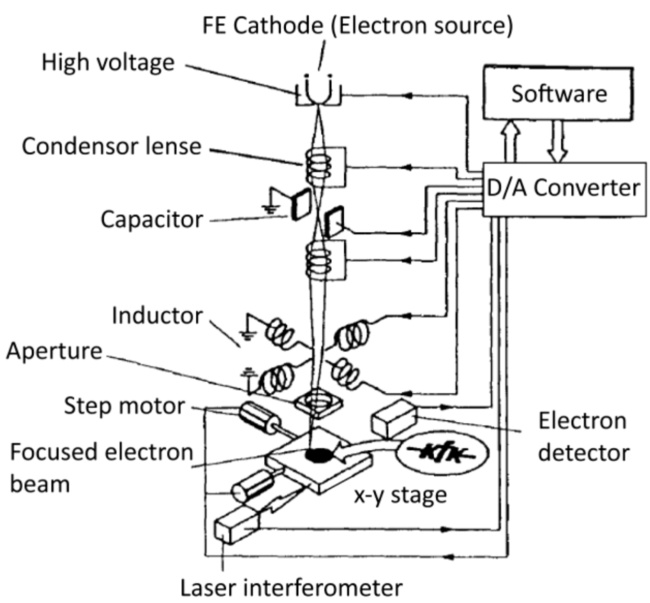
Undercutted edges are required for successfully removing of the resist



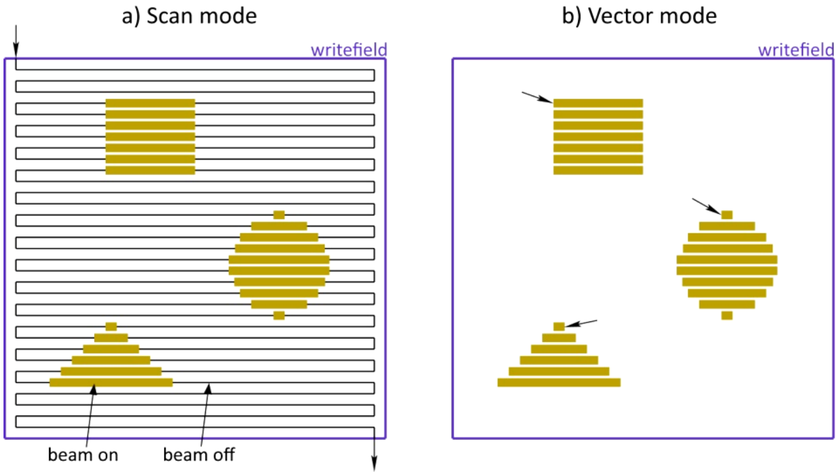
4. Resist types



5. Composition of EBL system



6. Beam blanking strategies



7. Dwell time

- Dwell time at each scanning step (pixel): $$t = \frac{S \cdot x^2}{I_B} \quad (1)$$

- Effective dwell time at each scanning step: $$t^* = F \cdot t = F \cdot \frac{S \cdot x^2}{I_B} \quad (2)$$

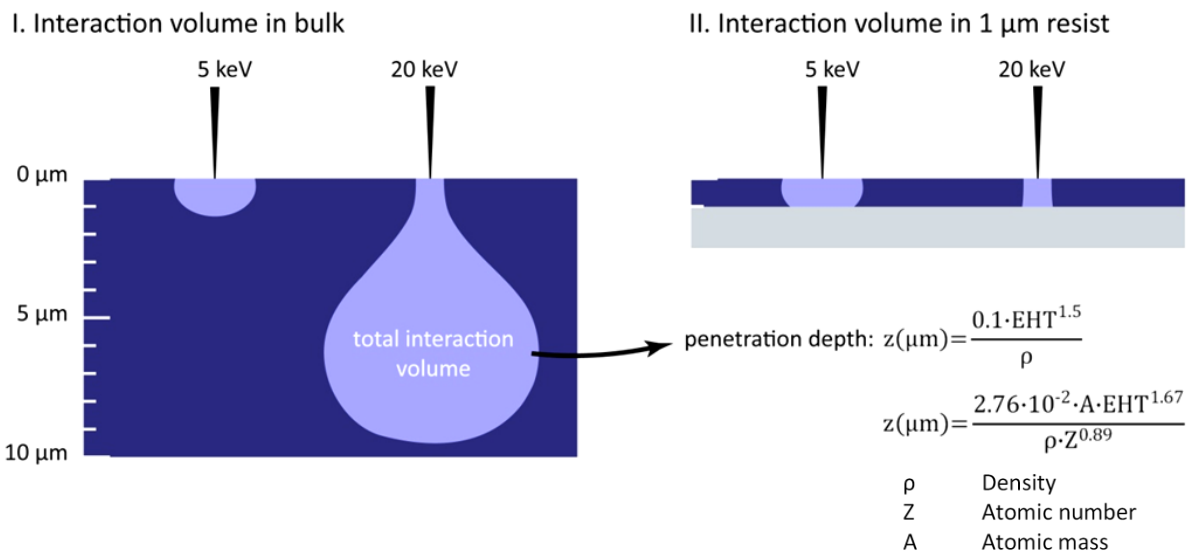
S	Sensitivity, (Area dose) [μAs/cm^2]
x	Step size [μm]
I_B	Beam current [pA]
F	Dose factor

8. Resolution

Even though the diameter of the incident electron beam in a field emission SEM is about 6 nm, the resolution is limited by beam broadening in the resist due to scattering effects of primary and secondary electrons. The scattering effects, also known as the proximity effect, cause the interaction volume and consequently the diameter of the irradiated material to increase dramatically. From this it follows that the smallest feasible pattern depends on the electron-resist- and electron-substrate-interactions which are function of the electron beam energy, resist type, resist thickness, exposure time (dose), development time and not preferential by electron beam diameter.

9. Proximity effect

9.1. Forward scattering

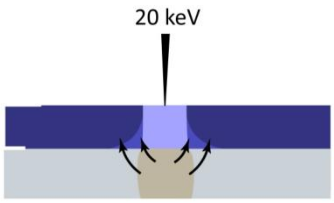


In forward scattering, an electron can collide with an electron from one of the atoms in the substrate/resist. The incident electron will change its direction and transfer part of its energy to the atom. When the target atom is part of a resist molecule, the molecular chain may break due to this excitation or ionization. The scattering angle due to inelastic scattering is, as a rule, small. Summarized, the forward scattering affects the broadening of the focused electron beam due to the electron-resist interactions and determines the single feature resolution limit.

Can be reduced by:

- Higher e-beam voltages, from 20 keV to 50 keV or more;
- Lower thickness (and atomic mass/number) of resist

9.2. Backscattering



In backscattering, an electron collides with the much heavier nucleus, which results in an elastic scattering event. The electron retains most of its energy, but changes its direction. The scattering angle may be large in this case. After large angle scattering events in the substrate, electrons may return back through the resist at a significant distance from the incident beam, thereby cause additional resist exposure. Summarized, backscattered electrons from the underlying substrate affect undercuts of the features due to an additionally exposure (overexposing) of the bottom side of the resist. These electrons limit the pitch resolution due to the ability to expose adjacent features.

Can be reduced by:

- Lower atomic mass/number of substrate.

10. Dose modulation

In dose modulation a different dose factor *F* can be applied to each pixel and is one of most common methods for proximity effect correction. Usually each individual shape in the pattern is assigned a dose such that (in theory) the shape prints at its correct size. The calculations needed to solve the shape-to-shape interactions are computationally very time-consuming. Although the actual effect of electron scattering is to increase the dose received by large areas, for practical reasons proximity correction is normally thought of in terms of the large areas receiving a base dose of unity, with the smaller and/or isolated features receiving a larger dose to compensate.

11. Literature

[1] Braun, H.G.: *Script Electron Beam Lithography*.
http://www.ipfdd.de/uploads/media/Lithohbmain_02.pdf

[2] McCord, M.A. und Rooks, M.J.: *SPIE Handbook of Microlithography, Micromachining and Microfabrication*, Vol. 1
http://www.cnf.cornell.edu/cnf_spietoc.html

12. Questions

1. Explain the general aim of a lithography process?
2. What is a resist?
3. Which lithography techniques do you know?
4. Explain at least 3 parameters that are favorable to change the resist layer thickness.
5. What are the key parameters you need to know for correct exposure time calculation and how do you measure the e-beam current experimentally?
6. Estimate the total exposure time that you need to irradiate a 100 µm sized square with an e-beam current of 150 pA using a standard PMMA resist with sensitivity (area dose) of 150 $\mu C/cm^2$ and an e-beam step size of 25 nm?
7. Why is EBL not used in industrial mass production?
8. What limits the resolution of EBL compared with the resolution limit of photolithography?
9. What is the meaning of proximity effect (definition) and how can this effect be reduced?
10. How is the duty cycle of a line-space grating defined?
11. What are the steps of the lift-off process?
12. Why are the vacuum conditions important in a metal evaporation process?
13. How can you measure the thickness of the metal layer during vapor deposition?
14. Why do we need a chromium coating before gold coating onto a silicon/glass substrate?
15. If you replicate a structure with PDMS from a silicon master, what surface treatment is important to avoid grafting of the PDMS to the master and therefore irreversible destruction of the master?
16. How can you improve the adhesion between PDMS and glass in order to prepare a pressure resistant sealing between the two components?

13. Agenda

Monday – Wednesday

Fundamentals of electron beam lithography

- Sample preparation
- Lithography: shape, size, dose modulation
- Lithography: duty cycle of line-space gratings
- Lift-off process
- Characterization

Thursday

Protocol

Friday

Soft lithography

- PDMS stamp preparation
- µ Contact printing
- Characterization