Measurement of Current Density Distribution in Electron Beam Writer

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Introduction

An e-beam writer with a variable shaped beam needs a bright and stable source of electrons and also a homogeneous square beam segment. This is the starting element out of which smaller rectangular-shaped variable-sized patterns are selected (stamps). Current inhomogeneity of the starting element would cause a different current density of various stamps that negatively impacts the exposure quality. This problem implies the necessity of analysing and monitoring the current density distribution in the starting beam element.

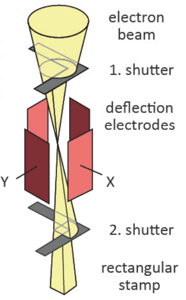
Current distrubution measurement

A set of methods enabling the measurement of the beam current distribution was presented in the past. But only a part of them is suitable for the evaluation of the current density distribution of the fine focused beam with the spot size below 10 µm. In this work, we present three methods of the current density distribution measurement:

1. **Modified knife-edge method**
2. **Irradiated luminescent screen method**
3. **Electron resist exposure method**

E-beam writer

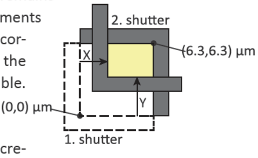
The measurements were performed using the e-beam writer Tesla BS600. The forming system is composed of the first and the second rectangular shutter; the beam cross-over is in between them [1]. The beam size is adjusted by the electrostatic beam deflection in the cross-over plane independently in the two axes.



Modified knife-edge method

We implemented a method based on the knife edge approach [2], when a part of the scanned element is blanked out and the current within the remaining „open“ part (segment) is measured. The 2D information of the current distribution is obtained by stepwise opening of selected segments.

The forming system of the e-beam writer BS600 was used for the segment opening and a Faraday cage positioned under the beam was used to measure the electron current in the segment. However, using the forming system of BS600, it wasn't possible to directly open all necessary beam segments. The reason is, that the mutual position of the beam and the first shutter remains unchanged. Thus only the segments having the identical upper right corner (the position [6.3; 6.3] µm in the selected coordinates) are available. Those segments are called stamps. The limitation of the forming system implied the creation of a modification of the knife-edge method: the current density of an arbitrary beam segment is derived from the current measurement of several appropriate stamps.

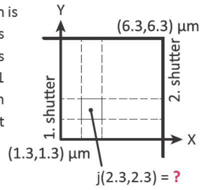


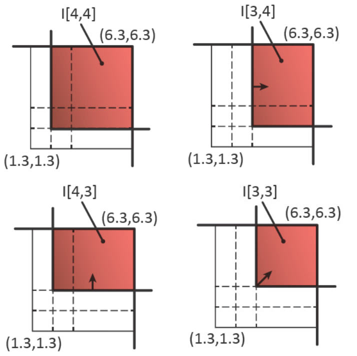
Our modified knife-edge method can be defined as follows. We are searching the current density *j(x,y)* of the segment sized *Δx × Δy* whose lower left corner has the coordinates *(x;y)*, where *x* є *{0;6.3 – Δx}* and *y* є {0; 6.3 – Δy}:

$$j(x,y)=\frac{1}{\Delta x\Delta y}\sum_{j=y-1}^{y}\sum_{i=x-1}^{x}(-1)^{(x+y)-(i+j)}I\left[s_i,s_j\right]$$

The $I[s_i,s_j]$ is the measured current of the stamp with s_i width and s_j height; this stamp size being $[s_i;s_j] = [(6.3–x);(6,3–y)]$ *µm*. By the current measurement in the appropriate stamps and using the equation above, the current density distribution within the whole scanned element can be evaluated.

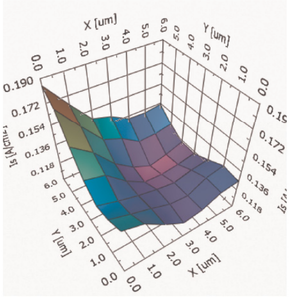
An example of the presented equation is shown below. Let the scanned element is divided to a grid with the 5 × 5 segments and the segment size Δx × Δy = 1 × 1 µm². Thus, the coordinate origin is in (1.3;1.3) µm. Now, let's search the current density in one element, for example in the coordination (2.3;2.3) µm. From the equation, the current *I* in the stamp *[si; sj] = [4;4]* is measured, then current *I[3,4]* is subtracted, *I[4,3]* is subtracted and *I[3,3]* is added. The result gives current density in the chosen segment. Continuing with these steps, one can get current density distribution in the whole scanned element grid.





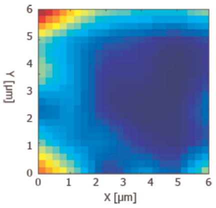
The presented algorithm for current density measurement was implemented using National Instruments LabVIEW environment. Appropriate stamp size is set automatically through the service channel to the basic exposure SW, Expo.NET. The current was measured using the Faraday cage and the pA-meter Keithley 487 through the IEEE-488 bus and the Agilent IEEE-488 to USB converter.

An example of the current density distribution obtained by the modified knife-edge method is shown below. The size of the scanned element was chosen to be 6 × 6 µm² and the element was divided to the 6 × 6 segments. The electron current in each segment was appropriately averaged to decrease the signal noise. The total time of current density measurement in the defined scanned element took approximately 10 minutes.

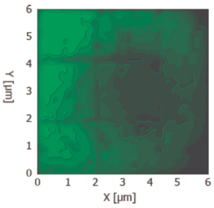


Irradiated luminescent screen method

The current distribution obtained by the modified knife-edge method was compared with a method using a luminescent screen. The YAG:Ce single-crystal screen was irradiated by the e-beam stamp of the size 6 × 6 µm² and the areal light emission of the screen was recorded by a magnifying optical system with a CCD camera. The light emission of the screen is proportional to the e-beam current density, thus the knife-edge method and the irradiated luminescent screen method can be compared. As shown below, the current distribution obtained by the two methods is more or less the same, however the knife-edge method provide better dynamic range and higher signal-to-noise ratio.



The knife-edge method current distribution

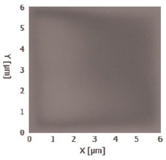


Current distribution obtained by luminescent screen emission

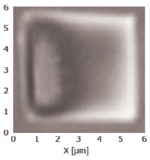
Electron resist exposure method

Another method for obtaining the e-beam current density distribution is based on evaluation of developed electron resist. A positive electron polymer film (resist) deposited on a semiconductor substrate was exposed by the shaped e-beam. Afterwards, the exposed resist was chemically removed (developed). The depth of the developed resist is directly proportional to the e-beam current density. Thus, one can obtain the e-beam current density distribution from observing the profile of the developed resist.

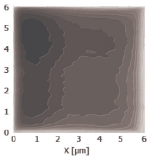
The PMMA positive resist was exposed by the e-beam with the e-beam stamp of the size 6 × 6 µm². After the development, the resist was observed using the three microscopic techniques: light microscopy, confocal laser scanning microscopy and atomic force microscopy. The results are shown below.



Light microscope



Confocal laser scanning microscope



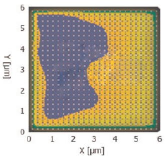
Atomic force microscope

As seen from the microscopy images, the profile of the developed resist isn't in direct agreement with the current density distribution obtained from the knife-edge method. The reason is the scattering of the e-beam electrons in the resist volume, so called proximity effect. The proximity effect causes enlarging the exposed area and reducing the relief contrast. Due to this effect, the developed resist images unfortunately don't provide direct information about the e-beam current density distribution.

To compare the developed resist images with e-beam current density distribution, there are two approaches:

1. **Forward problem** – if we know the e-beam current density distribution and scattering parameters of the electrons in the resist, we can calculate the developed resist image.
2. **Inverse problem** – if we have the developed resist image and we know scattering parameters of the electrons in the resist, we can calculate the e-beam current density distribution.

We calculated the forward problem, which is easier to solve. Using the measured e-beam current distribution and scattering parameters for the PMMA resist, we ran the computer simulation of the resist development. The calculated image can be now directly compared with the microscopy images. The images are in great agreement.



Computer simulation of resist development

References

[1] V. Kolarik et al., Jemná mechanika a optika **53** (2008), p. 11–16, in Czech.
[2] M. Sakakibara et al., Japanese J. of Applied Phys. **46** (2007), p. 6616–6170.
[3] F. Matejka et al., In Proc. 12th Int'l Sem. on Recent Trends in Charged Particle Optics and Surface Phys. Instr., Brno (2010), p. 13-14.

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