Monte-Carlo Simulation of Charge-Induced Pattern Displacement in E-Beam Lithography

K.T. Arat, C.W Hagen, P. Kruit
Delft University of Technology, Faculty of Applied Sciences, Lorentzweg 1,
2628CJ Delft, the Netherlands
k.t.arat@tudelft.nl

A.C. Zonnevylle, W.S.M.M. Ketelaars
Raith B.V., De Dintel 27a, 5684PS Best, the Netherlands

T. Klimpel
GenISys GmbH, Eschenstrasse 66, 82024 Taufkirchen, Germany

In electron beam lithography (EBL) pattern displacement errors due to sample charging pose an important problem, especially in cases where the substrate is not sufficiently conductive. As a solution, different experimental techniques are used: introduction of a discharging layer, operating in environmental conditions, reducing the surface potential by operating at the critical energy, or using different scan strategies. While the first three techniques aim at reducing the charging, they cause additional process and/or tool related complications. The last method is applicable without additional complexity, dismissing the fact that finding the right strategy is already complex in itself. In literature, modelling studies aim to provide a more general solution[1,2]. However, they are mostly based on empirical electron-matter scattering models or do not include charge redistribution models.

To understand charging effects in lithography, we are developing a Monte-Carlo simulator based on first principle scattering models which includes electric fields and charge redistribution models[3]. Here, we focus on the deflection of a primary beam due to the substrate charging in high energy EBL. The exposure follows a dot array scheme (Fig. 1) such that the deflection can be easily determined by measuring the deviation from regularity. It is assumed that most of the deflection is due to the charging of the substrate which is SiO_2 in this study. A sensitivity analysis is done to analyze the effect of different scan strategies such as TV, meander, and spiral modes (Fig. 2). Simulations show that the beam deflection is sensitive to energy, dose, scanning mode, scanning area and step size, which makes the pattern displacement very specific to the exposure setup (Fig. 3). The simulation results also show that the charge redistribution models, such as electron beam induced conductivity, have a significant impact on the results especially at higher doses. More results and verification experiments, with an Electron Beam Pattern Generator (EBPG) tool at 50keV will be presented at the conference.

---

[1] J.J. Hwu and D.C. Joy, Scanning **21**, 264 (1999).
[2] Y. Ko, J.J. Ha, and C. David, Proc. SPIE **3998**, 694 (2000).
[3] K.T. Arat, T. Klimpel, and C.W. Hagen, in *Proc. SPIE - Int. Soc. Opt. Eng.* (2018).

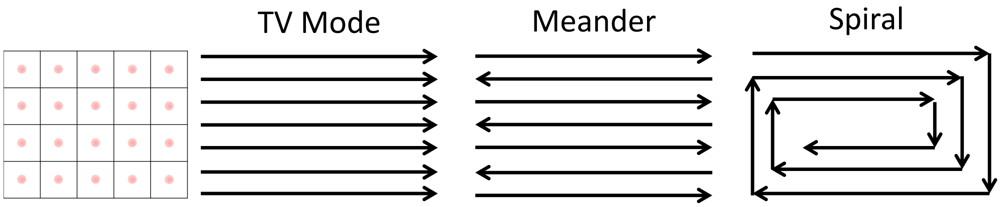

Figure 1 – Dot array exposure: the red dots represent the focused beams, the black frame represents the pixels and the area is exposed with different scan strategies.

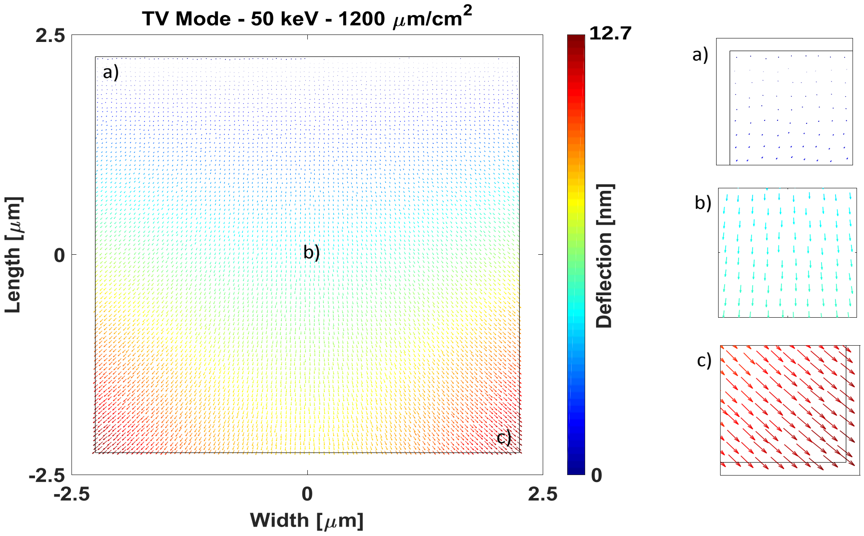

Figure 2 – Deflection map: the magnitude and the direction of the deflection of each beam are given in the left hand side graph. The area is 4.5 µm by 4.5 µm where the outer frame is drawn by the black square. The right hand side shows zoomed in areas of the deflection map for a better visualization.

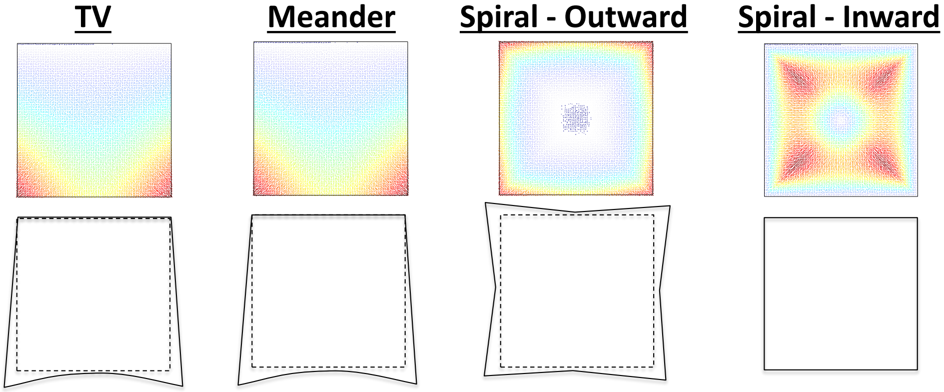

Figure 3 - Effect of scan strategy: the deflections observed in 4 different strategies are compared. The deflection is in the outward direction of the squares in all cases, but leading to a qualitatively different shape. It is expected to observe a square shape, after development, only for the spiral-inward mode.