Effects of Abnormal Beams on Writing Qualities in Massively-parallel E-beam Systems

M. N. Hasan and S.-Y. Lee
Department of Electrical and Computer Engineering, Auburn University, Auburn, AL 36849
Fax: (334) 844-1809, *leesooy@eng.auburn.edu*
B.-S. Ahn, J. Choi, S.-B. Kim, and C.-U. Jeon
Samsung Electronics, Mask Development Team, 16 Banwol-Dong, Hwasung, Kyunggi-Do 445-701, Korea

While electron-beam (e-beam) lithography is widely used in transferring fine-feature patterns onto a substrate, its major drawback is the low throughput, especially for large-scale patterns. To increase the writing throughput, e-beam machines with massively-parallel beams were recently developed. In such a system, it is highly likely that some beams may not be normal, e.g., being permanently off ("faulty"), having a significant current deviation, etc. It is important to understand how abnormal beams affect the writing quality. In this study, the effects of such beams on the writing quality are analyzed for three different writing methods, *Single-row writing I, Single-row writing II, Multi-row writing*, through an extensive simulation in order to suggest ways to reduce their negative effects.

A typical massively-parallel e-beam system is equipped with a 2D array of beams where beams in each row are spaced at a certain interval, I_{bx}. In the single-row writing I method, a specified dose D for a pixel is achieved through n_s steps forming a cycle where $n_s = I_{bx} + 1$. That is, each beam exposes a pixel n_s times such that $D = n_s d$ where d is the dose given in a step. Therefore, a faulty beam can result in a large dose reduction at a pixel. The single-row writing II method mitigates this effect, exposing each pixel by a group of n_g consecutive beams. The dose reduction by a faulty beam is decreased by the factor of n_g. The multi-row writing method uses each beam to expose pixels on multiple rows in each writing path to spread the pixels affected by a faulty beam and minimize the dose reduction. An abnormal beam is modeled with its probability (p_b) of being faulty and fluctuation of beam current, and the writing quality is quantified in terms of metrics such as the exposure uniformity, critical dimension, line edge roughness and maximum indent. The effects of abnormal beams on the quality metrics are analyzed considering the number of cycles, n_c, the beam blurring factor, σ, etc., and the three writing methods are compared in terms of the quality metrics.

In Fig. 1, the three writing methods are compared in terms of the exposure fluctuation (standard deviation) and line edge roughness with p_b varied in a typical case. In Fig. 2, for a fixed p_b, the line edge roughness and maximum indent (on the feature boundary) are analyzed as a function of n_c. In both figures, it is seen that the multi-row writing method performs better. In this paper, the simulation results will be presented with a detailed discussion.

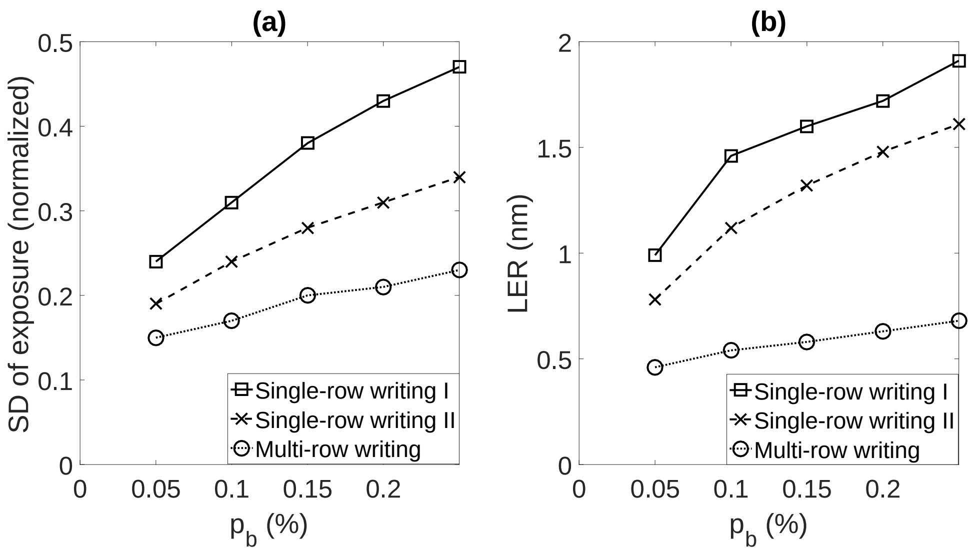

Figure 1: (a) Standard deviation of exposure and (b) line edge roughness: the feature size of $80 \times 320nm^2$, beam size of $10 \times 10nm^2$, $D = 4d$, $I_{bx} = 40nm$, $\sigma = 4nm$, and beam energy of 50keV. The substrate system is composed of 100nm PMMA on Si. The beam array is of size 4×32 for the single-row writing methods and 16×8 for the multi-row writing method.

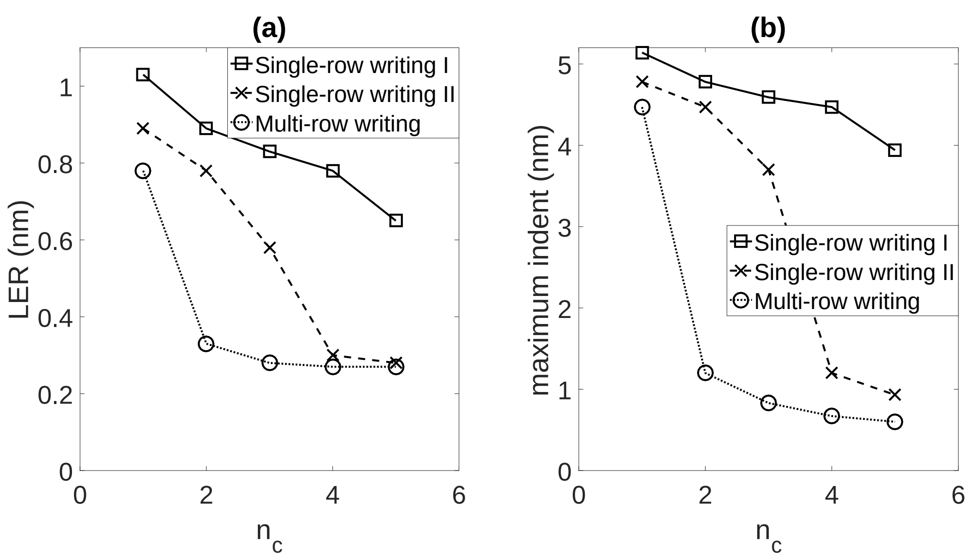

Figure 2: (a) Line edge roughness and (b) maximum indent: the feature size of $80 \times 320nm^2$, beam size of $10 \times 10nm^2$, $D = 4d$, $I_{bx} = 40nm$, $\sigma = 2nm$, and beam energy of 50keV. The substrate system is composed of 100nm PMMA on Si. The beam array is of size $4n_c \times 32$ for the single-row writing methods and $16n_c \times 8$ for the multi-row writing method. $p_b = 0.05\%$.