Available online at www.sciencedirect.com

ScienceDirect

Microelectronic Engineering 85 (2008) 778–781

MICROELECTRONIC ENGINEERING

www.elsevier.com/locate/mee

Determination of best focus and optimum dose for variable shaped e-beam systems by applying the isofocal dose method

Katja Keil [a,*], Kang-Hoon Choi [b], Christoph Hohle [b], Johannes Kretz [b], Tarek Lutz [b], Lutz Bettin [c], Monika Boettcher [c], Peter Hahmann [c], Karl-Heinz Kliem [c], Bernd Schnabel [c], Mathias Irmscher [d], Holger Sailer [d]

[a] *Fraunhofer CNT, Koenigsbruecker Straße 180, D-01099 Dresden, Germany*
[b] *Qimonda Dresden GmbH & Co. OHG, Koenigsbruecker Straße 180, D-01099 Dresden, Germany*
[c] *Vistec Electron Beam GmbH, Goeschwitzer Straße 25, D-07745 Jena, Germany*
[d] *IMS Chips, Allmandring 30a, D-70569 Stuttgart, Germany*

Received 7 October 2007; received in revised form 11 January 2008; accepted 15 January 2008
Available online 26 January 2008

Abstract

Electron beam direct write (EBDW) provides high resolution for device and technology development. A new variable shaped beam system with improved electron optics was introduced, which features the capability for the 32 nm node. Because of the limited resolution of commercially available chemically amplified resists at this node, it is important to determine a stable and optimum resist process window. To compare a process window under different premises, a universally applicable and low error-prone method is needed. The isofocal dose method is investigated with regard to these properties for its use in EBDW. Experiments were performed on 50 kV variable shaped electron beam direct writers using the new electron-optical column SB3050 DW (Vistec Electron Beam GmbH). Exposures are performed at different sites in Dresden (Fraunhofer CNT/Qimonda Dresden), Jena (Vistec) and Stuttgart (IMS Chips); also patterns are exposed on different layer stacks at one site. The strong need for a process window can be fulfilled by the isofocal dose method, which will be shown by contour plots.

Keywords: E-Beam lithography; Isofocal dose; Bossung plot; High resolution; Process window

1. Introduction

One major advantage of electron beam direct write for use in device and technology development is its high resolution. E-Beam techniques must exceed the resolution capability of state-of-the-art optical lithography systems to maintain their edge in research. New variable shaped beam systems with improved electron optics [1] are being operated at three different sites in Germany: these are Fraunhofer CNT whose e-beam writer is run by Qimonda Dresden, furthermore Vistec Electron Beam GmbH in Jena and IMS Chips in Stuttgart. The new electron-optical column SB3050DW from Vistec features the capability for the challenging 32 nm node. Higher resolution results in a higher sensitivity against defocus and other deviations from the optimum working point, although the numerical aperture of the column is roughly two orders of magnitude less than in photolithography (Rayleigh criterion). Furthermore, the resolution of commercially available chemically amplified resists (CARs) currently limits the total system performance. This emphasizes the importance of using a stable and optimum resist process window. The three sites apply a common resist process. To compare a process window under different premises, a universally applicable and low error-prone method is needed.

* Corresponding author. Tel.: +49 351 4388 3467.
E-mail address: katja.keil@cnt.fraunhofer.de (K. Keil).

0167-9317/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.mee.2008.01.042

The isofocal dose method is well known in optical lithography for the determination of process limits [2], particularly for wafers with topography. In this paper, the method is investigated with regard to the above-mentioned properties for its use in e-beam direct write.

2. Background and interpretation of the isofocal dose method

The isofocal dose method was introduced by John W. Bossung in 1977 to ensure the process window in optical lithography [3]. The original reason for the application of the method was the small depth-of-focus together with problems that arose from poor wafer flatness. Therefore, a focus-dose-matrix was exposed and the measured CD response versus focal position for various exposure doses was plotted (Bossung plots).

Linewidths change with defocus at a given dose, and the amount of change depends on the exposure dose. The Bossung plots show parabolas (CD plotted versus focus) with different curvatures. The curvature of the parabola changes from negative to positive values if the dose increases starting at low doses. One result is the so-called isofocal dose, in which the linewidth changes as a function of focus are minimized. Operating at this isofocal dose provides the largest expectable process window [4].

Adapted from optical lithography, the isofocal dose method was applied for EBDW. An array-like lines/spaces pattern was exposed varying both the focus as well as the dose. A line/space ratio of 1:1 has the advantage that the backscattering of electrons is independent from the pitch. A proximity correction is not necessary in this case.

The pattern was printed at different sites in Dresden, Jena and Stuttgart. Furthermore, exposures were tested on different layer stacks at the Dresden site. As a result, the isofocal dose method is interpreted concerning the isofocal dose itself, the correct focus and the process window.

3. Site comparison

The three different sites are working closely together in a project funded by the Federal Ministry of Education and Research of Germany. To save time and resources a division of labour is stipulated. The isofocal dose test can answer the question how comparable the exposure results of the used tools and processes are.

The electron-optical column, which is seen as the resolution determining part of the e-beam exposure tool, is a Vistec SB3050DW column operating at 50 kV in all three cases. Concerning the processing techniques, small differences emerge. Whereas Stuttgart and Jena are using a Modu Track 2000 (Steag Hamatech), the Dresden site deploys a Clean Track ACT-12 (Tokyo Electron Ltd.). Main differences are the uniformity of the hotplates and the nozzle type used in the developer system.

A positive chemically amplified resist (pCAR) was used with a conformal film thickness of 100 nm after development.

All exposures have been performed on 300 mm bare silicon wafers. A 70 nm dense line/space pattern with a 1:1 pitch has been chosen to ensure measurable CD over a large dose range as well as over a large focus range. CD values were obtained even for a defocus of ±12 μm and an under-/overexposure of ±20%, respectively. A variety of dose factors has been applied to provide a sufficient process window for comparison. The pattern has been laterally sized by −5 nm per edge. No proximity correction has been applied. The CD measurements were accomplished with a Hitachi CG4000 CD-SEM at the Vistec facility.

Fig. 1a–c shows the Bossung plots of the exposures carried out at the three different sites. The target CD is plotted versus the focus for a number of different doses. The parabola with the curvature of approximately zero (bold marked) belongs to the isofocal dose. Despite the different processing tools, the isofocal dose equals between all three sites and ranges between 24 and 25.2 μC/cm². Differences in CD response are visible; these are not traced back to the e-beam tool, but to the resist process. Therefore, the isofocal dose method can be applied for tool matching without process influences.

Fig. 2 shows the exposure dose latitude derived from the isofocal dose diagram (Fig. 1a). The CD is plotted versus the dose over a range of 10 μC/cm². The slope of the fitted

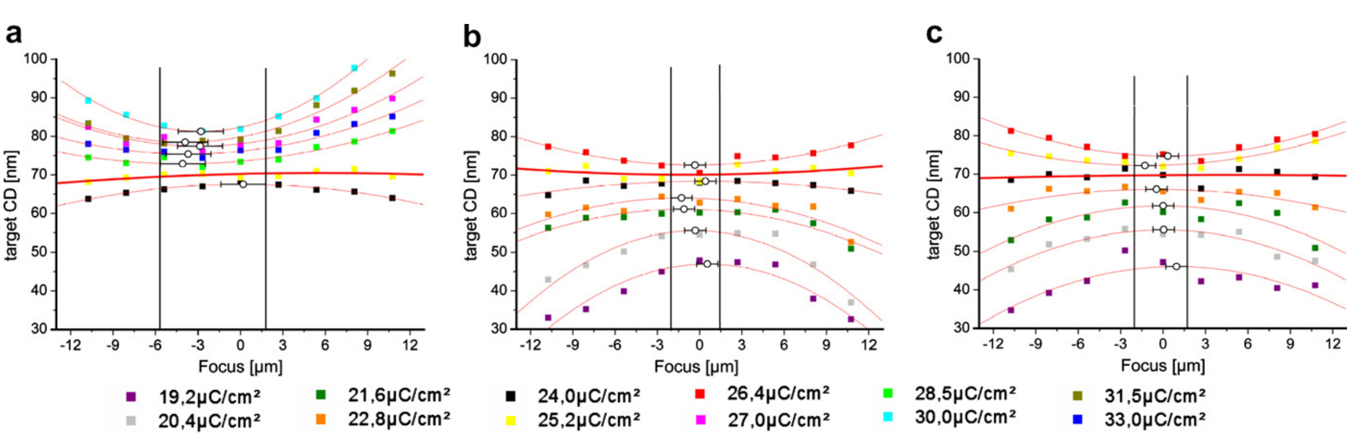

Fig. 1. Bossung plots of 70 nm dense horizontal lines at different sites in Dresden (a), Jena (b) and Stuttgart (c).