Available online at www.sciencedirect.com
ScienceDirect
Microelectronic Engineering 84 (2007) 814–817
MICROELECTRONIC ENGINEERING
www.elsevier.com/locate/mee

Fogging effect correction method in high-resolution electron beam lithography

Peter Hudek [a,*], Ulrich Denker [b], Dirk Beyer [b], Nikola Belic [c], Hans Eisenmann [c]

[a] *Vorarlberg University of Applied Sciences, Dornbirn A-6850, Austria*
[b] *Vistec Electron Beam GmbH, Jena D-07745, Germany*
[c] *PDF Solutions GmbH, Munich D-80331, Germany*

Available online 25 January 2007

Abstract

We report on a fogging effect correction (FEC) method to be used in high-resolution e-beam lithography (EBL). In the new version of the previously presented PROX-In software tool, originally developed to determine the numerical proximity parameters for the proximity effect correction (PEC), was now implemented also the possibility of correcting large-range pattern distortion effects in connection with the modified PROXECCO™ tool from PDF Solutions. This allows a complex exposure optimization by dose modulation of long-range fogging and/or loading effects with the standard PEC method using the same corrector. The presented approach is fast and effective, does not use any special additional technology steps and uses only standard high-resolution measuring techniques. The reviewed method was successfully implemented into mask production at different absorber stacks. It is also used for the determination of FEC input parameters and complex exposure optimization in e-beam direct write and step and flash imprint lithography (SFIL) template manufacturing with sub-50 nm resolution capability.

Keywords: e-Beam lithography; Fogging effect; Proximity effect; Maskmaking; Direct writing

1. Introduction

The electron fogging effect [1] is caused by a very broad energy band of electrons that are re-scattered by the lower surface of the objective lens pole-piece (Fig. 1) and from the stages or substrate holders of the e-beam writer. FEC is executed to achieve a better global CD-uniformity (GCDU) of resist patterns within a mask plate or a wafer. The global loading effect, dominant in post-exposure processes (development [2], dry etching [3]), causes an additional CD deviation of the transferred patterns.

Both effects are critical issues (at higher acceleration voltages) in high-end technology nodes, especially in mask making for complex designs, where the pattern density is not uniform and the correction must be executed as a function of the global pattern load.

The first rough reduction of the re-scattering of electrons can be done by using a specially structured anti-fogging plate [4], made of low atomic number materials and placed between the pole piece of the last lens of the exposure tool and the resist/substrate. The fogging reduction effect depends on the plate quality and tool-chamber environment, but using this plate, the fogging effect can not be fully eliminated. Further improvement of the writing uniformity is only possible by application of an additional dose correction, similarly as used in the PEC.

The new version of the previously presented PROX-In [5] software tool, originally developed to determine the proximity-control point spread function (PSF_{PEC}) for an arbitrary PEC system[1], was enhanced also to the possibility of correcting large-range pattern distortion effects in connection with the modified PROXECCO™ [6] tool from

* Corresponding author. Tel.: +43 5572 792 7202; fax: +43 5572 792 9500.
E-mail address: peter.hudek@fhv.at (P. Hudek).

[1] Assuming the PEC is based on schemes using a linear combination of double or multiple Gaussian functions and approximating the electron scattering phenomena ("proximity function" or PSF) as described in [7].

0167-9317/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.mee.2007.01.025

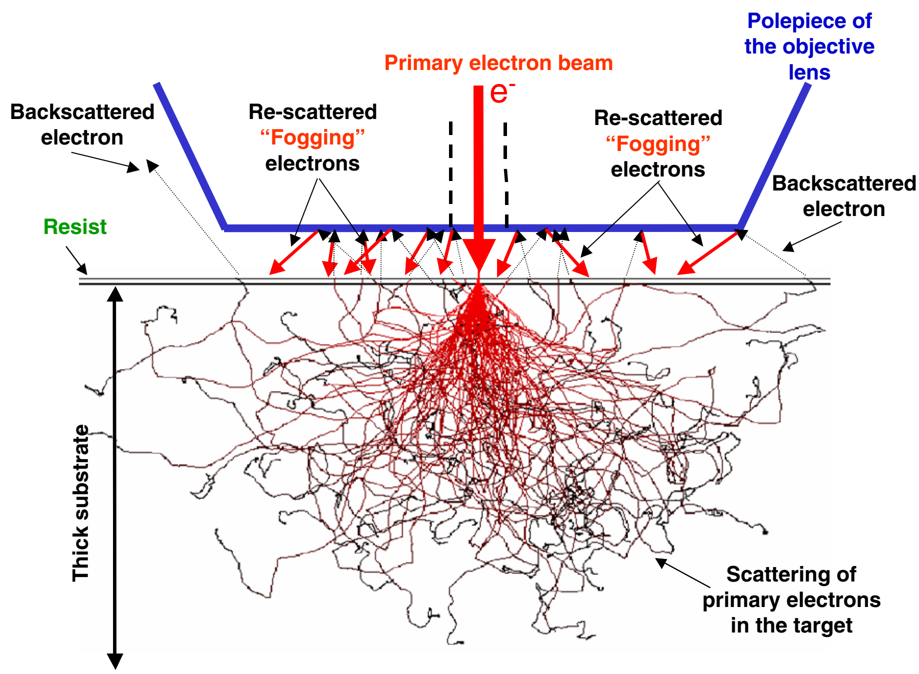

Fig. 1. Fogging effect: the re-scattered electrons produce a broadband background additional parasitic exposure.

PDF Solutions. In this paper the methods will be described, how to extract the additional numerical fogging parameters for the common point spread function ($PSF_{PEC+FEC}$) and how to proceed with the exposure optimization using PROXECCO corrector to achieve tighter dimensional control in the high-resolution mask- and direct-write EBL.

The experimental work including test exposures and verification of the correction were performed using Vistec SB350 and Vistec SB3050 variable shaped electron beam writers.

2. FEC method description

2.1. FEC-parameter determination

PROX-In applies a combination of experimental measurements and simulations to extract an effective n-Gaussian PSF for a given EBL process [5]. Before starting with the FEC, the main proximity-PSF_{PEC} (Fig. 2a) must be already correctly estimated for the current process. The main task of the long-range FEC is to determine a reasonable set of – at least two – additional numerical (again assumed to be Gaussian) parameters for the fogging PSF_{FEC} (Fig. 2b): γ_F = "Range" and ν_F = "Weight". γ_F - characterizes the lateral spread of the fogging electrons (fogging-scatter characteristic range), i.e. the influence of the FEC at different positions depending on the current pattern loading within the substrate. ν_F – represents the relative fogging intensity.

The FEC parameters can be extracted by measurements on a carefully processed substrate (mask/wafer). The fogging-test layout (Fig. 3) uses the whole area of a 6-in. mask substrate (the layout may also be exposed on 8-in. or larger

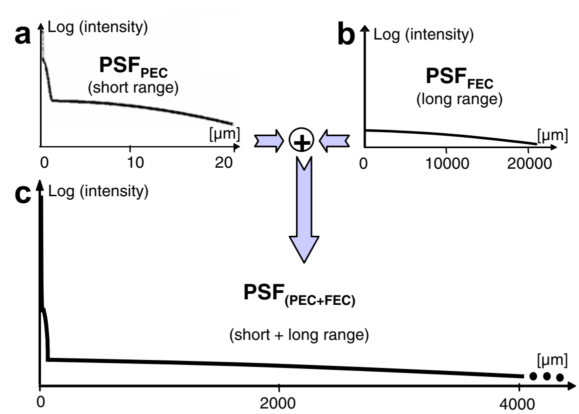

Fig. 2. Resulting control function $PSF_{PEC+FEC}$ (c) for pattern distortion effect correction as a combination of both proximity PSF_{PEC} (a) and long-range PSF_{FEC} (b) obtained from PROX-In 0. The numerical parameters of this combined function $PSF_{PEC+FEC}$ (c) are used as the input parameters for the PROXECCO^{TM} corrector.

wafers) and contains two main groups of proximity corrected patterns ("I" and "II") consisting of single lines and other test structures. A large "fogging-area" is created by exposing approx. 1/4 of the substrate area using the *Base-Dose* [5] [2].

The initial determination of the values for γ_F and ν_F requires measurements over the pattern group "I" in x or y direction. "I" contains 23 identical test patterns (isolated lines) written along a substrate with a period of 3000 µm. Test-features located closely to the substrate edge should

[2] Base-Dose = a dose adjusted to give the correct linewidth for the equal line/space case.