A multi column lithography system for low and medium volume mask manufacturing

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In the paper is presented multicolumn e-beam lithography (MCL) system intended generally for production of templates.

The system was designed in two versions: with Schottky emitter and LaB_6/CeB_6 emitter.

System with Schottky emitter can be used for both mask making down to 7 nm HP node and for direct writing for 22 nm HP node. The system with LaB_6/CeB_6 cathode is for mask manufacturing with technology 45 nm HP node.

System consists of four small size columns with diameter about 70 mm. Accelerating voltage is 50 kV. Operating total beam current for the first system can be as high as 2 μA, for the second one – 1.2 μA. Writing speed on PMMA resist with sensitivity 100 μC/cm2 – 0.02 cm^2/sec and 0.012 cm^2/sec. Throughput is between 0.5 ÷ 1 mask per hour.

In the paper also there is a comparison of MCL and VSB (variable shaped beam) systems.

Keywords – e-beam lithography, Gaussian beam, mask manufacturing, multicolumn systems, variable shaped beam.

Introduction

In the last decade e-beam lithography finds more and more broad application in various fields of microelectronics as when developing new devices and directly in technological lines for production of integrated circuits. The main efforts of developers are focused on creation of high-throughput e-beam systems for technology nodes 22 nm and below.

The purpose of this project is development of lithography system for the existing technologies from 45 nanometers and above for production mask and replacement of the obsolete equipment. Actually, this project is continuation of the works presented at the EBT 2014 Conference [1].

The main objective of the project is achievement in the range of technology nodes 45 ÷ 250 nm such balance between throughput, writing accuracy and cost of ownership that would make economically justified mask manufacturing for small and medium volume production, in particular, of CMOS Application Specific Integrated Circuit (ASIC).

The aspiration to increase throughput has led to development of multi beam and multicolumn systems.

In turn dependently on beam shape in the target plane multi beam systems are subdivided into units with variable shaped beam (VSB) [2, 3], multi shaped beam (MSB) [4], multi-stencil character projection [5] and Gaussian beam (GB).

The basic difference between multi beam and multicolumn systems consists in the following. In multi beam system there is the one powerful enough cathode. The electronic beam is divided into some amount of beams by means of apertures placed at image plane of demagnifying lens. The lens transfers image of aperture to target plane.

The multicolumn systems (MCS) consist of some number of miniaturized conventional columns with Gaussian beam. Each of column acts independently. Typically, columns form a square matrix of 2×2, 3×3 etc.

As fully complete developments don't exist that now to judge a complex of characteristics including throughput, the accuracy of writing and other parameters isn't possible. Nevertheless, for better understanding of possible application fields of different writing strategies in part 3 of this paper a comparison of throughput of various systems is given.

Electron optics

Electron optics consists of four identical columns (see Fig. 1).

The columns are placed above mask platform as it shown on Fig. 2. The size of standard platform for mask is 153 × 153 mm^2. Write field size is 108 × 128 mm^2.

One can see that any point on platform is accessible for one of e-beam. Therefore, outside part of platform can be used for each column calibration.

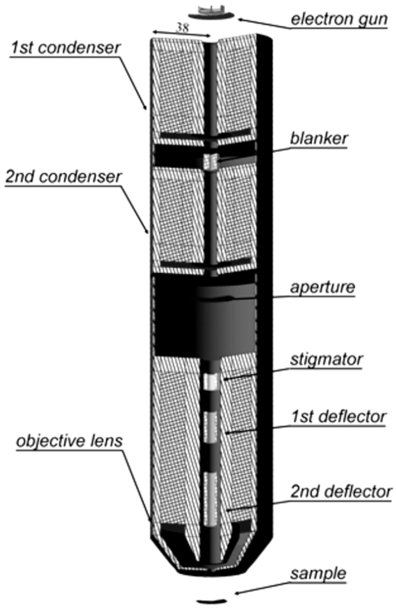


Fig. 1. Cross section of the column .

As it can be seen from Fig. 2 the column diameter should be less than 76 mm. At energy of electrons 50 keV the design of the small size column faces two serious challenges: electrical discharge in electron gun chamber and danger of magnetic lenses saturation. Solutions have been found both at the stage electron optics design and when developing a construction.

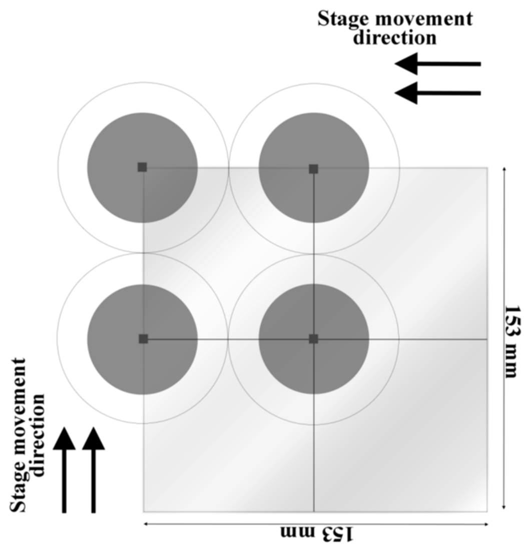


Fig. 2. Configuration of electron optics.

All electron-optical elements as lenses, deflectors, stigmator have been calculated by a finite element method with use of the EOD program [6]. Special attention has been paid to prevention of saturation.

After that synthesis of a column was made and optimization of parameters was performed.

The ideas of optimization consists in increasing a working distance having kept at the same time beam about 20 nm and beam current 300 nA.

First of all, the optimal convergence angle is found in analytical form, using data for chromatic and spherical aberration from EOD (Fig. 3).

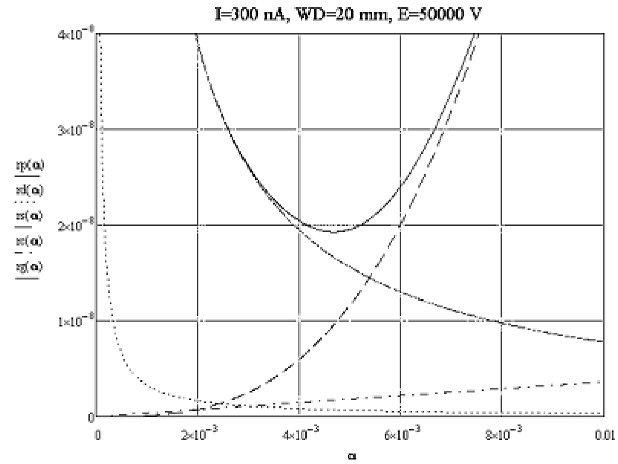


Fig. 3. Dependence beam diameter of convergence angle.

After that value of the optimal angle is used in EOD for simulations of the beam parameters by trajectory method.

Electron optics control

Control of electron optics is the same before [1] and performed by a separate local PC. In multi beam configuration is implemented super PC with throughput 1.3 TFlops/sec.

Main system specifications:

• Accelerating voltage	25, 50 kV
• Beam current	10 – 300 nA
• Beam diameter	10 – 20 nm
• Cathode	Schottky emitter, LaB_6/CeB_6
• Half Pitch Size	45 nm min
• Writing Field Size	100 × 100 μm^2 200 × 200 μm^2
• Dwell time	min. 1.25 nsec
• Deflector	2 stage electrostatic
• Possibility to change dwell time for individual pixel	increment 1.25 nsec
• Writing mode	Write-on-the-fly
• Input data formats	OASIS, GDS
• Detector	BSE

- Throughput, mask/hour 0.3 -1
- On line change focusing in selected area or individual pixel
- Dynamic distortions, astigmatism and focus correction

Comparison of various strategy of e-beam writing

Writing process is described by a formula:

(1) $$I \times \frac{t}{S} = D,$$

where I is beam current, S – irradiated area and D – resist sensitivity.

From (1) follows that the velocity of lithographic process $V = S/t = I/D$ beyond all bounds grows at increase in beam current. However, in practice it is limited by two essential factors: need to distribute a radiation dose evenly along the line of scanning and the clock frequency of pattern generator.

We have chosen from our experience 50 shots on micron for the line and 2500 shots on square micron for the VIA. As clock frequency of pattern generator is 800 MHz that duration of the shortest shot is 1.25 ns. Therefore, the highest possible write speed for the one shot line is 1.6 × 107 µm/sec and for the VIA layers it is equal 3.2 × 105 µm^2/sec.

For comparison we are using data from [3] for CP machine Vistec SB350 OS, 50 keV. As a test structure has been chosen "Starfish" shown on Fig. 4. Shot distribution is shown on Fig. 5.

Other data for write time calculation are provided in Table 1.

Thus, from data and calculations of Table 1 follows that write time for the MCS is less than time of CP and VSB respectively in 4 and 97 times. The result of write time normalized to CP for 1 cm^2 are presented on Fig. 5.

Table 1

Write time and data for its calculation

Write time for one star, µsec		
MCS (GB)	VSB	CP
7.5	728	28
Data for calculations		
VSB, CP – current density – 9 A/cm^2		
MCS I_{beam} = 8.3 nA, dwell time τ = 80 nsec		
Resist sensitivity D = 250 µC/cm^2		

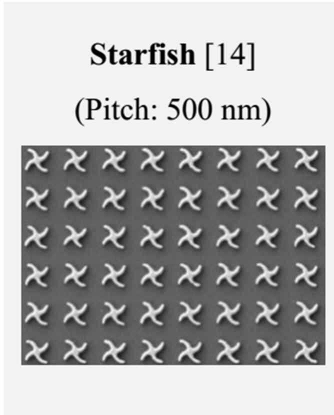


Fig. 4. Test structure Starfish.

Discussion

As the data obtained by us and provided in [3] contradict with each other it is necessary to offer an explanation to this fact.

First of all it has to be noted that we have calculated just write time without taking into consideration other factors. At such approach the ratio of normalized write time for VSB/CP has to be equal 26/1 but not 160/1, as it follows from Fig. 5. Apparently, authors considered some additional losses of time, for example, moving of a stage, alignment procedures, etc.

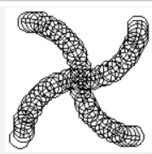
Method	**Gaussian beam[2] (GB)**	**Variable shaped beam[1] (VSB)**	**Character projection[1] (CP)**
Write-shots per star (schematic)	 94 shots per shape	 26 shots per shape	 Resulted in 1 star
Write time normalized to CP for 1 cm² (400 million stars)	150.000	160	1

Fig. 5. Shot distribution for different writing strategies.

Secondly, for comparison SEM based vector scan system with beam current of only 10 pA has been chosen. But in MCS beam current can be 30000 times higher.

In the third, experimental parameters the sensitivity of the resist and density of beam current aren't optimum for VSB, MSB and CP systems.

If CAR resist with sensitivity 10 μC/cm^2 and current density 50 A/cm^2 [4] to use is used, then write time for CP and VSB is 200 nsec and 5.2 μsec correspondingly. Therefore, MCS still overcomes VSB and can compete with CP if it is operating with shortest dwell time 1.25 nsec and beam current is 21nA. In this case write time is 117.5 nsec, but here is not included the time to switch from on curved line to another one.

However, if for shape writing requires more than 160 shots it makes further competition of MCS and CP impossible.

Conclusions

As we can see from above consideration MCS with Gaussian beam can be efficient and competitive tool for mask making for technology nodes 45 ÷ 300 nm.

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