Mask Less Lithography Cluster for Low and Medium Volume Manufacturing

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In the paper is presented a technological cluster for mask less e-beam lithography (ML2) and metrology for fast non destructive defect inspection and review, and for CD, 2D and 3D measurement.

The cluster potentialities comply ITRS targets for the next generations of microelectronics technologies up to 2020.

At the heart of cluster there are four dedicated e-beam based systems:

1. *Electron Beam Direct Writer(EBDW)*
2. *Ultra fast SEM for CD, 2D, 2.5D and 3D measurements (UF SEM).*
3. *Defect inspection system (DIS)*
4. *Ultra low voltage SEM (ULV SEM) with electrons landing energy down to 1V.*

Such a combination of lithography and metrology tools enables one to maximize productivity for particular application while maintaining acceptable cost of ownership.

The cluster forms the basis for start up factories and pilot lines when it is equipped with necessary standard tools for wafer processing. However, the cluster can be used successfully jointly with the mature factories for high volume production.

Безмасков литографски клъстер за ниско- и средно-серийно производство (В. Казмирюк, И. Курганов, Т. Савитская). *В работата е представен технологичен клъстер за безмасковаелектронна литография и метрология за бързо неразрушително намиране на дефекти и обзор , както и за CD, 2D и 3D измервания. Клъстерът има потенциал да съответства на ITRSмишени за следващата генерация на микроелектронните технологии до 2020 г. В сърцето на клъстера има четири електроннолъчеви системи: а) Електроннолъчева експонираща машина; б) Свръх-бърз СЕМ за CD, 2D, 2.5D и 3D измервания; в) Система за инспекция на дефекти; г) СЕМ със свръх-ниска енергия на кацане на електроните – до 1eV. Тази комбинация от литографски и измерителни инструменти позволява да се повиши производителността при специфични приложения при приемлива цена на собственост. Клъстерът формира база за първоначално производство и пилотни линии, когато се екипира със стандартни инструменти за обработка на пластини. Обаче, клъстерът може да се използва успешно заедно с изпитана фабрика за производство на големи обеми микроелектронни изделия.*

Introduction

The electron beam lithography (EBL) and metrology (EBM) are widely used in research laboratories and Universities to provide R&D for a large field of applications. However, their application for manufacturing purposes is limited because of low throughput and high cost of ownership. Nevertheless, the permanent trend of size decreasing leads to the need for more complex optical lithography and masks, and it opens opportunities for high throughput electron beam direct writing (EBDW) systems. One of the possible solutions for EBDW to address ASIC manufacturing is presented in [1]. It was shown that high throughput mask less systems may represent a viable alternative to optical lithography and reduce manufacturing cost by mask budget reduction, especially in the case of ASIC makers and foundries.

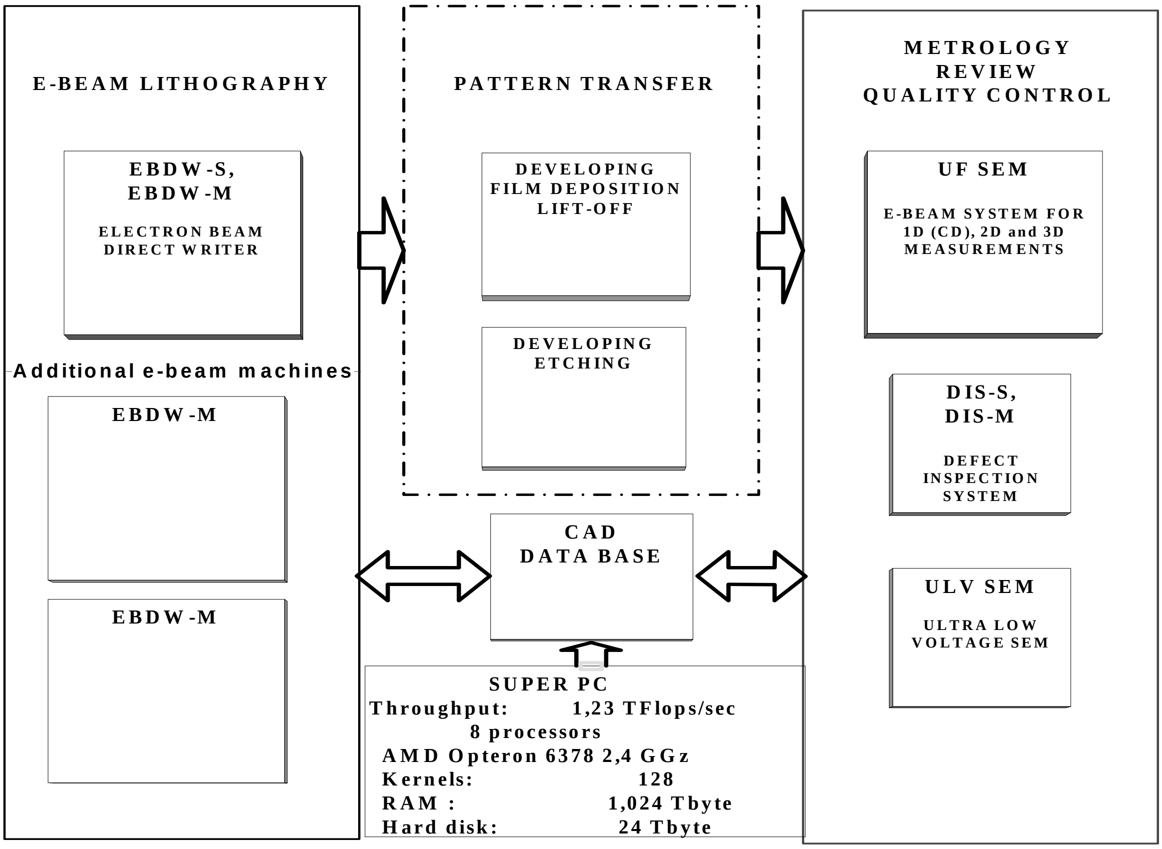

Fig. 1.Cluster configuration

Besides, it was proposed to use 10% of started wafers for prototyping purposes. However, such an approach is suitable for relatively big production volume – 10 000 wafers out per week, and cost of EBDW tools is between 10 to 30 M$. Therefore, it could be a solution for R&D departments at maturity factories.

EBM is used in most of the core technology processes [2]. Its applications beyond imaging include CD, 2D and 3D measurements along with defect detection, review and automatic classification. Conventional SEM based measurement methods have severe limitations when considering the issues presented by the 90 nm nodes and lower because of low throughput. The capability to improve throughput and perform a complete verification of the entire die was demonstrated in [3]. Optimization of e-beam systems for defect inspection and die-to- database verification was presented in [4], electron optics design of single beam and multi beam systems as well as their application have been considered in [5-7].

Presented work is focused on a methodology of joint application lithography and metrology tools at different stages of new product development (NPD) process, and mainly on the step of prototype development and fabrication. Also featuring a cluster configuration and specification of the basic characteristics of electron-beam systems is presented.

Cluster Configuration

The cluster could be configured from the following e-beam tools (Fig.1):

Electron Beam Direct Writer with single or multi columns –**EBDW–S, EBDW–M**

Ultra Fast SEM for CD, 2D and 3D measurements – **UF SEM**

Ultra Low Voltage SEM with SE spectrometer and Aberration Corrector – **ULV SEM**

Defect Inspection System with single or multi columns **--- DIS-S, DIS-M**

The key feature of these e-beam tools is a modular design which expanded on all sub-systems, including electron optics, control electronics, wafer stages and software. Such a way each tool can be additionally adapted to meet in the best way the user’s particular needs.

There are available single or multi column configuration both EBDW and DIS. The number of columns *N* depends of wafer size and such parameters as Writing Field Size (WFS) and HP size. Considering throughput and other technical parameters together

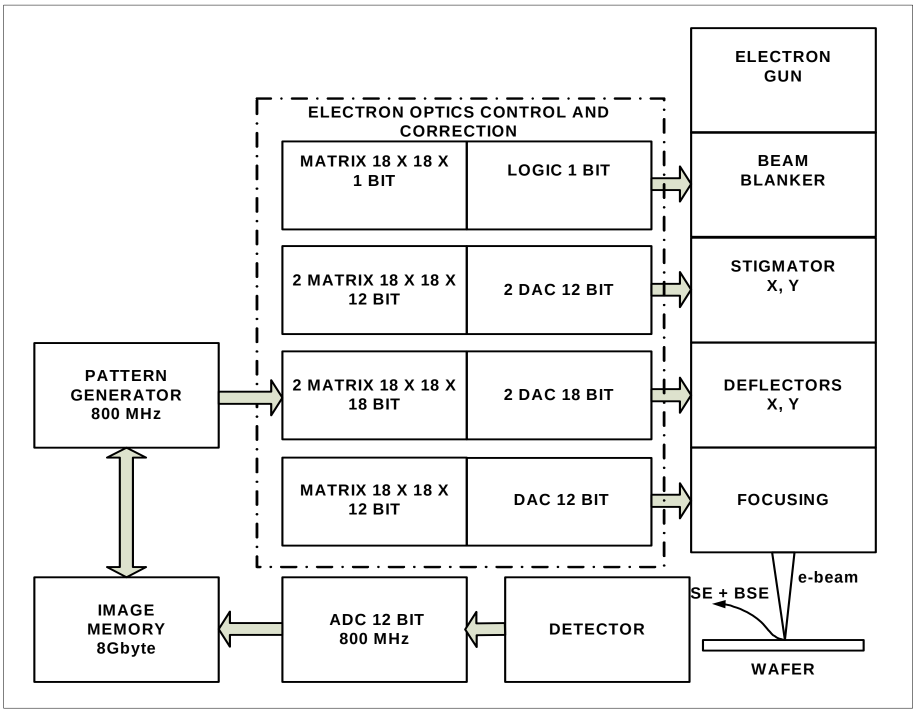

Fig.2. Control of e-beam tool electron optics in lithography and image acquisition mode

with cost of ownership we have found that for HP=22 nm and 200 mm wafer optimal *N* is 9, and *N* =15 for 300 mm wafer.

Main system specifications

• Accelerating voltage	1V to 5.0 kV
• Beam current in lithography and defect inspection mode	10 – 50 nA
• Beam current in verification mode	1 – 10 nA
• Beam current density	60 kA/cm^2
• Resolution in verification mode	1 – 5 nm
• Half Pitch Size	22 nm
• Writing Field Size	400 x 400 μm^2
• Dwell time	min. 1,25 nsec
• Beam velocity in vector scan mode	20 km/sec
• Possibility to change dwell time for individual pixel	increment 1,25 nsec
• Acquisition rate	800 Mpixel/sec
• Detector efficiency	95% for SE&BSE
• Throughput, wafers/hour	1 -10

- On line change focusing in selected area or individual pixel
- Dynamic distortions, astigmatism and focus correction

Further, depending on the task, the volume of production and the company's budget there are possible various combinations of e-beam systems. The workhorse of the cluster is a pair EBDW – UF SEM, although on a limited budget, one can start even from single UF SEM.

Electron optics control

Control of electron optics is the same for all instruments and performed by a separate local PC. In multi beam configuration is implemented super PC with throughput 1,3 TFlops/sec. In Fig. 2 is shown part of the fast electronics responsible for image acquisition as well as e-beam scanning and correction. For correction each DAC module has on board a memory up to 6 Gbytes wherein the correction data recorded .for e-beam position, focusing and stigmator. Such a way, when e-beam is addressed from CAD design to some point X_0, Y_0 these data are automatically converted into a space of the sample, and simultaneously determines focus and astigmatism correction. An advantage of this solution is that no additional time is required to set the desired parameters of the beam. Furthermore, it may be implemented a number of new algorithms. For example, the dwell time of each pixel can be set independently, which enables on line dose modulation for proximity effect correction or 3D lithography. Another advantage is the ability to minimize the diameter of the e- beam at a sufficiently large field of 400 x 400 μm^2. In image acquisition mode, along with increased accuracy of 2D measurements focus control allows to obtain images of three-dimensional objects at precisely controlled height position of the beam focus point relative to the surface, and hence improve the accuracy of 3D reconstruction.

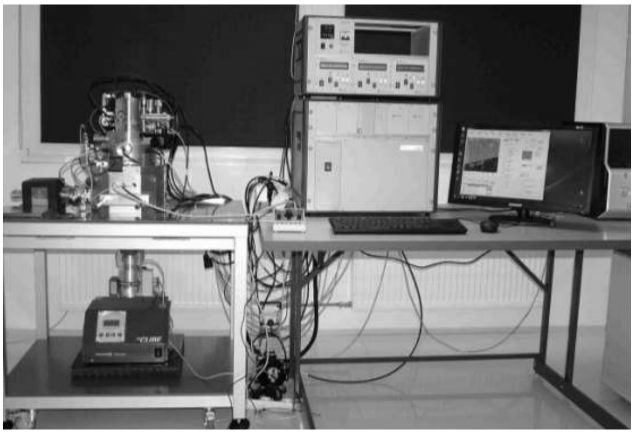

Fig.3. UF SEM prototype

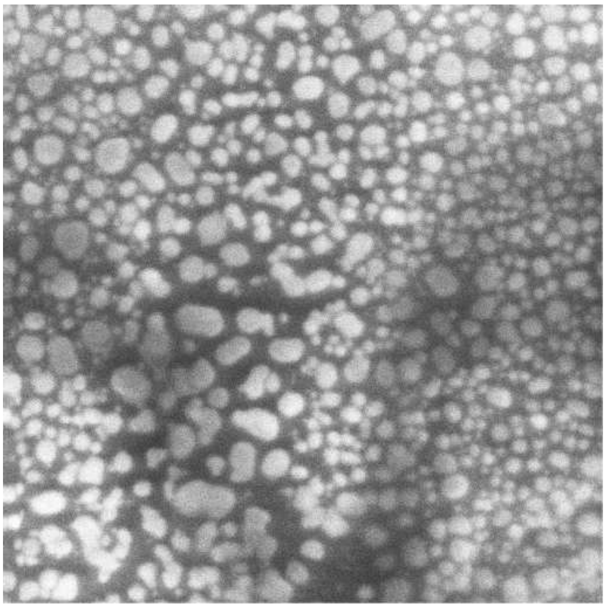

Fig.4. Test Image. Sample – gold particles on carbon. Image format: 8192x8192 pixels; field size – 690 nm; beam current -0,8 nA; acquisition rate – 200 MPixel/sec

The results

To date has been designed, manufactured and fully tested a prototype of electron-optical system in configuration UF SEM (Fig.3). Basic parameters as resolution, scanning field and others were evaluated by standard methods. To verify the information capabilities was used methodology described in [4]. Estimates produced by the images of test structures - gold particles on carbon (see Fig.4) obtained under well-defined experimental conditions. The results are shown in Table 1.

Table 1.

UF SEM		
Parameter		Value achieved
Resolution, nm		2
Beam Current Density, kA/cm^2		62
Detection Efficiency, %		~90
Acquisition rate, µC/sec	d=2nm	1,17 x 10^{-2}
	d=20 nm	1,17
Dwell time, nsec for s/n = 10	d=2nm	1,4
	d=20 nm	0,014
Quality factor (throughput/price), a.u.		2170
Scan field, µm x µm		400 x 400

Besides, there were developed and manufactured the basic electron optical elements of ULV SEM and electron beam column for multi beam configuration.

Application of pair UF SEM – EBDW at the stage of microelectronics device prototype development and fabrication

The main objectives at the step of prototype development and fabrication:

- Development of the complete technological process, including process steps, process modules, and complete process sequences.
- Perform process integration for the development of a complete fabrication process
- Development detailed documentation, perform statistical analysis, and transition to production.

One of the most powerful methodologies for fast prototyping called Design for Manufacturing (DFM). As any statistical method it can not only determine the best conditions for particular case, but also to identify the common functional dependences of the process parameters. In turn, this helps to clarify the physical model for lithography, ion etching and implantation, and to adjust parameters of e-beam tools. In our case, these parameters are the distortions, astigmatism and correct focus position upon the whole writing field.

With respect to the development of microelectronic structures it may be implemented as follows:

- For each elementary process step is performed lithography of test patterns with variable parameters. The total number of test pattern in one set is 80 – 100 pieces, which allows one to get representative data for statistical analysis.
- After each technological step are acquired images of all the patterns with required lateral resolution and signal-to-noise ratio (s/n).
- Carry out a full statistical analysis of the images

Table 2.

Comparison of the Standard EBL-SEM and EBDW-S, UF SEM pair at stage of prototyping

e-beam tool	Exposure time HP= 22 nm Writing field 200 x 200 μm^2		Image acquisition time in 2D measuring mode, Resolution =1 nm		Image acquisition time in 3D measuring mode, Resolution =10 nm Measured depth -50 μm	
	1 pattern	80 patterns	1 pattern	80 patterns	1 pattern	80 patterns
Standard EBL-SEM	10 sec	≈2 hours	≈111 hours	222 work weeks more than 4 years	555 hours	22,2 years
EBDW-S UF SEM	20 msec	1,5 min	200 sec	5,6 hours	1,11 hour	≈ 2 weeks

[1] Correct choice of resolution and s/n is very important because it has a significant impact on the throughput of metrology system. As for instance, if half pitch (HP) size is 22 nm and measurement accuracy has to be 5%, then both resolution and pixel size 1 nm should be selected. In other words, to see the spot exposured in resist by e-beam diameter of 20 nm in one shot, each spot must be scanned by matrix of 20 x 20 pixels with size of 1 nm This circumstance decreases the system throughput automatically at least to 400 times if dwell time for pixel irradiation both for lithography and image acquisition is the same. However, the current of the beam focused into spot 1 nm is much lower than for beam 20 nm. Therefore, in image acquisition mode (IAM) dwell time should be additionally increased in 10-50 times to get desirable s/n ratio. At whole, IAM is slower in 8000 – 20000 times than lithography.

At R&D step for lithography and image acquisition often is used the same commercially available lithography machine equipped with SE or BSE detector. To investigate the possibility of such a strategy at the step of prototyping, consider the time for lithography and image acquisition for set of 80 test patterns for such a system and compare it with time for presented pair EBDW–S as single beam lithography system and UF SEM as a metrology system.

At Table 2 is given a comparison of application standard combination EBL-SEM and presented pair EBDW-S and UF SEM at the stage of prototyping of two- and three dimensional structures with half pitch size 22 nm. It is assumed also that depth of 3D structure is 50 μm.

Discussion

One can see from the Table 2 that at DFM process of prototyping the main limiting factor is not low throughput of EBL tool, but low acquisition rate of SEM. Because of the last one, in fact, the feedback between process parameters and experimental results is broken. Therefore, DFM methodology can not be implemented for standard combination EBL-SEM. Moreover, even for one test pattern image acquisition time is about 3 working weeks, which makes such a procedure impractical. In the contrast, presented UF SEM can do both lithography and imaging set of 80 test patterns in one working day. At 3D measurement mode, when a structure is deeper than 3-5 microns, the situation becomes hard even for UF SEM. Direct implementation of approach used in light confocal microscopy is very time consuming. Therefore, new approaches and image processing algorithms have to be developed.

Conclusion

It is demonstrated high efficiency of developed e-beam tools for application in production, especially at the stage of prototyping.

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