INFLUENCE OF BACKSCATTERED ELECTRONS ON THE QUALITY OF STRUCTURES IN THE THIN RESIST LAYER PATTERNED USING E-BEAM WITH THE GAUSSIAN DISTRIBUTION OF ELECTRON ENERGIES

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1. Introduction

In the past decade, the feature size in ultra large-scale integration (ULSI) has been continuously decreasing, leading to nanostructure fabrication. Nowadays, various lithographic techniques ranging from conventional methods (e.g. photolithography, x-rays) to unconventional ones (e.g. nanoimprint lithography, self-assembled monolayers) are used to create small features. The current development is concentrated on multiple sub-22nm lithography technologies, including immersion ArF lithography extensions, EUV and e-beam lithography. Among all these, resist-based electron beam lithography (EBL) seems to be the most suitable technique when nanostructures are desired. The achievement of sub-22-nm structures using EBL is a very sensitive process determined by various factors, starting with the choice of resist material and ending with the development process.

2. Experimental

2.1 Experiment

E-beam patterning suffers from the laterally scattered electrons that passes through the resist layer (forward scattering) as a fraction of the dose is returns in the solid substrate after backscattering. It is very useful to know how this influences the deformation of structure shapes. The accurate definition of patterned structures is limited mainly by the electron scattering well-known as proximity-effects [1]. Although other effects, like local-heating and charging, caused by interactions of electrons with the resist/substrate binary system, must not be neglected, the main factor influencing the accurate definition of patterned structures in resist are backscattered electrons from the substrate .

Estimation of the lithographic parameters is required for the correction of pattern-distortions as are proximity-, local-heating- and charging effects caused by the electron scattering in the resist/substrate material.

Line edge roughness (LER) or the linewidth fluctuation becomes a serious issue when the pattern size shrinks. For nanolithography, the LER should be as small as possible in order to avoid pattern distortion or deterioration of the resolution. The σ value (the root mean square (RMS) of the fluctuations in edge position) is the most frequently used parameter for characterization of LER. A typical measured value for LER is about 3 nm [2] or 10 nm (3σ) [3], when resists with a very high contrast are used. The linewidth, the line width roughness and the line edge roughness of structures created by e-beam irradiation in e-beam resist have been investigated to evaluate the influcence of backscattered electrons in nanopatterning. For this purpose, the stripe exposure test and the exposure wedge test have been designed with a simple editor available in the SEM operating software which allows the manual adjustment of the exposure dose only. The exposure wedge test was used to extract the dose-to-clear and the contrast numerical value from the characteristic curve. The strips exposure test contains isolated lines and gratings exposed in single line mode in order to obtain the highest resolution. The stripes are written with a beam step size (the distance between two adjacent pixel exposures) that is as small as possible. Depending on the designed linewidth, an exposure is performed by scanning the beam once (single pass) over one (single exel) or n adjacent lines (n-exel line). The exposure dose for individual shapes was controlled by varying the e-beam dwell time, while keeping the electron energy at 30 keV and the current density of the incident beam constant. Thus, it was possible to derive the sensitivity curve, the dose compensation curve, as well as to evaluate the proximity effect parameters. Observation and measurement of the test structures details enabled us to determine the influence of the proximity effects on the resulting pattern deformation.

2.2 Equipment

As the quality of equipment is an important factor in nanopatterning, there is a more detailed description of the equipment related characteristics. All experiments have been done using the scanning electron micrsocopy VEGA II SBH (*TESCAN*) equiped with control system for nanolithography (*developed by TESCAN*). E-beam spot size determinates resolution of the microscope as well as an usable magnification. Mostly, it is supposed that the spot is circular and has got Gaussian intensity profile. So we can specify its size e.g. with half-width of intensity distribution. If there are no aberrations of the optical system taken in the account the spot size is determined with the size of the electron source and its demagnification. Practically, the spot size is influenced by the optical aberrations of the objective lens. VEGA II SBH is equipped with thermal emission cathode, accelerating voltage in the range of 1 – 30 kV, the minimal probe size can be around 7 nm at 10 pA beam current (indicator on the panel), but for the most experiments it was 15 nm at 30 pA due to a smaller noice. The beam current is adjustable in the range of 10 pA to 10 nA and it was measured using the Faraday cup on the sample holder. The probe parameters influence each other, so the mode "operation at the high magnification" was used, when high resolution, small spot size as well as aberrations of the lens (short working distance), small aperture angle, small probe current and slow scanning speed are used. The maximal reasonable write field size is around 800x800 μm^2 but for nanolithography is rather 200x200 μm^2 due to electron optics distortions. The working distance is variing from 2 up to 12 mm, but for lithography it was usually 4 mm as the lens aberrations grow less due to the shortened working distance. Writing speed was 10 MHz area mode, 2ns resolution. Maximal sample size is 1”. There was no stage laser interferometer, so the test was designed for one working field. Current stability 0.5% per hour what was enough for tests exposures. For data preparation, there is a very simple editor, which allows to design exposure tests for lithographic parameters evaluation.

2.3 Materials

The other crucial factor in e-beam nanopatterning are materials sensitive to electron irradiation. Over the past decades, different types of resist materials have been investigated. As the most exploited resist for high resolution e-beam lithography has been used polymethyl methacrylate (PMMA) since it was discovered [4]. In conclusion, PMMA can be used to reproducibly obtain patterns with nm sizes. The resolution can be improved by adjusting different steps of the lithographic process such as the writing strategy or the development process. The fabrication of very small structures were reported (<5 nm) in [5, 6].

PMMA (*Microchem*) with 950 000 high molecular weight has been chosen for nanostructure pattern transfer due to its high resolution, high contrast for EBL exposures, uniform resist coating, long shelf life, and good adhesion to most substrates. The investigation of negative organic resist SU-8 (*MicroChemicals*) under e-beam exposure have been performed because of very high sensitivity and very good dry etch resistance.

3. Results

The bacscattered electron are simulated by method of Monte Carlo. Figure 1 is showing an example of Monte Carlo simulation for electron energy 20 keV and 1000 electrons [7].

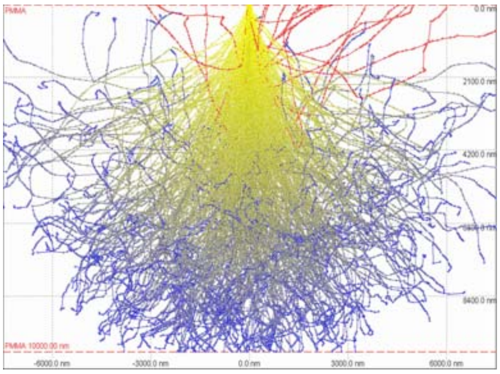
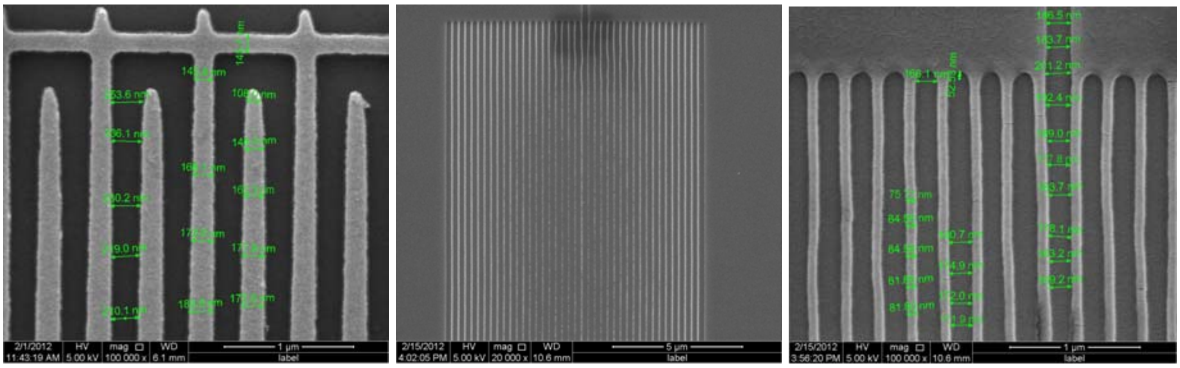


Fig. 1 *An example of Monte Carlo simulation of electron scattering in solid*

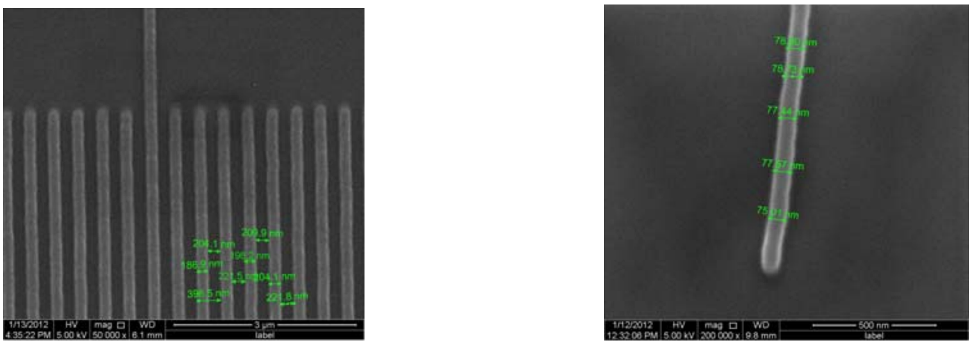
Nevertheless, experimental investigation is important as this method doesn't include the influence of the development process and equipment related characteristics. Some observations in case of PMMA positive resist are shown in Fig. 2. The area of remarkable influence of backscattered electrons is around 3 μm. The end of stripes is of 20 % narrower as in the middle. Stripe are made by lit-off method using PMMA positive resist. b) The linewidth in the middle of periodical stripes is significantly less as at the border. c) The minimal linewidth of stripes in PMMA resist achieved was 83 nm with the space 175 nm.



a) b) c)

Fig. 2 *The influence of backscattered electrons: a) at the end of submicrometer stripes.*

The influence of backscattered electrons in the case of the negative resist SU-8 is is denstrated on Fig. 3. The linewidth of the single line is the same as the linewidth of periodical stripes, so the influence is negligible in this case. Line/Space of periodical stripes is 200 nm. The minimal linewidth 77 nm achieved is shown in Fig. 3 b). It was exposed with 15 nm probe size.



a) b)

Fig. 3 *Stripes exposed in SU-8 negative resist at 30 keV.*

4. Conclusions

The limitations e-beam nanostructure paterning was investigated for the Gaussian e-beam at 30 keV electron energy. The influence of backscattered electrons on the accurate definition of patterned structures in e-beam resist was evaluated. The use of SEM based e-beam lithography system VEGA II SBH (*TESCAN*) for patterning of structures with dimensions below 100 nm was demonstrated. The minimal linewidth 77 nm for the single line and periodical stripes with Line/Space 83/175 nm was achieved.

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