EXPOSURE TIME COMPARISON BETWEEN E-BEAM WRITER WITH GAUSSIAN BEAM AND VARIABLE SHAPED BEAM

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Abstract

One of the main goals in e-beam lithography is to increase exposure speed to achieve higher throughput. There are basically two types of electron-beam writers, shaped beam lithography systems and Gaussian beam lithography systems. The exposure time of both e-beam writers consist in essence of beam-on time, deflection system stabilization time and stage movement time. Exposure time testing was carried out on two types of patterns. There were completely filled in areas, binary period gratings (ratio 1:1 between exposed and unexposed areas), and multileveled structures (computer generated holograms). Exposures data was prepared according to standard technology (PMMA resist, exposure dose, non-alcoholic based developer) for both systems. The result of experiment shows that variable shaped beam system has advantage in multileveled structures while the Gaussian beam system is more suitable for gratings type of pattern. It was proved that combination of both systems has its use to increase exposures throughput.

Key words: e-beam writer, Gaussian beam, variable shaped beam

1. INTRODUCTION

The e-beam lithography based on the direct exposure of the electron sensitive resist by focused electron beam is most frequently used technique for micro and nano structures preparation [1]. Originated almost 50 years before this technique is continuously developed both on the side of instrumentation and on the side of technological processing. One of the main goals nowadays in the e-beam lithography is to increase exposure speed in order to achieve higher throughput.

There are two basic types of e-beam lithography systems, shaped beam lithography systems [1]2[3]**Chyba! Nenalezen zdroj odkazů.** and Gaussian beam lithography systems. Besides this basic types, the development yield non standard solutions, for example multi-beam systems where are hundreds parallel beams [5] or so called multi-shaped beam systems [6]. The progress is in motion in electron gun, electron optical column and in stage as well. However, the Schottky electron emitter is typically used in electron gun of the current systems. Two e-beam lithography systems incorporating in our laboratories use Schottky emitter too. First, variable shaped e-beam lithography system BS600, working with fixed electron energy 15 keV and resolution 100 nm [7]. And second, Gaussian e-beam lithography system, working with electron energy of 50 keV or 100 keV and resolution 10 nm (Figure 1).

Our aim is to utilize the advantages of both different lithography systems in order to increase the exposure speed, thus the throughput. Every aspects of the complete lithography process such as device itself, electron resist and its treatment before and after exposure, data preparation process, proximity effect correction procedure and so on affect this parameter. Theoretical comparison of both systems is nearly impossible. Therefore, this contribution deals with the exposure time comparison between two e-beam writers based on the real testing exposures. The comparison should give us the conception what type of pattern is more suitable (from exposure time point of view) for each system.

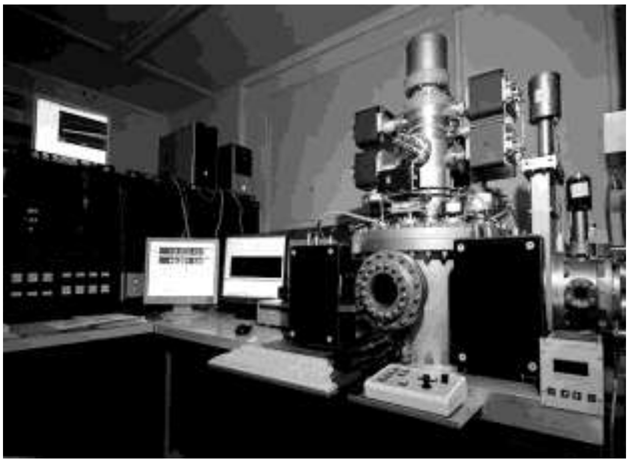


Fig. 1 Variable shaped e-beam lithography system BS600 (left) and Gaussian e-beam lithography system Vistec (right).

2. WRITING SPEED AND EXPOSURE TIME

Usually, the writing speed is not stated in data sheet of the system, for that reason it is difficult to compare different systems. We tried to make at least rough comparison of shaped beam lithography system and Gaussian beam lithography system.

Let's take the current *I* in an electron beam as a basic parameter for determination of the writing speed s_w. The period *t* needed for filling of exposed area A_E using desired exposure dose *D* can be derived from definition of the dose

$$D = Q / A_E \quad [\mu C/cm^2; \mu C, cm^2] \tag{1}$$

and the charge

$$Q = I \cdot t \quad [\mu C; \mu A, s] \; . \tag{2}$$

Considering there is no sense to expose homogeneous area, let's take into account percentage of the exposition area by introducing the filling parameter *p* [%],

$$A_E = A_o \cdot p / 100 \quad [cm^2; cm^2, \%] \, , \tag{3}$$

where A_0 is the total size of exposure and A_E is the area really drawn with electron beam. Then writing speed s_w is

$$s_w = \frac{A_0}{t/3600} s = 3600 \frac{I}{D} \cdot \frac{100}{p} \cdot s \quad [cm^2/hour; cm^2, s; \mu A, \mu C/cm^2, \%] \; . \tag{4}$$

The coefficient *s* represents the impact of the electron beam current on the writing speed. Systems with variable-size beam have the beam current variable depending on the currently used stamp size. Systems with Gaussian beam have the beam current always constant. The unit [cm²/hour] was chosen for writing speed because its practical importance for commonly exposed structure size and time.

Basic comparison of the systems with Gaussian beam and system with variable-size shaped beam based on Eq. (4) is shown in Fig. 2. As follows from principle of constant current in electron beam during exposition with Gaussian beam the writing speed is almost constant and independent of resolution of exposition, i.e. spatial frequency of lines and fineness of details, thus coefficient *s* is constant and equals 1. System with shaped beam reaches the highest writing speed for low resolution exposition where highest stamps are used, thus the utilization of primary beam current is maximal. For area of exposition with finer resolution a lower size stamps must be used and writing speed decreases significantly. It is evident, that such systems with Gaussian beam are not usable for exposition of high area masks (about 100 cm^2). The system with shaped beam can be used for exposition of such masks only in the case that the large part of the mask uses small resolution and only minute part uses high resolution.

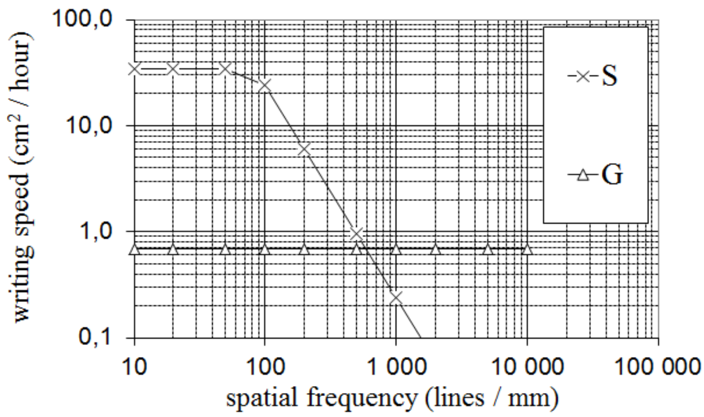

Fig.2 Writing speed comparison between shaped beam lithography system (S) and Gaussian beam lithography system (G).

In the case of real exposure we have to take into account not only total time t_{BEAM} when beam is on (corresponding to writing speed s_w) but we have to add total beam deflection settling time t_{DEFL} and total time of stage movement. Thus the total exposure time t_{EXPO} must be calculated as

$$t_{EXPO} = t_{BEAM} + t_{DEFL} + t_{STAGE} \quad [s; s, s, s] \,. \tag{5}$$

In practice, deflection system settling time and stage movement time significantly contribute to the total exposure time. What is more, these times strongly depends on the way how the data preparation software manipulate with the data and on the exposure strategy of the lithography system itself. Thus, in order to minimize the exposure time the user of the lithography system has to deeply understand the whole process. Unfortunately, due to the complexity of this process we have to conclude that only experiment consisting of identical testing exposures made on different lithography systems can brings relevant data for exposure time comparison.

3. EXPERIMENT

Exposure time testing was carried out on two typical types of pattern, binary gratings and multilevel structures. The set of identical structures, continuous area of 10 mm × 10 mm, gratings with periods 2 μm, 1 μm, 500 nm, 200 nm and multilevel structures with 2, 10, 50 and 255 levels, were exposed on both lithography systems. The gratings and multilevel structures of area of 2×2 mm were designed. You can see the examples of the used structures in the Figure 3.

The exposures on variable shaped lithography system BS600 were made in both standard mode (ST) and stamp reduced mode (TZ). The testing exposures for both lithography system were design in order to achieve the same results from the point of view of depth of developed relief (150nm standardly). So, we used for testing on the one hand the structures with one main exposure time (binary gratings) and on the other hand the structures with the set of different exposure time used (*n* level structures with *n* different exposure times). The proximity effect correction was done in both cases. The results are summarized graphically in the Figure 4.

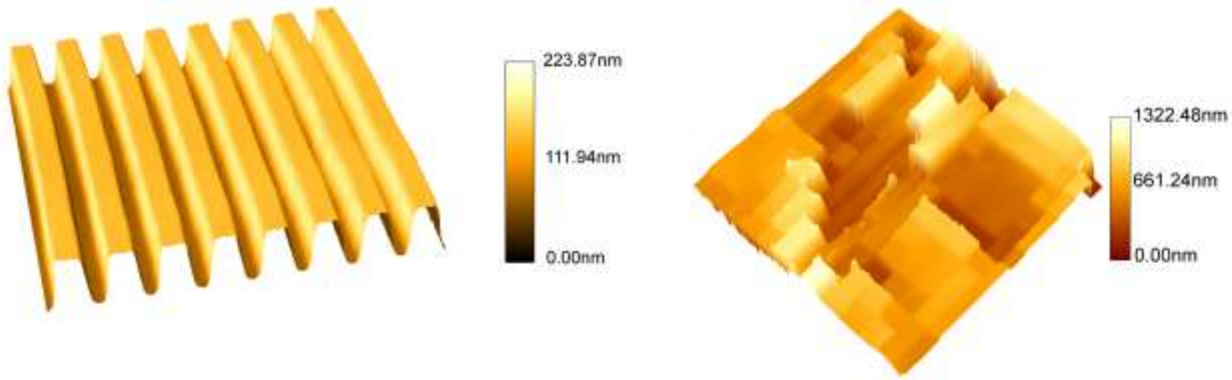

Fig. 3 Binary period gratings (ratio 1:1 between exposed and unexposed areas) with period 1 µm (left), and multileveled structures (computer generated holograms) 25 µm × 25 µm (right).

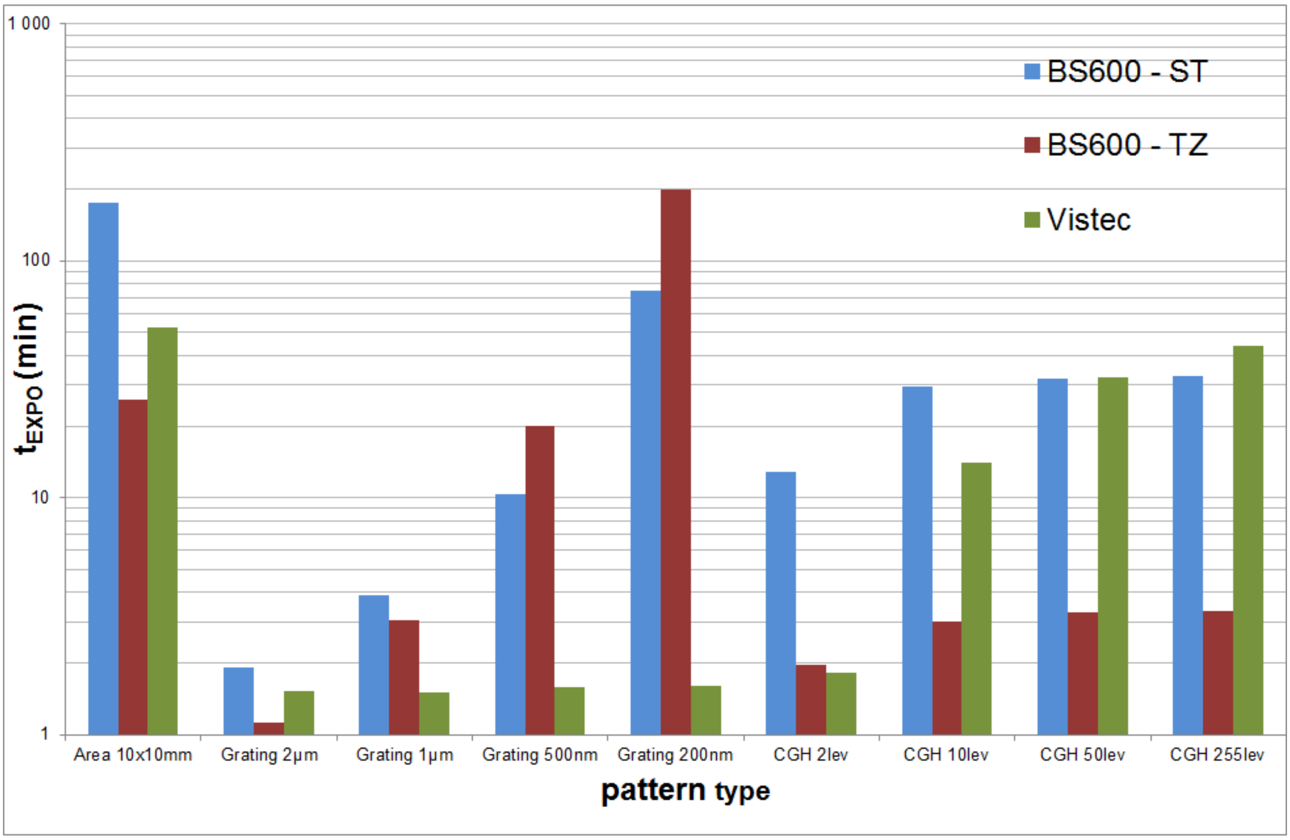

Fig. 4 Exposure time comparison for variable shaped beam lithography system BS600 and Gaussian beam lithography system Vistec on various pattern types (continuous area of 10 mm × 10 mm, gratings with periods 2 µm, 1 µm, 500 nm, 200 nm and multilevel structures with 2, 10, 50 and 255 levels).

3. RESULTS

Exposure time testing was carried out on various types of patterns. There were completely filled in areas, binary period gratings (ratio 1:1 between exposed and unexposed areas), and multileveled structures (computer generated holograms). The resolution was chosen with respect to achievable resolution of variable shaped beam lithography system BS600. Exposures data was prepared according to standard technology (PMMA resist, exposure dose, non-alcoholic based developer) for both systems. It is clear that variable shaped beam lithography system BS600 has advantage in multileveled structures while the Gaussian beam lithography system Vistec is more suitable for gratings type of pattern. It was proved that combination of both systems has its use to increase exposures throughput.

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