ANALYSIS OF ELECTRON CURRENT INSTABILITY IN E-BEAM WRITER

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Abstract

The electron beam writer Tesla BS600 works with a thermal-field electron emitter, fixed electron energy of 15 keV and a rectangular shaped variable-size electron beam. The size of the shaped beam (stamp) can be set from 50 to 6300 nm in standard mode and from 16 to 2100 nm in high-resolution mode. The basic increment of the stamp size is 50 nm, resp. 16 nm. Electron current density inhomogeneity and long-term instability in stamps can have negative impact on the exposure quality. Therefore, we focused on a study of the current time instability. The current density in variously sized stamps was measured by a picoameter and a PIN diode video channel as a function of time. We analyzed short-term and long-term current instabilities using filtering techniques, as well as the Fourier analysis. Based on the results, we could be able to find reasons of the current instabilities and to propose improvements to achieve higher exposure quality.

Keywords

Electron beam, current measurement, current drift and noise, Fourier analysis

1. INTRODUCTION

In the e-beam writer, nanoscopic and microscopic scale regions of the electron sensitive resist are exposed by the e-beam. The exposed or non-exposed regions are then chemically removed and the obtained structure is transferred to the substrate material. For "writing" of well-defined shapes, a rectangular-shaped and variable-sized e-beam pattern, called a stamp, is formed from the original round-pattern e-beam. One of the crucial parameters of the stamp is its current homogeneity, intensity and time stability. This paper deals with the current intensity and time stability, since the current homogeneity was analyzed before [1].

The low current density can result in significant exposure time prolongation, because sufficient electron dose has to be supplied for satisfactory resist exposure. In the case of poor current stability, the different regions of the resist are exposed by different dose during the exposure time which decreases the exposure quality. These problems imply the necessity of the current instabilities measurement and analysis.

In general, the e-beam current instabilities can be caused by emission instabilities of the electron emitter and by external influences on the electron optical system, such as temperature variations, electromagnetic fluctuations and surrounding vibrations. The current instabilities can be divided by the time region of their variations to short-term and long-term fluctuations. The long-term fluctuations with frequencies in order of 1 Hz and lower are called drift. The short-term fluctuations with frequencies over 1 Hz can be generalized as noise. The both types of fluctuations can be isolated and examined separately. In this paper, we describe techniques of the current monitoring as a function of time. The measured values were inspected by filtering techniques and by the Fourier analysis. The study of the short- and long-term fluctuations helped us to find reasons of the current instabilities and to propose improvements to achieve higher exposure quality.
2. EXPERIMENTAL SET-UP

The e-beam writer Tesla BS-600 uses the thermal-field electron emitter with fixed electron energy of 15 keV to create an e-beam passing through the electron optical system (see Fig. 1). The optical system is composed by two magnetic condenser lenses between which the stamp forming system is situated. The stamp forming system serves for creating of the rectangular stamps from the original round-pattern e-beam. It’s composed of two right-angled shutters; the beam cross-over is in between them. The size of the rectangular stamp is adjusted independently in two perpendicular directions using the electrostatic field between two pairs of deflection plates located near the cross-over plane. The deflection plates are operated by the 16 bit D/A converter, which enables stamp size between 50 and 6300 nm in standard mode and between 16 and 2100 nm in high-resolution mode. The D/A converter is controlled using an e-beam writer exposition software by the direct stamp size setting.

Another two lenses serves to e-beam pattern demagnification and projection onto the exposure plane, where the substrate is placed. The e-beam can be scanned across the exposure plane by a magnetic deflection system. The maximum scanned area on the exposure plane is 3 mm × 3 mm. The e-beam writer is equipped with the magnetic field cancelling system Spicer Consulting SC20. This system effectively suppresses influences of the external magnetic field to the electron optical system.

The electron current in the selected stamp can be measured directly by the Faraday cap, or indirectly by the PIN detector. The movable Faraday cap is situated under the exposure plane and the e-beam can enter in it only when the substrate is not presented. The current from the Faraday cap is measured by the picoammeter Keithley 487. The picoammeter uses 50 Hz signal integration frequency, so it’s useful for the measurement of slowly varying currents. The second detector, PIN detector, is composed of four PIN diodes positioned around the e-beam just above the exposure plane. It enables the detection of the back-scattered electrons from the substrate. The detected current from the selected PIN diode is converted to the voltage by an amplifier and digitalized by the 8bit A/D video channel converter. The PIN detector can be used for the fast varying current measurements because of its 1 MHz integration frequency, however the signal-to-noise ratio and the dynamic range is rather lower than in the case of the picoammeter.

Fig. 1 The optical system of the e-beam writer Tesla BS-600.
3. RESULTS AND DISCUSSION

3.1 Software for current density measurement

A software application for the time dependent measurement of the current density was written in the development environment National Instruments LabVIEW. It acquires data from the picoammeter using the GPIB digital connection between the computer and the picoammeter. Moreover, the application enables automatic setting of the stamp sizes using serial communication with the e-beam writer exposition software. Using this feature, the application changes the stamp sizes and measures the current in the formed stamps. The measured current is divided by the stamp area and thereby the current density is obtained. The current density in a number of selected stamps is instantly drawn to the time dependent graph and the data are stored to a file for further processing.

The abilities of the measurement application are used practically in case of forming system adjustment. The stamp forming system possesses fine adjustment instabilities caused by external influences, such as temperature fluctuations and the incoherence between the position of the electron emitter and the forming system. Therefore, the forming system setting has to be occasionally corrected. The correction was used to do manually using a stamp projected on the luminescent screen. This process can be done more precisely now with the software application. The forming system can be adjusted by the observing of the current density in various stamps. It has to be supposed that the current in the e-beam area, from which is the stamp formed, is homogeneous. Then the current density in every stamp is the same.

An example of the adjustment is shown in the time dependent graph of the current density of stamps with \( X \times Y \) dimensions (Fig. 2). At the beginning, the current density of the stamps doesn't correspond to each other, therefore the forming system isn't well adjusted. In the time A, an operator deflects the e-beam with the step -30 nm in the direction of the X axis. In the time B, the e-beam is deflected more with the step -30 nm in the X axis and in the time C, the e-beam is deflected +30 nm in the Y axis. In this moment, the current density in the observed stamps matches within the measurement error and thus the forming system is adjusted.

![Fig. 2](image)

**Fig. 2** An example of the forming system adjustment using the time dependent measurement of the current density in various stamps. See details in the text.
3.2 E-beam current drift

The long-term current instabilities, called drift, were measured and analyzed in various stamp sizes. The time dependent measurements were carried out using the software application presented in the previous section. We performed several measurements, one of which is shown in Fig. 3. Herein, the current density time dependence in the square stamps of 1 µm × 1 µm (blue, dotted black), 3 µm × 3 µm (green, dashed black) and 6 µm × 6 µm (red, solid black) is plotted over one hour period with the sampling frequency of 1 Hz. All values are relative to the initial value of current density in the 1 micron stamp. Values in the largest stamp are visibly larger due to slight current density inhomogeneity (as discussed earlier in [1] or [2]). The measured (colored) values were further low pass filtered at a frequency of 1/30 Hz in order to separate the long term drift component (black lines). The remaining component (the difference between the measured line and the filtered one) representing let us say the slow noise (with respect to the fast noise discussed in the next section which is in the Hz and kHz domain) remains constant independently on the stamp size and time span of the measurements. Its 1σ deviation value ranges between 1.9 % and 2.5 % of the nominal current density value.

Concerning the current density drift, its 1σ deviation value ranges between 2.2 % and 6.0 %. This value depends mainly on the time span of the measurements (the longest time period we analyzed was 14 hours). This observation confirms the expected behavior, however the numerical evaluation of the drift helps us in the selection of the exposure strategy and the scheduling of different lithographic tasks.

On the other hand we conclude that the differences in time dependency within the various stamps is practically negligible. In fact, originally we expected that this analysis can reveal the variations in current distribution over the projected electron beam spot. These variations are however quite small as it can be observed both from the Fig. 3 and the statistical evaluation of the measured data sets.

Fig. 3 An example of current density (J) time dependence in various sized stamps.
3.3 **E-beam current noise**

As described above, the signal from the PIN detector can serve for the fast varying current measurement because of the fast sampling rate. The signal from the detector is digitalized by the A/D video channel converter and each signal sample is shown as a pixel of an image. This regime serves normally to display the substrate surface by the e-beam scanning across the surface. However for our purposes, the e-beam scanning is not needed and the created image can be read as a time sequence of the e-beam current intensity – the gray level of the pixel is proportional to the e-beam current intensity.

The e-beam current was acquired from the image with $512 \times 512$ pixels (samples) obtained with 35 kHz sampling frequency. The data-set was analyzed by the Fourier transform. The analysis shown, that the current fluctuations contains the drift with frequencies below 100 Hz. The 68 Hz harmonic oscillation also appears in the frequency spectrum. This frequency corresponds to the end of the image line and therefore it’s only an image artifact and it doesn’t arise from the e-beam current. Other high sinusoidal components are at the frequencies 50 Hz and 150 Hz, which represents the power-line frequency and its third harmonic, respectively. Although the amplitude of the 50 Hz component is lower than current drift and reaches only 0.1 % of the current average, its presence in the spectrum is unwanted. Therefore, the same measurement was repeated with the magnetic field cancelling system activated. The result shown, that the power-line frequency isn’t presented in the spectrum with the cancelling system activated. It can be concluded, that the power-line frequency has the form of the time-varying magnetic field originating in surrounding power circuits and can be suppressed by the magnetic field cancelling system.

Our previous work [3] concerned the analysis of beam position dependence on external magnetic field and the influence of the magnetic cancellation system application. Now, this is complemented by beam density variation analysis. We expect that the above discussed power line harmonic component is due to the external magnetic field presented in the region of the stamp forming system (see Fig. 1). In that case this influence should more pronounced within the small sized stamps. However, actually we have not been able to confirm this assumption because of the limited sensitivity of the video channel and currently the low cathode emission current. We expect to repeat this analysis when the emission current will be significantly higher (after the cathode reactivation process or after its replacement).

![Fig. 4 Frequency analysis of e-beam current signal obtained by the PIN detector. Image rows are scanned with frequency 68 Hz. The sinusoidal components at 50 and 150 Hz are (a) detected with the magnetic field cancelling system deactivated and (b) suppressed with the cancelling system activated.](image)
4. CONCLUSIONS
The presented measurement techniques and analysis of the e-beam current in the e-beam writer can be used in similar systems where the e-beam time stability is crucial.

The developed software application for the time dependent measurement of the current density handles the important measurement tasks. It helps to adjust the forming system with high accuracy which wasn't previously feasible in our laboratory. The future outlook is to implement a system for fully automatic adjustment of the forming system using the software application.

We also expect that the developed measuring system will be useful for analysis of cathode emission behavior at different periods of its lifetime.

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