EUV detection system with calibrated responsivity

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Abstract

We describe a measuring system of EUV radiation energy using special calibration responsivity. This system is specified by responsivity of 0.043 A/W at the wavelength range of 13.5±0.5 nm (FWHM=7.2%). A determination of the calibration responsivity for a laser-plasma source with Xe/He gas puff target is also discussed. This parameter makes it possible to reference measurement results to the standard wavelengths band of 13.5±0.13 nm (FWHM=2%). The value of the calibration responsivity depends on the spectra of measured radiation and features of the system elements. In this paper, the analysis and investigation results of the source and the measuring system are demonstrated.
Keywords: EUV radiation, optical sensors, energy meter.

1 Introduction

Accurate measurements of energy radiation are very important in nanolithography. The resists or masks can be damaged due to the measurements errors. Nowadays, energy meters of EUV radiation are also used for testing of lithography tools. The investigations are connected with characterization of EUV radiation sources, features of optical elements, etc. The responsivity and measurement accuracy are the main features of the measuring devices. The parameters are referenced to a standard wavelength range of 13.5±0.13 nm. The range corresponds with the FWHM=2%.

The developed commercial meters are usually built from multilayer mirrors and semiconductor detectors [1]. The mirrors simplify construction of the instruments. Using photodiodes makes it possible to achieve a high efficiency and plain measurements procedures. The pulse energy of radiation is determined by the measured charge generated in a photodiode, the value of the detector

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responsivity and the features of optical elements. Achievement of appropriate selectivity of measuring spectrum (FWHM=2%) is important issue of construction process of the meters.

The special mirrors with wavelength band of 2% have been constructed. Analyses and investigations showed that the mirrors are characterized by low reflectivity [2]. As the amount of photons reaching detector is limited, the instrument responsivity is decreased.

The described effect is avoided using the optical elements with broader wavelength range and a special calibration factor. This factor provides to refer measured data taken in the broader spectrum to the arbitrary one. The factor value depends on spectra of the measured radiation and some performances of the instrument elements. Basing on this factor and the meter responsivity, the calibrated responsivity is calculated by

$$S_S = C_\lambda \, S_\lambda \, . \tag{1}$$

The construction of the laser-plasma source with gas-puff target necessitated application of an appropriate system for energy measurement [3]. The features of the commercial meters (their dimensions and prices) forced to design a special measuring system (*M-EUV system*) [4]. The small size, the high-calibrated responsivity and the fully automated measuring process, all are the main system advantages. M-EUV system uses Mo/Si multilayer mirror (FWHM=7.3%), silicon photodiode with integrated absorption filter and the calibration factor.

To the best of analysed knowledge, this work presents the experimental results of the first investigation of the system with calibrated responsivity used for measurements of energy emitted by the laser plasma source with Xe/He gas puff target.

2 Calibrated responsivity

The determined value and the measured range of wavelengths describe the energy of source radiation using M-EUV system. The spectrum influence on measurement results is taken into consideration by determination of the system responsivity. The responsivity is the most important parameter of absolute energy measurements and it is defined by

$$R_D = \frac{\Delta I_{ph}}{P_\lambda} , \tag{2}$$

where I_{ph} is the current signal generated in detector and P_λ is the power of the exposing radiation.

The spectral characteristic of M-EUV system responsivity depends on the mirror reflectivity and the detector responsivity. This characteristic is given by

$$S_\lambda = S_{Det} \, R_{Mir} \, . \tag{3}$$

Theoretically determined characteristic of the system responsivity is shown in Fig. 1.

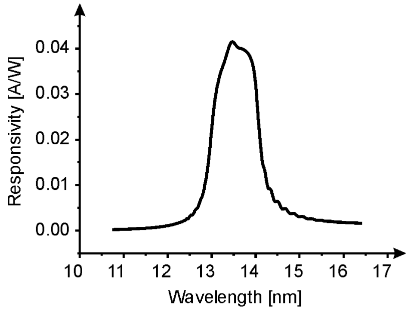

Figure 1: Theoretical characteristic of the system responsivity [5].

The maximum value is 0.043 A/W at the wavelength range of 13.5±0.5 nm. Analyses and investigations of the spectra generated from Xe/He gas-puff target gave an opportunity to calculate the calibrated responsivity of the M-EUV system. In Fig. 2, it is presented the spectrum of the source radiation in the two ranges of wavelengths 13.5±0.5 nm and 13.5±0.13 nm describing the system responsivity.

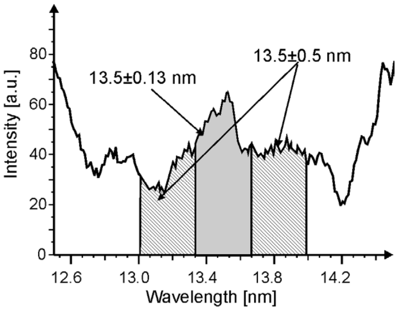

Figure 2: Radiation spectrum with analysed ranges of wavelength [5].

The marked areas specify the radiation energies in the chosen wavelength ranges. The energies are connected with the charge generated in the irradiated photodiode. The value of this charge is given by

$$Q = \Omega \int_0^\infty E(\lambda)\, S_\lambda \, d\lambda , \tag{4}$$

where Ω is the solid angle of the source radiation.

The energy value of radiation at the range of wavelengths of 13.5±0.13 nm is determined by

$$E_{2\%}(\lambda) = \frac{Q}{\Omega \int_0^\infty I(\lambda)\, S_\lambda \, d\lambda} , \tag{5}$$

where I(λ) is the normalized function characterising the spectrum of radiation and it is described by

$$\int_{13.5\pm0.13\ \mathrm{nm}} I(\lambda)\ d\lambda = 1. \tag{6}$$

The expression given by

$$S_{S(\lambda)} = \int_0^\infty I(\lambda)\ S_\lambda\ d\lambda\,, \tag{7}$$

defines the calibration responsivity of the M-EUV system [1]. This responsivity depends on features of system elements and the source spectra. The spectra can be shifted by changing conditions of the plasma generation in the investigated source. The aforesaid conditions concern a delay of the nozzles valve opening with respect to a laser pulse, power density of Nd:YAG laser radiation on the target surface, position of a laser beam focus with respect to the gas target axis, pressure of the remaining gases in the source chamber, gases pressures in the valve nozzles [6].

3 Measurement method

Measurements of the calibration responsivity were taken using the laser plasma source with Xe/He gas puff target and the model instrument (E-Mon energy meter [1]). The main aim of the investigations was determination of energy radiation in two ranges of wavelengths 13.5±0.27 nm and 13.5±0.5 nm. The ranges are defined by spectral characteristics of mirrors reflectivity used in E-Mon meter and M-EUV system.

The calibration responsivity ($S_{S\ E\text{-}Mon}$) and measurement uncertainty of E-Mon meter referenced to the wavelength range of 13.5±0.13 nm is taken into consideration for determination of the M-EUV system responsivity.

The calibration factor ($C_{M\text{-}EUV}$) is determined by measured energies with E-Mon meter and M-EUV system. The value of the factor is given by

$$C_{M-EUV} = \frac{E_{7\%}}{E_{3\%}}\,, \tag{8}$$

where $E_{7\%}$ and $E_{3\%}$ are the energy values in the wavelength ranges of 13.5±0.5 nm and 13.5±0.27 nm.

This factor makes it possible to specify the calibrated responsivity of M-EUV system referenced to FWHM=2%. This responsivity is calculated by

$$S_{S\ M-EUV} = C_{M-EUV}\ S_{S\ E-Mon} \tag{9}$$

4 Experimental results

The measurements of the source energy and determination of the energies ratio in two wavelength ranges were the main aim of the investigations. The researches defined the calibration responsivity and also the calibration factor of

M-EUV system. The spectra of the radiation emitted by the laser-plasma source with Xe/He gas puff target were also analysed. The measurements were taken for different conditions of plasma generation in the source.

4.1 Influence of delay of Xe/He nozzles valve opening

The delay of the nozzles valve opening with respect to a laser pulse has direct impact on a dimension and density of the gas target. Measured characteristics of the energy and the calibration factor as a function of the delay of Xe and Xe gas nozzles are shown in Fig. 3.

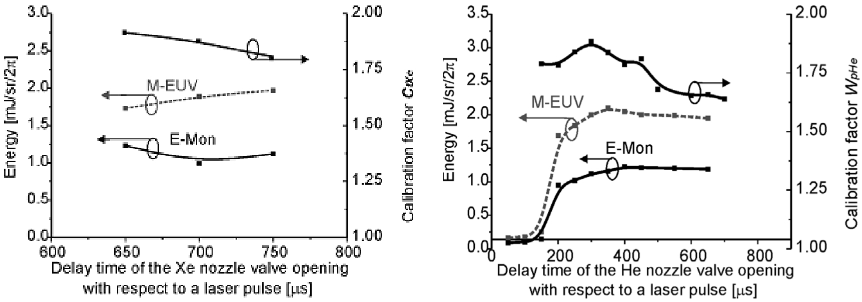

Figure 3: Energy radiation and the calibration factor at various delays of Xe and Xe gas nozzles.

The value changes of the calibration factor with delay of Xe gas nozzle are up to relative value of 10%. Its mean value is 1.85±0.06. The maximum energy emitted by the source was achieved for delay from 650 to 850 μs.

For He gas, a threshold delay was observed. The energy drops off dramatically for the delay of 200 μs. The noticed threshold has no influence on the factor characteristic.

4.2 Influence of Xe/He gases pressures in the valve nozzles

The gases pressure similar to nozzles delay forms the target performances. This influence concerns the source spectra. The characteristic changes of energy and calibration factor as a function of the pressures are shown in Fig. 4.

The increase in the energy radiation is determined by simultaneous increase in the Xe gas pressure. The maximum value of energy is limited by strength of gas pipes. The calibration factor characteristic follows the energy characteristics.

For He gas pressure below 0.5 MPa, the optimal range of energies is observed. In this case, the calibrated factor decreases negligibly with He gas pressure.

4.3 Influence of pressure of the remaining gases

The EUV radiation is absorbed not only by a solid body but also by a gaseous one. The remaining gas target can be accumulated in the chamber of the laser-plasma source. The pressure of the remaining gas depends on the source repetition and the efficiency of the vacuum pump. The measured value of the pressure was shifted from 10^{-6} to 10^{-2} mbar at the source repetition of 10 Hz. The changes of energy and the calibration factor for the remaining gases are shown in Fig. 6.

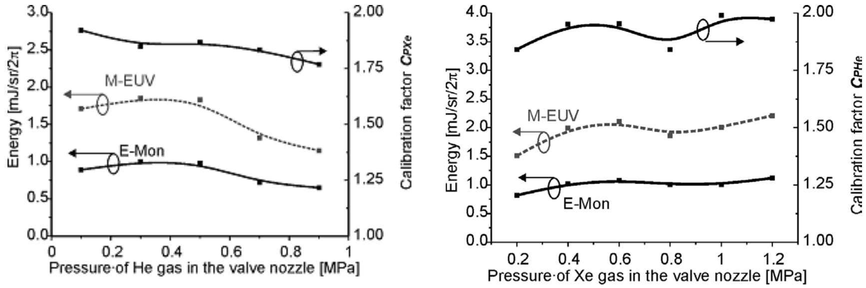

Figure 4: Energy radiation and the calibration factor vs. Xe/He gases pressures in the valve nozzles.

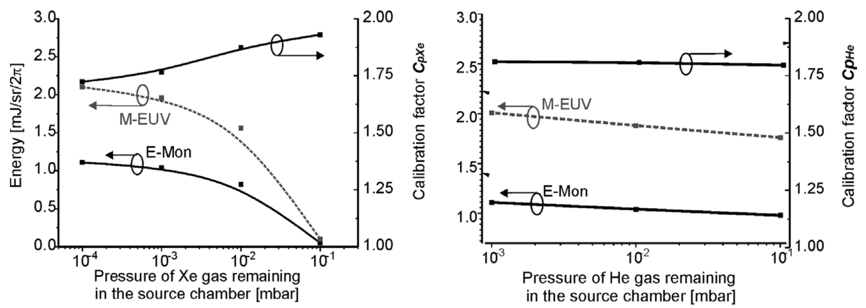

Figure 5: Energy and the calibration factor as a function of pressure of the remaining gases in the source chamber.

The energy and the calibration factor vary significantly with the Xe remaining gas. The threshold pressure of the energy dropping is observed near the value of 10^{-2} mbar. The calibration factor increases with the pressure build-up. Its mean value is 1.82±0.06. For the He gas, the described influences are not so noticeable. The mean value of the calibrated factor is 1.83±0.03.

4.4 Influence of position of a laser beam focus

The valve construction makes it possible to control a beam focus position on the gas target space. Figure 6 shows energy and calibration factor characteristics varied with a position of a laser beam focus.

The measured energy and the calibration factor decrease with shifting the target position more than value of +10 μm. The mean value of the calibrated factor was 1.77±0.06.

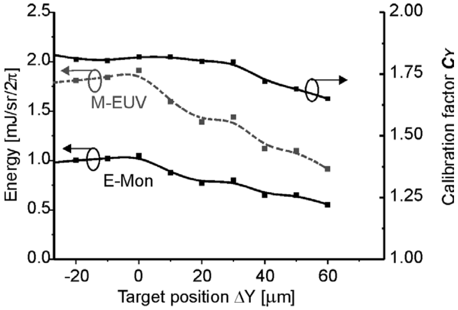

Figure 6: Energy and the calibration factor as a function of positions of a laser beam focus.

4.5 Influence of energy radiation of Nd:YAG laser

The Nd:YAG laser with output energy adjustment was used during the investigation procedures. The energy control was executed by changing a duration time of the active laser pumping. This time can be adjusted in the range from 200 to 2000 μs. Figure 7 shows the source energies and the calibrated factor for changes of duration time of the active laser pumping.

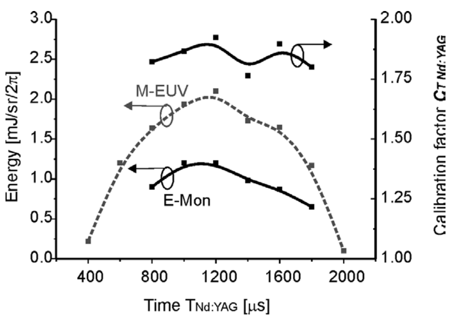

Figure 7: Energy and the calibration factor vs. duration time of the laser pumping.

5 Results verification

The results were verified by spectral measuring of the source radiation. The analysed spectra were taken by the spectrometer consisted of the reflecting grating (HITACHI 1200 l/mm) and CCD camera (Roper Scientists).

The values of the calibrated factor were calculated using the processed graphs of the measured spectra. The graphs were given by multiplication of the spectral characteristics of multilayer mirrors (used in the E-Mon meter and M-EUV system) and the source spectra. The example of the analysed graph is shown in Fig. 8.

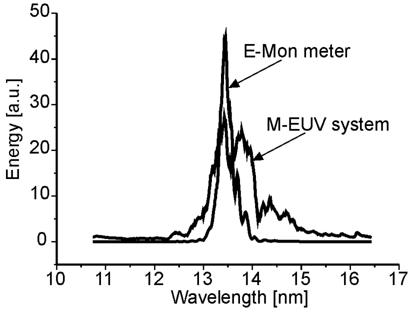

Figure 8: Resultant graphs of the spectra detected by the E-Mon meter and M-EUV system.

The maximum differences between the data taken by the measuring instruments and the spectral analyses were observed for changes of position of a laser beam focus (12%), pressure of the remaining gases (9.5%), and delay of the Xe nozzle valve opening (8.8%). For other conditions of the plasma generations, the noticed differences were less than 4%.

6 Conclusions

The paper presents a unique system for energy measurement of radiation emitted by the laser-plasma source with Xe/He gas puff target. The experimental results specified not only the features of the system, but also characterized an influence of the conditions of the plasma generation on the source spectra. The measured responsivity of the system is 0.043 A/W in the range of wavelengths of 13.5±0.5 nm.

For the maximum efficiency of the source, the calculated value of the calibrated factor is 1.79±0.03 in the wavelength range of 13.5 ±0.13 nm hence the system responsivity of 0.291±0.027 A/W. Using the mirrors with wider spectral characteristic of the reflectivity (worse selectivity) has improved the measuring performance of the system.

Acceptance of the constant value of the calibration factor (independent on conditions of the plasma generation) is able to make the measurement error of 14%. The uncertainty of factor calculation was 7.4%. The relative value of the determined uncertainty of energy measurement in the spectrum of FWHM=2% is 10.1%. The presented system provides a simple, reliable solution to EUV energy measurements. That is why it is promising alternative for commercial meters.

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