Optical element for full spectral purity from IR-generated EUV light sources

A.J.R. van den Boogaard[1,*], E. Louis[1], F.A. van Goor[2] and F. Bijkerk[1,2]
[1] FOM Institute for Plasma Physics Rijnhuizen, P.O. Box 1207, Nieuwegein, The Netherlands, www.rijnhuizen.nl
[2] MESA+ Institute for Nanotechnology, University of Twente, P.O.Box 217, Enschede, The Netherlands

ABSTRACT

Laser produced plasma (LLP) sources are generally considered attractive for high power EUV production in next generation lithography equipment. Such plasmas are most efficiently excited by the relatively long, infrared wavelengths of CO_2-lasers, but a significant part of the rotational-vibrational excitation lines of the CO_2 radiation will be back-scattered by the plasma's critical density surface and consequently will be present as parasitic radiation in the spectrum of such sources. Since most optical elements in the EUV collecting and imaging train have a high reflection coefficient for IR radiation, undesirable heating phenomena at the resist level are likely to occur.

In this study a completely new principle is employed to obtain full separation of EUV and IR radiation from the source by a single optical component. While the application of a transmission filter would come at the expense of EUV throughput, this technique potentially enables wavelength separation without loosing reflectance compared to a conventional Mo/Si multilayer coated element. As a result this method provides full spectral purity from the source without loss in EUV throughput. Detailed calculations on the principal of functioning are presented.

Keywords: Mo/Si Multilayers, Blazed Grating, Spectral Purity, EUV Source, Infrared, Out of Band Radiation, EUV Lithography

1. INTRODUCTION

Extreme Ultra Violet Lithography (EUVL) is a main candidate for production of next generation integrated circuits (ICs), and its potential has been further established since the first proof of principle wafer steppers, so called Alpha Demo Tools, successfully demonstrated printing of 32 nm structures[1]. EUVL is aimed to enable high volume IC manufacturing, requiring that the exposure time per treated wafer is minimized. The yield expressed in wafers per hour is generally determined by the EUV intensity offered at the photoresist, and is primarily depending on source intensity, throughput of the optical system, and resist sensitivity.

[*]Corresponding author: a.j.r.vandenboogaard@rijnhuizen.nl

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Several source suppliers worldwide are spending great efforts to enhance the efficiency of the EUV sources towards the industrial needs of approximately 200 W of narrow band EUV yield. Laser produced Sn plasma sources in which a droplet of tin is irradiated with a powerful drivelaser to excite an EUV emitting plasma are considered attractive. As a drivelaser, especially 10.6 µm emitting CO_2-lasers may have high yield possibilities. Due to the effective backscattering of the 10.6 µm infrared radiation at the surface of critical density of the Sn plasma, a high load of infrared will be present in the LPP source spectrum and will reach the collector jointly with the EUV.

High throughput of the optical system for EUV is achieved by using Mo/Si based multilayer coated elements, for which near normal incidence reflectance values just over 70% have been reported[2]. However, EUV optimized multilayer coatings efficiently reflect radiation from deep UV to infrared as well (fig.1). As a consequence, the convolution of the source spectrum and response of the optical elements in a EUVL tool will result in a large spectral range of radiation reaching the photoresist, degrading the EUV projected image quality and causing undesired heating. The successful suppression of out of band radiation in the Deep UV range, by application of a spectral purity layer on top of a Mo/Si multilayer stack has been reported,[3,4] but for 10.6 µm radiation this is not feasible due to the large wavelength and low absorption relative to EUV, leading to an unacceptable loss of 13.5 nm light. The application of transmission IR filters has also been suggested, requiring delicate handling due to the extreme fragileness when sufficiently thin to maintain the throughput in EUV.

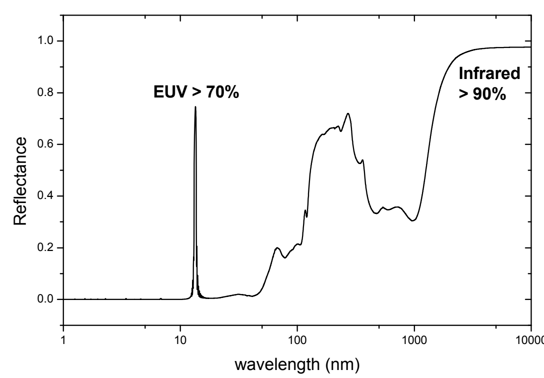

Fig.1) *Calculated[5] reflectance of a 50 bilayers Mo/Si multilayer coating of 6.9 nm periodicity and a Mo ratio of 0.4. The refractive index and absorption for IR are obtained by extrapolation of the scattering factors for EUV towards larger wavelengths.*

2. SPECTRAL PURITY GRATING DESIGN

In this paper the use of a blazed reflection grating is suggested, to be employed to shift reflected energy out of the mode of specular reflection with respect to the normal of the average optical plane. The angular position of the orders in reflection thus arising is given by the grating equation (eq.1):

$$a \cdot (\sin(\theta_m) - \sin(\theta_i)) = \lambda m \,, \qquad (1)$$

in which a is grating period, θ_m is the angle of reflection of order m, θ_i is the angle of incidence and λ is the wavelength of the radiation. The dependence of θ_m on λ directly reveals the possibility of spectral separation of different wavelengths over an angular range $\Delta\theta = \theta_m(\lambda_1) - \theta_m(\lambda_2)$. Obviously, a considerable EUV reflectance from a grating can only be obtained when the optical surface is coated with a Mo/Si multilayer. The very large wavelength difference between EUV and IR conveniently allows angular spectral separation by a Mo/Si multilayer coated grating, in particular when a grating design is chosen such that the high efficiency orders for the IR radiation are well separated. Unlike the angular position, the efficiency of the orders depends on the grating design. For this purpose a Mo/Si multilayer coated *blazed grating*, having a saw-tooth profile, is considered a candidate (fig.2). Due to the orientation of the multilayer coating along the plane of the blazed facets of the grating, the orders of highest efficiency in EUV angularly deviate from the orders of high efficiency in the IR (generally close to $m = 0$). In another application the use of Mo/Si multilayers on blazed gratings has been reported with EUV reflection efficiencies up to 63 % in a single order[6].

The novel approach presented here is based on choosing the grating period to be comparable to, or larger than, the wavelength of the IR, in combination with a Mo/Si multilayer coating optimized for near normal incidence and reflectance. It has been verified by rigorous calculations performed with the software package PCGrate-SX6.1, that unperturbed flat mirror EUV reflectance can be approached for the proposed grating/multilayer system in the case of large grating facets, provided that multilayer performance is not influenced negatively by the deposition on the blazed grating. The main part of the power in EUV will be reflected under angles close to the blaze angle while the IR is diffracted under sufficiently large angles to obtain full spectral purity.

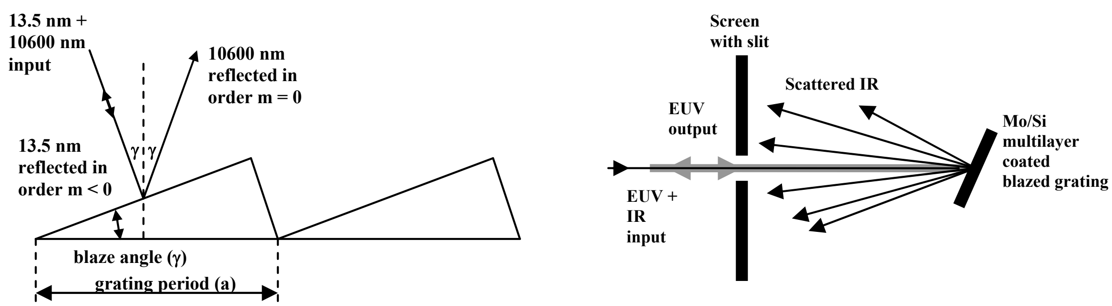

Fig.2) *Schematics illustrating the response of a Mo/Si multilayer coated blazed grating and the possible geometry for spectral purity enhancement purposes.*

In the calculations, the blaze angle is treated as a fixed parameter; in this example $\gamma = 21$ deg. On the blazed grating 50 bilayers Mo/Si of 6.9 nm thickness, optimized for reflectance at 13.5 nm and 1.5 deg normal angle of incidence, are assumed to be applied. It should be noticed that the angle of incidence with respect to the normal of the grating plane is 19.5 deg, while specular reflection in the multilayer plane would yield an angle of -22.5 deg. Since both the incident as the reflected beam are on the same site of the normal to the grating plane, the angle of reflection has a negative sign. The angular acceptance for the diverging beam of different reflected orders in EUV is chosen to be $\Delta\theta_{accept} = 3$ deg. For different values of the grating period a = 100, 333 and 1000 nm, the diffraction angle of the reflected orders and the convolution with the acceptance angle are calculated as a function of wavelength in the EUV range.

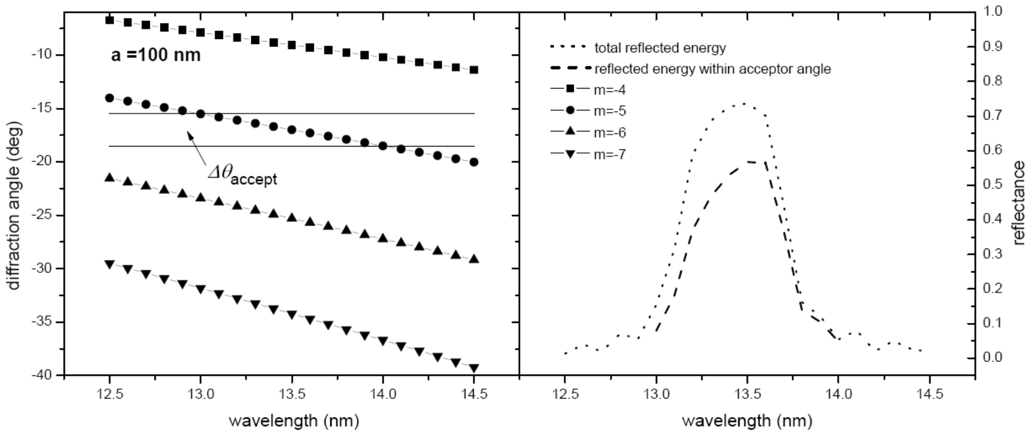

fig.3a

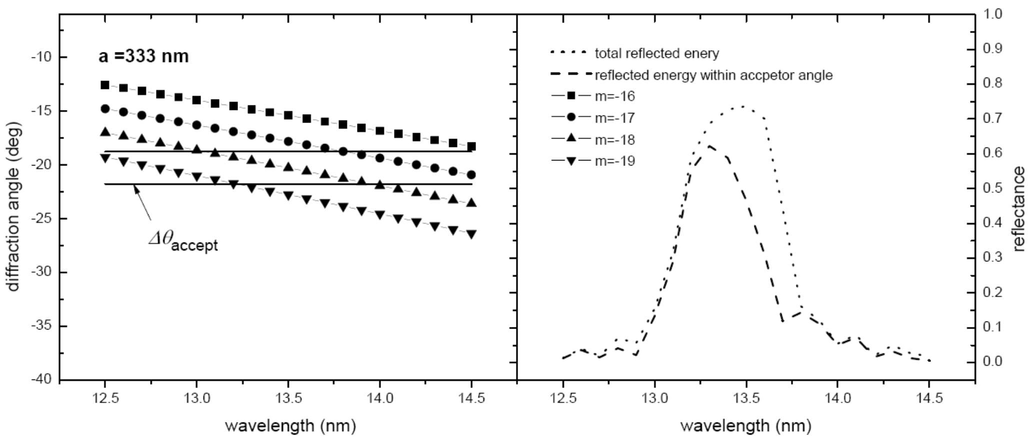

fig.3b

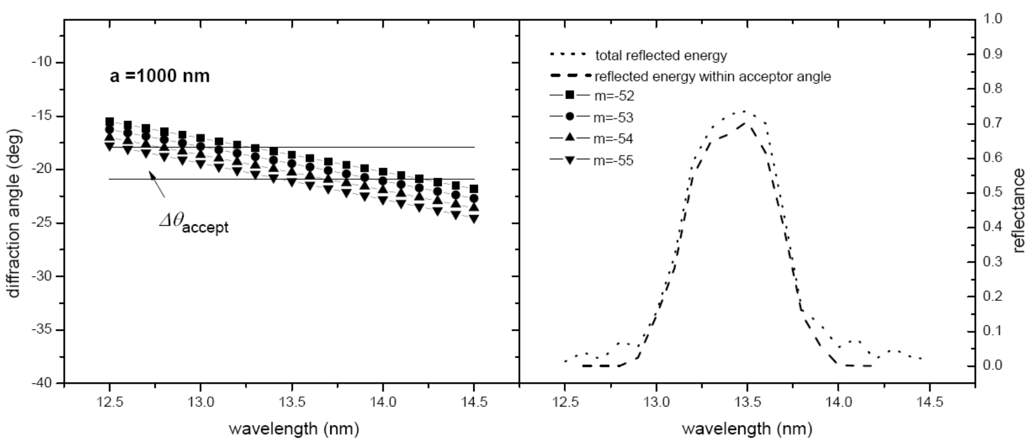

fig.3c

Fig.3a-c) *The diffraction angle of the different orders and the reflectance as a function of wavelength, plotted for several values of grating period. The four orders of highest efficiency at 13.5 nm are considered.* $\Delta\theta_{accept}$ *is indicated by the horizontal lines in the diffraction angle plot and is centered around the order of highest efficiency at 13.5 nm.*

Fig.2a-c reveals that only one order in reflection (m = -5) contributes to the reflected energy within the acceptance angle for a = 100 nm. For the larger grating periods, apart from the four orders taken into account, several more orders contribute to the reflectance, although efficiencies are low. It is observed that for increasing grating period, up to a = 1000 nm, the response of the Mo/Si multilayer coated blazed grating rapidly approaches flat Mo/Si mirror reflectance (equaling the total reflected energy in fig.3a-c). It is expected that for grating periods of 50 to 100 μm the response curve of the grating will be practically indistinguishable from the total reflected energy curve, resulting in a Mo/Si multilayer coated blazed grating reflectance above 70% at 13.5 nm within the acceptance angle.

The grating periods up to 1000 nm, as used in above calculations, are relatively small compared to the wavelength of the 10.6 μm IR. Therefore the only possible order in IR reflection will be m = 0 at 21 deg (which can be seen as a case of specular reflection with respect to the grating plane) yielding a full separation of EUV and IR in the order over tens of degrees. Regarding the desired up scaling of the grating period to enhance efficiency in EUV reflectance and to prospectively facilitate the coating process, eq.1 is employed to calculate the separation of the orders in IR as a function of grating period (fig.4).

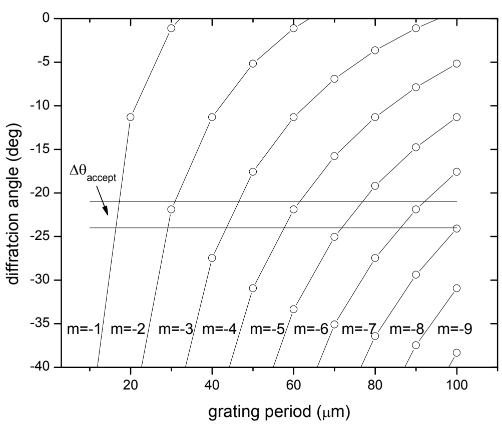

fig.4) *Diffraction angle for 10.6 μm IR as a function of grating period up to 100 μm. The acceptance angle is chosen 3 deg centered around -21 deg. The main part of the energy in EUV will be reflected within this window for the grating periods under consideration.*

It is demonstrated that for grating periods up to 100 μm the separation of the orders in IR is approximately 6 deg. This is still sufficiently larger than the acceptance angle $\Delta\theta_{accept}$, which minimum requirement should be fulfilled in order to allow convenient spectral separation of the EUV an IR.

3. SUMMARY AND OUTLOOK

This study shows the potential of achieving full spectral separation of EUV and IR by application of a Mo/Si multilayer coated blazed grating in a special geometry. Based on rigorous calculations it is expected that for coating friendly grating periods (50 μm and upwards) the response of the proposed system equals an unperturbed Mo/Si multilayer EUV reflectance, while the diffracted orders in the IR angularly deviate sufficiently to be spatially fully isolated from the EUV. This enables spectral purity enhancement of especially CO_2 generated Sn LPP sources without losses in throughput of the EUV imaging system. An additional technical advantage over transmission filters is the robustness of the reflective optical component, allowing straightforward integration and cooling. Further study will be mainly devoted to the deposition process of EUV optimized multilayer coatings on blazed gratings, whereas the focus is on replicating the blazed grating structure through the multilayer stack of gratings with relatively large and straightforwardly realizable periods of ~10 μm and upwards.

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