Photoionization of gases by EUV pulses from a laser-plasma source

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In this work a laser-plasma EUV source was used for photoionization of noble and molecular gases. The resulting photoelectrons excited various electronic states in neutrals and ions leading to emission of radiation in EUV/VUV range. Irradiation was performed using a full wavelength range of the source or a short wavelength part selected with a Zr filter. The corresponding spectra were recorded using a toroidal grating spectrograph. Significant differences for spectra obtained in different conditions were revealed.

Ionization of a gaseous medium can be obtained by an electrical discharge or intense laser pulse irradiation. In both cases the electron collisional ionization is a dominating mechanism leading to plasma creation. In both cases electrons are accelerated by an electric field and some threshold must be exceeded to initialize the discharge or a laser spark. Quite different possibility ofers irradiation with X-rays or extreme ultraviolet (EUV). In this case a single photon carries enough energy to ionize any atom or molecule. Thus ionization is possible even with low intensity radiation beams. Some photoionization experiments were performed on high power laser or Z-pinch facilities for laboratory simulation of astrophysical plasmas [1,2].

In this work different gases were irradiated with a focused EUV beam from a laser-plasma source. In the experiments, a 10-Hz laser-plasma EUV source, based on a double-stream gas-puff target, irradiated with the 3-ns/0.8J Nd:YAG laser pulse, was used. The radiation was focused using a gold-plated grazing incidence ellipsoidal collector, manufactured in Reflex s.r.o., Czech Republic. The collector allowed for effective focusing of radiation emitted from Kr/Xe plasma in the wavelength range $\lambda = 9 \div 70$ nm. The most intense emission was in the relatively narrow spectral region centred at $\lambda = 11 \pm 1$ nm. The spectral intensity at longer wavelength range was much smaller, however, the spectrally integrated intensities in both ranges were comparable. The EUV fluence in the focal plane of the collector exceeded 60 mJ/cm^2 in the center of the focal spot. Detailed description of the source and parameters of the focused EUV radiation can be found elsewhere [3].

Different gases were injected into the interaction region, perpendicularly to an optical axis of the irradiation system, using an additional gas puff valve. The valve was equipped with a nozzle having a form of a 30 mm long tube with an inner diameter $\Phi = 0.7$ mm. An outlet of the nozzle was located 2.5 mm from the optical axis of the EUV collector. The gas density in the interaction region was controlled by adjustment of backing pressure or an opening time of the valve. The density was of the order of $1 \div 10\%$ of the atmospheric density.

Irradiation of gases injected into the interaction region resulted in ionization and excitation of atoms and molecules. Spectra in EUV/VUV range were measured using a grazing incidence, flat-field spectrometer (McPherson Model 251), equipped with a 450 lines/mm toroidal grating. Examples of the spectra for noble (Ne) and molecular (O_2) gases are shown in Fig. 1. In both cases the most intense emission lines were assigned to singly charged ions. The other emission lines belong to neutral or doubly ionized atoms. The spectra were excited in low density gases of approximately 2% of atmospheric density. For higher densities close to 10% of atmospheric density, only He and Ne spectra could be obtained. In case of Ar, O_2 and N_2 absorption in a cold gas surrounding the interaction region strongly attenuates the radiation. The spectral lines in most cases correspond to $2s^22p^k$-$2s^22p^{k-1}nl$ transitions but there are also emission lines corresponding to $2s^22p^k$-$2s2p^{k+1}$ transitions. In case of Ar lines corresponding to $3s^23p^5$-$3s^23p^4nl$ and $3s^23p^5$-$3s3p^6$ were registered. The simplest spectrum was for He with a strong 1s-2p emission line and much weaker 1s-np and $1s^2$-1snp lines. Photoionization mechanism results in some interesting effects. Irradiation of helium gas with the short wavelength part of EUV radiation selected with a Zr 140 nm filter results in relative increase of intensity of the $1s^2$-1s2p line in respect to $1s^2$-1s3p and He II lines. In case of neon there was an opposite effect: strong decrease of relative intensities of Ne I emission lines in respect to Ne II lines.

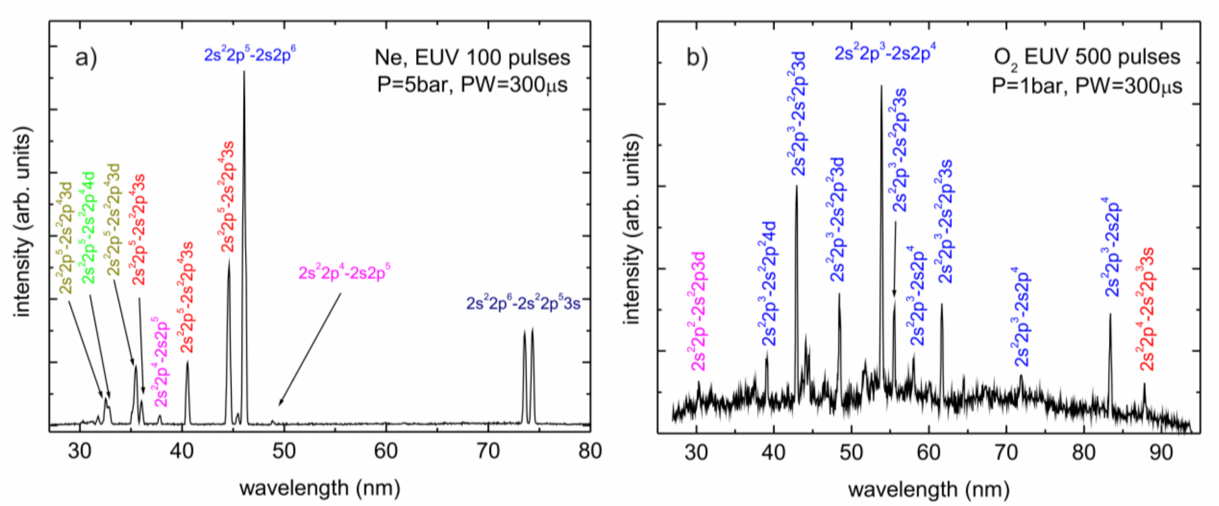

Fig. 1: Spectra of gases ionized with EUV radiation pulses from a laser-plasma source: a) neon, b) oxygen

Apart from that irradiation of Ne gas through the Zr filter results in relative decrease of intensity, of an emission line corresponding to the $2s^22p^5$-$2s^22p^43s$ transition at 44,6 nm. On the other hand relative intensities of another two spectral lines, corresponding to transitions between the same subshells (with different spin configurations), at the wavelengths 36.0 mn, 40.5 nm respectively remain almost unaltered. The corresponding spectra are presented in Fig. 2.

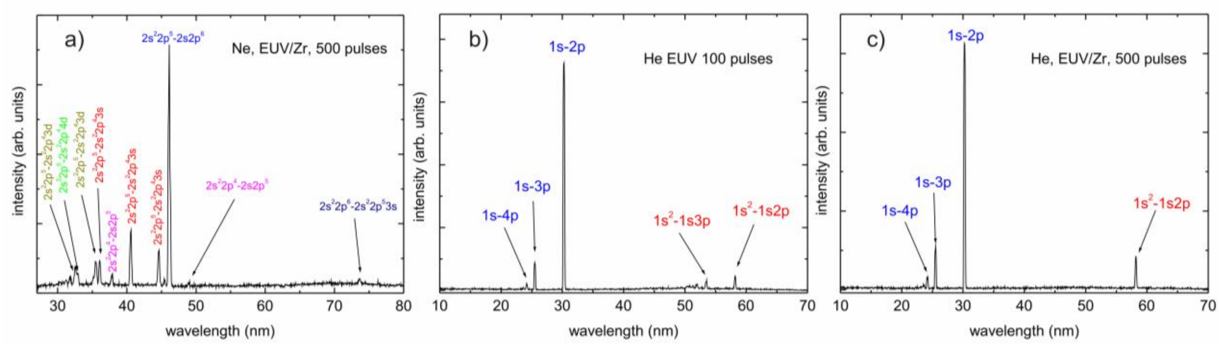

Fig. 2: Spectra of Ne and He gases ionized with EUV radiation pulses with and without Zr filter: a) Ne gas irradiated through Zr filter, b) He gas irradiated with no filter, c) He gas irradiated through Zr filter

The Zr filter used for wavelength selection reduces of course the total flux of the EUV radiation from the plasma source. Thus the above mentioned effects can be related both to narrowing of the EUV spectrum and decrease of the irradiation energy. Additional measurements with lower irradiation flux should be performed to clarify this issue.

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