Radiation Physics and Chemistry 93 (2013) 9–13

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Luminescence of He and Ne gases induced by EUV pulses from a laser plasma source

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HIGHLIGHTS

- He and Ne gases were photoionized by a focused EUV radiation beam.
- Luminescence spectra of weakly ionized gases in EUV range were registered.
- Significant influence of irradiation conditions on emission spectra was revealed.

ARTICLE INFO

Article history:
Received 12 May 2012
Accepted 20 February 2013
Available online 16 March 2013

Keywords:
Laser plasma
Extreme ultraviolet
Photoionization
Photoexcitation

ABSTRACT

In this work helium and neon photoionization experiments, using a laser-plasma EUV (extreme ultraviolet) source were performed. The EUV radiation was focused onto a gas stream, injected into a vacuum chamber synchronously with the EUV pulse. The most intense emission from the source spanned a relatively narrow spectral region centered at $\lambda = 11 \pm 1$ nm, however, spectrally integrated intensity at longer wavelengths was also significant. Additionally Zr and Al filters were used to narrow the irradiation spectrum and to change the irradiation conditions. Irradiation of gases resulted in EUV luminescence, acquired by a toroidal grating spectrometer. The dominating spectral lines originate from singly charged ions, however, Ne III lines were also detected. Significant differences were observed between spectra obtained for different irradiation conditions. The differences were mainly due to various possibilities of photoexcitation of corresponding states depending on energy distribution of irradiating photons.

1. Introduction

Ionization of a gaseous medium can be obtained by an electrical discharge or by irradiation with intense optical laser pulses. In both cases the electron impact ionization is a dominating mechanism, leading to plasma formation. In either case electrons are accelerated by strong electric fields and some threshold must be exceeded to initialize the discharge or a laser spark. Gases can be also ionized or excited by electrons accelerated in vacuum by a constant electric field. The monoenergetic electron beam formed this way can be used for measurements of cross sections for these processes. The corresponding investigations were performed for different rare or molecular gases including neon and helium (Register et al., 1984; Man et al., 1987; Muller et al., 1980; Sharpton et al., 1970).

Quite a different possibility offers irradiation with X-rays or extreme ultraviolet (EUV). In this case a single photon carries sufficient energy to ionize any atom or molecule. Thus, ionization is possible even with low intensity radiation and does not require exceeding any intensity threshold. This is important for measurements of photoionization and photoexcitation cross-sections. Such measurements were performed using EUV or soft X-ray synchrotron radiation (Watson, 1972; Woodruff and Samson, 1980; Wuilleumier and Krause, 1974; Carter and Kelly, 1977; Schulz et al., 1996; Covington et al., 2002; Bizau and Wuilleumier, 1995; Samson and Stolte, 2002) where neither thermal nor multiphoton effects took place. On the other hand the multiphoton ionization can be observed in case of using free electron lasers (FEL) for irradiation of different gases. It was shown in many experiments that a power density offered by FELs is sufficiently high even for multiple ionization (Moshammer et al., 2007; Richter et al., 2008,

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http://dx.doi.org/10.1016/j.radphyschem.2013.02.039

2010; Kurka et al., 2009; Palacios et al., 2010; Sorokin et al., 2007). All the experiments, mentioned above, utilize monochromatic radiation with either low or high intensity depending on single or multiphoton processes to be studied.

Quite different requirements for irradiation parameters are needed for laboratory simulation of astrophysical processes. In this case photoionization of gases is a key process in formation of different kinds of astrophysical plasmas, especially located close to strongly radiating compact objects. For laboratory simulation of such plasmas, high intensity X-ray sources with spectral distribution close to blackbody radiation, are employed. Intense X-rays, necessary for such photoionization experiments, are created in high temperature, dense plasmas. These kinds of plasmas are produced in high-energy density (HED) laboratory facilities by high power lasers or high current Z-pinch discharges, for example using the GEKKO XII (Fujioka et al., 2009) and Shenguang II (Wei et al., 2008) high-power laser facilities and also Sandia National Laboratories pulsed-power Z facility (Bailey et al., 2001; Cohen et al., 2003). In these experiments the irradiated media were placed close to the X-ray radiating plasmas. X-ray power density was sufficient to form a photoionized plasma with high ionization degree. A brief review of interpretation of astrophysical observations, supported by the laboratory astrophysics experiments, was presented in Mancini et al. (2009).

In this work a laser-plasma EUV source was used for photoionization of helium and neon gases. Irradiation was performed using a focused EUV beam. Due to much lower power density comparing to already mentioned experiments, the photoionized plasma formation was not expected. Nevertheless, intense photoionization led to luminescence in the EUV range. The corresponding spectra from neutral and singly ionized atoms were measured. Low intensity spectral lines, originating from Ne III ions were also recorded.

2. Experimental setup

In the experiments, a 10-Hz laser-plasma EUV source, based on a double-stream gas-puff target, irradiated with 3-ns/0.8 J Nd:YAG laser pulses, was used. The radiation was focused using a gold-plated grazing incidence ellipsoidal collector, manufactured by Rigaku Innovative Technologies Europe s.r.o., Czech Republic. The collector allowed for efficient focusing of radiation, emitted from Kr/Xe plasma, in $\lambda = 9$–70 nm wavelength range. The most intense emission was in a relatively narrow spectral region, centered at $\lambda = 11 \pm 1$ nm. The spectral intensity at longer wavelengths was much smaller, however, 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 focused EUV radiation can be found elsewhere (Bartnik et al., 2011).

Ne (N 4.5) or He (N 5.0) gases from Linde Gaz Polska Sp. z o.o. were injected into the interaction region, perpendicularly to an optical axis of the irradiation system, using auxiliary gas puff valve. The valve was equipped with a nozzle in a form of 30 mm long tube with inner diameter of $\Phi = 0.7$ 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 adjusting a backing pressure or opening time of the valve. The gas density was of the order of 1–10% of the atmospheric density. The gases were irradiated using either unfiltered focused EUV radiation or filtered EUV radiation, spectrally-narrowed by Zr or Al filters. Transmissions of the filters were high in the wavelength ranges 6–18 nm and 17–70 nm, respectively.

Irradiation of gases, injected into the interaction region, results in ionization and excitation of atoms or ions. EUV spectra were measured using a grazing incidence, flat-field spectrometer (McPherson, Model 251), equipped with a 450 lines/mm toroidal grating. The spectral range of the spectrometer was $\lambda = 10$–95 nm. Schematic view of the experimental setup is presented in Fig. 1. Optical axis of the spectrometer is perpendicular to the optical axis of the EUV collector thus the luminescence spectra are well separated from the spectra of plasma radiation. It is very important because plasma emission is approximately 10^5 times higher comparing to the luminescence of excited gases. The spectra,

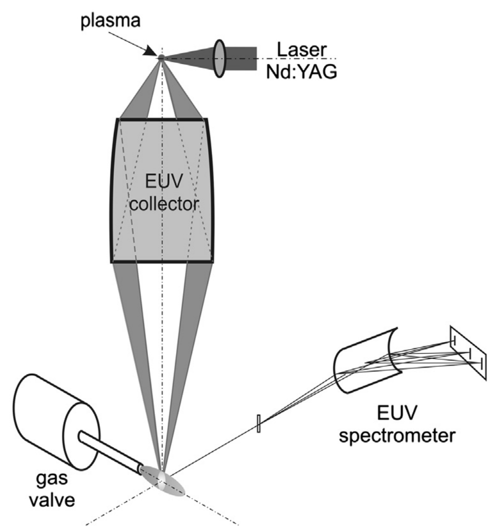

Fig. 1. Schematic view of the experimental arrangement consisting of irradiation system, gas injection system and EUV spectrometer.

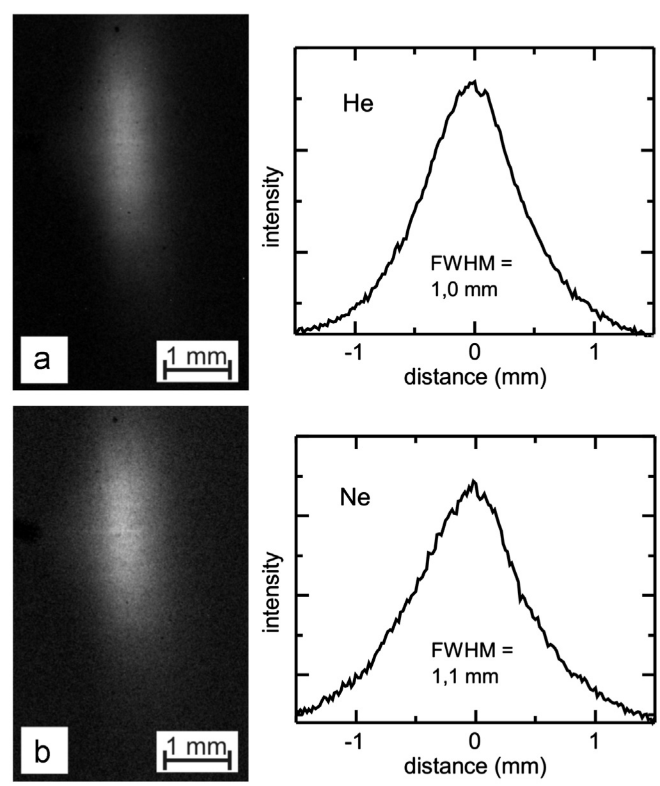

Fig. 2. EUV images of luminescence region together with horizontal intensity profile for: (a) He, (b) Ne.