EUV induced, low temperature, plasma source

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Abstract: In this work a low temperature plasma source, based on photoionization of different gases, is presented. Gases injected into a vacuum chamber were ionized by intense extreme ultraviolet (EUV) pulses. The EUV radiation pulses originated from laser produced Xe plasmas. The EUV induced plasmas were investigated mainly by spectral measurements in ultraviolet and visible ranges. Spectra corresponding to molecular ions were recorded and analysed. Vibrational and rotational temperatures were estimated.

Keywords: photoionization, extreme ultraviolet, EUV induced plasma.

1. Introduction

Low temperature plasmas are widely used in different technologies including microelectronics, deposition of thin films, plasma etching, surface activation and functionalization of polymers, surface treatment etc. Concerning microelectronics, production of integrated circuits requires several, plasma based, steps [1]. Deposition of thin films allows for production of layers having unique properties [2]. Reactive etching concerns for example tungsten, germanium, silicon or chemical compounds of these elements [3]. Such etching can be employed for manufacturing of micro-electromechanical systems (MEMS), microfluidic devices, optical diffractive components etc. Plasma treatment allows to incorporate various functional groups into polymer chains, in order to change various surface properties like wettability, adhesion characteristics or biocompatibility [4]. The plasma treatment of a silicon surface can cause its blackening with a very low reflection losses [5]. Excitation of atomic or molecular species in low temperature plasmas is also a powerful method for spectrochemical analysis [6]. In this work a low temperature plasma source, based on photoionization of gases, is described. Plasmas were created employing extreme ultraviolet (EUV) pulses for irradiation of gases, injected into a vacuum chamber. Time resolved spectral measurements in the optical range were performed. Examples of molecular spectra recorded in an optical range are presented. Based on ionic and molecular spectra, vibrational and rotational temperatures were estimated.

2. Experimental arrangement

Two experimental arrangements based on different laser produced plasma (LPP) EUV sources, driven by 10 Hz Nd:YAG lasers, were used to perform studies of low temperature plasmas induced in molecular gases. The EUV source employed in the first arrangement was based on a gas-puff target system and the 4 ns / 0.8 J Nd:YAG laser (NL 303 HT, EXPLA, Lithuania). The target was created by injection of a small portion of Xe gas into a hollow stream of helium (Xe/He target) using a pulsed valve system, equipped with a double nozzle set-up. The laser beam was focused onto the Xe stream creating the high temperature plasma. The EUV radiation was focused employing a gold-plated ellipsoidal mirror (RITE s.r.o.), Czech Republic. The EUV fluence at the center of a focal spot exceeded 50 mJ/cm^2.

The EUV source employed in the second arrangement also utilized the double stream gas-puff target system and the Nd:YAG laser. In this case, however, the laser pulse parameters were different: time duration was longer ~ 10 ns and the pulse energy was higher, up to 10 J (NL 129, EXPLA). An important difference between the irradiation systems concerned formation of the EUV beam. In case of the second system none EUV collector was employed. To obtain a sufficiently high radiation fluence, for efficient photoionization gases, they were injected close to the LPP, at a distance of approximately 10 mm. In both arrangements an auxiliary gas puff valve, synchronized with the laser pulses, was employed for the gas injection. Its density in the region of interaction with EUV pulses, was regulated, within the range of 1 ÷ 10% of the atmospheric density. More detailed description of experimental arrangements can be found elsewhere [7].

For spectral measurements in a UV/VIS range (λ = 200 ÷ 780 nm), an Echelle Spectra Analyzer ESA 4000 was used. Its spectral resolution was $\lambda/\Delta\lambda \approx 20000$. The measurements were performed with a temporal resolution, which in case of the second system allowed to record spectral lines originating exclusively from the low temperature plasmas, however, some lines from He or Xe admixtures were also recorded.

3. Experimental results

Spectral measurements performed for low temperature plasmas, created in molecular gases, gave multiple lines corresponding to various molecular bands. Examples of the spectra recorded for plasmas induced in a carbon dioxide are presented in Fig.1 The spectra are composed of bands corresponding to electronic transitions in CO_2^+ molecular ions. This type of spectral distribution were obtained in both experimental arrangements. In both systems also an intense spectral line corresponding to radiative transitions $2s^22p^2$ – $2s^22p3s$ in carbon atoms, however, in case of the second experimental system an intensity of this line is approximately 5 times higher comparing to the most intense heads of the molecular bands. In case of the first experimental arrangement a relative intensity of this line is comparable to the band heads, which means that the dissociation degree is lower in this case.

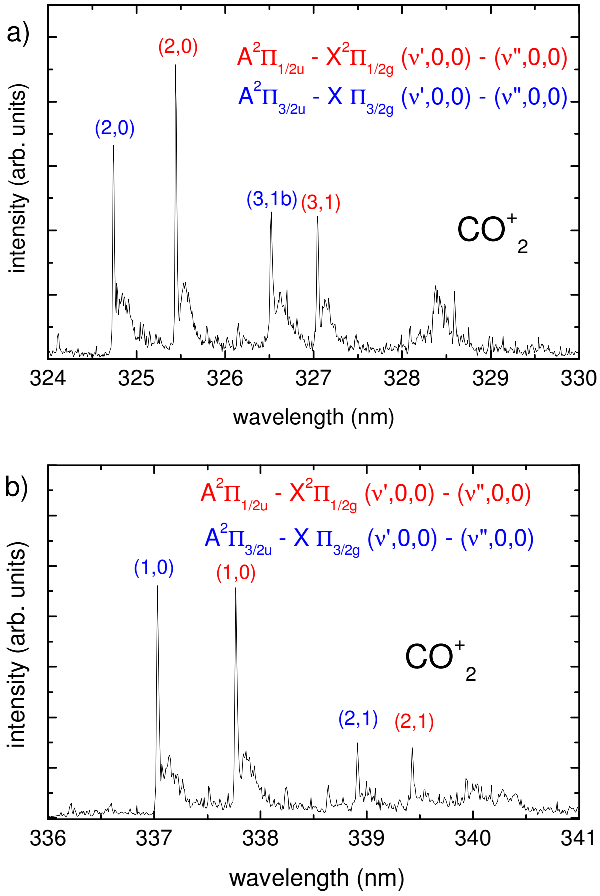

Fig. 1. Spectra obtained for the EUV induced plasmas produced in the CO_2 gas, recorded in different wavelength ranges a) 324 – 330 nm, b) 336 – 341 nm.

In Fig.2 an example of the spectrum recorded for plasmas induced in methane, together with a calculated spectrum obtained from numerical simulations is presented. The spectrum is composed of lines corresponding to electronic transitions between rotational levels in CH species. Simulations of the spectrum were performed employing a Specair code (SpectralFit company, France). A reasonable fit to the experimental spectrum was obtained for a vibration temperature $T_v = 6000K$ and rotational temperature $T_r = 4000K$. Also in this case spectral lines corresponding to radiative transitions $2s^22p^2 - 2s^22p3s$ in both cases were recorded. Similarly to the CO_2^+ spectra, in case of the second experimental system an intensity of the C I line was higher comparing to the most intense heads of the molecular bands. In this case, however, it was over 10 times higher. Additionally in this system spectra corresponding to C_2 molecules were detected.

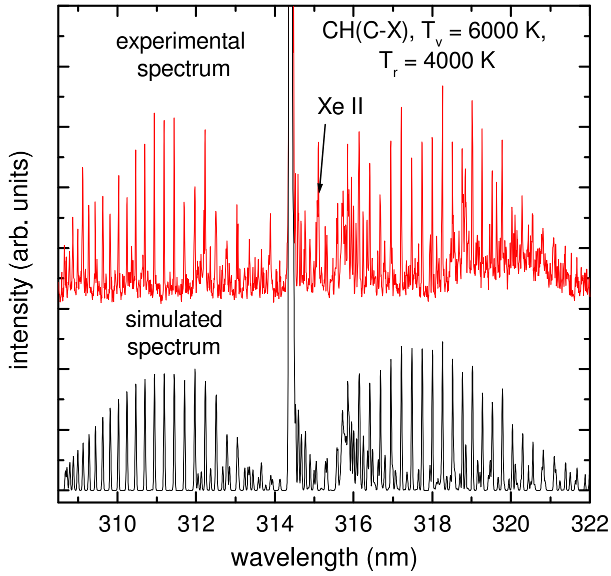

Fig. 1. Spectrum obtained for the EUV induced plasmas produced in the CH_4 gas, together with a simulated spectrum.

4. Summary

The source of low temperature plasmas driven by intense EUV pulses was investigated. Low temperature plasmas were induced in molecular gases. Spectra corresponding to molecular ions were measured. In case of plasmas produced by irradiation of the CO_2 gas, molecular bands corresponding to CO_2^+ ions were identified. Numerical simulations performed for CH species allowed to estimate vibrational and rotational temperatures.

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5. References

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