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Line X-Ray Emission from Laser Irradiated Low-Density Foams Doped by Chlorine

J. Limpouch[1], O. Renner[2], O. Klimo[1], D. Klir[1], V. Kmetik[3], E. Krousky[2], R. Liska[1], K. Masek[2], W. Nazarov[4], M. Sinor[1]

[1] *Czech Technical Univ. in Prague, FNSPE, Brehova 7, 115 19 Prague, Czech Republic*
[2] *Institute of Physics, AS CR, Na Slovance 2, 182 21 Prague 8, Czech Republic*
[3] *Institute of Plasma Physics, AS CR, Za Slovankou 3, 182 21 Prague 8, Czech Republic*
[4] *University of St. Andrews, School of Chemistry, St. Andrews, Fife KY16 9ST, UK*

1. Introduction

Detailed knowledge of laser interactions with low-density porous materials is important for foam incorporation in the target designs that may significantly facilitate various applications of high power lasers. Foam layers may be used in inertial fusion targets to improve implosion symmetry [1]. Alternatively, transparent underdense foam may be applied as a dynamic phase plate in order to randomize and partly wash out inhomogeneity patterns inside laser beams [2]. Laser irradiation of the foams containing high-Z dopants results in creation of quasi-homogeneous layers of relatively dense and hot plasma that can be used for atomic physics and X-ray spectroscopy studies [3], as well as for astrophysically related experiments [4]. Such volumetrically heated plasmas have been used for benchmarking of numerical codes solving non-LTE kinetics [5].

We shall present here results of our recent experiment studying X-ray emission in the vicinity of chlorine He-α and Ly-α lines from chlorine-doped TMPTA ($C_{15}H_{20}O_6$) aerogel foams [6]. These foams with submicron pore size [7] are homogenized very quickly and a relatively thick, nearly homogeneous hot plasma layer is formed. Our time-integrated high-resolution spectra are absolutely calibrated and thus absolute radiance of doped-foams in X-ray spectral lines is obtained and its dependence on laser and target parameters is presented. The efficiency of laser energy transfer to particular spectral lines is calculated. Effective temperature of the foam plasma is deduced from the optically thin intercombination and satellite lines.

2. Experimental set-up

Experimental setup is schematically presented in Figure 1. Third harmonic (λ= 439 nm) of the PALS laser was focused normally on the 480 μm-thick foam layer of diameter 1 mm.

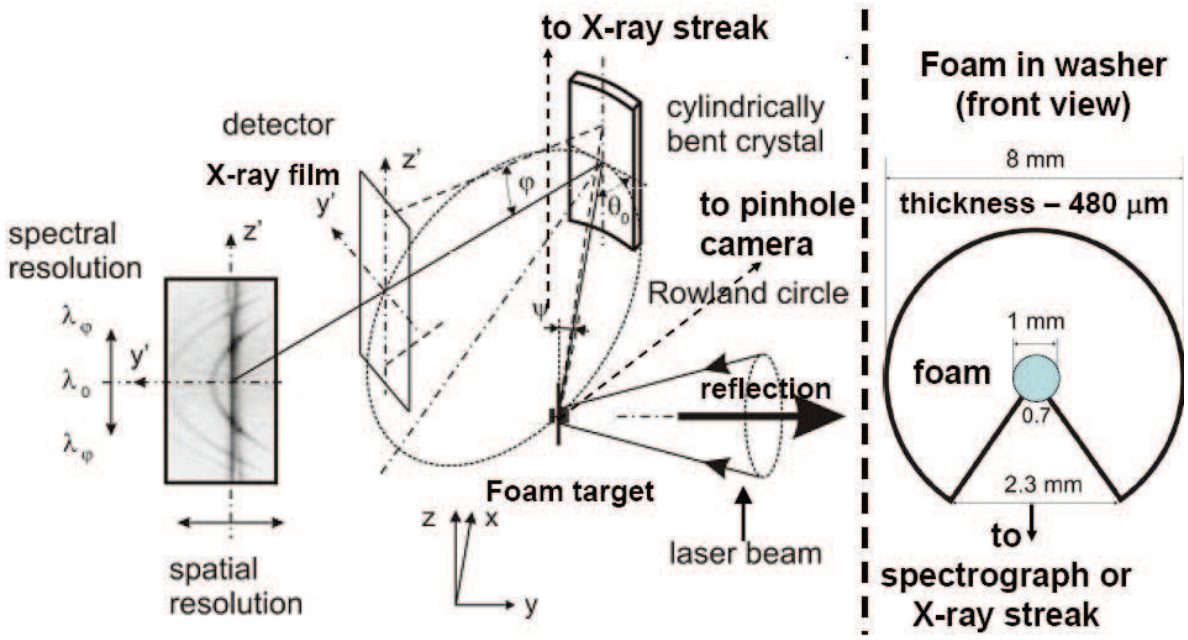

Figure 1: X-ray spectroscopy experimental set-up and foam target design. The principle diagnostics is a vertical-geometry Johann spectrometer using cylindrically bent crystal. Additionally, streaked X-ray slit image and X-ray pinhole image are recorded. Foam is placed into a metallic washer with a widening slit in order to enable detection of X-rays emitted below the foam surface, either by X-ray spectrograph or by X-ray streak camera. Foam density is either 10 mg/cc with 20 weight % of Cl or 20 mg/cc with 10% or 20% of Cl.

The best laser focus was placed either on the foam surface (diameter of the focal spot is approximately 80 μm) or 500 μm ahead or behind the foam surface (diameter of the laser spot at the target is approximately 250 μm).

The principle diagnostics used in this experiment was a vertical-geometry Johann spectrometer (VJS). The VJS disperses the radiation in a direction parallel to the axis of the cylindrically bent crystal, i.e., as a function of the vertical divergence angle φ. The instrument provides two identical sets of spectra symmetrically disposed about the central wavelength λ_0 [8]. The VJS was fitted with a crystal of quartz (100) bent to a radius of 77.2 mm and the spectral resolution in 100 mÅ regions in the vicinity of chlorine He-α or Ly-α lines was > 5000. The VJS observed the spectrum emitted in direction parallel to the target surface with the accuracy of alignment $\psi < 1°$, the spatial resolution of 8 μm is in the direction normal to the target surface. A hole widening with angle of 45° was cut through the foam washer to provide view below the foam surface. Alternatively, the hole in washer could be pointed to the X-ray streak camera through a slit providing spatial resolution in the direction normal to the target surface. In this case, the spectra below the foam surface were blocked out by the washer, which was used for the detection of the foam surface with the accuracy better than ±16 μm. Additionally, X-ray pinhole images filtered to photon energies above 1 keV were recorded from the target front side under the angle of 30°.

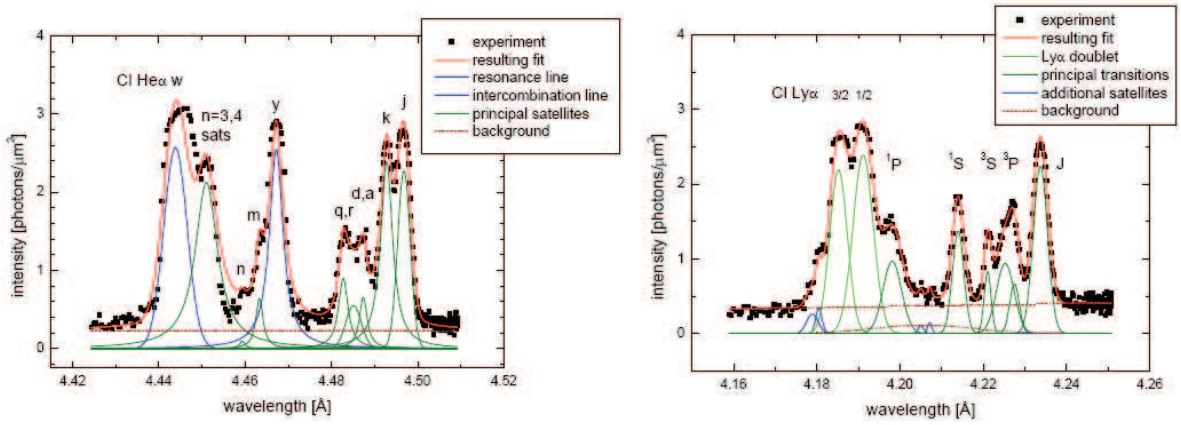

Figure 2: Decomposition of the emission spectra in vicinity of He-α (panel a) and of Ly-α (panel b) lines in the depth of 32 μm below the foam surface. The line spectra were emitted by chlorine dopant (20 weight %) in TMPTA foam of density 10 mg/cm^3. Laser pulse (320 ps FWHM, λ=439 nm) was incident normally on the foam surface and focused to spot ∅=0.25 mm (with laser best focus 0.5 mm above surface). (a) Laser energy was E_L=128 J (w is the He-α line, y is the intercombination line, n, m, q, r, d, a, k, j are Li-like satellites from 1s2l2l' levels, while n=3,4 denote Li-like satellites from 1s2l3l' and 1s2l4l' levels. (b) Laser energy was E_L= 151 J. In addition to Ly-α doublet, He-like satellites 2l2l' are denoted using final transition configurations.

3. Experimental results

Computerized reconstruction of the raw high-resolution and high-dispersion spectral data was based on previously published algorithm [8]. Cuts at the depth of 32 μm of the left part of the measured spectra in the vicinity of chlorine He-α and Ly-α lines are presented in Figure 2. The measured spectra were decomposed via GASPED code [9], based on genetic algorithm using pseudo-Voigt line profiles. We used the code option performing refinement of the genetic algorithm optimization results via Levenberg-Marquardt method. The macroscopic plasma parameters were estimated using FLYCHK code [10]. Resonance lines were found to be optically thick even in low-density foams (optical depths ~100 and ~10 for He-α and Ly-α, respectively), hence the method of isocontour intersections providing couples of (T_e, n_e) for experimentally determined ratios of the optically thin intercombination and satellite lines was applied. Effective values of the electron density were consistent with the electron content in the foams. Effective T_e determined from the individual spectral components in Cl He-α and Ly-α

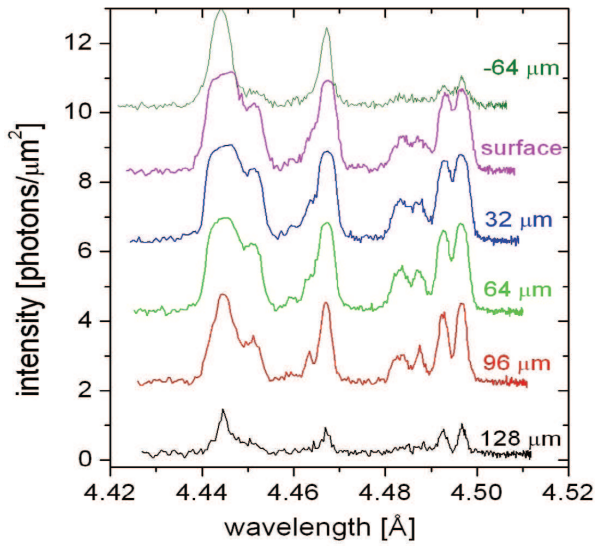

Figure 3 Left part of the recorded spectra in different depths below the foam surface (successively vertically shifted by 2). The same shot as in the Figure 2a.

groups varied within 520-670 eV. The emitted spectra are plotted versus the depths below the foam surface in Figure 3. Spectra are observable up to depth of ~150 μm. The registered spectra are very similar for the depths from 32 μm up to 96 μm and thus, formation of a homogeneously emitting volume is confirmed.

Radiance of homogeneously emitting foam volumes in spectral lines was derived using the transfer function of the absolutely calibrated VJS, hitherto processed results demonstrate the relevance of three investigated factors for source radiance S_r [ph/(μm^2× mrad^2)]: The source radiance S_r in Cl He-α emission from TMPTA foam of density 10 mg/cc with 20 weight % of Cl and laser focus 500 μm above the foam surface was 42, 82, and 246 for the laser energies 60, 128, and 212 J, respectively. The integrated source emission was practically independent of the focal position, while the radiance was higher for the best laser focus on the foam surface due to the smaller emitting volume. Laser light conversion efficiency into full He-α group was approximately 0.02%.

4. Conclusions

Absolutely calibrated emission spectra from low-density plastic foams heated by intense subnanosecond laser pulses were measured. Numerical simulations of the interactions are underway using arbitrary Lagrangian-Eulerian fluid code PALE [11].

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