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Investigation of x-ray radiation interaction with matter on “Iskra-5” laser

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Abstract. In the concept of indirect fusion X-ray transport and material heating by x-ray radiation are the main physical processes. In this report we present main experimental results obtained at “Iskra-5” laser operating at the first and second harmonics: Cylindrical box-converter, so called “Illuminator”, has been used for x-ray generation. Up to 3 kJ of laser energy at 1ω ($\lambda = 1.315$ μm) and pulse duration ~0.4 ns can be introduced into “Illuminator”. In this case the “effective” x-ray temperature is of $T_{eff} \approx 160 \pm 15$ eV. At the second harmonic ($\lambda=0.66$ μm) the absolute values of x-ray flux and spectral distribution corresponding to the effective x-ray temperature of $T_{eff} \approx 170 \pm 15$ eV have been registered at the total laser energy up to 1.4 kJ and pulse duration ~0.5 ns. The x-ray transport in gold cylindrical channels, and results of thin foil heating by x-ray radiation. The comparison of experimental data with theoretical results, carrying out in RFNC-VNIIEF is also presented.

X-ray source. X-ray source design is similar for various facilities. Typically it is cylindrical box-converter with laser entrance holes (LEH) and hole for x-ray radiation output. Experimental data obtained from various facilities at the third harmonic of Nd laser are shown in figure 1. Thick solid line is the scaling for maximum x-ray temperature in the gold box-converter, which is the following[1]: $T[eV] \approx 62\ (\eta I[TW/cm^2]\ t^{0.5}[ns])^{1/3..3}$, where η - conversion efficiency of laser energy into x -ray. The value of η depends on laser wavelength ($\eta \approx 0.7$ if $\lambda \approx 0.35$ μ). From the presented experimental data it is seen, that the temperature saturation at the level of $T_{eff} \approx 300$ eV occurs when 3ω laser radiation flux reaches $It^{0.5} > 300$ TW ns$^{0.5}$/cm^2. This effect is appeared due to the box filling by plasma during the laser pulse and rapid increasing of non-linear processes in laser - plasma interaction. Our experimental data at the first and second harmonic of iodine laser are also presented in the figure 1. A temperature saturation for the first harmonic is observed for $It^{0.5} > (50 \div 100)$ TW ns$^{0.5}$/cm^2. Here the measured temperature is about 160 eV. For the second harmonic, the temperature of ≈ 170 eV was reached for $It^{0.5} \approx 100$ TW ns$^{0.5}$/cm^2.

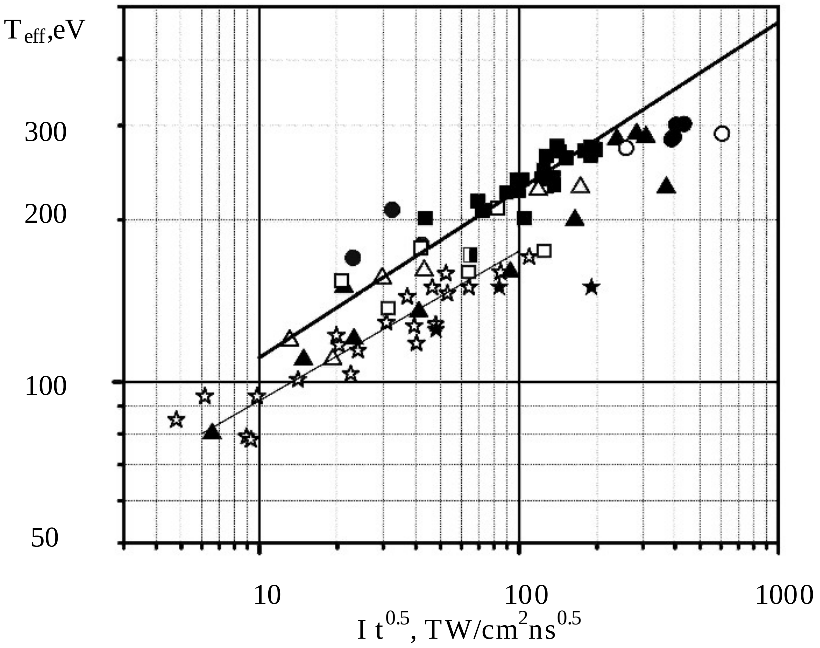


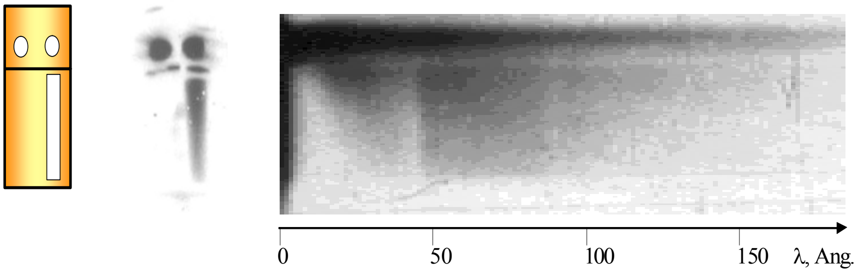
Figure1. X-ray temperature in box-converter versus $I_{14} t^{0.5}$.

■▲●○ Nova, □ Phebus, △ GekkoXII, ▬ Scaling λ = 0.35 mkm [1]

◧ Novetta λ = 0.53 mkm [1], ▲ Helen(UK) λ =0.53 mkm [2]

★ Iskra5 λ = 1.3 mkm, ☆ Iskra5 λ = 0.66 mkm [this work]

X-ray transport along the cylindrical channel. Examples of x -ray transport registration are shown in figure 2. The transport cylinder with the special diagnostic slit on the cylinder lateral surface was jointed to “Illuminator” in these experiments [3]. In some experiments the additional cylinder of smaller diameter and the same length was arranged inside the transport cylinder. So the cylindrical gap for x-ray transport was formed by the internal surface of the external cylinder and the external surface of the internal cylinder. X -ray radiation transport along vacuum channel and gap as well as filled by $C_5H_8O_2$ foam with the density $\rho \approx (1\pm0.2)\cdot10^{-2}$ g/cm^3 was investigated.



Target view X-ray image TGS spectrogram

Figure 2. Example of x -ray transport registration along the gold cylindrical channel

The experimental results show that the exponential reduction of x-ray brightness is observed for gold channel with diameter D_0: $Q/Q_0 \approx 0.7 \exp(-L/L_{eff})$, where Q_0 is x -ray flux at “Illuminator” output and $L_{eff} \approx 0.8\,D_0$ (± 10%). In the experiments with the cylindrical channel filled by the foam ($C_{15}H_{20}O_6$) with $\rho = 5 \div 10$ mg/cm^3 value of L_{eff} reduces up to $L_{eff} \approx 0.35\,D_0$. In the case of the gold cylindrical gap the value of $L_{eff} \approx 0.5\,(D_0 - D_i)$ was obtained (D_0 is the external cylinder diameter and D_i is the internal cylinder diameter). For comparison with theoretical models it is very important to know the velocities of heat propagation along the channel or the gap. This information can be obtained by streak- or frame cameras. The examples of the obtained images are shown in figure 3.

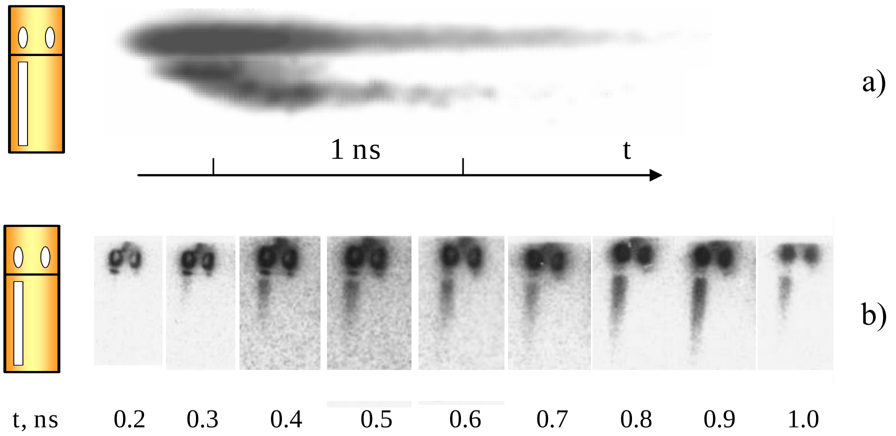
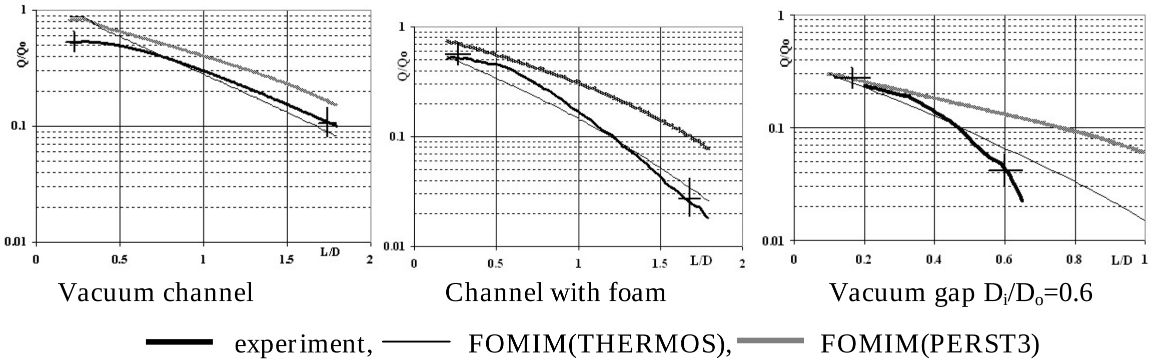


Figure 3. Examples of streak-a) and frame camera-b) registrations

From the figures one can see, that slit luminescence starts with delay relative to the luminescence of LEHs. This delay appears due to the heating of separating film between “Illuminator” and the channel. The velocity of heat propagation along the channel was measured and was $(3.6 \pm 0.6)\ 10^8$ cm/s. Registration threshold of the method was ~50 eV, i.e. the obtained velocities correspond to the velocity of cylindrical channel wall heating up to the temperature of ~50 eV.

Theoretical researches. The analysis of "Iskra-5" experimental results on the x-ray radiation – plasma interaction was carried out using 2D numerical methods for x-ray radiation transport. These methods are based on the kinetic and spectral approximations[4]. The main attention was directed on the comparison of x-ray parameters calculated with the use of opacity codes PERST-3[5] and THERMOS[6]. The results are shown in figure 4. It is seen the satisfactory fit of theoretical results (with the THERMOS opacity database) to experiment.



Vacuum channel Channel with foam Vacuum gap D_i/D_o=0.6

experiment, FOMIM(THERMOS), FOMIM(PERST3)

Figure 4. Comparison of the experimental and calculated results on x-ray transport

Comparison of theoretical and experimental pulse profiles after the burnthrough of CH layer (basic signal) and after the burnthrough of 0.2 μm gold layer is presented in figure 5.

The maximum intensity of Au signal is 2.5 times less than intensity of CH layer. Satisfactory agreement of experimental and theoretical data is observed for the gold foil.

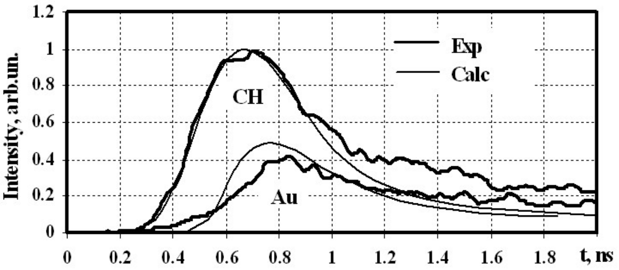


Figure 5. Experimental and calculated profiles of the streak camera signal

Summary. The radiation temperature up to 160eV for the laser operation on the 1st harmonic (3 kJ, 0.4 ns), and 170eV for the 2nd harmonic (1.5 kJ, 0.5 ns) were achieved at Iskra-5 laser. Experimental investigations of the x-ray transport along cylindrical channels and cylindrical gaps as well as material heating by the x-ray radiation were carried out. Application of theoretical model is checked by good coincidence between the calculated x-ray flux parameters and experimental data. Taking into account experimental errors and theoretical accuracy, good agreement between theoretical and experimental data is observed if we used in our calculations THERMOS opacity code.

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References: 1. J.Lindl. Phys. Plasmas, 2 (11), p.3933 (1995).

2. R.M.Stevenson, K.Oades, B.R.Thomas et al. Phys.Rev.Lett, 94, p.055006 (2005)

3. F.Abzaev, A.Bazin, A.Bessarab, et al. Proceedings of the 1st IFSA, p.279, Elsevier, (2000).

4. V.Afanasieva, A.Bazin, et al. Proceedings of the 2nd IFSA, pp 532, Elsevier, (2002)

5. N.Degtyarenko, G.Eliseev. VANT, Ser.MMPP 3, p.54. 1999

6. A.F.Nikiforov, V.G.Novikov, V.B.Uvarov. Quantum-statistical models of hot dense matter and methods for computation opacity and equation of state. Moscow. FIZMATLIT. 2000