Stable laser-plasma picosecond kHz x-ray source using melted metal target


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Femtosecond laser plasma
– unique source of hard x-ray, fast electrons, ions and neutrons with high energies

Applications:
• x-ray spectroscopy with high temporal resolution;
• nanostructures investigation;
• medical researches;
• biology;
• etc.
Plasma properties

• Solid state density, \( n_e \approx 10^{24} \text{ cm}^{-3} \)

• Non-Maxwellian distribution of electrons:
  - thermal electrons, \( E_e = \text{up to } 1 \text{ keV} \)
  - hot electrons, \( E_h \approx 20 \text{ keV} \)

• Emission of hard x-ray:
  - bremsstrahlung
  - radiation of lines

• Duration of x-ray pulses – few ps;

• High efficiency of conversion of laser radiation into x-ray – \( \approx 1\% \)

\[ I = 10^{17} \text{ W/cm}^2 \]
Advantages of a liquid target

- Simplicity of target construction;
- Stability at high repetition rate of pulses.
Ti:Sa laser parameters:
- pulse duration: 60 fs;
- wavelength: 800 nm;
- energy of a pulse: 1 mJ;
- repetition rate: 10 Hz;
- peak intensity: 10^{17} W/cm^2.

1 – laser beam, 2 – objective (F/D=6), 3 – vacuum chamber (P=10^{-2} torr), 4 – heater, 5 – bath with melted Ga target (T=300 °C), 6 – filters, 7 – PMT with NaI(Tl) scintillator, 8 – spectrometer (PIN-diode Amptek AXRCR)

Spectrum of plasma

- $K_\alpha (Ga) - 9.3\, keV$
- $K_\beta (Ga) - 10.3\, keV$
- $K_\alpha (Cu) - 8.3\, keV$
Stability of x-ray source at 10 Hz(*)

X-ray source parameters:

- $10^6 K_\alpha$ quanta/pulse
- 1,4 nJ/pulse

1,6x10^{-4}%

(*) V.M. Gordienko, M.V. Kurilova, E.V. Rakov et al.// Quantum Electronics 37, 651
Stability of x-ray source at 1 kHz

**Ti:Sa laser parameters:** pulse duration – 100 fs; wavelength – 800 nm; pulse energy – 2 mJ; repetition rate – 1 kHz.
Laser pulse parameters:
- pulse duration: $60 \text{ fs}$;
- pulse energy: $1 \text{ mJ}$
- prepulse №2 energy (a.u.): $10^{-4}$
- prepulse №3 energy (a.u.): $2 \times 10^{-7}$, from $10^{-1}$ to $400^{-1}$;
- $s$- and $p$-polarization;

$1$ – main pulse, $2$ – prepulse at picosecond scale, $3$ – prepulse at nanosecond scale
Expected energy of hot electrons at $10^{17}$ W/cm$^2$: $E_h = 20$ keV

At prepulse amplitude $50^{-1}$ efficiency of conversion of laser radiation:

- into entire spectrum into range $>6$ keV – $4 \times 10^{-4}\%$
- into $K_\alpha$ and $K_\beta$ lines – $2 \times 10^{-4}\%$
Ti:Sa laser parameters:
- pulse duration: 60 fs;
- wavelength: 800 nm;
- energy of pulse: 5 mJ (200 µJ on target);
- repetition rate: 10 Hz.

1 – beam splitter, 2 – SHC, 3 – objective, 4 – CCD camera
Size of formations after 13ns of prepulse action:
- jets – ≤ 1 µm;
- opaque bubble – 10 µm;
- oblong jet – 130 µm.
Conclusions

- Liquid gallium can be used as a stable laser-plasma source of x-ray pulses with repetition rate up to 1 kHz with more than $10^9$ x-ray quanta per second;

- 60 times increase in hard x-ray yield and almost fourfold growth of hot electron energy in plasma is achieved using a laser pulse with a prepulse;

- Submicron jets are found, which might lead to local electric field amplification and also independence of plasma parameters on polarization.
Thank you for your attention