INTERACTION OF LASER RADIATION WITH CONTROLLABLE COHERENCE WITH MATTER AND ICF

Alexander N. Starodub

N.G.Basov Institute of Quantum Radiophysics of P.N.Lebedev Physical Institute of the RAS

Leninsky prospect 53, 119991, Moscow, Russia

Motivation

- Volume-structured materials are considered as different functional elements in the ICF targets.
  - Smoothing of a heating inhomogeneity
  - Production of a steady compression of ICF targets
- Investigation of the specific features of laser radiation absorption and scattering by such media, as well as the energy transfer, plasma formation and plasma dynamics, is a important problem.

- **Why low coherent light?**

New Approach for Laser Driver and High Power Laser Systems

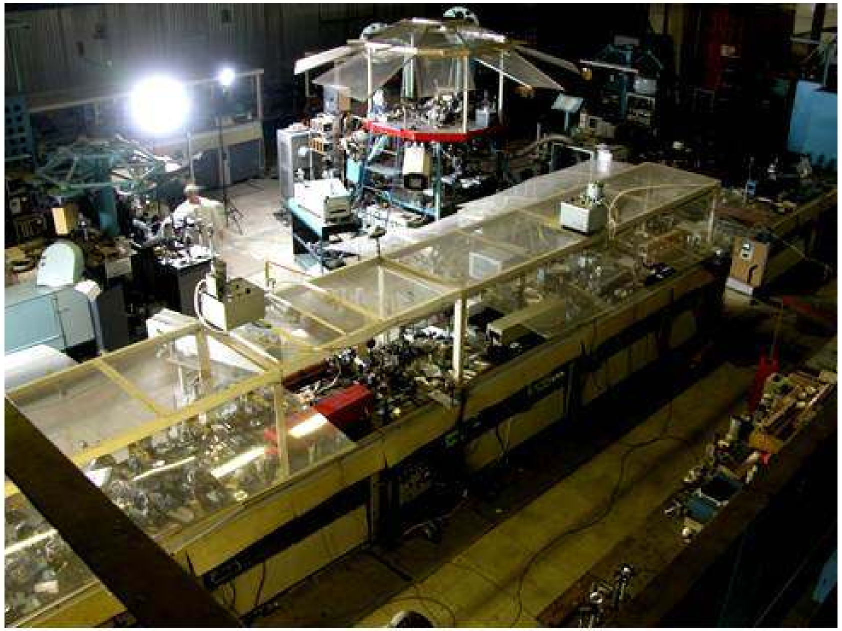
S.I. Fedotov, L.P. Feoktistov, M.V. Osipov, A.N Starodub (2002)

In connection with project of Hybrid Fusion-Fission Power Station *(N.G.Basov, L.P.Feoktistov, V.I.Subbotin (1993))* we suggested to use

- **Laser with Controllable Coherence of Radiation for creation of Laser Driver**
  - **To use physical properties of laser light, first of all its coherence, to exclude many difficulties which arising with growth of laser system energy**

Experimentally justified that Laser with Controllable Coherence of Radiation may be considered as basis for creation of high power laser systems and Laser Driver

- Suppression of speckle structures and self-focusing
- Control of flux distribution *I*(*x*,*y*) and spatial-angular characteristics
- Increasing of energy density in rods and increasing of output energy
- Higher laser efficiency
- No phase plates, adaptive optics, spatial filters
- More compact laser installation
- Lower requirements for cleaning
- Lower requirements for optics quality



- **The experiments have been performed with a Nd-glass laser facility KANAL-2 with controllable coherence of radiation with the following parameters**
  - laser pulse duration 2.5 ns
  - pulse energy up to 300 J
  - output aperture 60 mm
  - degree of spatial coherence ~ 0.05 – 0.015
  - degree of temporal coherence ~ $5x10^{-4}$ – $5x10^{-3}$
  - degree of radiation polarization ~ 0.5
  - pulse radiation contrast > 10^6

Team

N.G.Borisenko
M.I.Chernodub
A.A.Fronya
Yu.A.Merkuliev
M.V.Osipov
V.N.Puzyrev
A.T.Sahakyan
B.L.Vasin
O.F.Yakushev

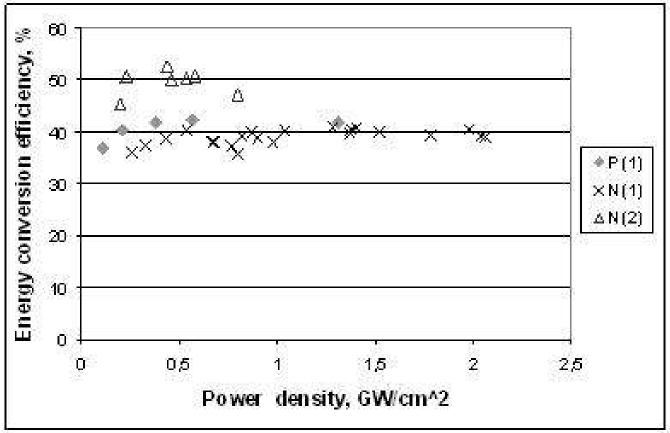
Directions of Experimental Researches

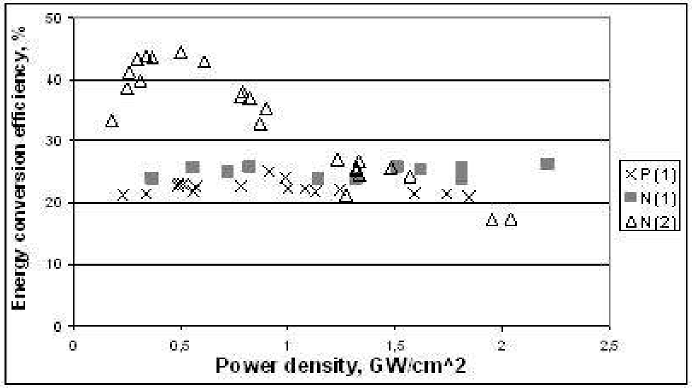
- Absorption and scattering of laser radiation;
- Laser radiation harmonic generation;
- X-ray generation;
- Crater formation and plasma expansion under laser pulse;
- Energetic particle generation and transportation under laser-target interaction;
- Conversion of laser radiation by means of nonlinear crystals;
- Influence of coherence degree on the processes mentioned above.

Second Harmonic Generation by KDP crystals

- Efficiency of conversion of low-coherent laser radiation into the second harmonic may achieve 40 - 50% depending on experimental conditions

- Right top:
  - Efficiency of conversion. P - polarized radiation, N – non-polarized radiation. Number of transverse modes, n ≈ 1×10^2; divergence (1) α = 1.17mrad, (2) α = 0.47mrad.
- Right bottom:
  - Efficiency of conversion. P - polarized radiation, N – non-polarized radiation. Number of transverse modes, n ≈ 1×10^3; divergence: (1) α = 3.5mrad, (2) α = 1.4mrad.

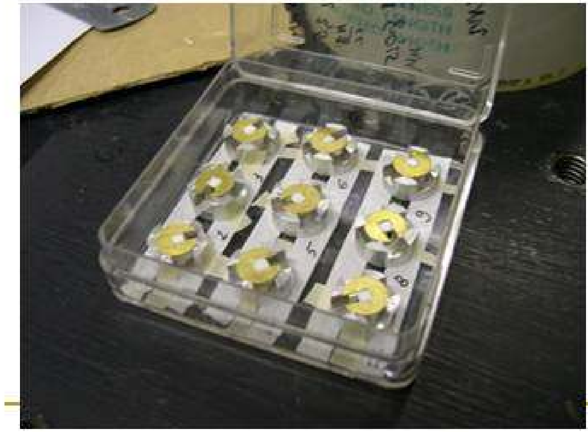


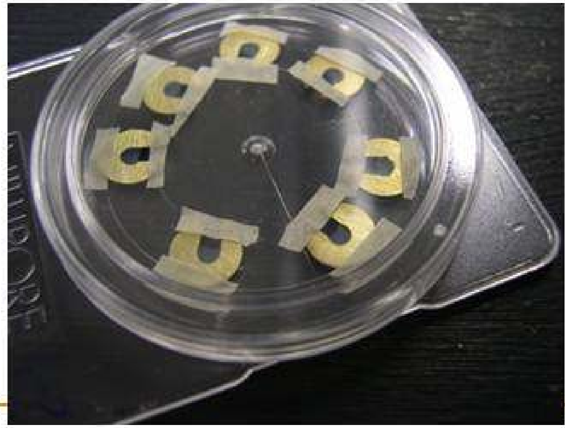


Foam Targets for «KANAL-2»

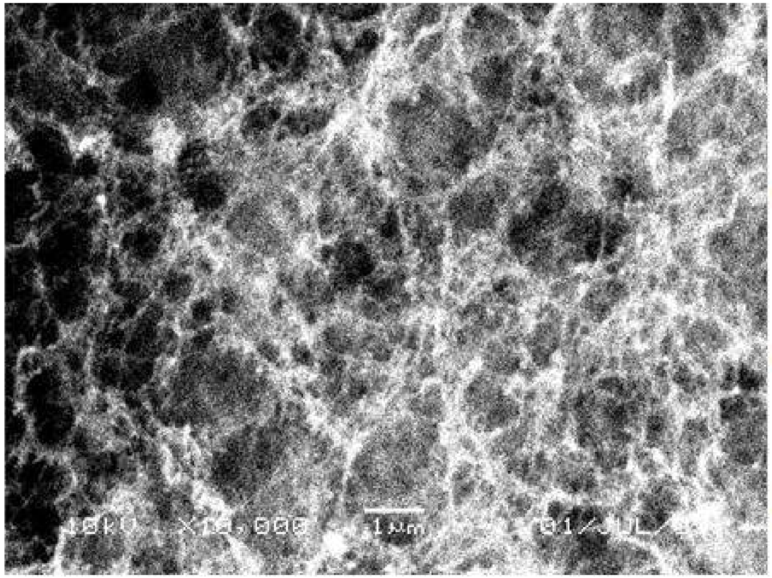
Yu.A.Merkul'ev,
N.G.Borisenko

TAC (µ cells)			TAC (µ cells)			
20 mg/cc, 5% Cu	20 mg/cc	10 mg/cc	9 mg/cc ,	4.5 mg/cc	2.5 mg/cc	10% hi-Z
No foil, c/o, 100-500µ			No foil, c/o, 100-500µ			
Foil 5 µ, c/o, 100-500µ			Foil 5µ, c/o, 100-500µ			



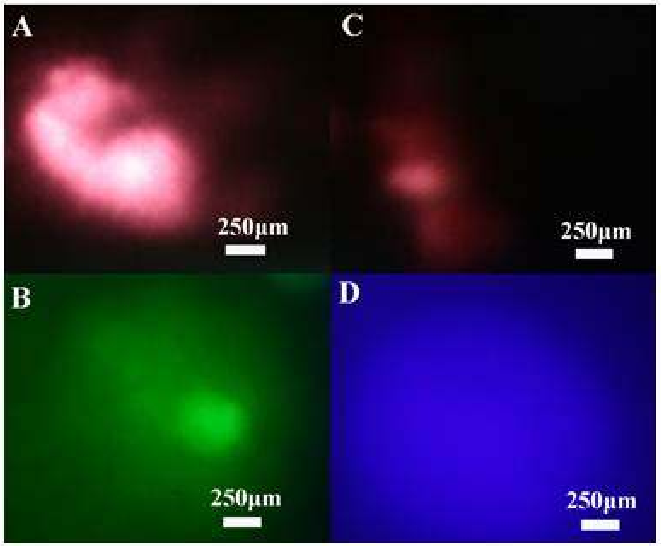


SEM Image of Target



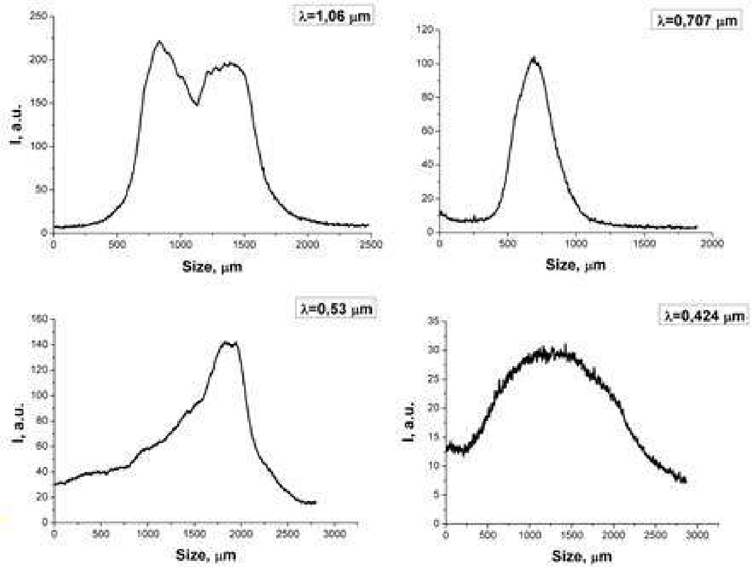
- The targets from triacetate cellulose aerogels (TAC) of the density of 9.1 mg/cm^3, 4.5 mg/cm^3 and 2.25 mg/cm^3 have been used. In several experiments up to 10 weight percent of copper nanoparticles of average diameter of 40 nm have been introduced into the polymer.
- 3D polymer nets do not change their structure under the change of density from 50 mg/cm^3 to 1 mg/cm^3 .
- The distance between the filaments is 0.6 to 1.7 mcm, and the filament diameter is 70 to 40 nm.
- The aerogel density fluctuations at volume averaging 0.3x0.3x0.3 mm^3 do not exceed 0.5% at the aerogel average density higher than 4 mg/cm^3, and grow up to 3% for the aerogel density of 1 mg/cm^3.

Image of Plasma on Frequencies $2\omega_o$, $3/2\omega_o$, $5/2\omega_o$ and on the Fundamental Frequency



Target TAC 9 mg/cm³ 400 µm
E_{inc}=17.8 J
E_{bs}=30 mJ
A – 1.06 µm;
B – 0.53 µm;
C – 0.71 µm;
D – 0.42 µm.

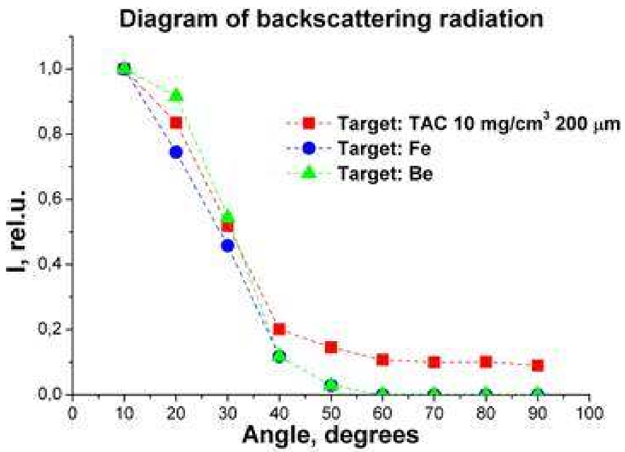
Spatial distribution of plasma radiation intensity on frequencies $2\omega_o$, $3/2\omega_o$, $5/2\omega_o$ and on fundamental frequency

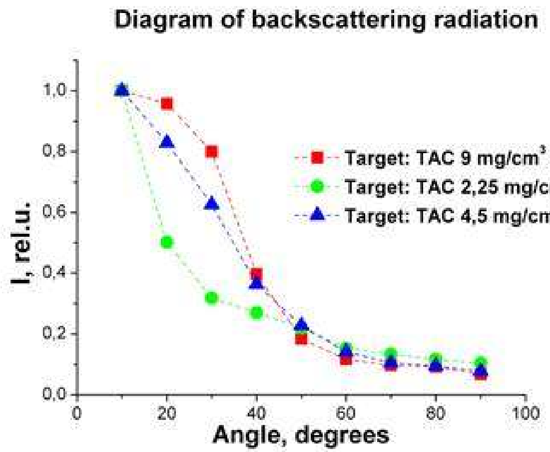


Size of focal spot 350 µm.
Energy concentrated in spot is ~ $2\cdot10^{-5}$ J for λ =1,06 µm in spatial angle $1.6\cdot10^{-4}$ steradian, and energy is ~ $2\cdot10^{-9}$ J for λ=0,53 µm.

Diagrams of Plasma Backscattering on Fundamental Frequency

- ***Diagrams of scattering for the microstructured triacetate cellulose targets with the density 2.25; 4.5; 9; 10 mg/cm³ are presented. The diagrams of scattering for solid-state Fe and Be targets are presented also.***
- ***With an increase in the linear mass of TAC targets the angle of divergence increases.***



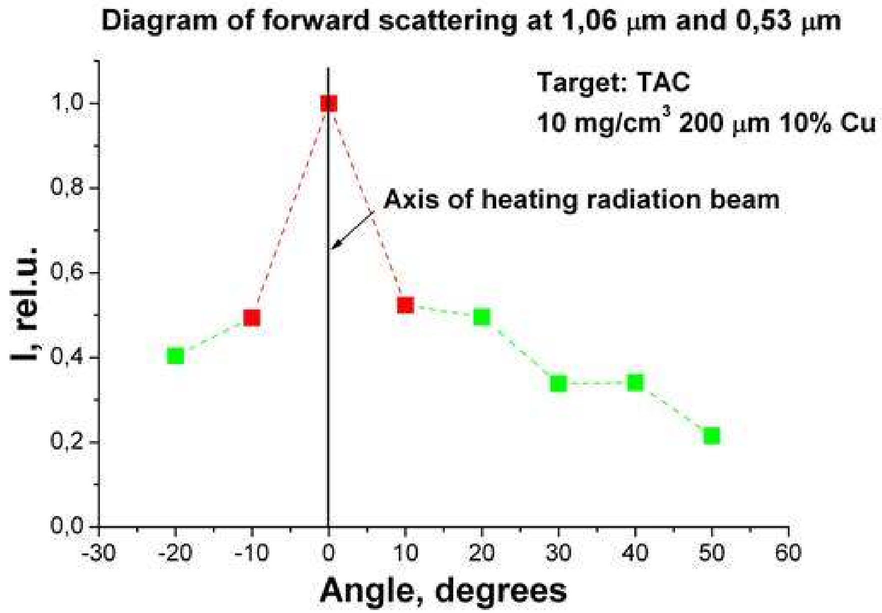


Diagrams for TAC targets 4.5/400 and 10/200 are similar. These diagrams seem also to correspond to the diagrams for solid-state targets on fundamental frequency as well.

Laser Radiation Backscattering

- **Energy of the backscattered radiation is less than 1%.**
  - **The nonlinear scattering processes (SMBS, SRS) are non-essential from the energetic viewpoint and may affect the scattered radiation linewidth only.**
  - **The nonlinear processes of forward scattering are not energetically essential as well.**

Diagrams of Forward Scattering Radiation

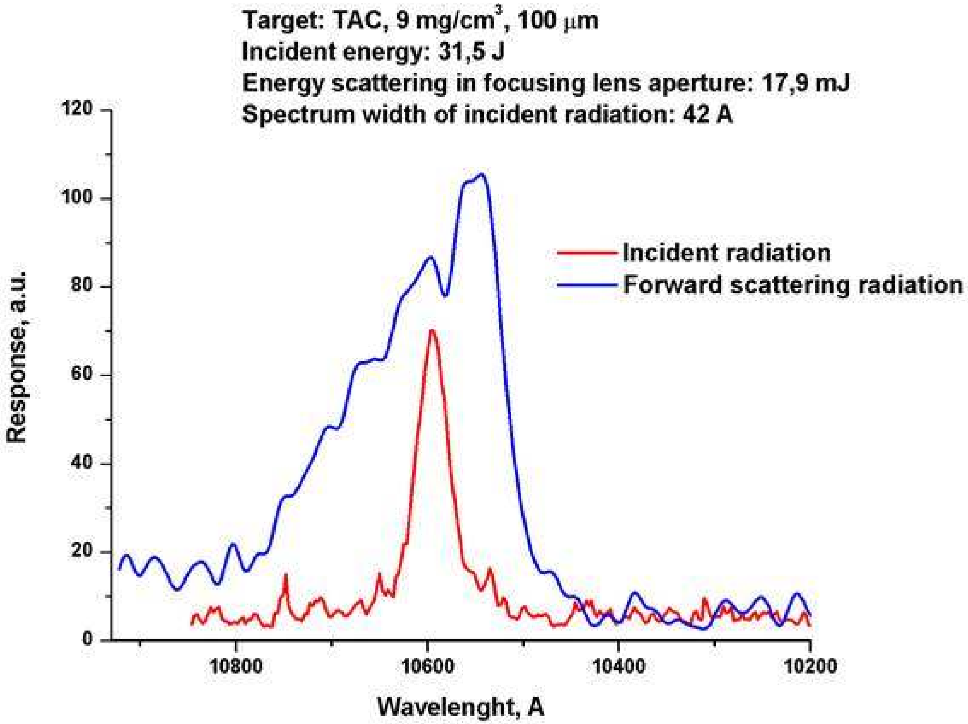


Forward scattering radiation on fundamental frequency concentrate practically in the aperture of an incident laser beam, and forward scattering on the second harmonic of fundamental frequency occurs practically diffusely in space.

Broadening of Spectrum of Forward Scattering Radiation

- Forward scattering radiation spectrum

- Incident radiation spectrum



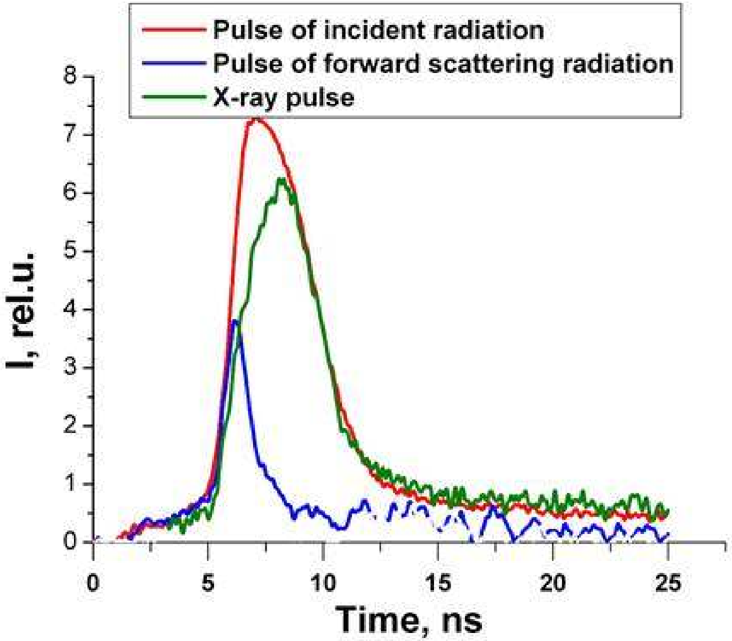
The Main Measurement Results on the Radiation Passed Through the Aerogel

- Under definite conditions energy of the passed radiation is comparable with the incident radiation energy
  - The passed radiation energy is 11.2 J at incident laser energy of 16.4 J, the TAC target thickness being 100 mcm and target density 4.5 mg/cm^3.
  - Target optimization
- The energy passed through the aerogel decreases
  - with increase in the aerogel thickness
  - with increase in the target density
  - with increase in the target linear mass
- Duration of the aerogel-passed pulse is comparable with pulse duration of the incident radiation.
- The passed radiation linewidth increases and may reach 200 Å.

Interpretation

- **The interpretations of the target geometrical transparency (Gus'kov, Rozanov (1997); Bugrov et al. (1999)) are not capable to explain the observed duration of a passed energy pulse and value of that energy.**
- **It is possible that conditions for a nonlinear transparency of plasma produced under aerogel irradiation are realized.**
- **Such a transparency arises due to the plasma density modulation in a laser field (Mironov (1971); Vladimirskiy, Silin, Starodub (1977); Gorbunov, Zauer (1977)). As a result, there may arise even a full transparency of a layer under certain relationship between laser intensity, plasma layer size and the radiation wavelength.**
- **The second harmonic registration show that such a density modulation actually takes place under laser-aerogel interaction for targets with both overcritical and undercritical density. The generation of $3/2\omega_o$, $5/2\omega_o$ harmonics indicates that this modulation is deep enough.**
- **Another reason for nonlinear transparency of aerogel target may be connected with anomalous burning (A.V. Koutsenko, I.G. Lebo, A.A. Matzveiko et al.).**

Temporal Evolution of Passing Pulse

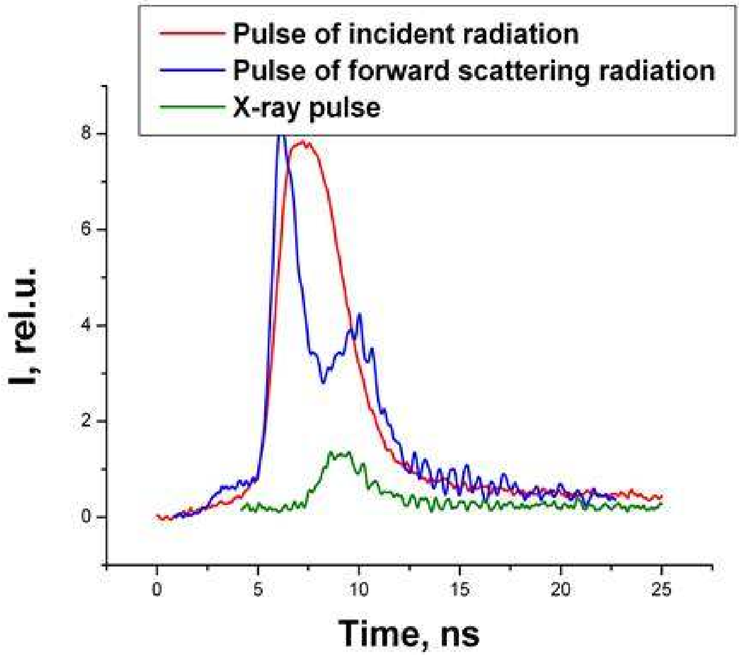


Target TAC 9 mg/cm^3 500 μm
E_{inc}=66,7 J
E_{fs}=0,4 J

- Pulse duration of a passed energy is comparable to the duration of the incident laser pulse.
- As the plasma develops the absorption grows, and the energy of passing pulse decreases. As seen from X-ray measurements the X-ray radiation intensity grows, which corresponds to heating of a going-on plasma .

Temporal Evolution of Passing Pulse

Target TAC 10 mg/cm^3 200 μm with 10% Cu
Size of focal spot 160 μm
E_{inc}=32 J
E_{fs}=5.2 J
E_{bs}=19.5 mJ in aperture of the focusing lens
λ_0=10598.6 Å
$\Delta\lambda$=21 Å



- It should be noted that the real picture of the nonlinear transparency of the arising plasma is more complicated and is defined by the conditions of energy absorption and transfer, plasma formation and plasma dynamics. This means that the temporal behavior of the pulse transmitted through the aerogel target may change from shot to shot.

Summary

- Recent results on the interaction of laser radiation with plastic aerogel target (TAC) are presented and discussed.
- The energy transmitted through the aerogel target is comparable with energy of the incident radiation. Value of this energy depends on an aerogel density and thickness and may achieves 70% even when the target density is higher than critical.
- The transmitted radiation is considerably broadened (up to 200 Å). The second-harmonic generation and other nonlinear effects were experimentally registered under the TAC target irradiation.
- The TAC target could be used for the laser radiation conversion to optimize the light absorption and to obtain a broad linewidth of incident radiation.
  - The efficiency of energy yield from active elements may be higher and therefore the laser efficiency may increase.
- Laser radiation transmission through aerogel is considered as nonlinear transparency of a plasma layer arising under laser interaction with the aerogel target.
- Nonlinear transparency of the aerogel plasma strongly depends on the conditions of laser energy absorption and its transfer, plasma formation and its dynamics.

Acknowledgements

This work is partially supported by

- the Russian Foundation for Basic Researches (grant # 10-02-00113),
- Program of the RAS "Nonlinear optical methods and materials for new generation of laser systems"
- Federal Target Program "Research and scientific-pedagogical cadres of innovative Russia" (grant # 2009-1.1-122-052-025).