Target aspects in plasma experiments with laser and heavy ion beams

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Outline

- Introduction. Several words about joint works of Thermonuclear Target Laboratory (TTL) LPI with the Russian Institutes and foreign Centers.
- TTL of LPI in large projects
- Novel results during past 5 years.
- Our targets in laser experiments.
- Application of our technologies.
- Conclusion.

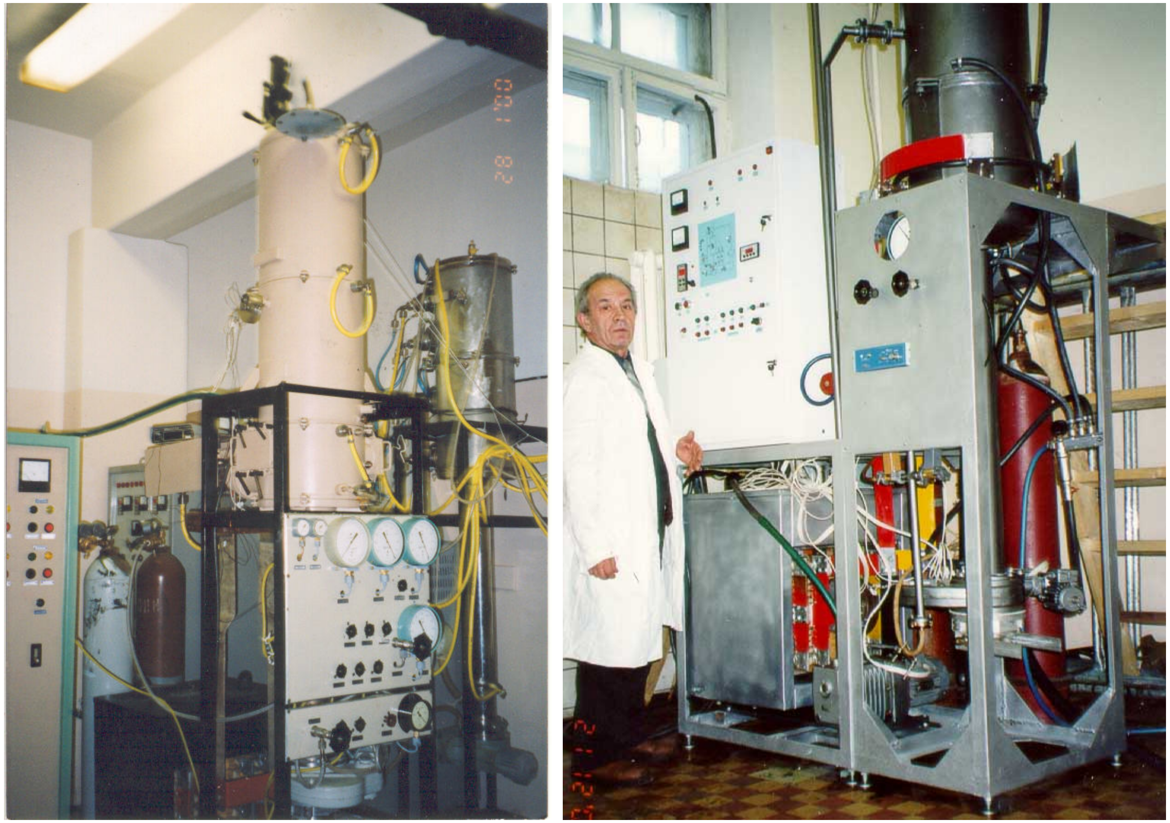
Introduction

- Thermonuclear Target Laboratory of LPI produces various targets. We also produce the equipment for target fabrication.
- TTL is the leader of target research in Russia and is responsible for “target factory” in “Iskra-6” program. We work in cooperation with different Institutes.
- We take part in large international projects (Iskra-6, HED&HOP (EC, GSI, Germany), HiPER (EC, UK), Petal (EC, France)
- Russian targets specialists take part in IFSA, ECLIM international conferences and IEAE meetings.
- Equipment and software developed in LPI and our laser targets are used in 7 Russian Institutes and in 9 Scientific Centers in 7 countries. Rep-rate cryogenic target fabrication and delivery to laser focus in interaction chamber.
- Current grants

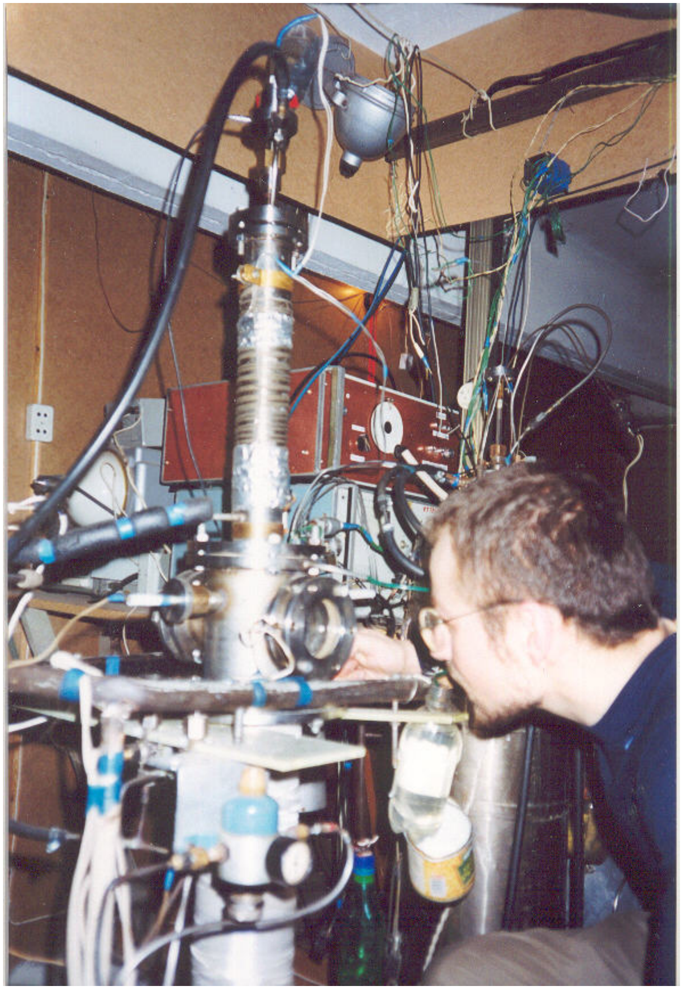
1. Extreme ultraviolet generation (EUV) and EUV diagnostic of dense cool turbulent plasma (magnetic fields and plasma viscosity)
2. Equation of state (EOS) and pressure increasing in multilayers targets
3. Laser irradiation smoothing by different methods (thermal – in polymer aerogel, x-ray – low-density metal or metal with polymer, optical – dynamic plasma phase plate).
4. Rep-rate cryogenic target fabrication and delivery to laser focus in interaction chamber.

- Remark: Projects of targets factory, many targets deliveries and equipment creation require financing and time (1-3 years).

Equipment for the scientific centers in foreign countries in the years 1998-2003



The installations produced by LPI for glass and plastic shell target



High-temperature droplet generator for concentrated (60%) silicate solution.

LPI TTL
Thermonuclear Targets Laboratory
ФИАН
Лаборатория Термоядерных Мишеней

Automatic precise D_2-filling system for polymer and glass shells up to 120 MPa.

Two step D_2-filling system lifts pressure in the filling chamber with special targets cassette

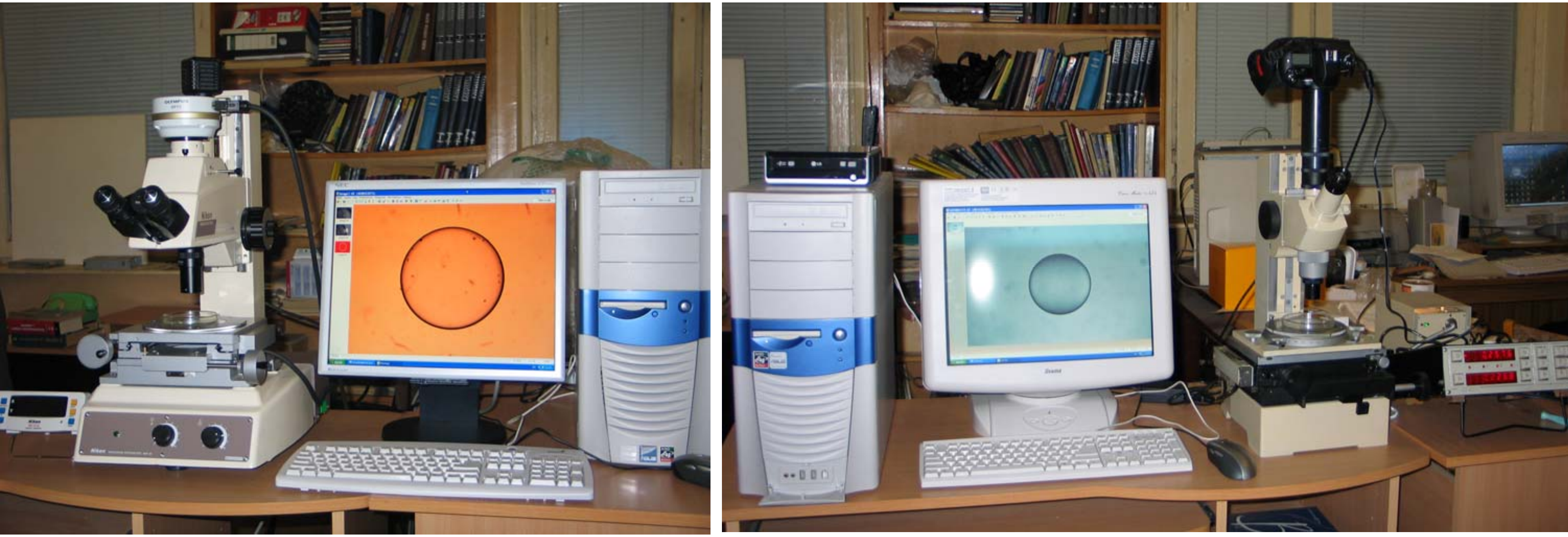
First step: ZrFeCr – D_2
SOURCE - SORPSION COMPRESSOR P≤20MPa
T=250-350°C
FILLING SHELL PRESSURE – 35 MPa
COMPUTER CONTROLLED FILLING PROCEDURE

Second step:
thermocompression

FILLING CHAMBER P≤ 200MPa, T=350-400°C
HIGH ACCURACY COMPRESSOR ΔP~0.1-0.2%

The system was created in LPI for VNIIEF in 2005.

Optical and x-ray shell characterization



Two automatic optical systems with high resolution CCD-camera and original software for shell characterization. Made in LPI and delivered to different Russian Institutes. Software had been written using ray-tracing method in 2001. Now it also includes wave-let analysis of 100 – 200 images for single or double-layer shell.

Koresheva E. R., Nikitenko A.I et al. Possible approaches to fast quality control of IFE targets Nucl. Fusion **46** (2006)
A.I.Nikitenko MP15 Report on Target Fabrication Meeting 1-5 October, 2006, San Diego, CA, USA

TARGET SYSTEM OPERATION IS BASED ON THE FREE-STANDING TARGET (FST) TECHNOLOGIES DEVELOPED in LEBEDEV PHYSICAL INSTITUTE

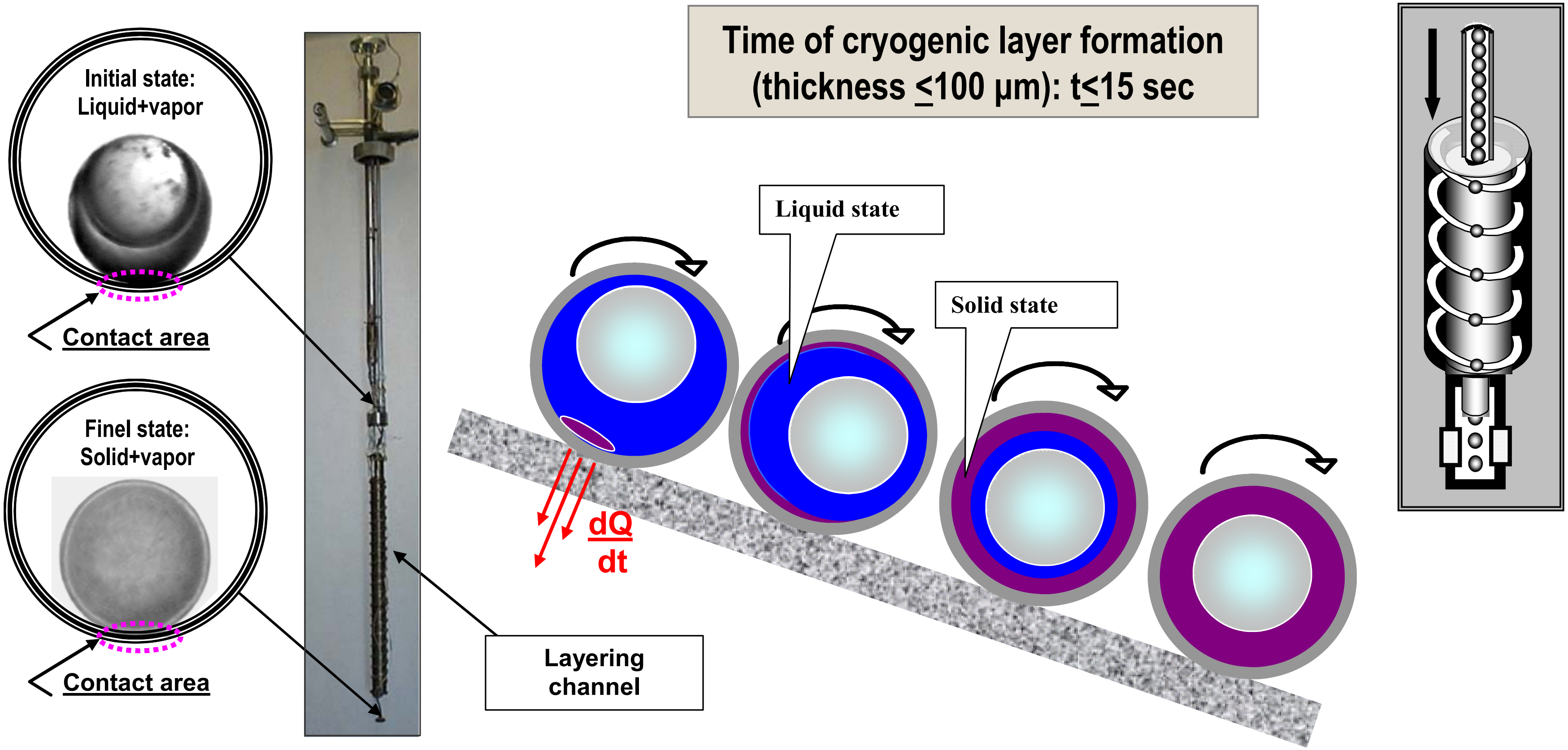
[E.R.Koresheva et al. J.Phys.D: Appl.Phys.**35**,2002; Fusion Sci.&Tech.**43**,N3,2003; Laser&Part.Beams,**23**,2005]

CRYOGENIC LAYER FORMATION USING THE COMBINED FST-LAYERING METHOD:

(1) Fuel cooling due to heat removal through the target / channel wall contact area

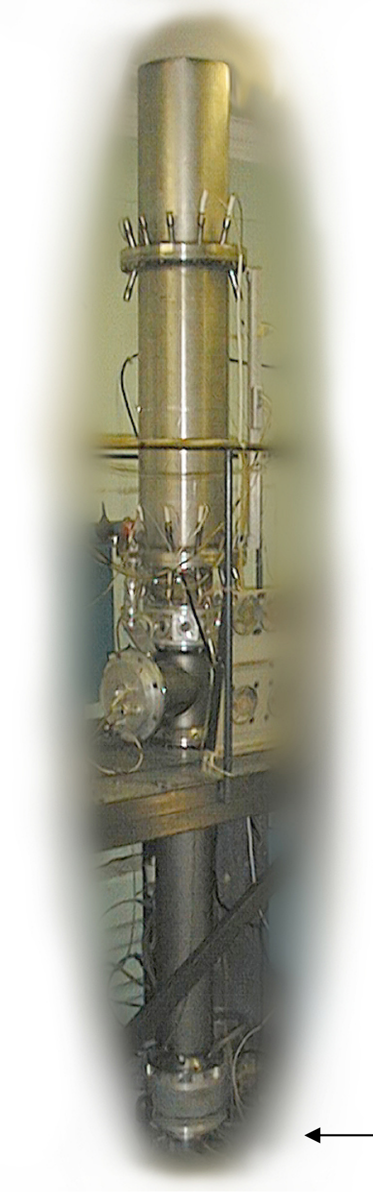
(2) Fuel layer simmetrization due to random rotation of a target

(3) Cryogenic fuel layer formation in an isotropic high dispersity (or amorphous) state and its stabilization due to application of a dopant from heavy hydrogen isotopes (or another material)



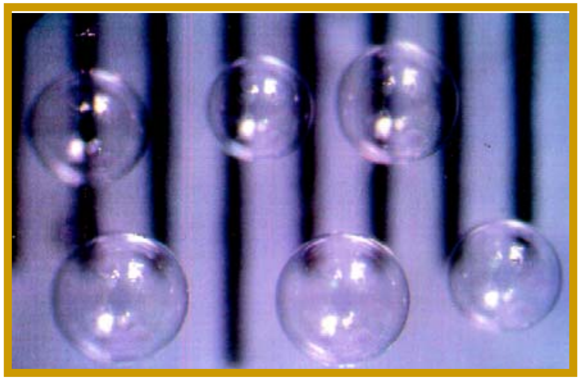
Time of cryogenic layer formation (thickness ≤100 μm): t≤15 sec

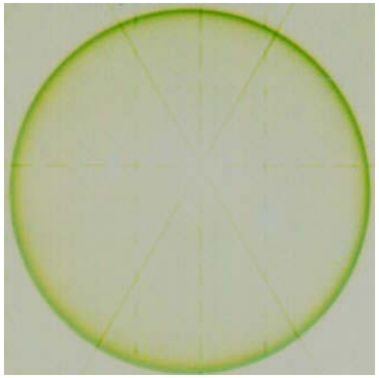
Furnaces for polystyrene microshells production

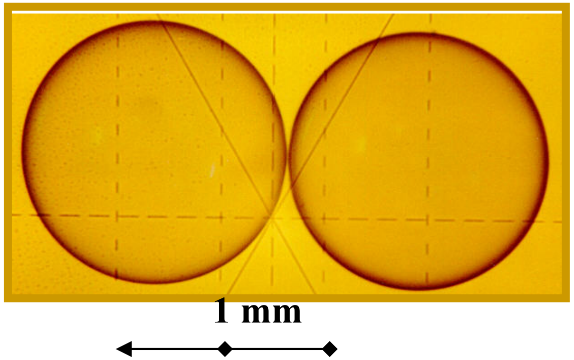


↑Drop tower furnace

← Ballistic furnace

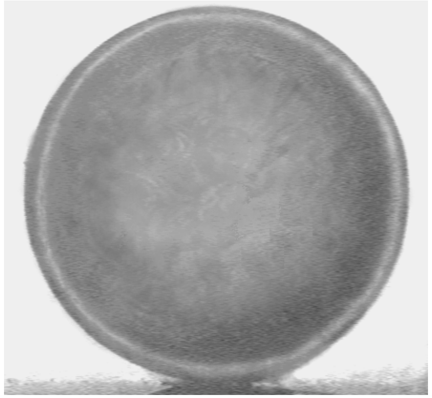




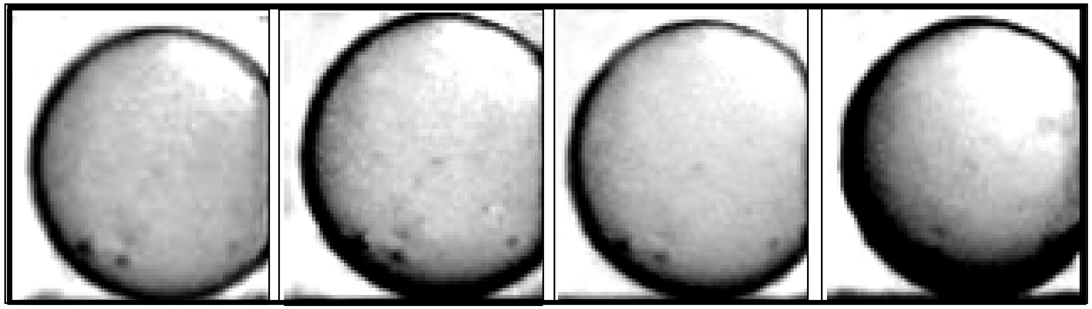


COMBINED FST-LAYERING: FUEL LAYER SIMMETRIZATION, COOLING AND AMORPHYSATION.

It has been demonstrated experimentally that using a certain doping allows to form transparent thermo stable spherically-symmetric D_2 – layer inside moving free-standing shells



Cryogenic layer formed using the combined FST-layering



5.2 K **10 K** **13.5 K** **20 K**

Transparent solid cryogenic layer does not spoil in the wide range of temperatures from 5 K up to the triple point

TARGET PARAMETERS

Polystyrene shell: ∅ =1500 mcm
Shell thickness: 20 mcm
Outer coating: 200 Å Pt/Pd
Fill pressure (300 К): ~270 atm
Gas density (300 К): ~38 mg/cm3
Cryolayer material: 80%D_2+3%Ne
Cryolayer thickness: 50 mcm

EXPERIMENTAL CONDITIONS

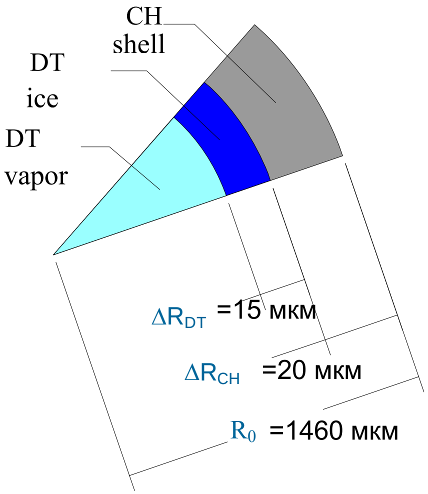
Spiral channel: L=1.5 m ID =2600 mcm
T_{IN} (target input temperature): 31 К
T of the test chamber bottom: 5 К
Pressure inside the channel: 1 mtorr
Time of target residence inside the channel: 10 сек

CALCULATED PARAMETERS

$\chi=S/4\pi R^2$	τ, sec	q, К/sec
0.035	1.57	7.9

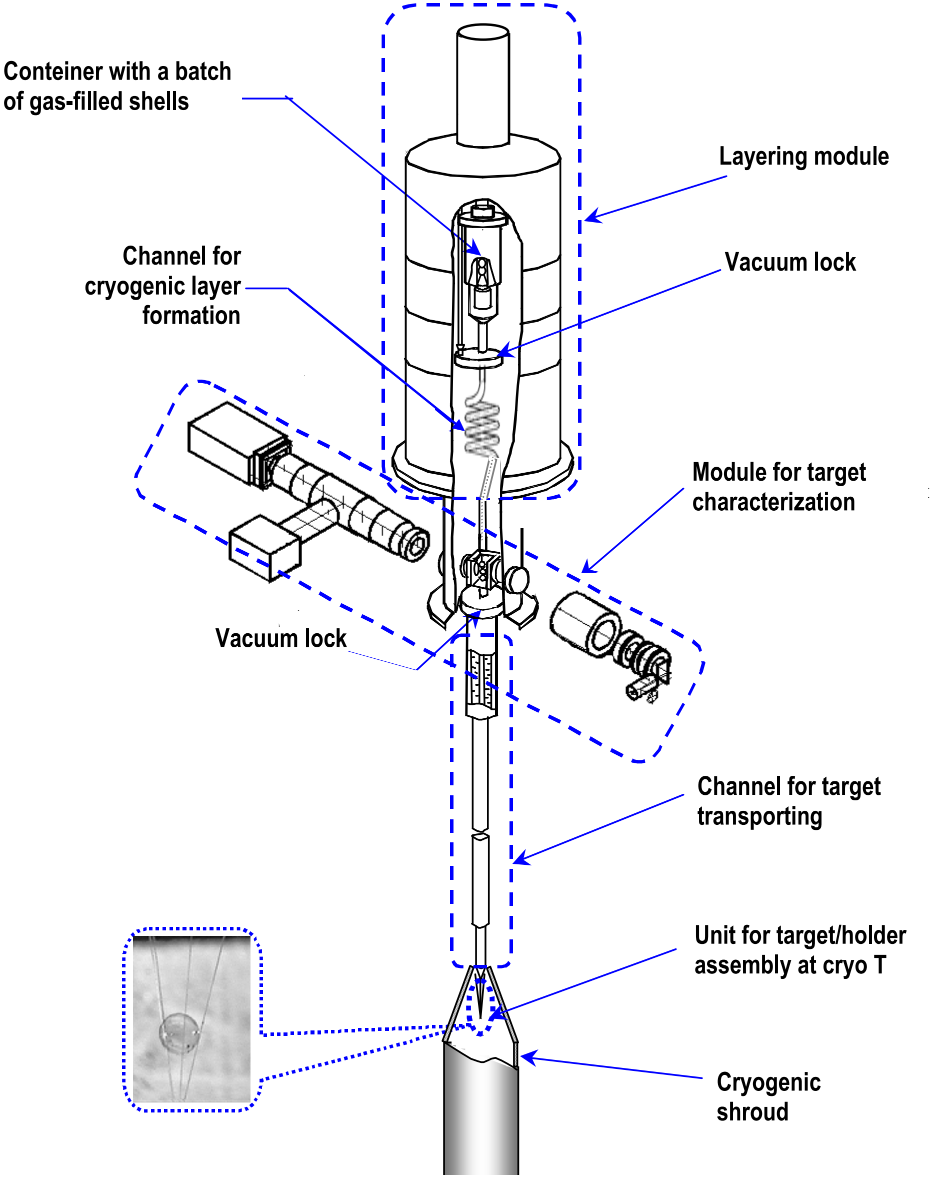
E.R.Koresheva et al. Report on Target Fabrication Meeting 1-5 October, 2006, San Diego, USA

OPTIMAL DIRECT-DRIVE TARGET FOR ISKRA-6 LASER FACILITY (300÷700 кДж) [S.A.Belkov, S.G.Garanin. Report at the Workshop of LPI-VNIIEF, Moscow, September 23, 2003]. TARGET SYSTEM FOR CRYOGENIC TARGET FABRICATION AND DELIVERY INTO THE CENTER OF TARGET CHAMBER OF ISKRA-6 [E.R.Koresheva. Ibid., 2003]



Parameters of laser radiation	Target parameters [1]	
Input Energy - 300 kJ Wave length - 0.351 mcm Pulse duration - 8.5 nsec	1.Mass of DT	0.1 mg
	2.ΔR_{DT}	15 mcm
	3.R_0	1.46 mm
	4.ΔR_{CH}	20 mcm
	5.ρ (DT-vapor)	$5{\cdot}10^{-4}$ g/cm^3
	6.T (DT-layer)	~19.6 К
	7.Fill pressure (300К)	42 atm
Input Energy - 500 kJ Wave length - 0.351 mcm Pulse duration - 8.5 nsec	1.Mass of DT	0.171 mg
	2.ΔR_{DT}	23 mcm
	3.R_0	1.54 mm
	4.ΔR_{CH}	33 mcm
	5.ρ (DT-vapor)	$5{\cdot}10^{-4}$ g/cm^3
	6.T (DT-layer)	~19.6 К
	7.Fill pressure (300К)	60 atm

[1] Fill pressure and gas density estimations have been carried out using software created at LPI [I.V.Aleksandrova et al.J.Phys.D: Appl.Phys. **37**, p.1-16, 2004.]



Properties of solid hydrides of light elements

Material	$LiBeD_3$	$LiBD_4$	BeD_2	$(CD_2)_n$	ND_3BD_3
Density, g/cm^3	≈0.83	≈0.86	0.765	1.10	0.92
Number $\Sigma(Z_i+1)$ to 4 (number D_2)	2.5	2.25	2.25	2.75	2.167
Module of elasticity, GPa			27.3	3.4	
Melting point, ^oC (Glassy temperature),			140 (134)		106
Boiling point, ^oC (Temperature of momentary disintegration)			(≈350)	(≈520)	(≈300)
Permeability for H_2, $cm^2/atm.s$,			$<5\cdot10^{-12}$	10^{-6}	$\approx<10^{-9}$
Optical transparency (<0,1 mm)	semi	yes	yes	yes	yes
Surface roughness, nm			<10	<60	<30
Structure (crystal, amorphous)	crys.	crys.	amor.	am-cr	crys-am

GNIIChTEOS specialists have been producing ND_3BD_3 since December 2004.

Dr. Yu.E. Markushkin with assistants fulfilled isotope exchange in ammonia-borane. In 6 hours 8 at% of H2 was substituted for D2

Yu.A.Merkuliev et al. Proceedings of SPIE 2001, Vol. 4424, pp. 139-143.

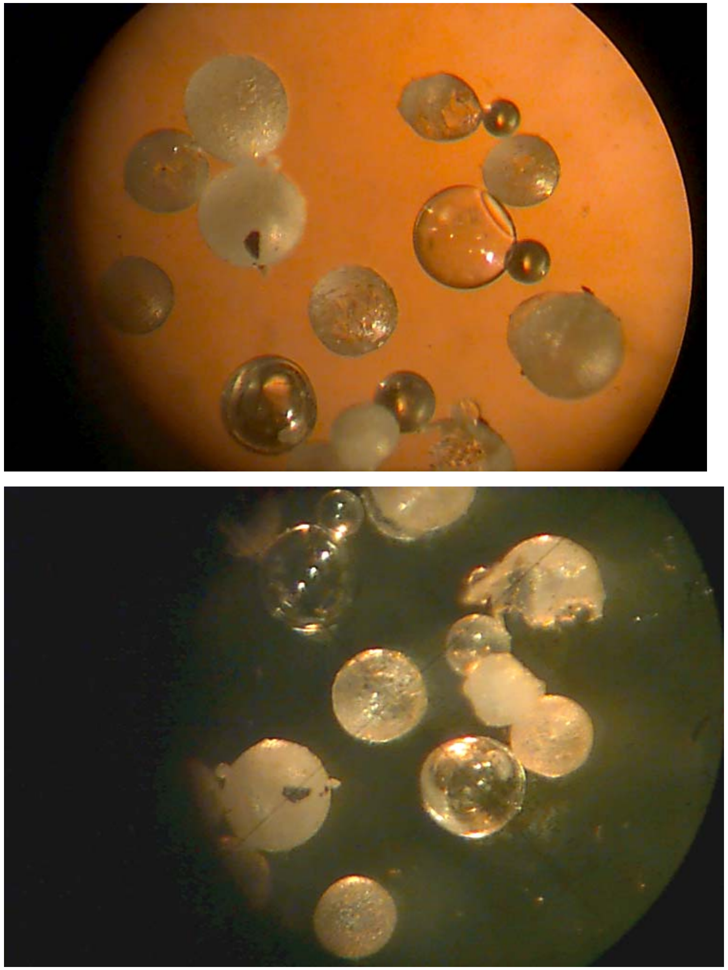
Yu.E. Markushkin, A.A. Akunets, N.G. Borisenko, et al. Beryllium and Lithium Deuterides in Direct and Indirect Laser Targets. // Inert. Fus. Sci. and Appl. Elsevier, Paris, 2002, p. 772-776.

Drop tower furnace for BeD_2 shells fabrication.

←Automatic vacuum drop tower furnace with 3 hot zones for formation of BeD_2 and $LiBeD_3$ shells (up to Ø 0.5 mm) with lock and vessel in which targets are transposed in vacuum to the laser chamber.

TTL of LPI, 2003.

Now in Bochvar Institute.



First shells from NH_3BH_3, fabricated in TTL on 14.04.03.
Some are optical transparent

Yu.A.Merkuliev, et al. Laser targets from new solid materials with high concentration of hydrogen isotopes for neutron generation. // Journal de Physique IV (France), June 2006, Vol. 133, pp. 887-890.

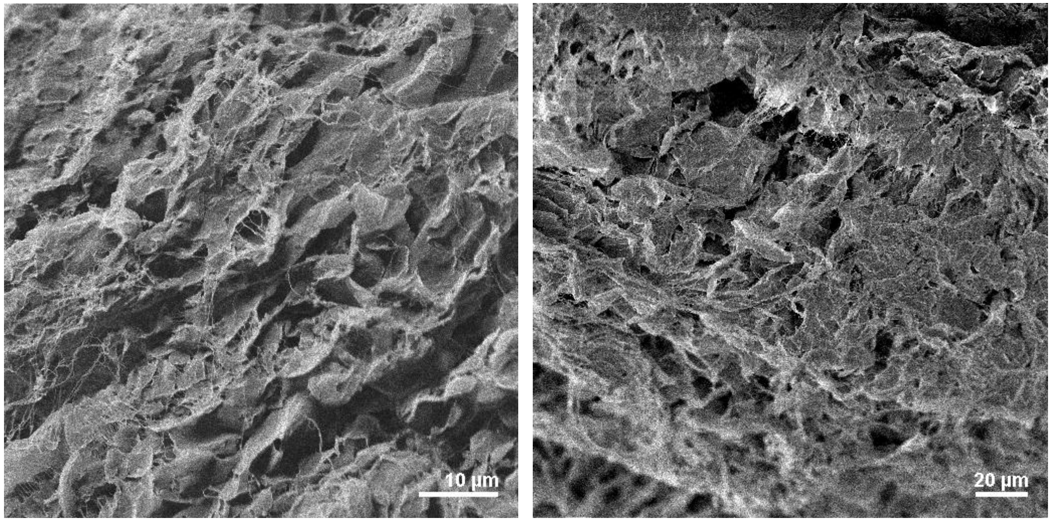
Solid materials with high concentration of hydrogen isotopes

Materials with high content of deuterium (for example LiD, BeD_2, $LiBeD_3$, $LiBD_4$ or ND_3BD_3) or T-containing materials can be used for large (reactor-scale) fusion target instead of beryllium or polyimide. The burning reactor-size targets are shown to be profitable [1] as regards energy yield. Possible methods of large fusion target fabrication for high power lasers are discussed both for direct and indirect schemes [1, 2]. It is the alternative to the burning target called “wetted foam” or “All DT” [3] (of the type: $CH(DT)_4$ or $CH(DT)_{64}$).

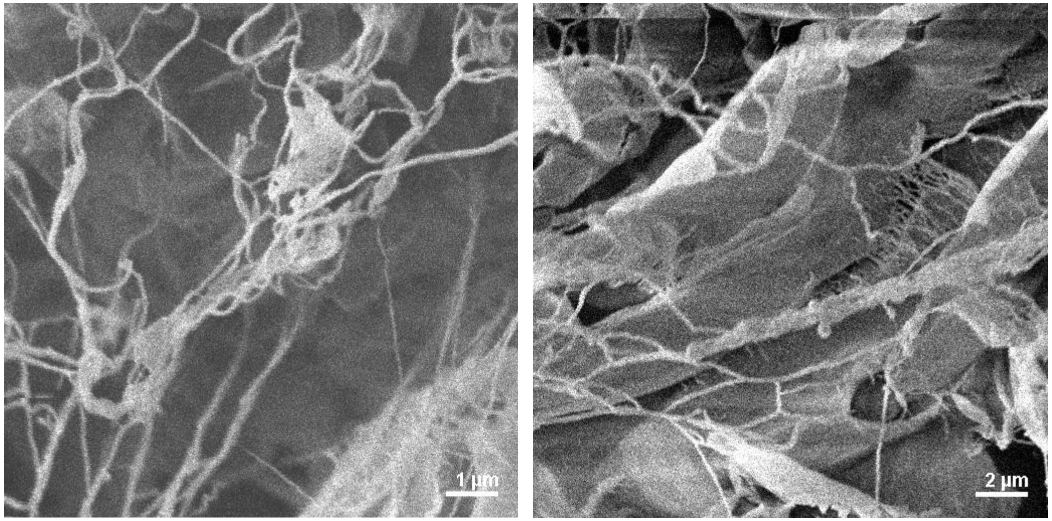
Shells from BeDT or NT_3BD_3 can be surrogate of cryogenic targets in experiments with large-scale lasers [4], Z-pinches or heavy ion drivers, when expensive DT cryogenic systems are not yet installed in interaction chamber. The targets of these materials are also used in the neutron generation research in super high intensity laser fields [5]. Low-density BeD_2 or $LiBeD_3$ foams layers can be used as absorbers of laser radiation and for fast heat transfer onto shell-target [6].

1. S.Yu. Gus’kov, Yu.E. Markushkin, Yu.A. Merkul’ev, N.V. Zmitrenko, J. Rus. Laser Res., 2007, V.28, #1 (LPI preprint, 2001, #20, 24 p.)
2. S.A. Belkov et al. Quantum Electronics (Russian), 2002, V. 32, No 1, p. 27.
3. S.E. Bodner, D.E. Colombant, A.J. Schmitt, M. Klapisch. Physics of plasmas, (2000), Vol. 7, No 6, 2298
4. Yu.E. Markushkin, et al. Inertial Fusion Sciences and Applications. Elsevier, Paris, 2002, pp. 772-776.
5. V.S.Belyaev, et al. Journal de Physique IV (France), June 2006, Vol. 133, pp. 507-509.
6. N.G. Borisenko, et al. Journal de Physique IV (France), June 2006, Vol. 133, pp. 305-308.

Deuterated polyethylene foams for ps-lasers and liners.

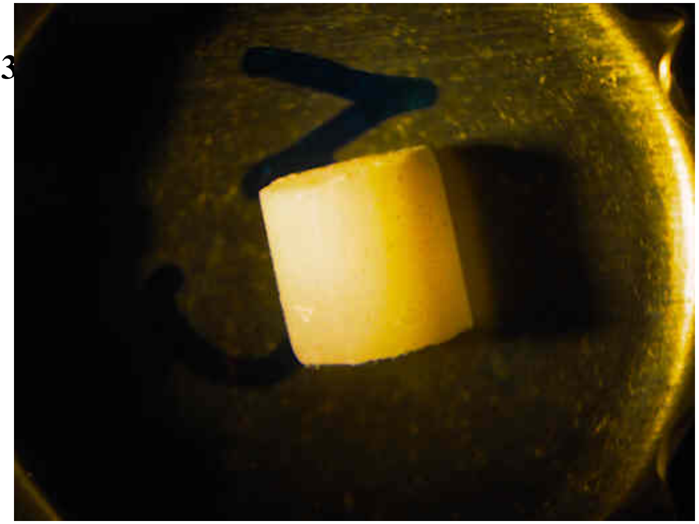


$(CD_2)_n$ foams, density 20 mg/cm^3 and 40 mg/cm^3



The targets for experimental demonstration of increased neutron yield when using the foam targets with cells 30-50 µm

Targets from $(CD_2)_n$ foam with density from 10 mg/cc to 100 mg/cc had been produced

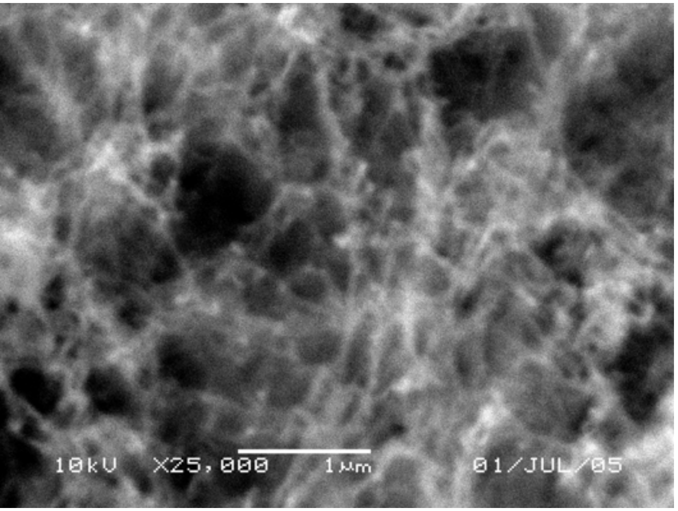


Photography of $(CD_2)_n$ foams for liners/

Belyaev V.S., et al. Composition, Density and Structure Dependent Neutron Yields from Deuterated Targets in High-Intensity Laser Shot. // Journal de Physique IV (France), June 2006, Vol. 133, pp. 507-509.

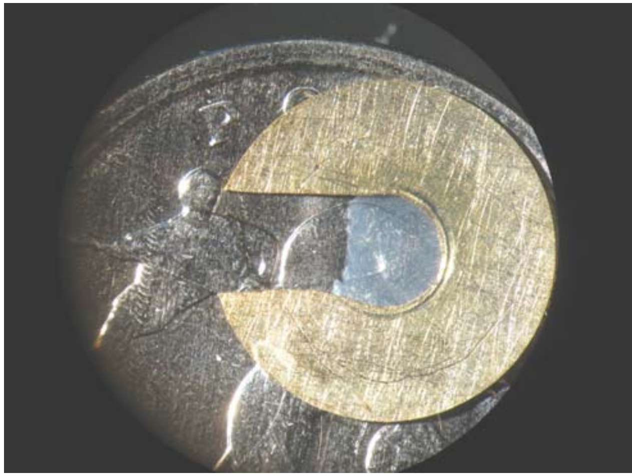
Belyaev V.S., et al. High-Intensity Laser Pulse Interaction with Solid of Variable Density. AIP Conference Proceedings, 2006, Vol. 849, pp. 237-241.

Targets of plastic aerogel TAC for experiments with undercritical plasma density

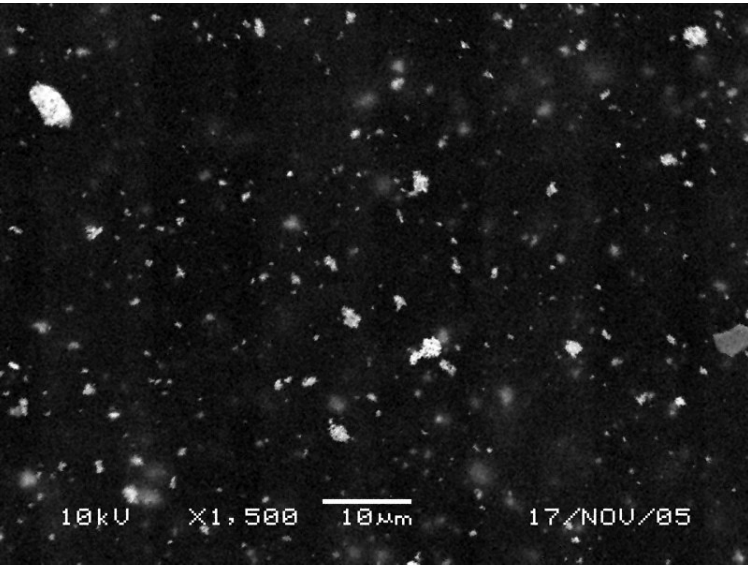


Density fluctuations <1% in the focal area Ø 300 µm.
←Scale – 1 µm

TAC 10 mg/cc 300 µm
in the holder with a slit
on the kopeik▶



Similar repeatable submicron structure
(in the range 50 down to 1 mg/cc, inter fiber distance 0.7- 1.6 µm, diameter 30-50nm, fiber density 0.2 g/cc)

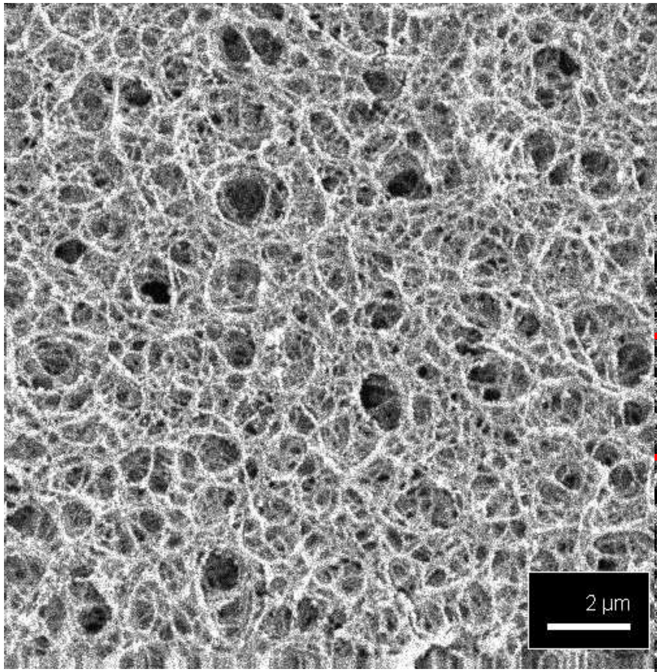


←**Doping with Cu or Cl (15% mass)** in TAC 10 mg/cc, Cu particles 40 nm, concentration $5 \cdot 10^{12}$ cm^{-3}, 3% nanoparticles agglomerated

Average pore size

Computer procedure of 3-D network analysis to measure the cell size and fiber diameter

TAC of 10 mg/cc done Jan 15 ,2005, average fiber distance (pore size) ≈ 1.5 μm



Initial SEM image, scale bar 2 μm

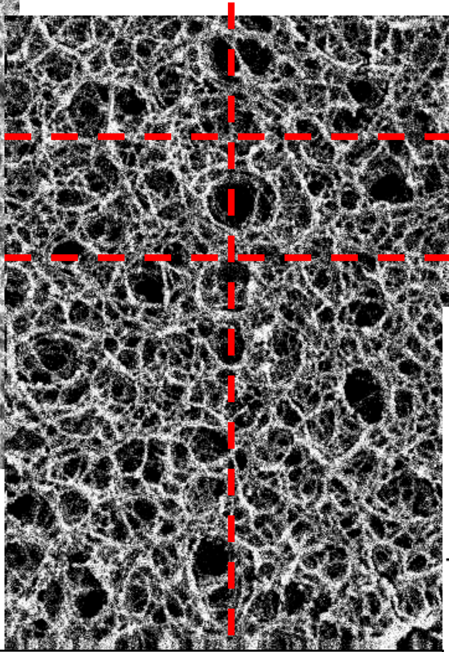
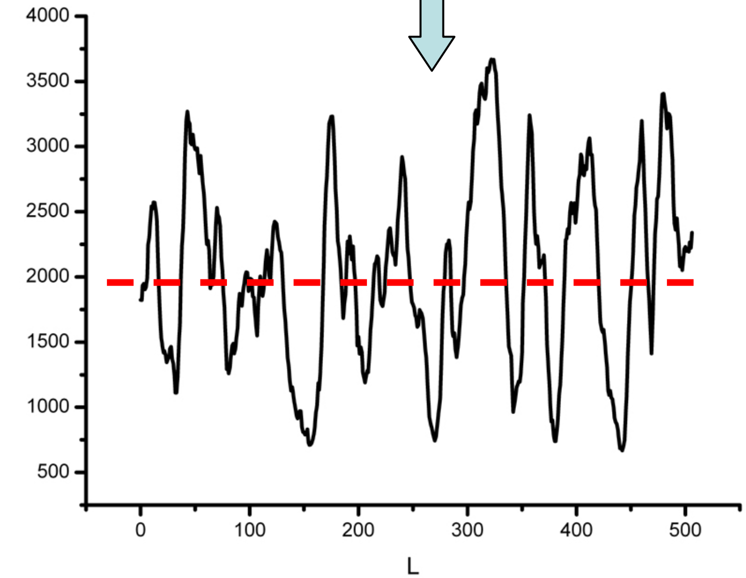


Image processed: denoised, illumination and contrast equalized, intensity scanning done along the red lines

Scanned intensity line ready for cell and fiber mathematical restoration



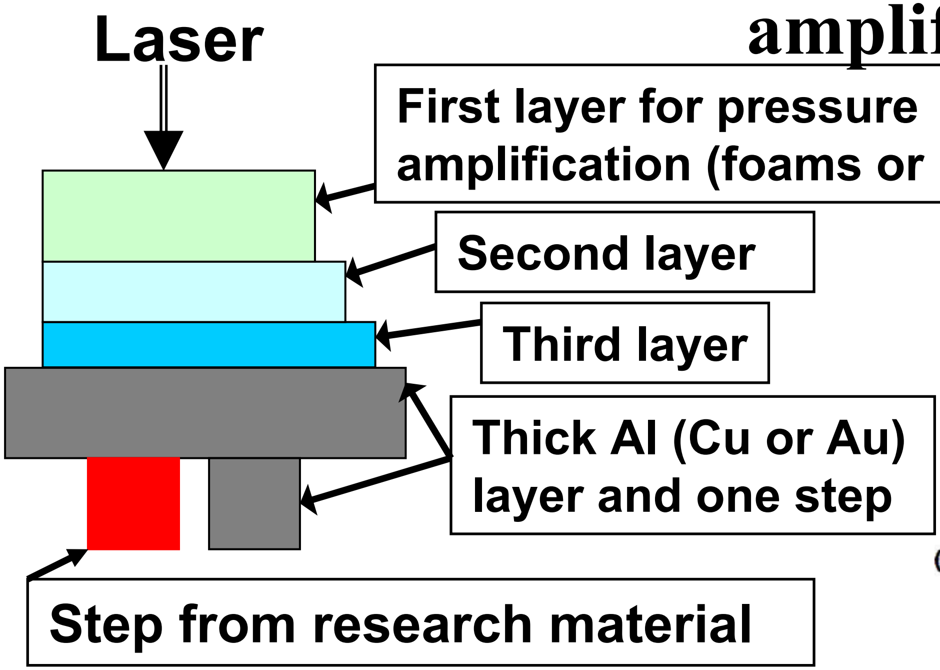
Layers with density gradient needed for laser experiments

1. Density gradient targets with decreasing density or increasing stepwise density layers were considered in experimental and theoretic papers on astrophysics modelling, equation-of-state (EOS) and shock wave dynamics research. Earlier we have done the multilayered targets with increasing density for pressure amplification and energy transport velocity change [1,2].
2. The EOS studies and astrophysical modeling in intense laser interaction experiments will be even more meaningful with targets of smooth density gradient.
3. We search for the method to prepare a single smoothly increasing low-density layer instead of steps of density in the target.
4. Laser targets require high ($>10\ \mathrm{g \cdot cm^{-3}/cm}$) density gradients of the spatial profile for EOS experiments. The first targets from silica aerogel and polymer foam (regular as aerogel) with density gradient are demonstrated, but these targets have less ($<1\ \mathrm{g \cdot cm^{-3}/cm}$) density gradient then it is required.

1.N.G. Borisenko, A.M. Khalenkov, Yu. A. Merkuliev, V.G. Pimenov. *Low-Density Material (<10 mg/cc) with High-Z Dopants for Laser Targets and Liners for Z-Pinch.* // Report, Target Specialists Meeting, San Diego, USA, September 2006. Book of Abstracts, p. 19.

2. N.G. Borisenko, V.G.Pimenov, A.M. Khalenkov. *Fabrication and characterization of low-density polymer laser targets both with or without high-Z dopants as nanoparticles.* // Report, Target Specialists Meeting, San Diego, USA, September 2006. Book of Abstracts, p. 53.

Targets for EOS experiments with the pressure amplification



Laser

First layer for pressure amplification (foams or plastic)

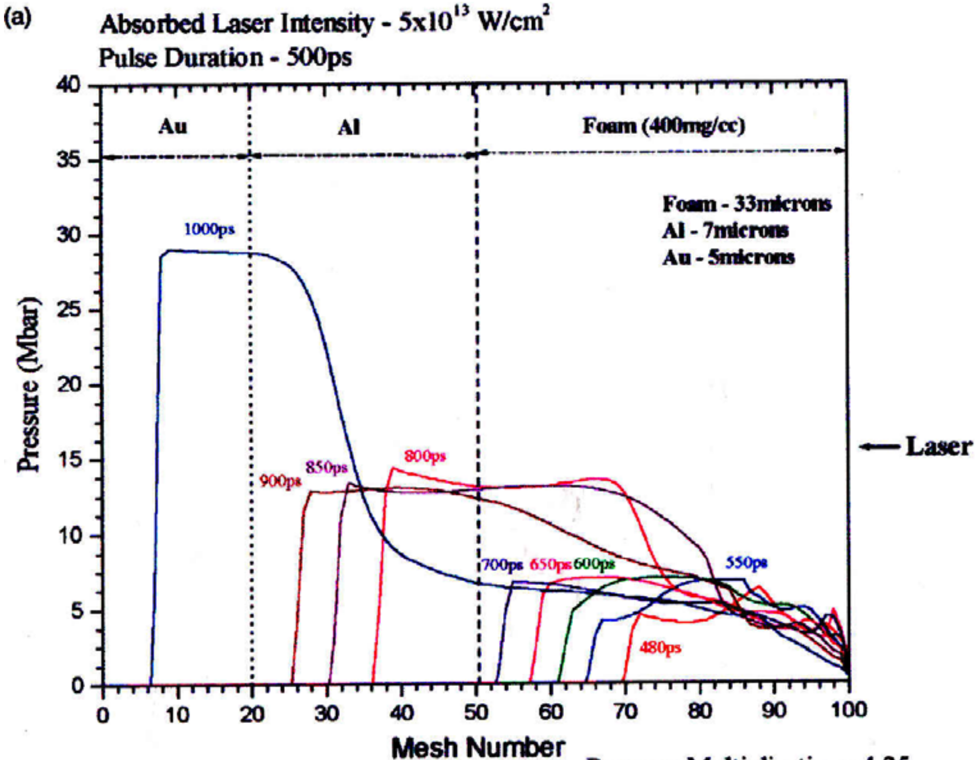
Second layer

Third layer

Thick Al (Cu or Au) layer and one step

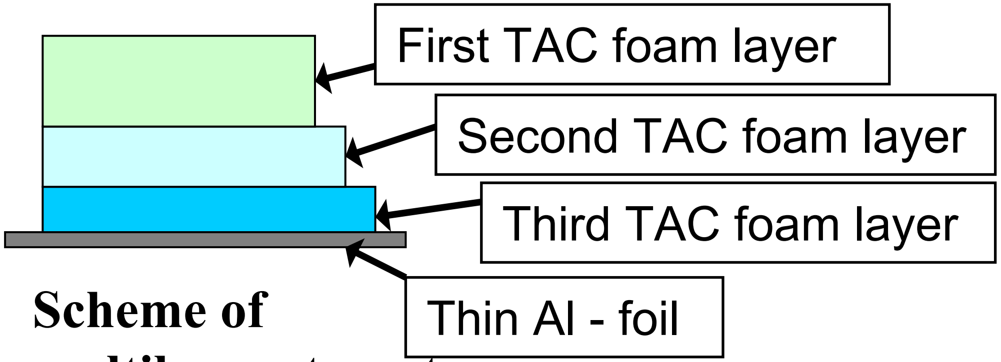
Step from research material

Scheme of EOS target



Pressure Multiplication ~4.25

First attempts to produce 2 and 3 low-density layers from TAC



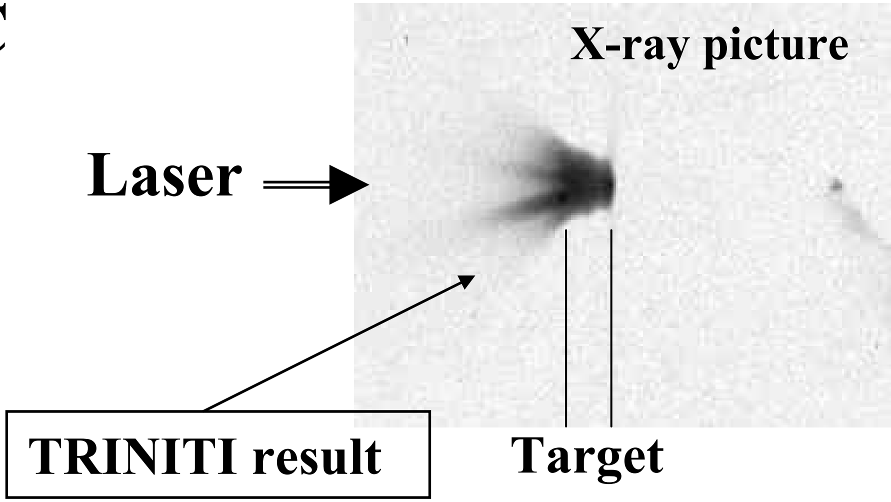
First TAC foam layer

Second TAC foam layer

Third TAC foam layer

Thin Al - foil

Scheme of multilayers target

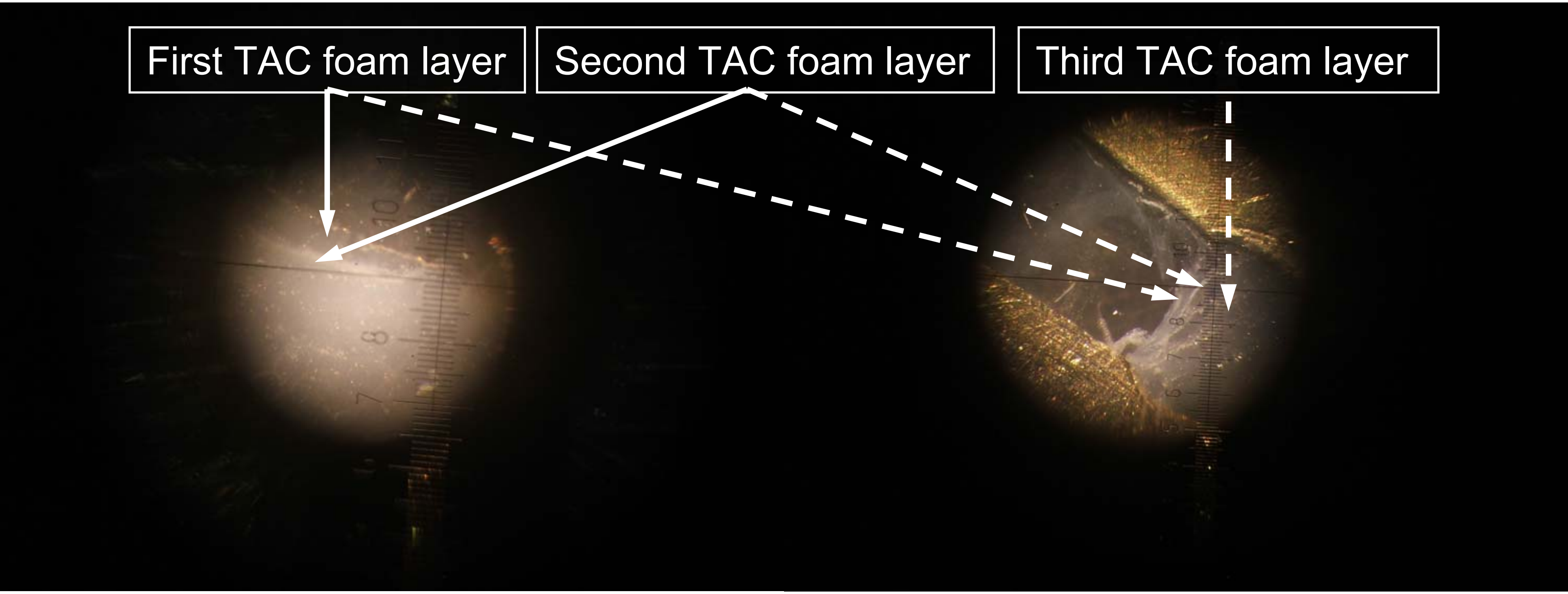


X-ray picture

Laser

TRINITI result

Target



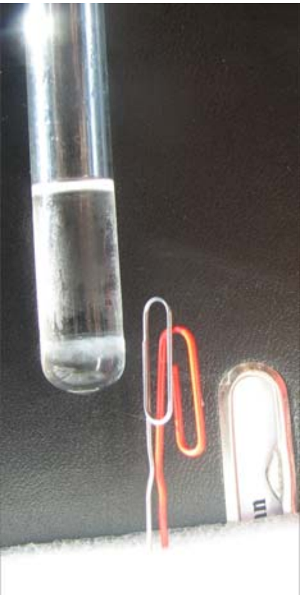
First TAC foam layer

Second TAC foam layer

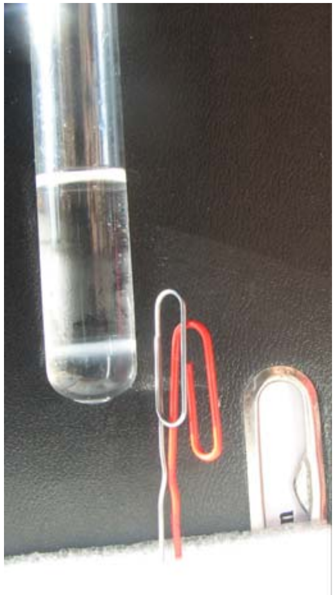
Third TAC foam layer

Photo of 3 TAC layers with density 2.5 mg/cc, 5 mg/cc and 10 mg/cc after cutting

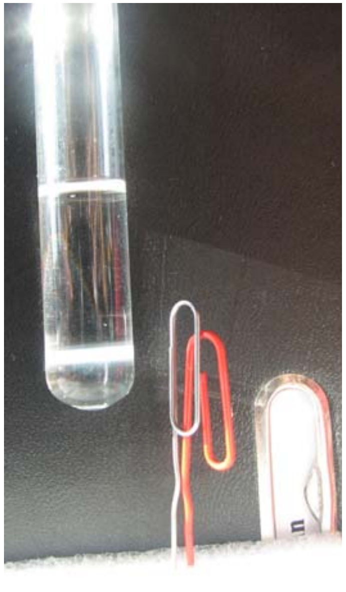
Growth of gel from catalyst boundary



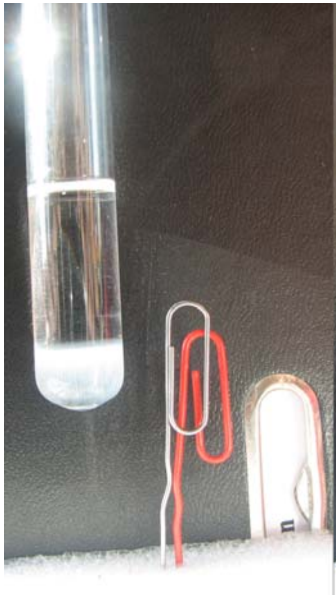
4:37 p.m. start
2nd frame: gel is being formed on the surface of the catalyst (5 min)



3rd frame: silica layer has become continuous (7 min)

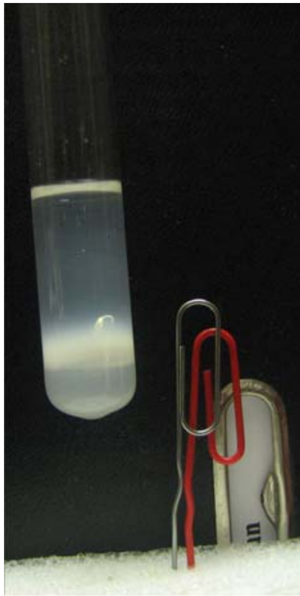


4th frame: ~2 mm of gel on the boundary between catalyst and TEOS solution (7 min)



5th frame: white sediment in the solution of ammonium in water (20 min)

8th frame: eroding and following dimness of the forming gel (93 min)



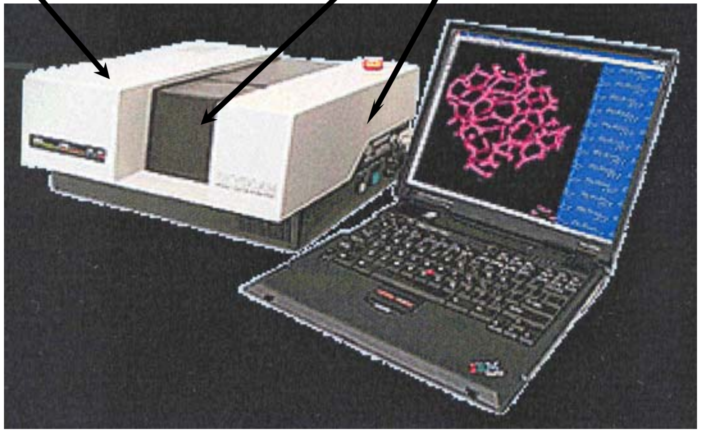
10th frame: the top of the substance is still swaying (228min)

X-ray computer microtomography – Skyscan 1074

Rotating table for samples

X- ray detector

X- ray tube



Microfocus x-ray tube – 40 kV, 40 W

Focus diameter – 100 microns

Tube window – Be, 0.5 mm

Sample size - < 20 mm

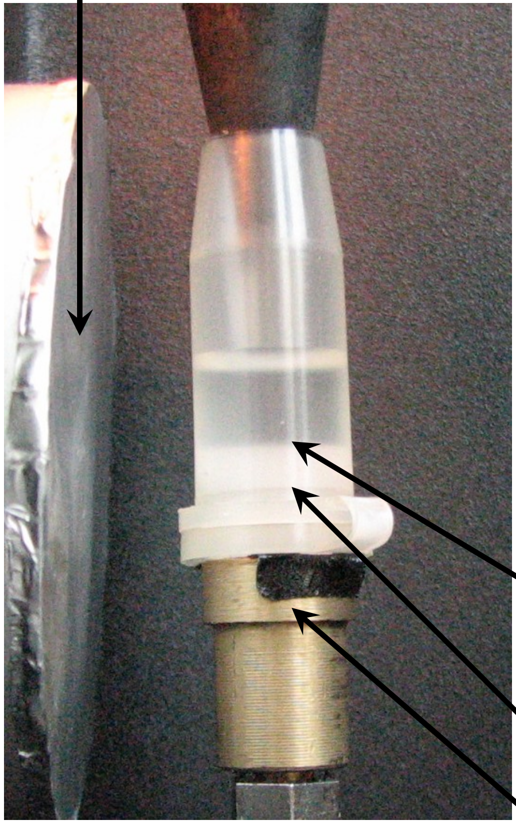
X-ray detector – luminophor P43 and CCD-TM6AS (8 bit)

Al-filter for detector – 26 microns

Spatial resolution – 20 microns

X-ray CD-detector closed Al-foil

There could be a doubt about the density variations in the gel via height. One can suspect the constant density that is accompanied by differing structure to give the visible optical density change. The direct proof could be the X-ray images of the realized density gradient in the layer.



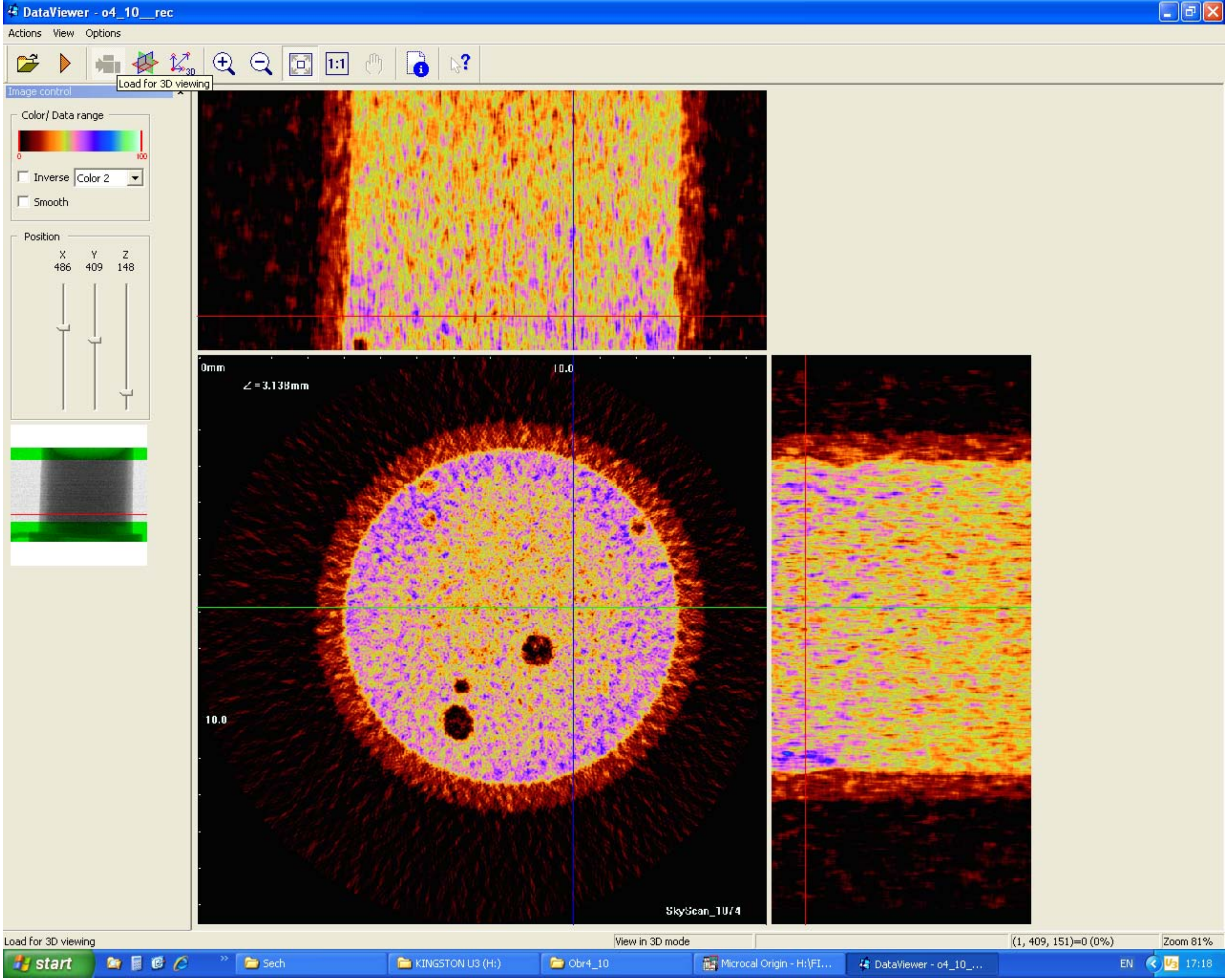
X-ray radiation

Plastic tube with grown silica gel

Catalysis layer

Table for rotation

Gradient density gel formation dynamics researched by 3D X-ray tomography images. Tetraethylorthosilicate (TEOS) – $(C_2H_5O)_4Si$ solution in alcohol with catalysis (ammonium hydroxide - NH_4OH 20% in water) on contact boundary used for high X-ray contrast images creation.



☐ Inverse Color 2

☐ Smooth

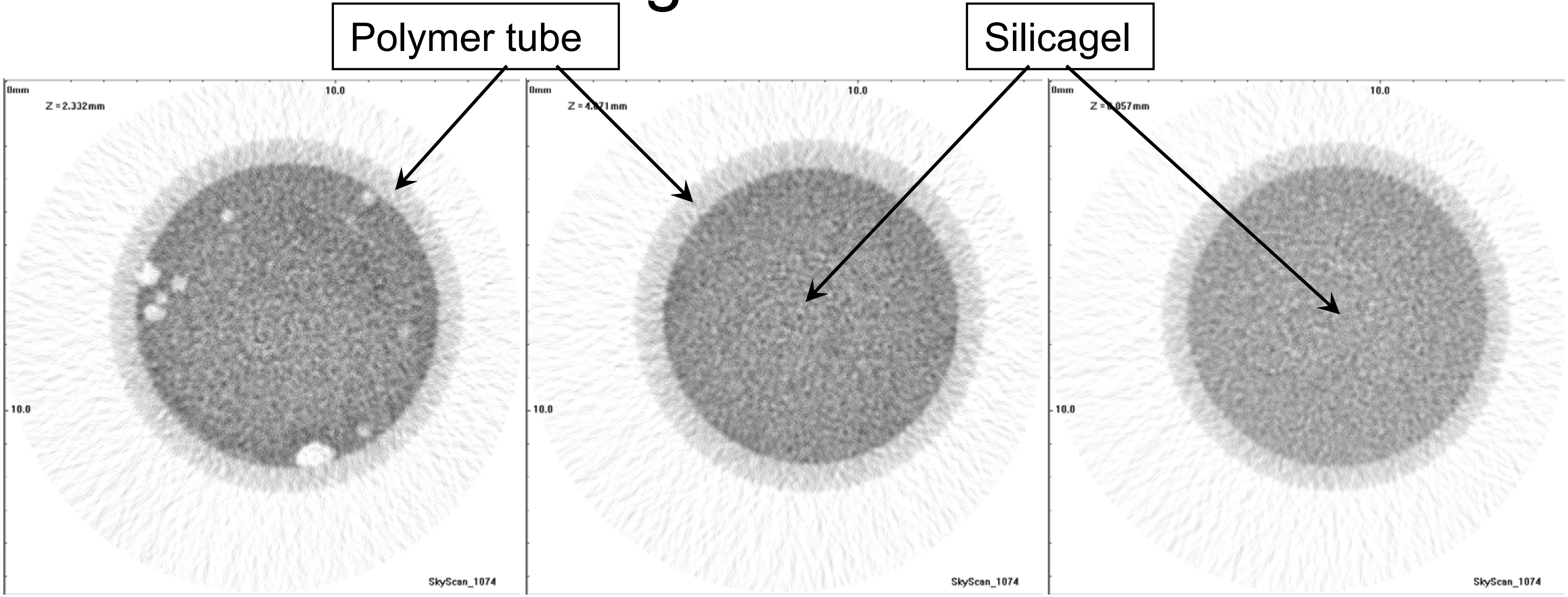
X	Y	Z
486	409	148

(1, 409, 151)=0 (0%)

Zoom 81%

Usual view of silicagel growth on x-ray tomography. Horizontal level of cross section is 3.14 mm. (near boundary TEOS solution and ammonia + water)

Horizontal cross section of silica gel with density gradient



Polymer tube

Silicagel

The pictures show horizontal cross sections silica gel during gel growth (from left to right) on levels 2.33 mm, 4.07 mm and 8.06 mm

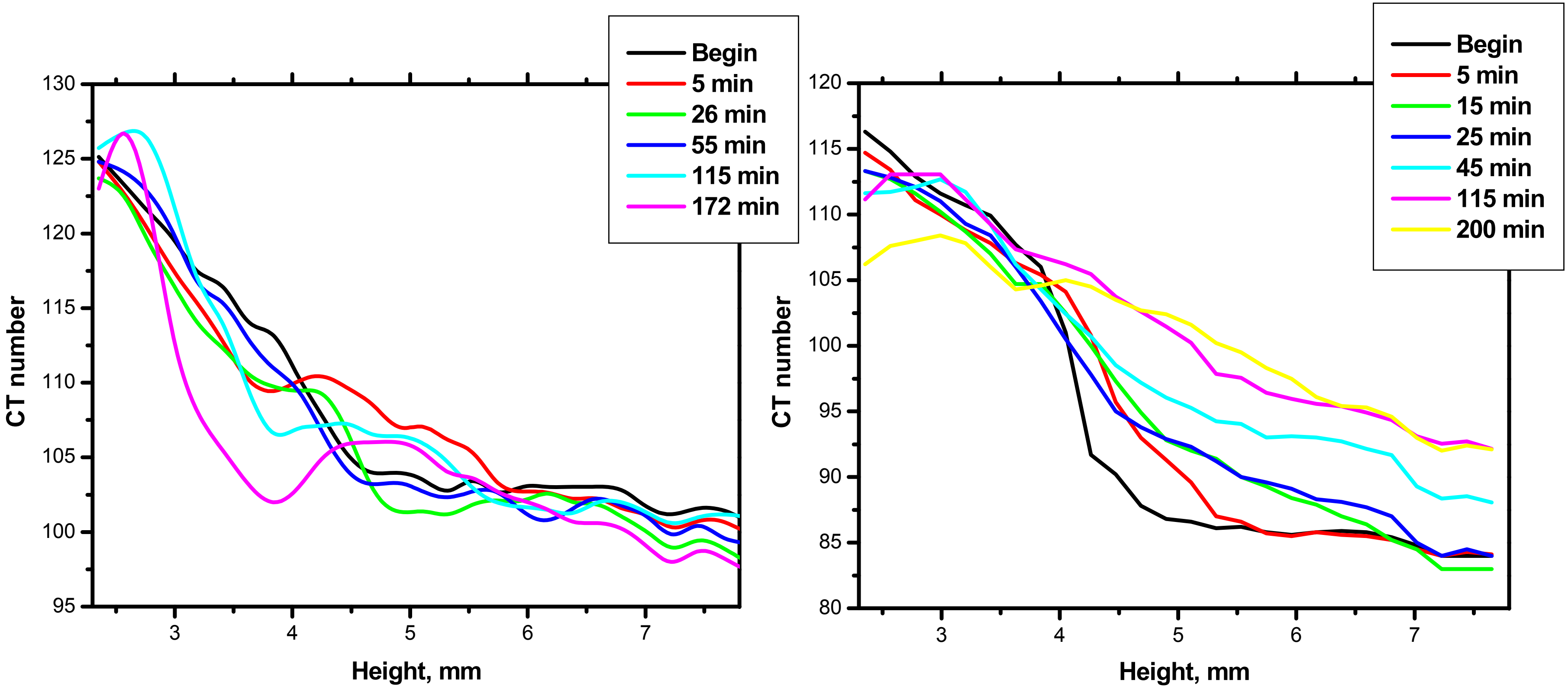
TEOS solution boundary levels for different samples change from 2.5 mm to 3.3 mm.

This sample boundary level is 2.7 mm from the bottom, left cross section has gas bubbles under silica gel membrane.

Lower cross section has darker color, then upper cross section and gel has higher SiO_2 concentration

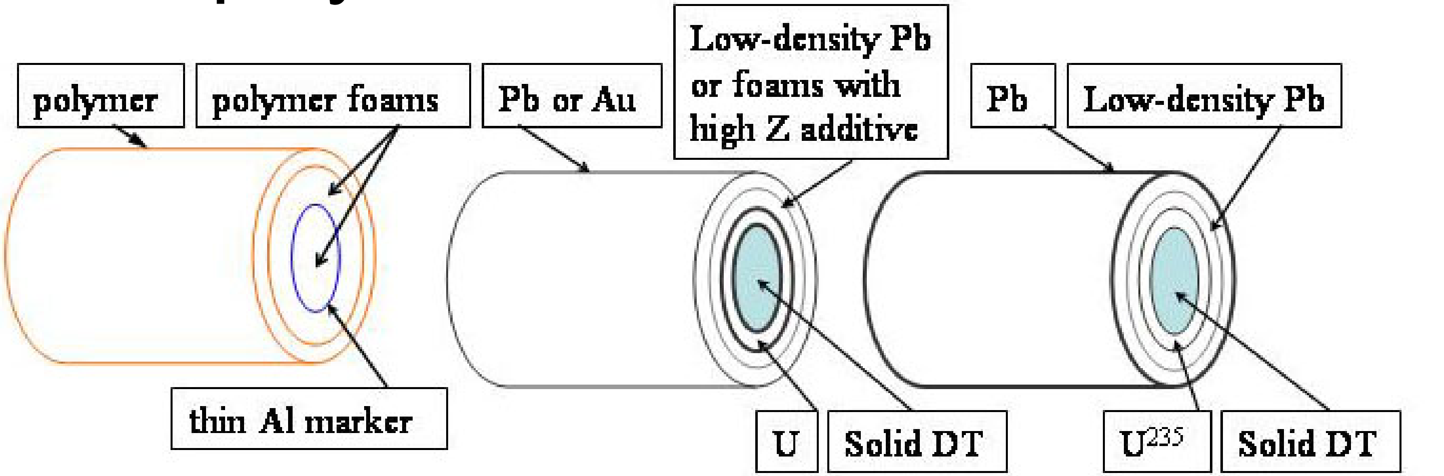
Middle and right cross sections have identical color. Gel growth front is stable (flat).

Dependence of SiO_2 concentration via height

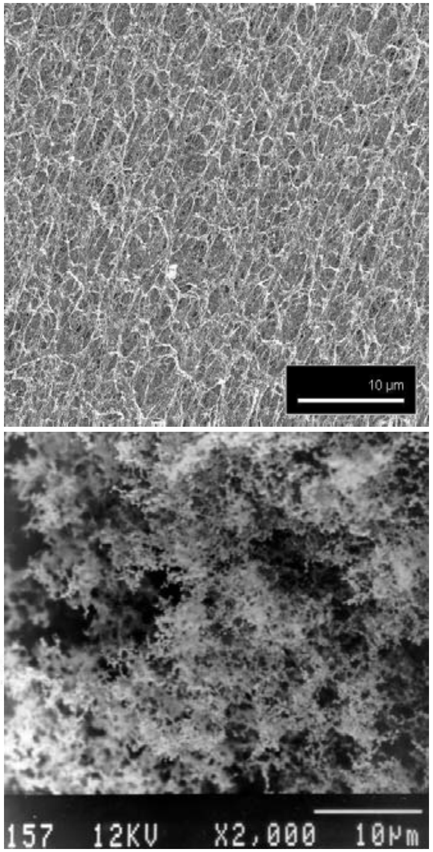


Dependences of count tomography (CT) numbers on (from) height of TEOS solution (tube) during gel growth at various time after TEOS solution is placed on catalyst for two start concentrations: left – 0.5 basic solution, right – 0.25 basic solution. SiO_2 concentration can be found from comparison on CT number in table with SiO_2 concentration. Water diffusion into upper (5-7 mm height) gel layers (mixture of alcohol with water) increases CT number after 25 min observation (see table).

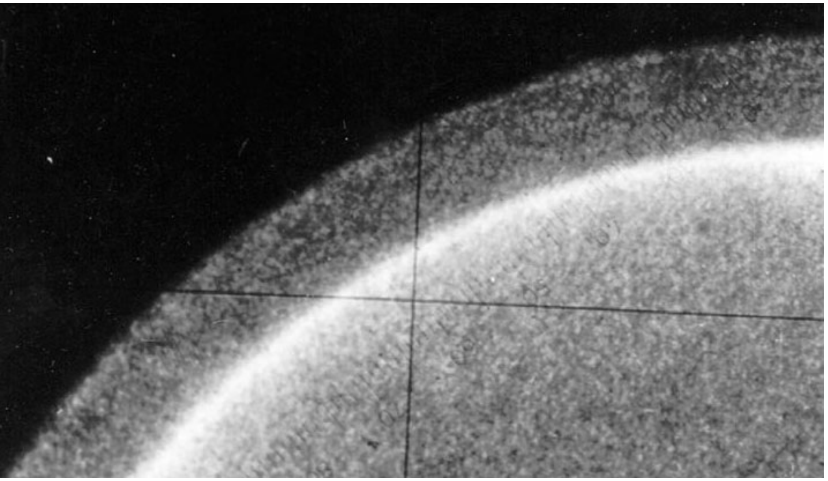
Target constructions with low-density layers from polymer foams and metal foams



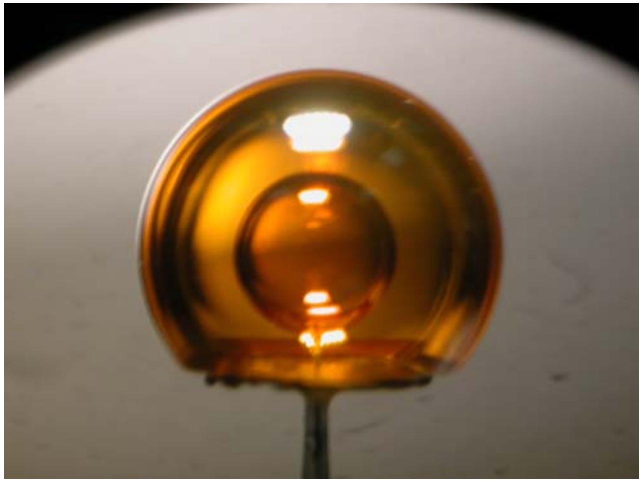
Cylindrical targets for laser compression: left – instability research; center – heavy ions research; right – U-critical lever achievement at compression for HICF



SEM images:
top – polymer aerogel with density 1 mg/cc;
bottom –metal low-density layer with nanoparticles of density 50 mg/cc.

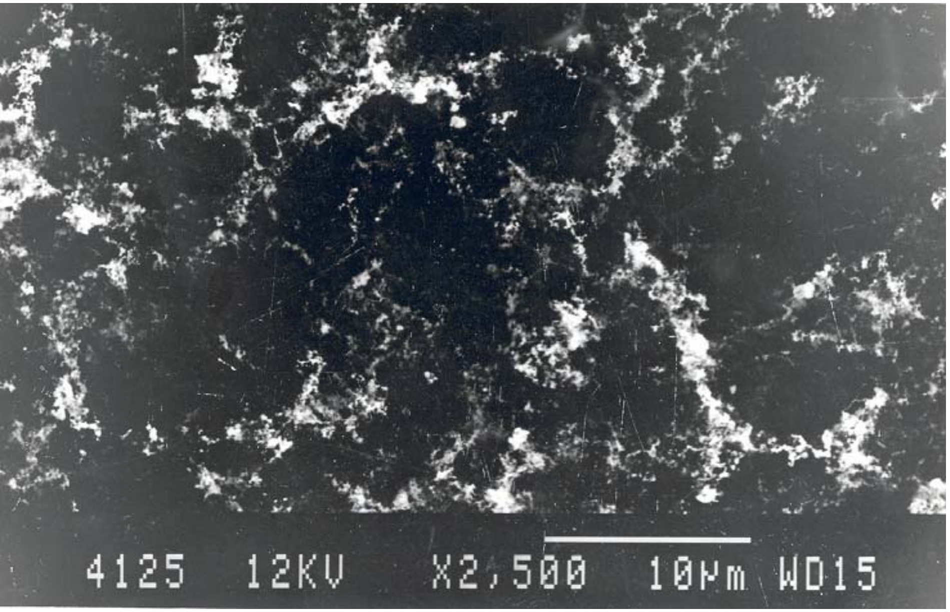


X-ray image of glass shell with outer low-density metal layer, LPI, Russia.

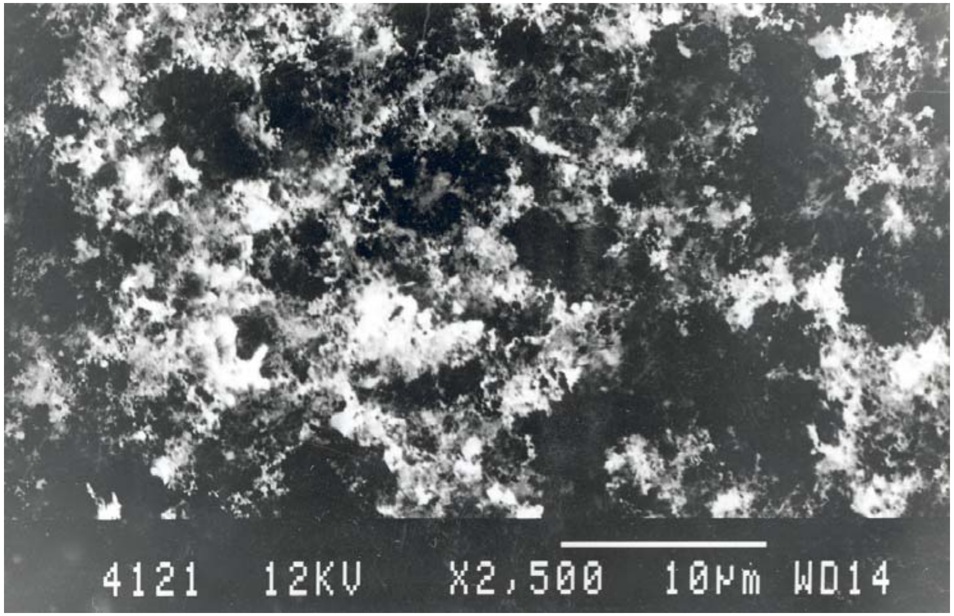


Double shell with low-density aerogel, GA, USA

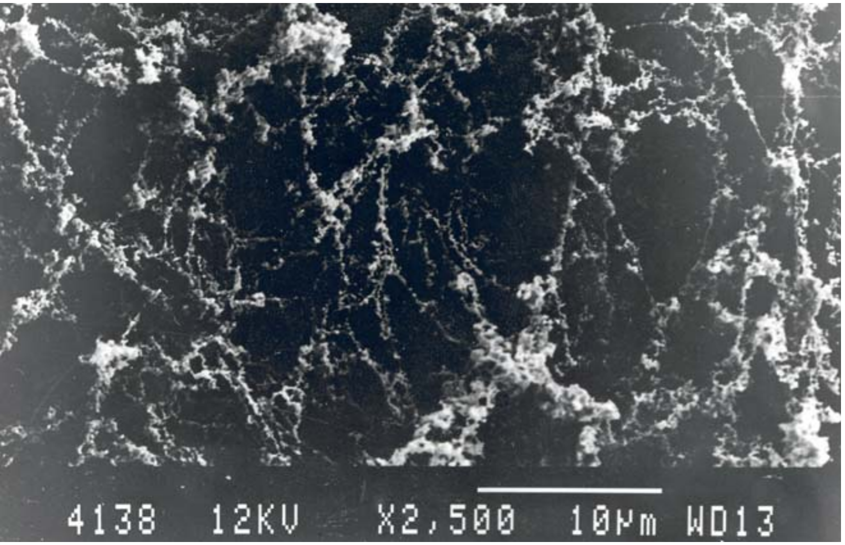
Metal foams



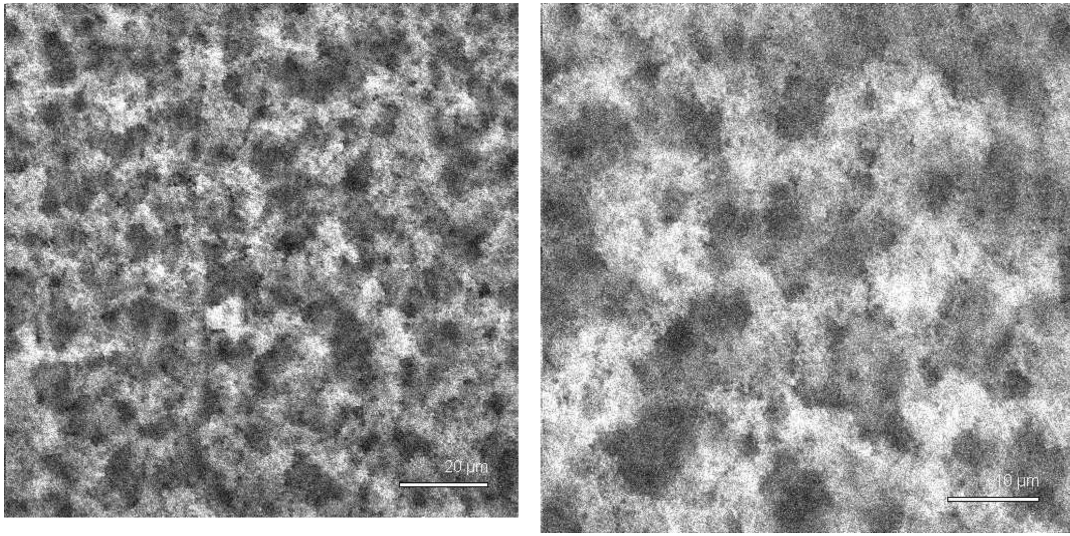
Cu



Cu **scale – 10 µm**



Au?? **scale – 10 µm**



Sn?? **scales – 20 and 10 µm**

Thermonuclear Target Laboratory (TTL) was established in 1974.

For about 30 years the laboratory has provided the targets and targets fabrication equipments for the 11 scientific centers of Russia, Great Britain, Germany, France, Italy, Czech Rep., USA, India and China.

«Target Factory» created at TTL is an integrated facility including subsystems for microshells fabrication, surface coating, target quality characterization, fuel filling, fuel layering and target injection

Prof. Yuriy Merkuliev, head of TTL since 1974

Available product:

- Hollow microshells from glass, polystyrene, Cu, etc.
- Mass glass and polymer hollow microspheres production
- Advanced materials to increase energy efficiency BeD_2, ND_3BD_3 and D↔T exchange in ready shell-targets
- Micro-heterogeneous and foam targets
- EOS experiments and astrophysics modeling targets for current research
- Surface coating
- Double-shell targets
- D_2 and DT-fuel filling
- Fuel layering
- Target quality characterization: interferometry, X-ray microscopy, micro-tomography

TTL staff (1980)

Thin beryllium hydride film transformation to nanocrystalline beryllium film by interaction with short laser pulse.

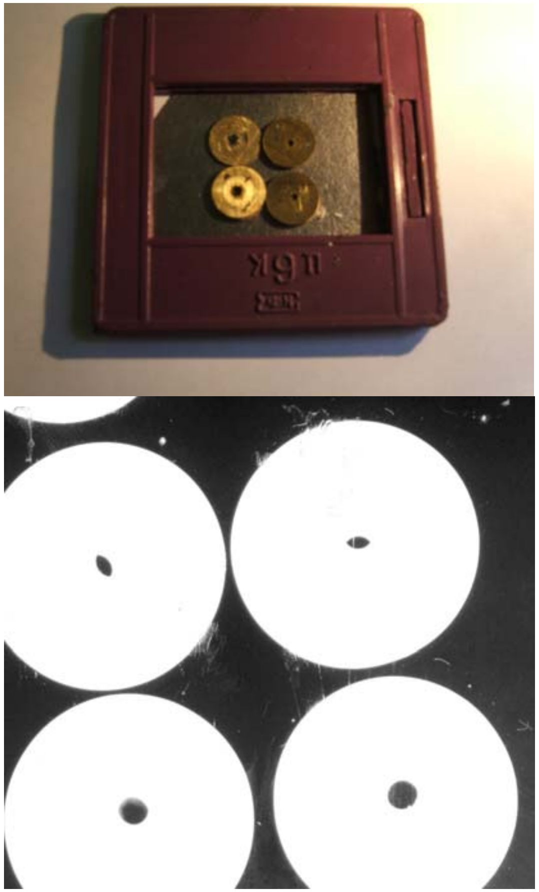
Yu.A. Merkuliev, N.G. Borisenko, A.I.Gromov, A.M.Khalenkov, (*Lebedev Phys. Ins.)*
Yu.E. Markushkin*, V.V. Gorlevsky*, A.V. Zabrodin*. (Bochvar Ins. Inorg. Materials).***

At ps-laser experiments of interactions with BeD_2 targets we accidentally found that BeD_2 can transform to Be-film with 3 µm thickness and nanocrystalline structure.
Now we try to produce Be-film and BeD_2+Be films with 0.5-1 µm thickness using various lasers.

BeD_2 targets after shot. Crater after intensive pulse. 3 µm Be-film appeared after laser irradiation of 10^{11} W/cm^2

Belyaev V.S., et al. Composition, Density and Structure Dependent Neutron Yields from Deuterated Targets in High-Intensity Laser Shot. // Journal de Physique IV (France), June 2006, Vol. 133, pp. 507-509.

Thin (<1 micron) film (Be+BeH_2) – x-ray filter for EUV multilayers (Mo/Si) mirrors (13.5 nm), EUV-streak and pin hole camera



←Photography of x-ray filters in optic and in 2 keV x-ray

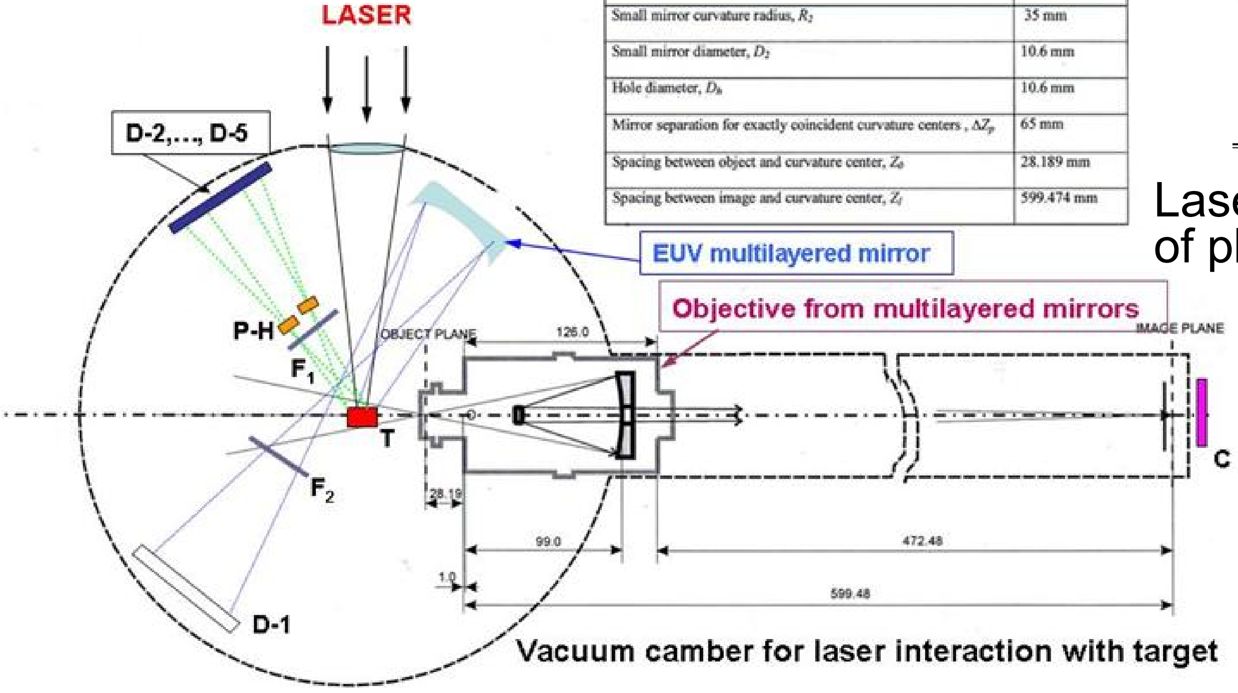
↑ Photography of pin hole camera with thin (0.5 micron) (Be+BeH_2) x-ray filters

Yu.A.Merkuliev et al. Report on 29 ECLIM, 11-16 June 2006, Madrid, Spain.

EUV generation in laser targets and first experiments with EUV diagnostics of plasma from laser-target interaction.

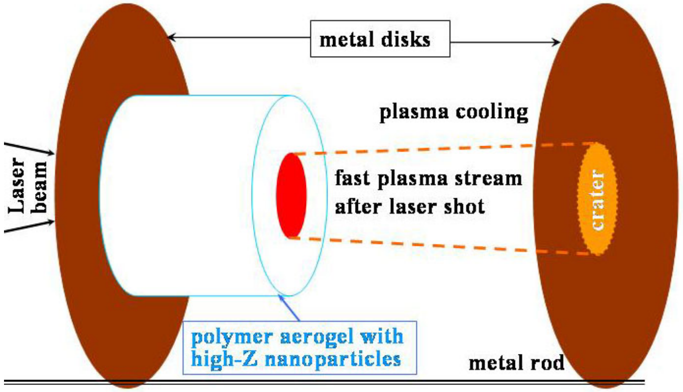
F_1 – filter from BeD_2+Be
P-H – pin-holes camera
D2 – D5 detectors with x-ray films

Magnification, M	– 21.26
Focal length, F	26.92 mm
Numerical aperture, N_a	0.19
Large mirror curvature radius, R_1	100 mm
Large mirror diameter, D_1	50 mm
Small mirror curvature radius, R_2	35 mm
Small mirror diameter, D_2	10.6 mm
Hole diameter, D_h	10.6 mm
Mirror separation for exactly coincident curvature centers, ΔZ_p	65 mm
Spacing between object and curvature center, Z_0	28.189 mm
Spacing between image and curvature center, Z_i	599.474 mm



Vacuum camber for laser interaction with target

EUV Diagnostic scheme of KANAL - laser



Laser targets for EUV registration of plasma cooling after laser shot

Pin-hole EUV camera with thin (1,5 μm) Be+BeD_2 composite optical filter

Shots comparison from PALS and LIL

The processes important for the energy balance were studied in these experiments:

1- laser light diffusion through microturbulent plasma and aerogel in the vicinity of the critical plasma density and light transmittance via target density and thickness;

2 – part of laser pulse energy transferred into SRS, SBS, harmonics;

3 – heating of Al (Cu)-foil (shell) by passed and by converted radiation, which result in the material flux meeting and slowing down the main heat-and-material wave in the low-density matter;

4 - special computer data processing of the images from large dynamic range (12-14 bit in black-and-white) streak cameras in X-rays and in the visible range was applied. It proved the weak preheat of the metal substrate long before the main shock and heat arrive to it through aerogel.

Results from third harmonic radiation lasers of PALS and from second harmonic of LIL : laser on light transmission through microheterogeneous plasma match each other.

Weak signals from x-ray and optical streak-cameras are recorded.

Results from basic frequency of PALS and of MISHEN on previous heating of Al-foils through aerogel/plasma are consistent to each other.

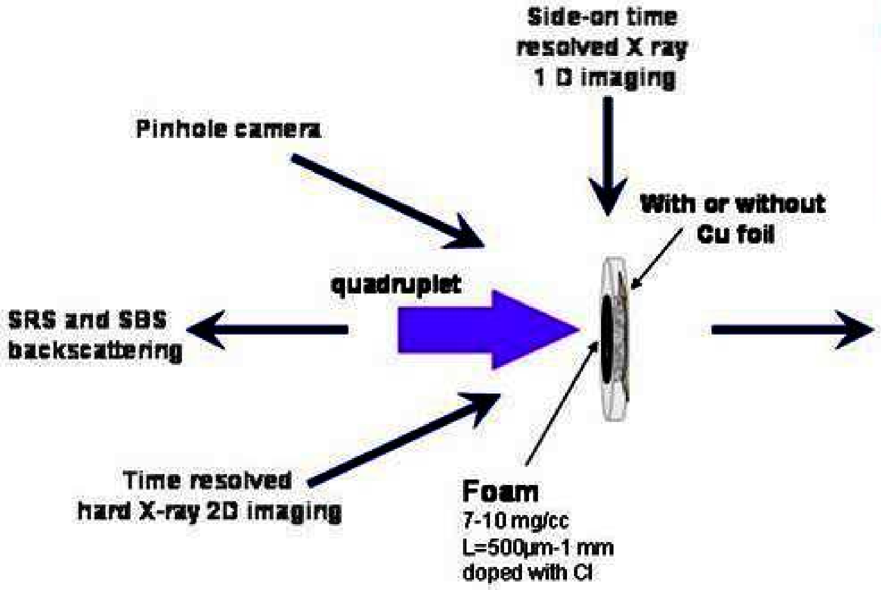
Results from PALS and from LIL on plasma formation velocity in two-layers (aerogel + metal foil) targets coincide.

Plasma jet flight through aerogel with copper nanoparticles is slower than without additives

LIL irradiation and diagnostic scheme

[IFSA 2007]

The LIL experiment



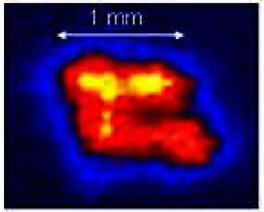
LASER

- 10 kJ of 351 nm light
- 2.7 ns square pulse
- minimum SSD level (< 1 Å)
- 1 mm spot size
- 3×10^{14} W/cm² on target

Transmitted beam diagnostic

- absolute power
- angular distribution

Laser focal spot

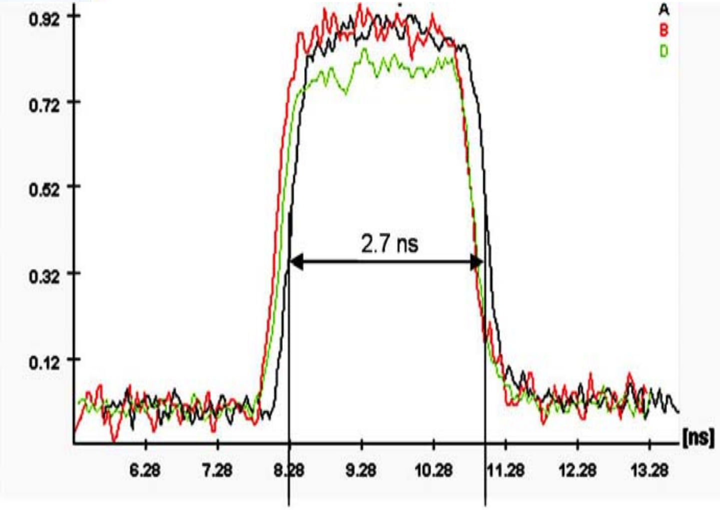


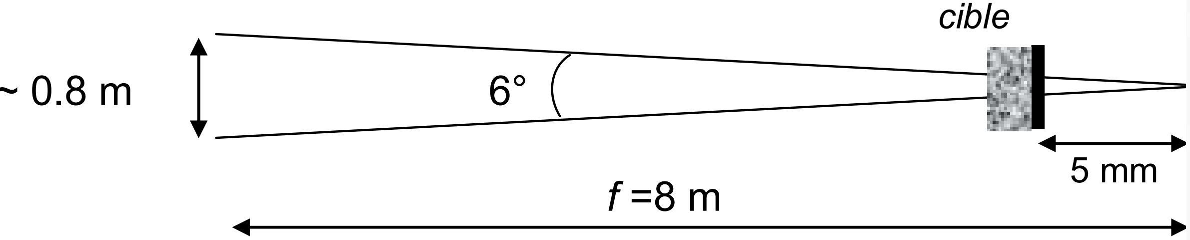
→ visualization of the ionization front

→ measurement of the foam ionization energy budget

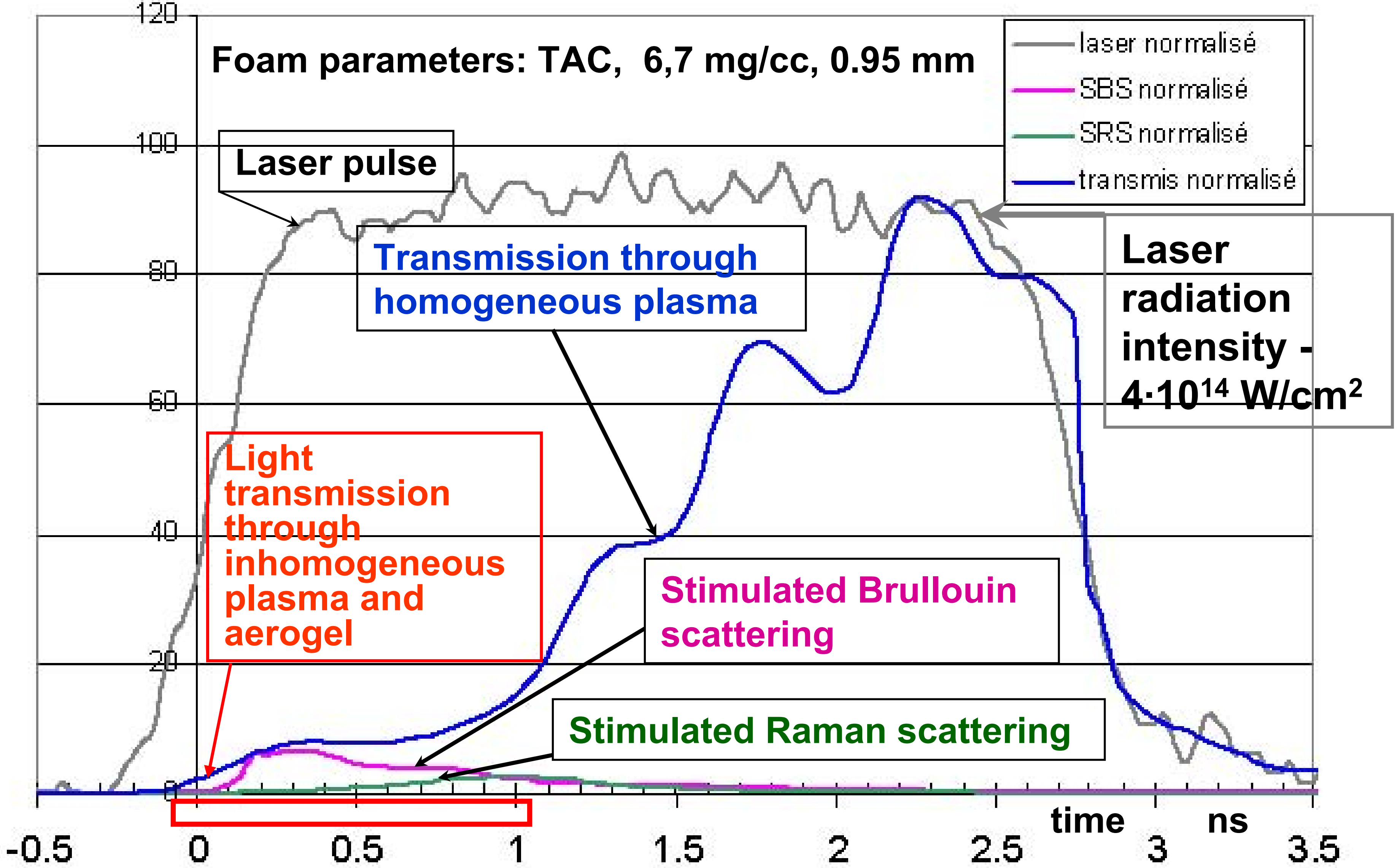
→ foam effect on laser backscattering

→ validation of the foam smoothing effect





Laser radiation transmission through undercritical aerogel.



Foam parameters: TAC, 6,7 mg/cc, 0.95 mm

Laser pulse

Transmission through homogeneous plasma

Laser radiation intensity - $4 \cdot 10^{14}$ W/cm^2

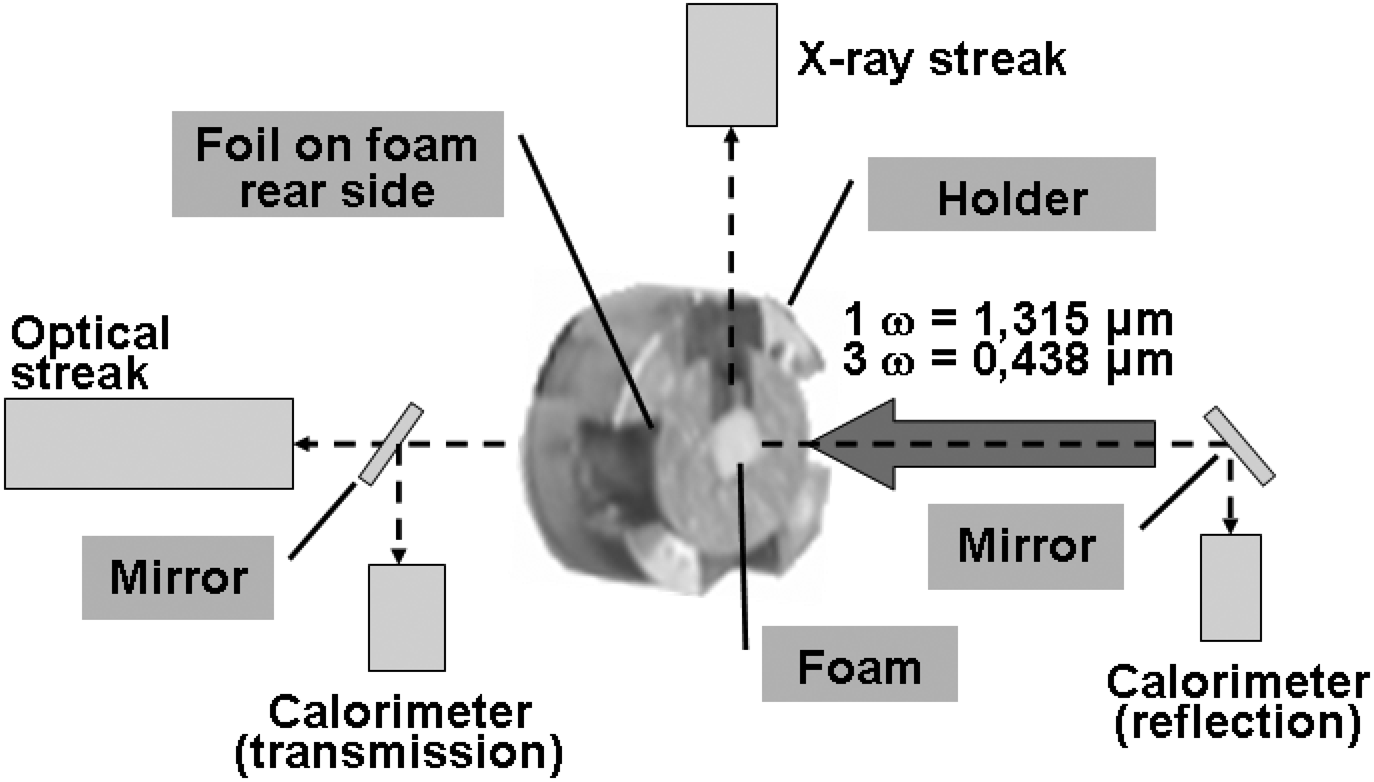
Light transmission through inhomogeneous plasma and aerogel

Stimulated Brullouin scattering

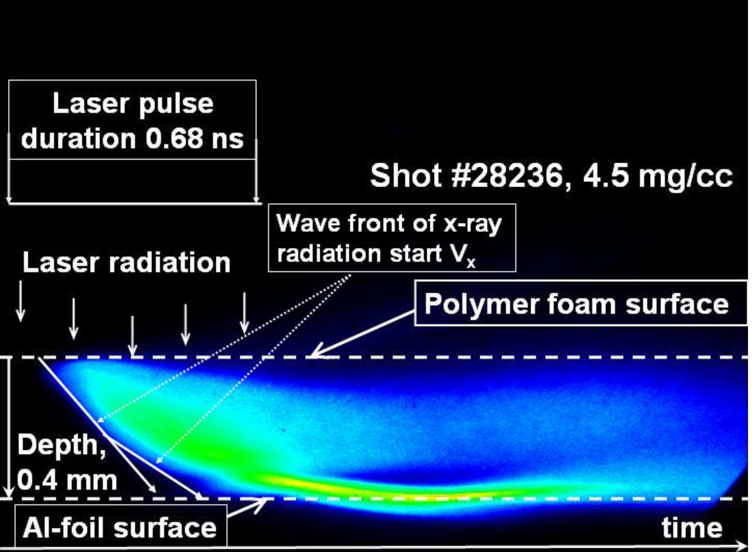
Stimulated Raman scattering

Normalized signals from laser, transmission of laser radiation, stimulated Bruillouin scattering, stimulated Raman scattering. (LIL 2007 experiment)

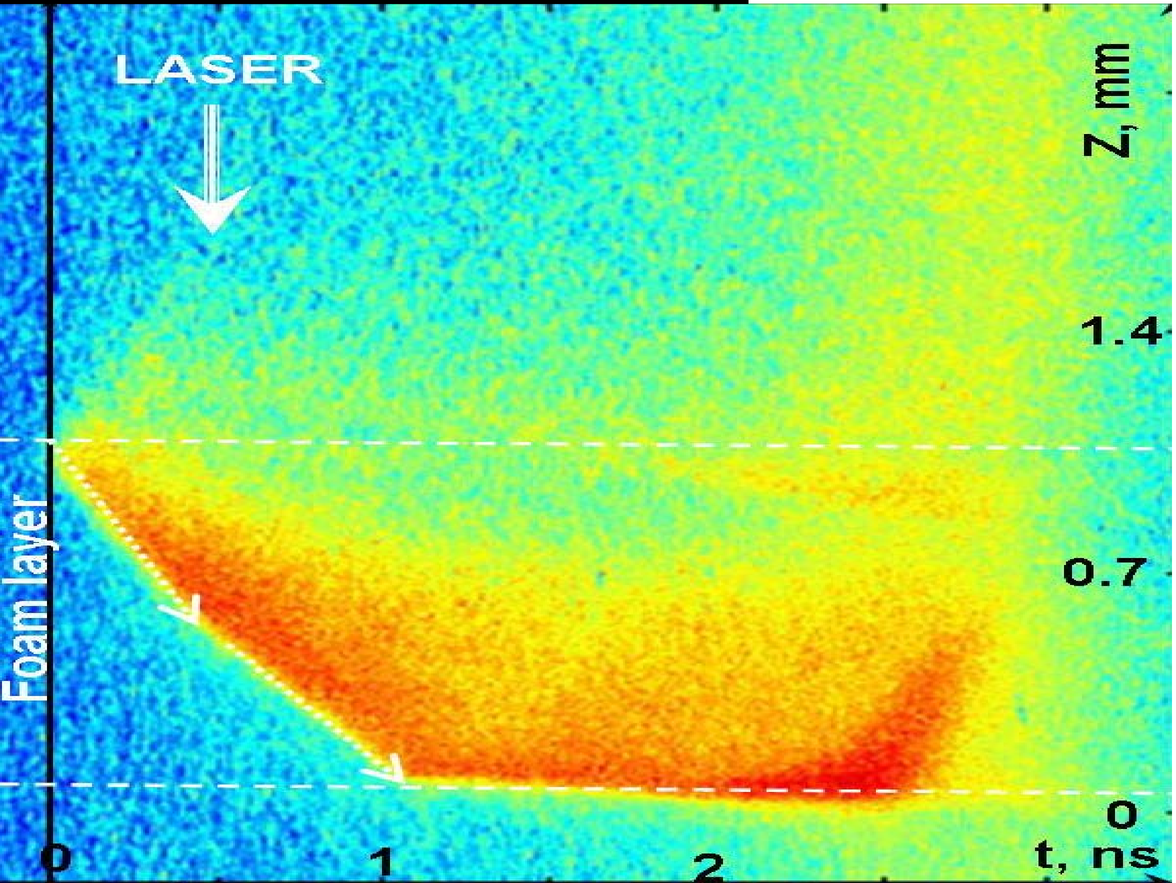
Diagnostic system of PALS



PALS x-ray streak-image in comparison with LIL data



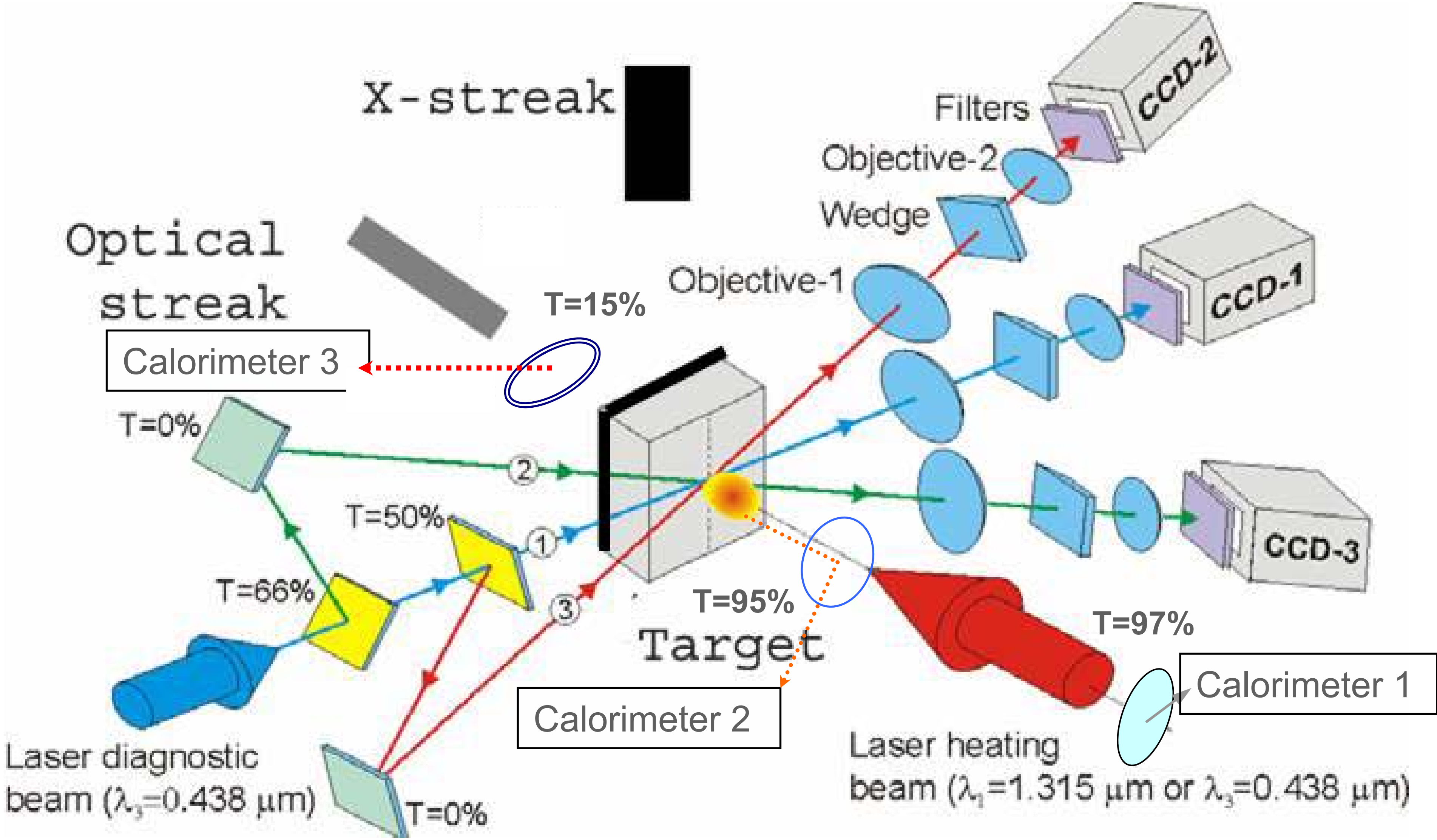
TAC +Al foil



TMPTA +Cu foil

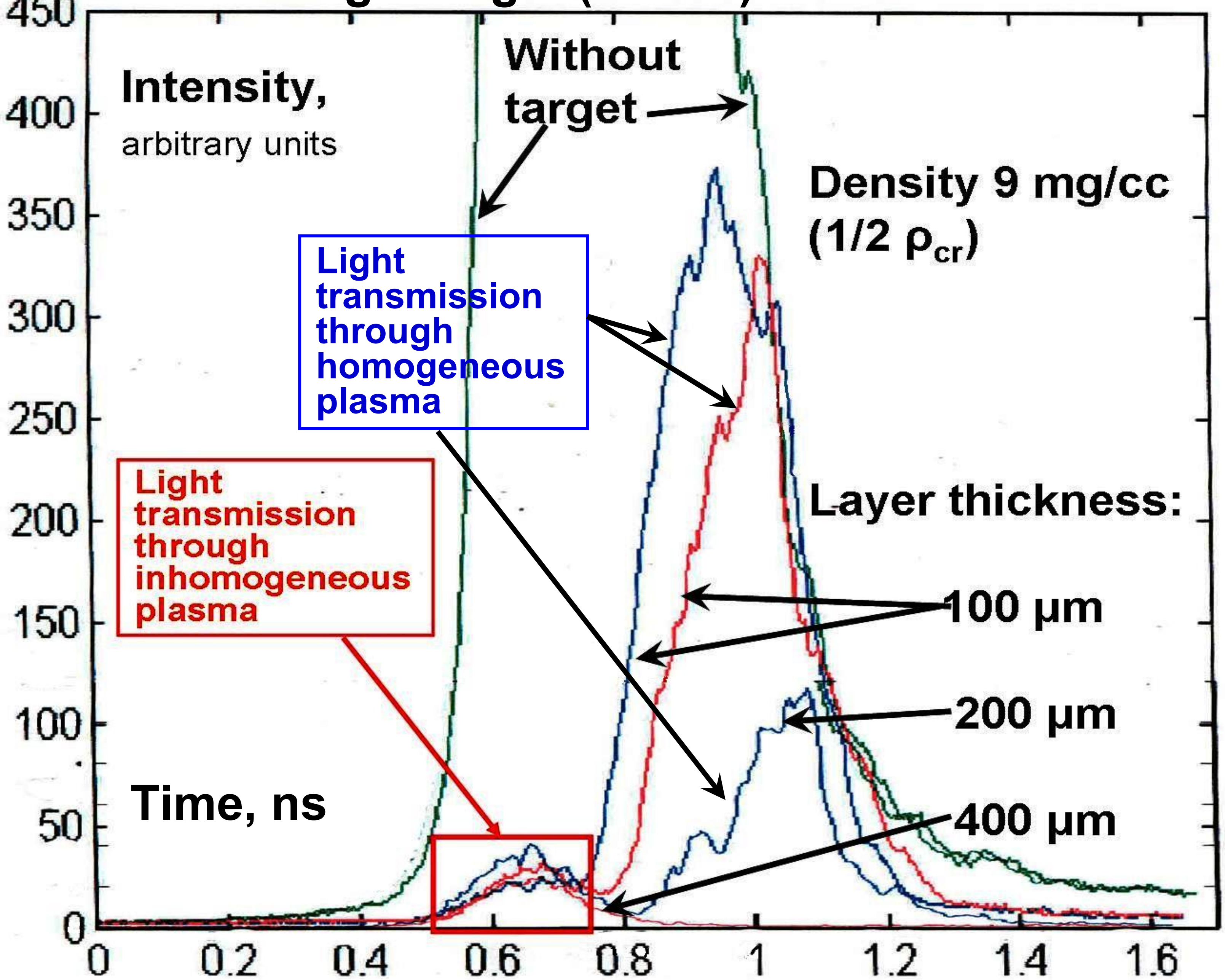
both scales match

Similar fluxes give close ionization front velocities



PALS irradiation and diagnostic scheme

Optical signal intensity via time on the rear side of the aerogel target (no foil) - PALS



Without target

Density 9 mg/cc ($1/2\ \rho_{cr}$)

Light transmission through homogeneous plasma

Light transmission through inhomogeneous plasma

Layer thickness:

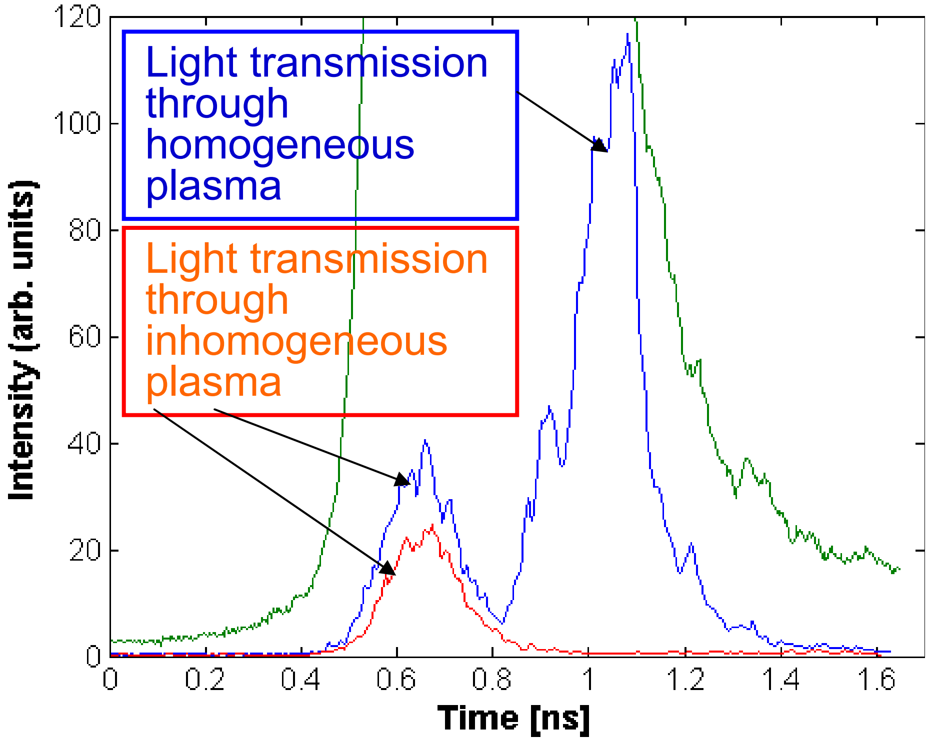
100 µm

200 µm

400 µm

Continued: the same density, varied thickness of target

Transmission dependence on aerogel density



Light transmission through homogeneous plasma

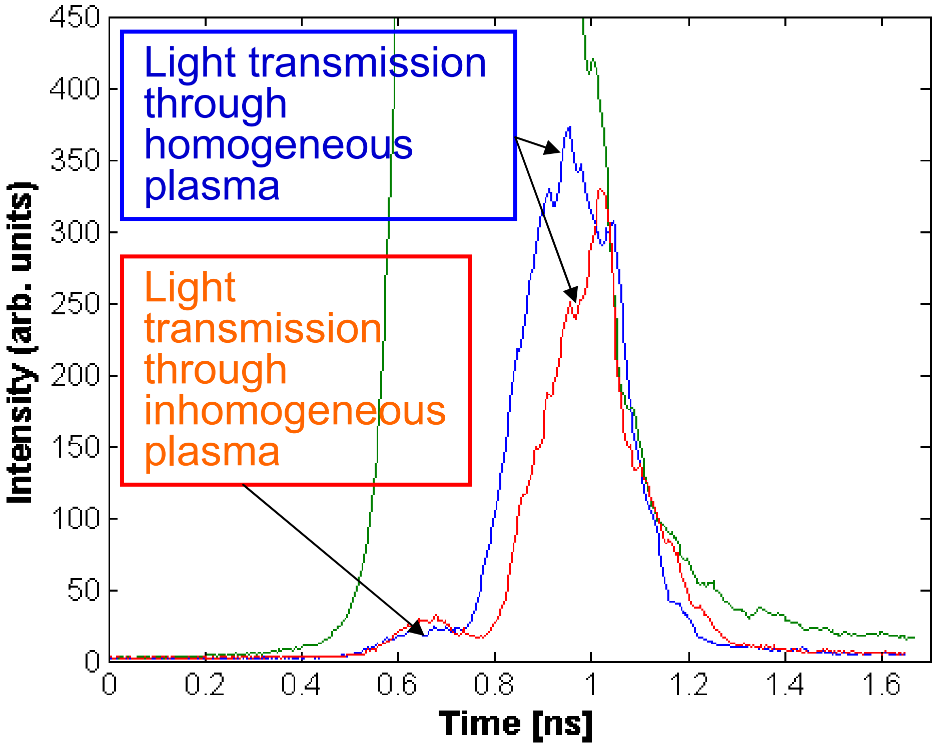
Light transmission through inhomogeneous plasma

TAC, 9 mg/cm^3 – 400 µm (245) 1/4 n_{cr}

TAC, 4.5 mg/cm^3 – 400 µm (251) 1/4 n_{cr}

no target (255)

Shot-to-shot reproducibility



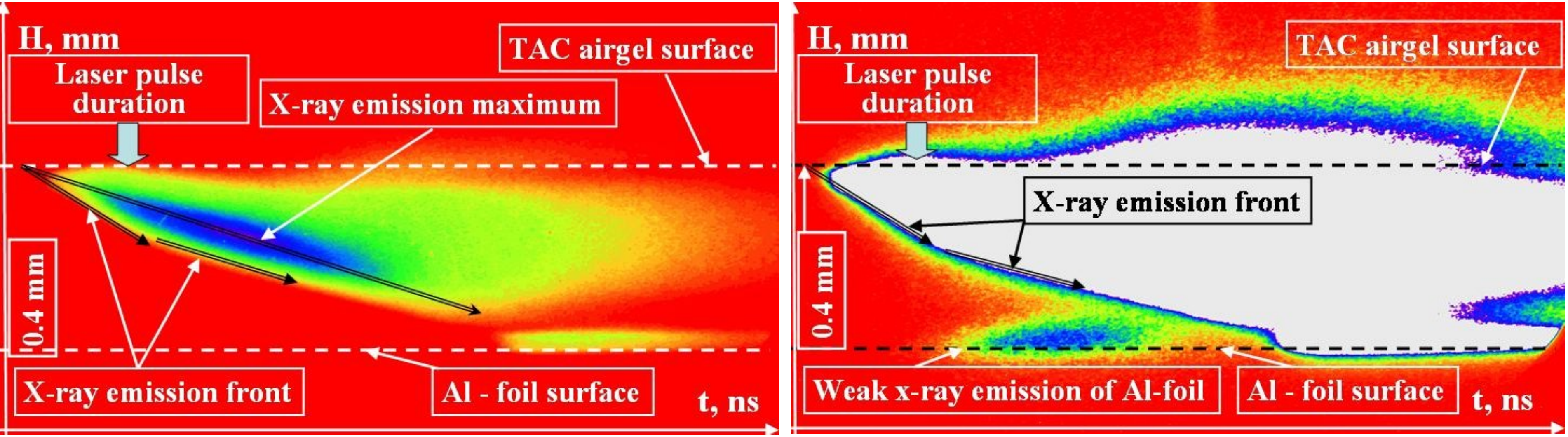
Light transmission through homogeneous plasma

Light transmission through inhomogeneous plasma

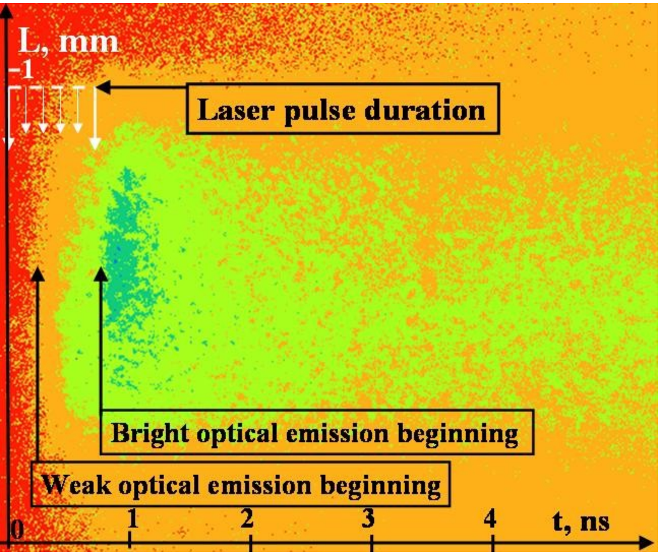
9 mg/cc – 100 µm (263 и 264).

(255) no target

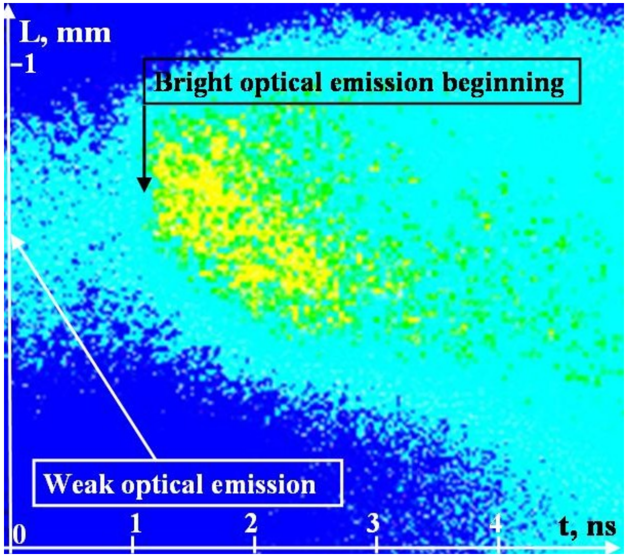
Weak signals of Al-foil emittance prior main heat arrival



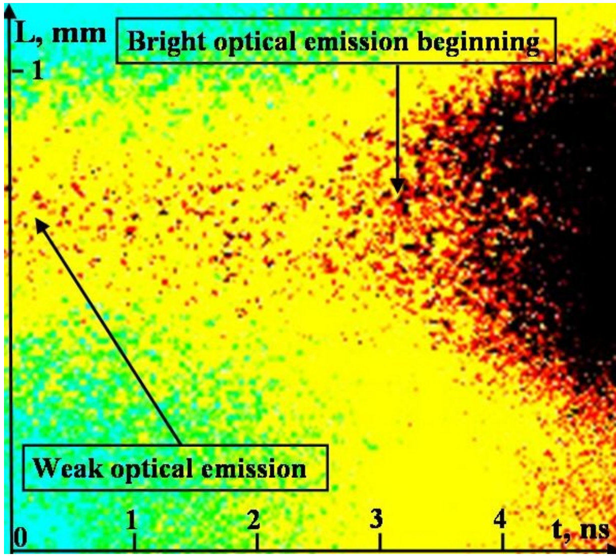
28204, 4.5 mg/cc, 400 μm



28204, 4.5 mg/cc, 400 μm

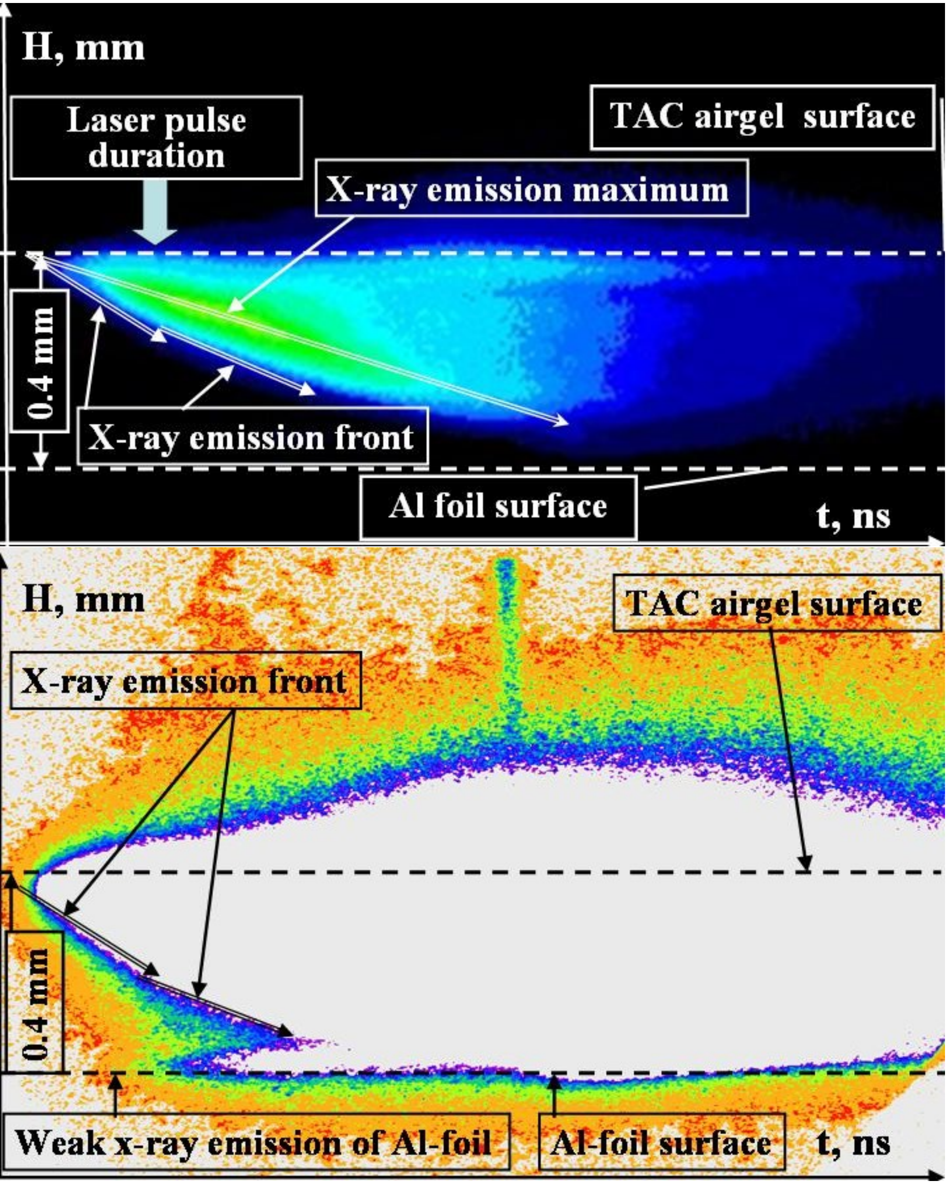


28232, 9.1 mg/cc, 400 μm

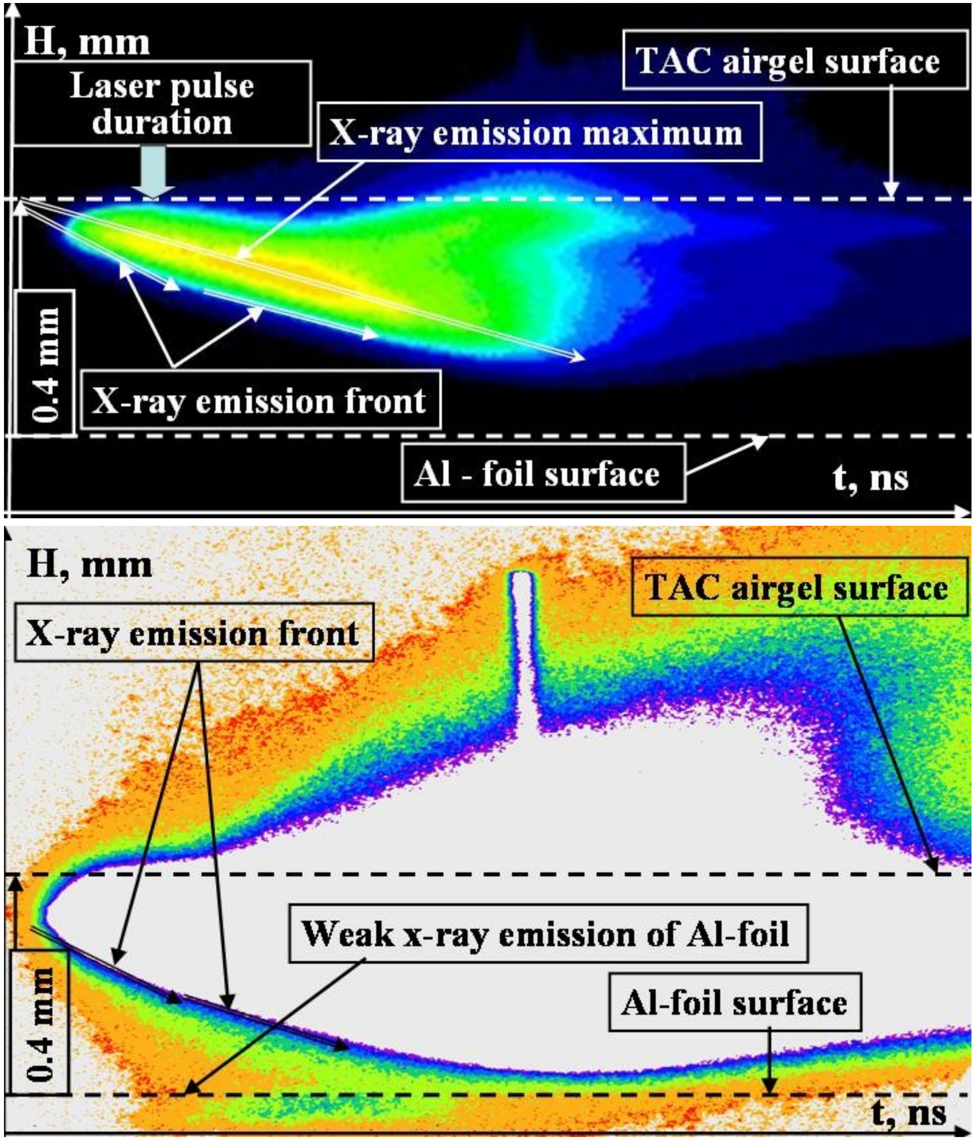


28231, 9.1 (TAC&Cu) mg/cc, 400 μm

Bright and weak signals from X-ray streak-camera



28232, TAC 9.1 mg/cc **1/4 ncr**, 400 μm



28231, 9.1 mg/cc, 0.9 TAC +0.1Cu, 400 μm

Basic interaction results.

- **Similar plastic aerogels (regular open-cell foams, 3-D networks) of TMPTA (Nazarov) & TAC (Borisenko) used to smooth the radiation nonuniformities from different powerful lasers perform other physical processes in microheterogeneous plasma as well, which are essential for the energy transfer models.**
- **Large dynamic range of registration characterized both optical and X-ray streak-camera images. The analysis of already published experiments on PALS and LIL is done addressing signals only several-fold higher than the noise.**
- **Their processing shows the weak heating of metal-foil on the rear of the aerogel (but not heating of polymer with close cells structure) to appear long before the main heat arrives by thermal conductivity and hydrodynamic waves. (on third harmonic its level is about 2-7% from full laser energy, on main frequency <0.3-0.8% < noise level)**
- **Part of the energy in the beginning of the laser pulse is transferred through the turbulent plasma and/or is transformed into SRS, SBS passing through optically transparent 3-D polymer network.**
- **Measured light transmission through the microturbulent plasma and the non-linear optical effects help to explain how the solid foil is heated through the aerogel.**
- Results on basic frequency of laser MISHEN and PALS indicate that main heat of plasma in polymer aerogel from laser energy absorption **localizes** in small volume and quickly (70-120 ps) cools at moving in polymer network. The energy transport from target surface realized then in hydrodynamic wave is low.

Acknowledgements

PALS: D. Klir, V. Kmetik, E. Krousky, J. Limpouch, K. Masek, M. Pfeifer, J. Ullschmied et al.

LULI: S. Depierreux, C. Labaune, D.T. Michel, C. Stenz, V. Tassin, et al.

LIL: S. Depierreux, C. Labaune, D.T. Michel, C. Stenz, M. Grech, S Huller, P. Nicolai, D. Pesme, W. Rozmus, C. Meyer, P. Di-Nicola, R. Wrobel, E. Alozy, P. Romary, G. Thiell, G. Soullie, C. Reverdin, B. Villette.

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References FS&T 2008

Ю. В. Афанасьев, Н. Г. Басов, Е. Г. Гамалий, В. Б. Розанов, А. А. Самарский, Л. П. Феоктистов Теория нагрева и сжатия низкоэнтропийных термоядерных мишеней. Труды ФИАН т. 134, М., Наука, 1982, 184 стр.

N. G. Borisenko, A. A. Akunets, I. A. Artyukov, K. E. Gorodnichev, Yu. A. Merkuliev, A. V. Vinogradov. X-ray tomography of the growing silicagel with density gradient. // 18th Target Fabrication Meeting, 12-15 May 2008, Tahoe Lake, California, USA, Book of Abstracts, p. 104.

A. B. Britan, I. N. Zinovik, V. A. Levin. Shock-wave propagation through a vertical foam column with a density gradient. // Prikladnaya Mekhanika I Tekhnicheskaya Fizika, No. 2 pp. 27-32, (1992).

B. W. Skews, M. D. Atkins, M. W. Seitz. The impact of a shock wave on porous compressible foams. //Journal of Fluid Mechanics Digital Archive **253**, 245-265, (1993).

N. Metzler, A. L. Velikovich, J. H. Gardner. Reduction of early-time perturbation growth in ablatively driven laser targets using tailored density profiles. // Physics of Plasmas, **6**, 3283-3295, (1999).

R. Teyssier, D. Ryutov, B. Remington. Accelerating shock waves in a laser-produced density gradient. // The Astrophysical Journal Supplement Series, 127, 503-508, (2000).

D. Batani, H. Stabile, A. Ravasio, G. Lucchini, F. Strati, T. Desai, J. Ullschmied, E. Krousky, J. Scala, L. Juha, B. Kralikova, M. Pfeifer, Ch. Kadlic, T. Mocek, A. Prag, H. Nishimura, Y. Ochi. Ablation pressure scaling at short laser wavelength. // Physical Review, E **68**, 06743, (2003).

Batani D., Balducci A., Nazarov W., Lower T.H., Hall T.A., Koenig M., Faral B., Benuzzi A., Temporal M. Use of low-density foams as pressure amplifiers in equation-of-state experiments with laser-driven shock waves. // Phys. Rev. E, 2001, V. 63, No 4 pt.2, 046410.

M. Shukla, Y. Kashyap, P.S. Sarkar, A. Sinha, H.C. Pant, R.S. Rao, N.K. Gupta, V.K. Senecha, B.K. Godwal. Laser induced shock pressure multiplication in multi layer thin foil targets. // Nuclear fusion, 2006, V. 46, p. 419-431.

M. Koenig, A Benuzzi, F. Philippe, D. Batani, T. Hall, N. Grandjouan,W. Nazarov. Equation of state data experiments for plastic foams using smoothed laser beams. // Physics of Plasmas, 6, 3296-3301, (1999).

Borisenko N.G, Akimova I.V., Gromov A.I., Khalenkov A.M., Kondrashov V.N., Limpouch J., Krousky E., Kuba J., Masek K., Merkuliev Yu.A., Nazarov W., Pimenov V.G. Regular 3-D Networks for Controlled Energy Transport Studies in Laser Plasma near Critical Density // Fusion Science and Technology. 2006, V. 49, No 4, pp. 676-685.

N. G. Borisenko, A. A. Akunets, A. M. Khalenkov, D. Klir, V. Kmetik, E. Krousky, J. Limpouch, K. Masek, Yu. A. Merkuliev, M. Pfeifer, V. G. Pimenov, and J. Ullschmied. Peculiarities of the transmission of laser radiation with a wavelength of 0.438 μm and intensity of (3--7)·1014 W/cm2 through undercritical plasma from polymer aerogels. // Journal of Russian laser research, **28**, 500-518, (2007).

N.G. Borisenko, A.A. Akunets, Ю.А. Меркульев. Polymer aerogel with density gradient for ICF targets. // 3rd Moscow Workshop on Targets and Applications, 15-19 October, 2007, Moscow, Russia. Book of Abstract, p.52.

K. Walter. Meeting the Target Challenge. // Science & Technology Review, Lawrence Livermore National Laboratory, p. 12-19, July/August 2007.

Koenig M., Krishnan J., Faral B., Nazarov W., Temporal M., Batani D., Muller L., Torsiello F., Hall T., Grandjouan N. Dynamics of laser produced shocks in foam-solid targets. // Physics of Plasmas, 1998, V. 5, No 8, pp. 2827-2829.

Benuzzi A., Koenig M., Krishnan J., Faral B., Nazarov W., Temporal M., Batani D., Muller L., Torsiello F., Hall T., Grandjouan N. Dynamics of laser produced shocks in foam-solid targets. // Physics of Plasmas, 1998, V. 5, No 8, pp. 2827-2829.