Nanostructured targets irradiated with intense laser beams

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Summary. Results of experiments on plasma formation at laser radiation interaction with low-density materials (3D-netlike polymer with fiber diameter 40-70 nm and smoglike metal Sn or Bi with particles diameter 40-100 nm) are discussed. In present we report new experimental results obtained on intense Nd:Glass laser with 0.5-ns pulse duration in BARC (India) with low-density targets from triacetate cellulose (TAC) – polymer aerogel and with low-density metal layers of Sn and Bi. The detailed study of plasma under powerful laser shot was performed measuring laser light transmission and scattering, x-ray and ion emission, shadowgraphy, optical luminosity temporal behavior. Initially microheterogeneous (turbulent) plasma is considered and energy transmittance dependences are measured via areal densities and thickness for several densities. The transparencies within 6% for plasma from plastic aergel are consistent with plasma experiments in the world. The papers with authors' participation [1] have shown that there exist a weak heating of foil at the initial period of laser pulse action in a double-layer target (polymer aerogel + Al foil) and a laser radiation transmission through turbulent plasma (without Al-foil) [2,3]. Present results are in agreement with data [1-3]. Shadowgraphy pictures are showing unusual dynamic of plasma flow after passing through "cold" polymer set. X-ray intensity from Bi plasma increased at changing Bi metal to Bi dust layer with density 100 mg/cm^3 at Bi particles diameter 40-100 nm. Technology of metal snow production and low-density metal layer characterization methods are demonstrated.

1. N. G. Borisenko and Yu. A. Merkuliev. Initial heating of a target by laser radiation through plasma and polymer aerogel. *J. Russ. Laser Research*, **31**, (3), 235- (2010).
2. J. Limpouch, P. Adamek, N. G. Borisenko, N. N. Demchenko, T. Kapin, M. Kalal, A. M. Khalenkov, D. Klir, V. Kmetik, E. Krousky, M. Kucharik, R. Liska, K. Masek, W. Nazarov, M. Pfeifer, M. Sinor, and J. Ullschmied, in: *33rd EPS Conference on Plasma Physics*, Rome 19–23 June 2006, ECA **30I**, P-5.001 (2006).
3. 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, *J. Russ. Laser Research*, **28**, (6), 500–518 (2007).

CONTENT

1. Introduction.
2. Experimental set up: laser and diagnostic apparatus.
3. Targets
4. Results.
5. Discussion.
6. Conclusion.

# TTL in experiments on powerful ns- and ps-lasers

Our laboratory (TTL) had delivered the shell targets with fuel and various flat targets to experiment on the ns-lasers of our Lebedev Physical Institute, on the ns- and ps-lasers of 5 Russian scientific centers and centers of 7 countries. We had produced target technological facilities and monitoring apparatus for Russian and foreign centers. We take part in large laser projects.

EXTREMES: Polymer aerogel targets with nanoparticles and low-density metal layers
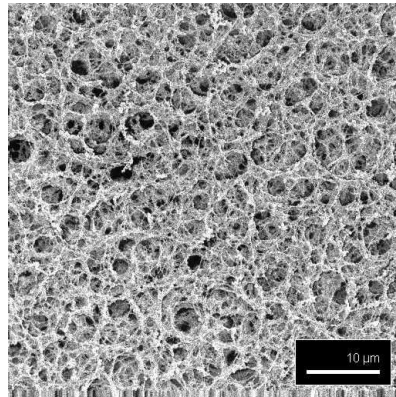
Polymer aerogel density 10 mg/cm^3 with 20 mass% copper nanoparticles, scale 10 μm
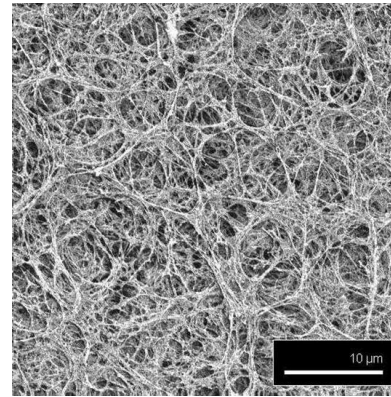
Polymer aerogel density 1 mg/cm^3, scale 10 μm. (Dr. V.G. Pimenov, ZIOC RAS)
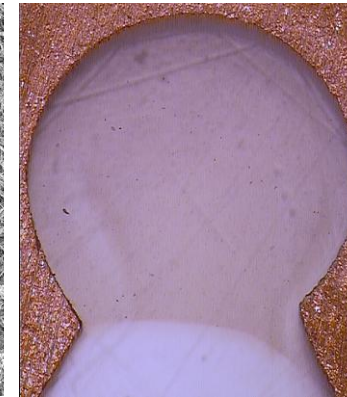
Real target with diameter 2.5 mm - polymer aerogel density 3 mg/cm^3 with 10 mass% Cu nanoparticles
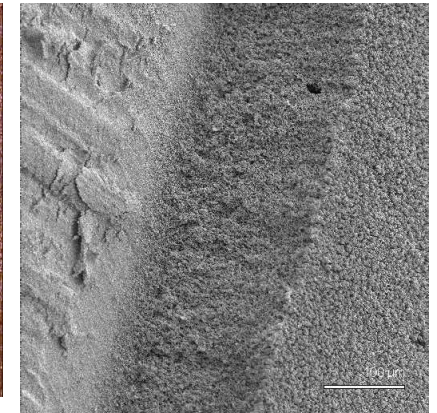
Layer of metal nanoparticles with density 50 mg/cm^3, scale 100 μm.

Dr. A.I. Gromov with apparatus for metal nanoparticles' production

Mr. A.S. Orekhov, Dr. A.M. Khalenkov and Dr. N.G. Borisenko with apparatus for characterization and preparation of laser targets/

New goals for low-density materials fabrication specialists

- High-Z nanoparticles dopant with different boiling temperatures for increasing uniform compression (microturbulent plasma life-time).
- Multilayers structure with density ranging from subcritical (2 mg/cc) to 100 mg/cc for increased hydrodynamic efficiency of targets.
- Layers with density gradient for pressure miltiplication in experiment by equation state of matter.
- Concentration wave of high-Z nanoparticles dopant in low-density layer for increasing of efficiency targets, and/or for x-ray converter.
- Optimal structure (distance between fiber, diameter fiber and low-density layer thickness) for random plasma phase plate.
- High-Z low-density layer for x-ray converter of indirect targets.
- High-Z low-density layer for the converters of ps-laser radiation to β-particles beam at the fast ignition.
- Perdeuterated (or deuterated-tritided) substances for neutron ignition sources.

Driver and fuel (size and cost, requirements)

1. **Fundamental contradiction between size & cost of fuel (target) and driver (laser) of Laser Fusion.**

	Driver	Targets
Quantity	1	10^{11} in 30 years
Volume per unit	$3 \cdot 10^6 \, m^3$	$10^{-7} \, m^3$
Cost per unit	10^{10}\$	0.1\$

2. **Second contradiction between mostly fixed laser system and fully variable target construction for different applications of Laser Fusion, between the requirements to laser (driver) and targets constructions**

During past 40 years all conditions, which driver cannot fulfill, went to targets construction additional strict requirements! (DT-solid sphere + strictly profiled laser pulse → shell target + simple laser pulse; laser radiation nonuniformity → indirect target; etc.).

This is why validation experiments with targets will always be necessary.
Indirect targets are beyond our present consideration, because we believe they must give way to the direct ones in Laser Fusion

Experiment: laser and diagnostics (BARC, Dhareshwar&Chaurasia).

Vacuum chamber

2 parts of laser beams with variation of time delay

Faraday cup 2

Target

Single XRD

Calorimeter

Main Laser Beam

L

L

Single XRD 1

Calorimeter

Three channel XRD

Faraday cup 1

CCD camera 1

CCD camera 2
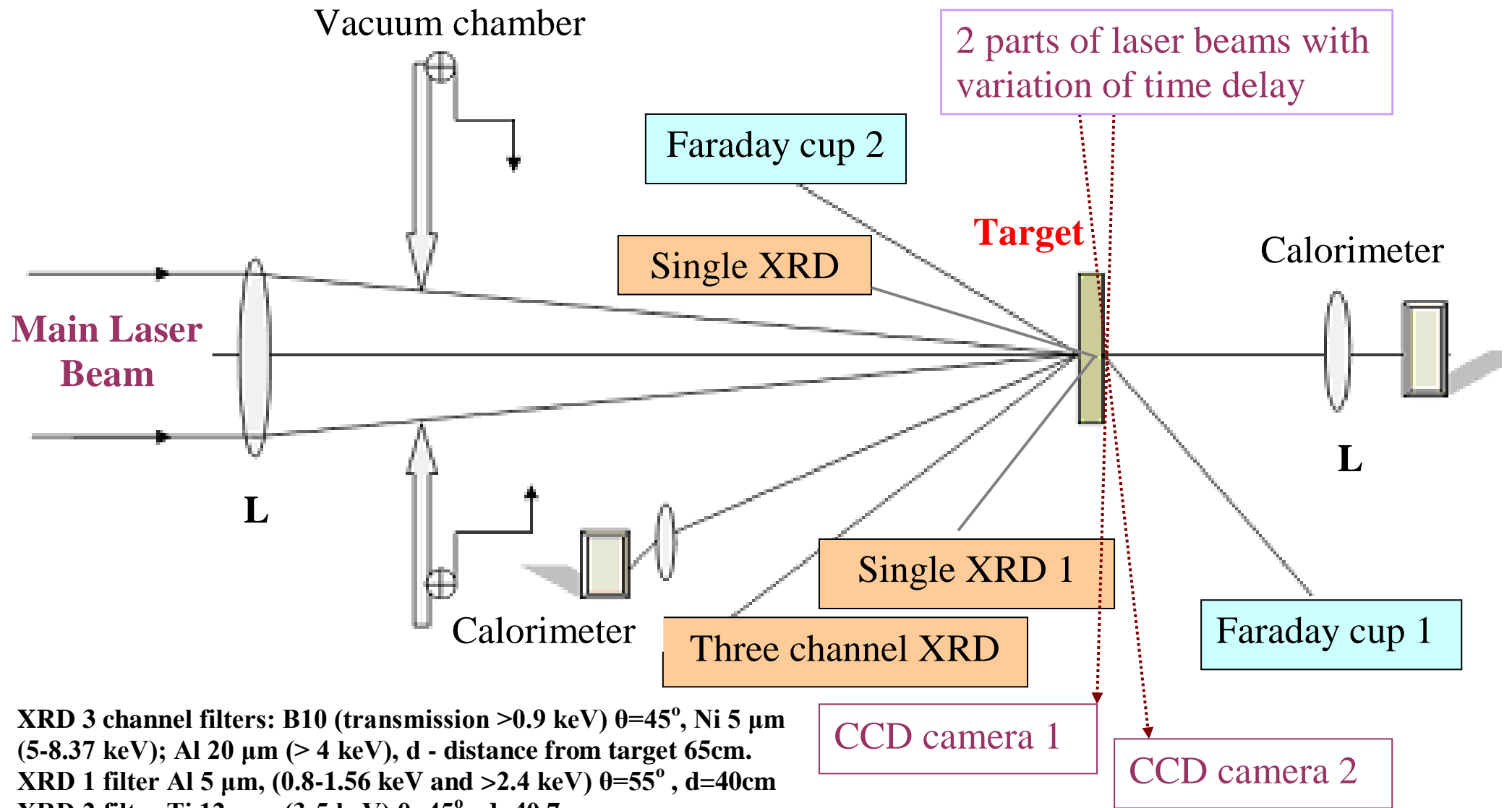
XRD 3 channel filters: B10 (transmission >0.9 keV) θ=45°, Ni 5 μm (5-8.37 keV); Al 20 μm (> 4 keV), d - distance from target 65cm.
XRD 1 filter Al 5 μm, (0.8-1.56 keV and >2.4 keV) θ=55°, d=40cm
XRD 2 filter Ti 12 μm, (3-5 keV) θ=45°, d=40,7cm.
Faraday caps θ=45°

TARGETS

Target fabrication

The technology of low-density target fabrication and the influence of gel formation and drying processes on target parameters (density, pore size, maximum high-Z loading, etc.) is discussed. The regular 3-D polymer networks of cellulose triacetate (TAC) with the densities down to 4.5 mg/cc, also doped with high-Z nano-particles are demonstrated as targets for different laser experiments.

TAC, 4.5 mg/cc

1µm
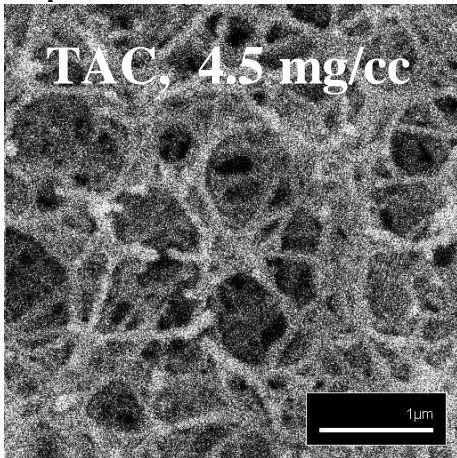
Scale – 1 μm ↑
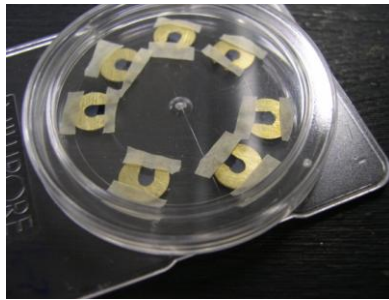
TAC targets in transport slide

Bi–dust layers produced on thin (0.2-0.3 μm) polymer film as metal snow from metal vapors in inert gas at low pressure in vacuum chamber.

Sn, ≈ 100 mg/cc

2 µm
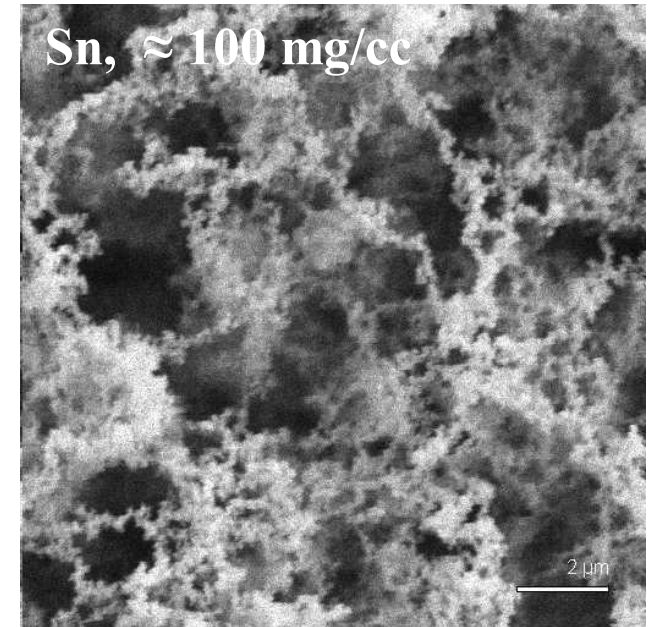
Scale – 2 μm ↑
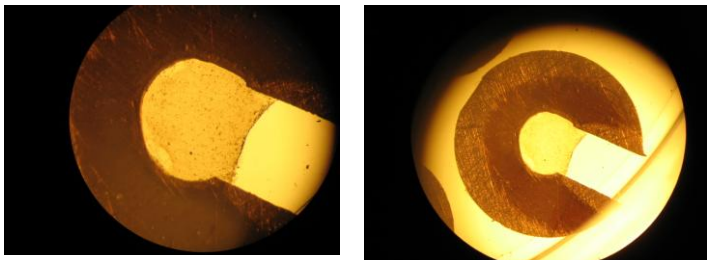
TAC foam on washers
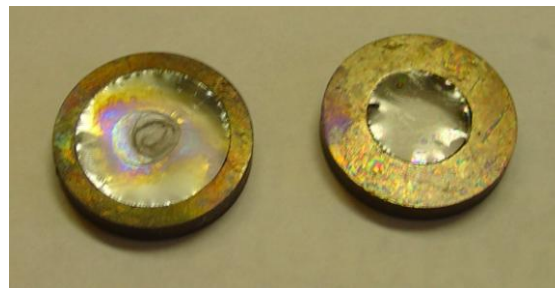
Thin polymer film on washer

Targets characterization

TAC density ≈ 4 mg/cc
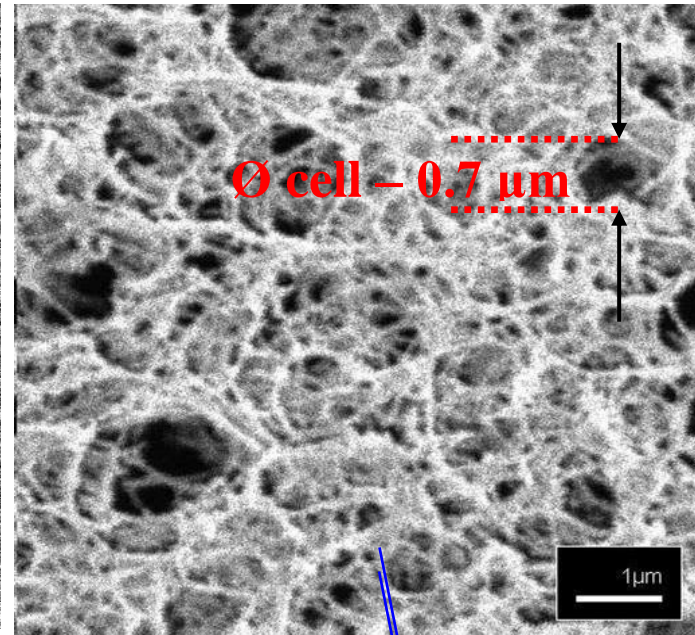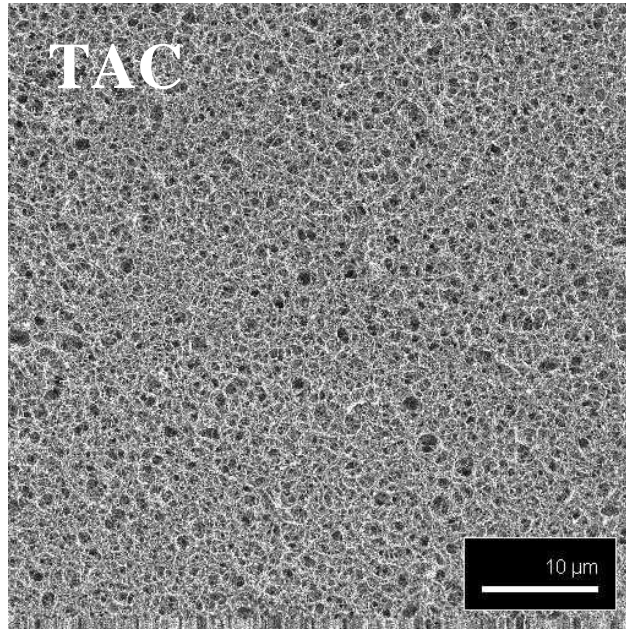
Scale – 10 μm →

Ø cell – 0.7 μm
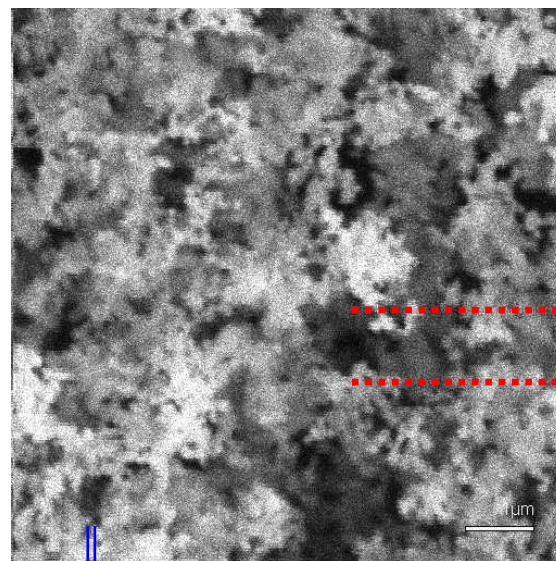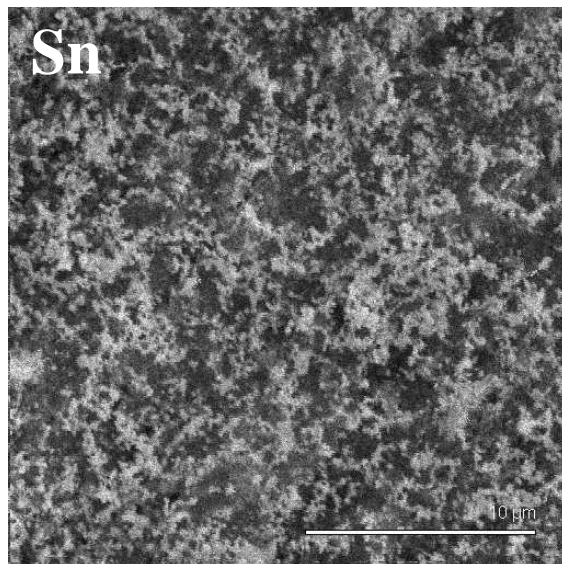
Scale – 1 μm

Ø fiber – 60 nm

Scale – 10 μm ↑

Ø cell – 0.8 μm

Sn density ≈ 70 mg/cc

Scale – 1 μm ↑

Ø particle – 70 nm

Targets characterization (microradiography)
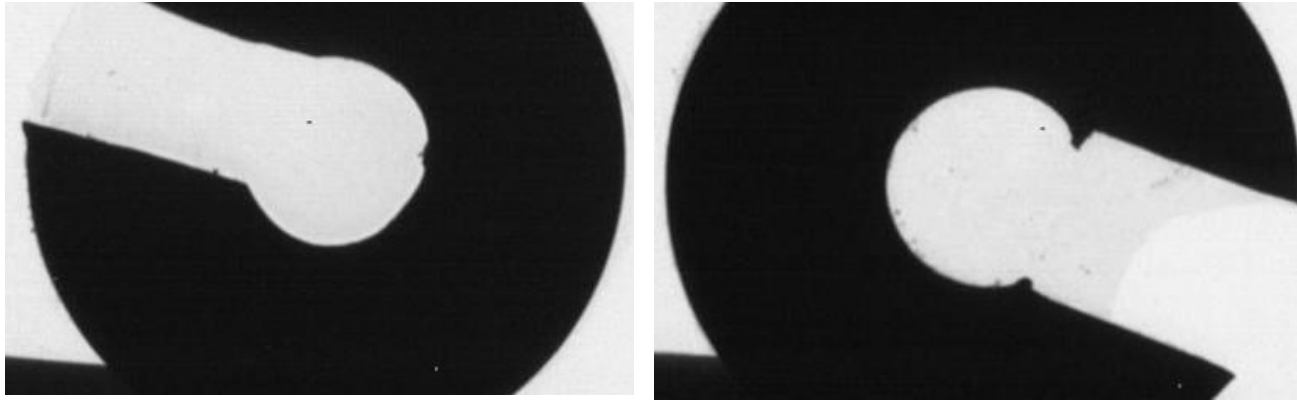
X-ray photo. Bi-dust layers on polymer film in washer.
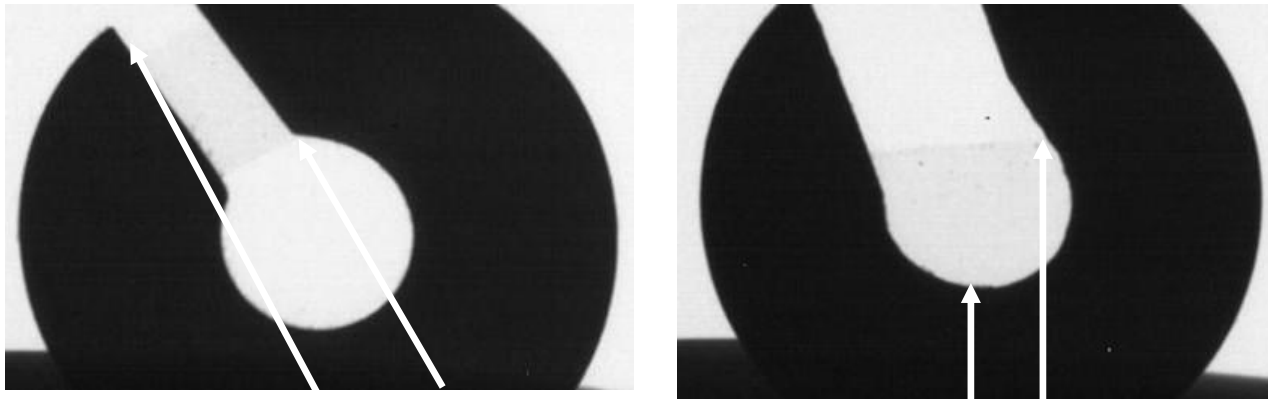
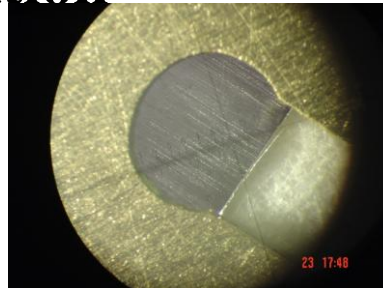X-ray photo. Bi metal layers on polymer film in washer.
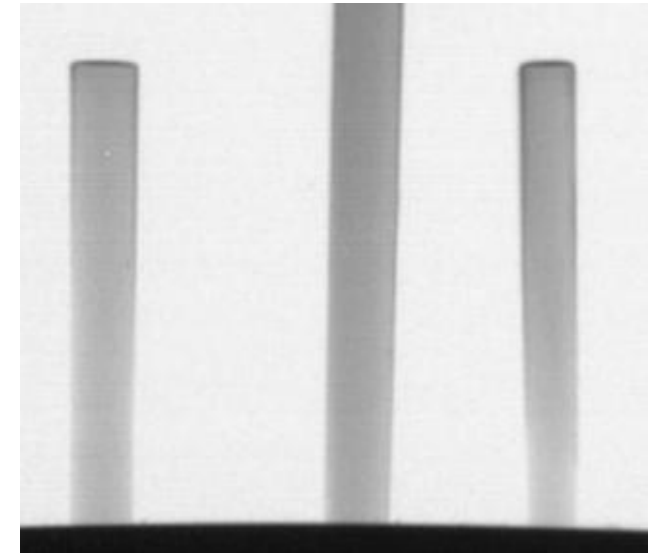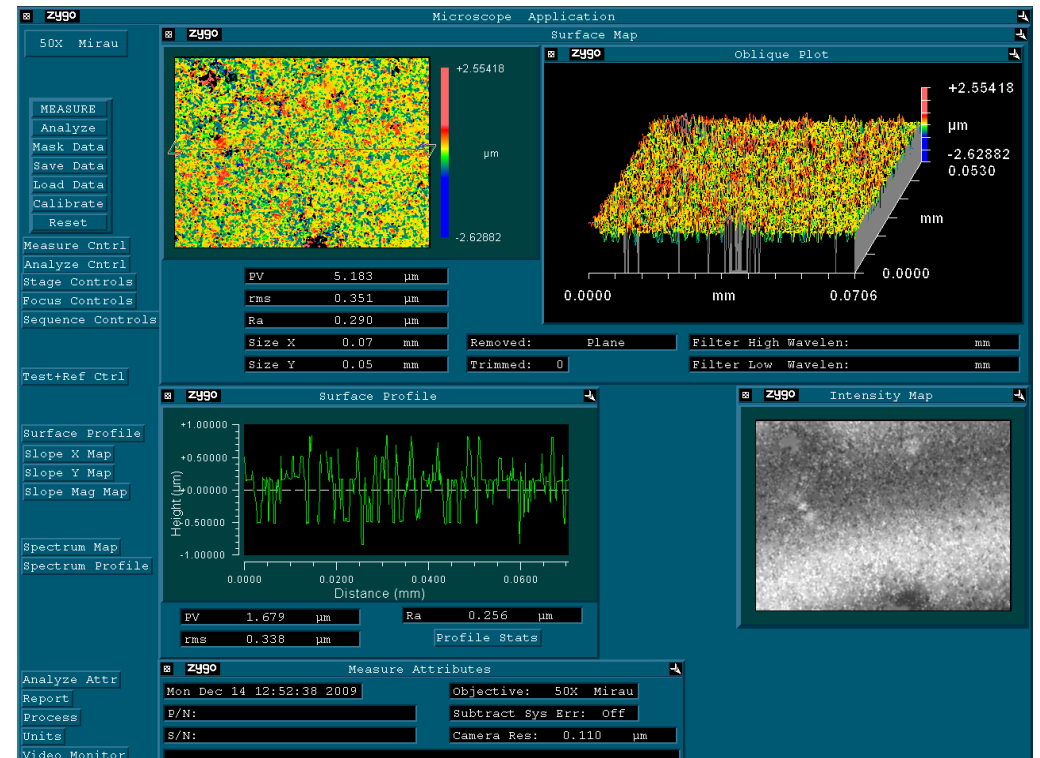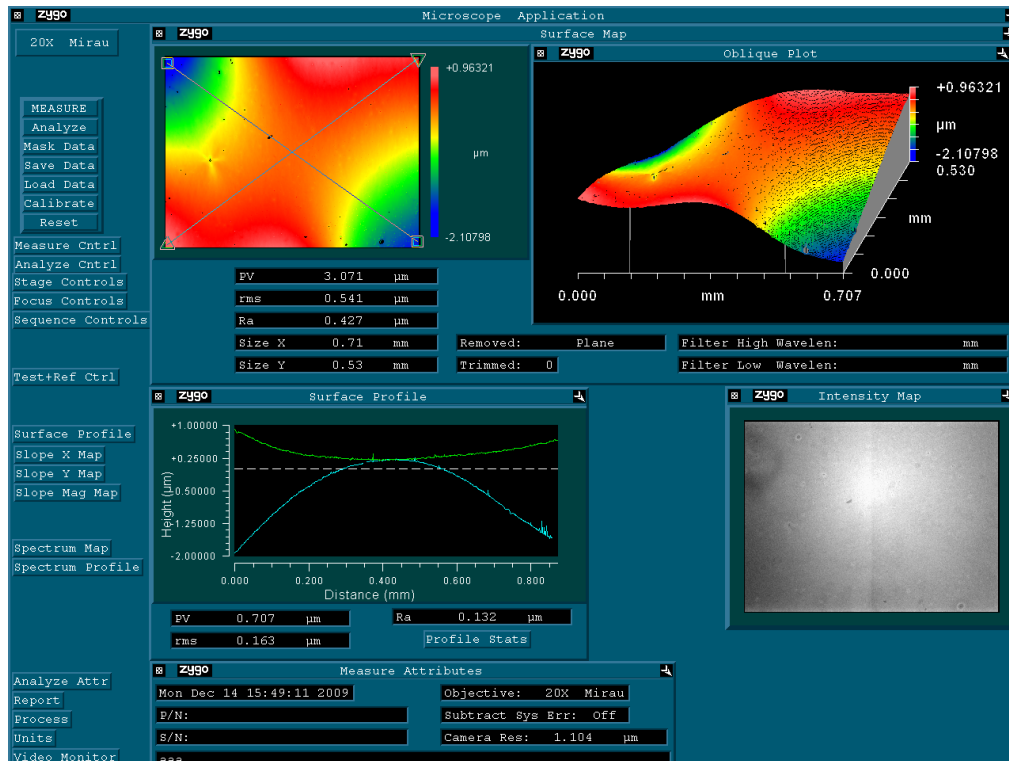

Thin graphite pilots – witnesses used for measurement of metal dust density
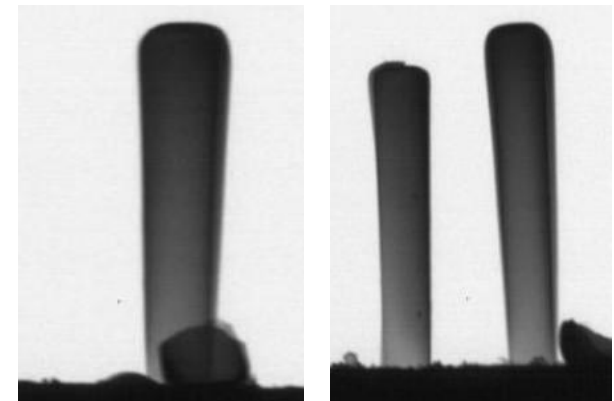
Thick graphite pilots – witnesses used for measurement of metal dust density

Targets surface characterization
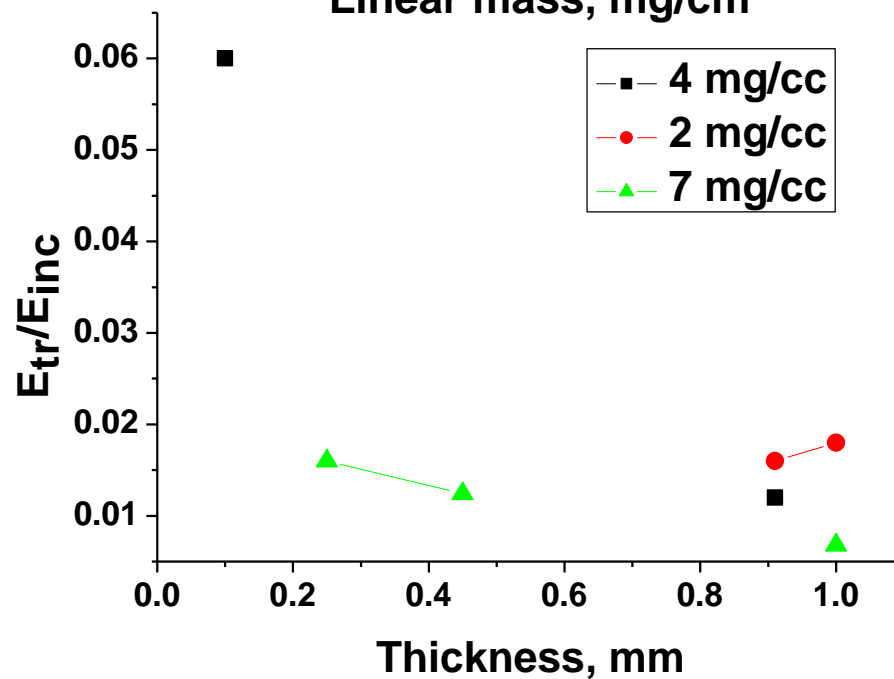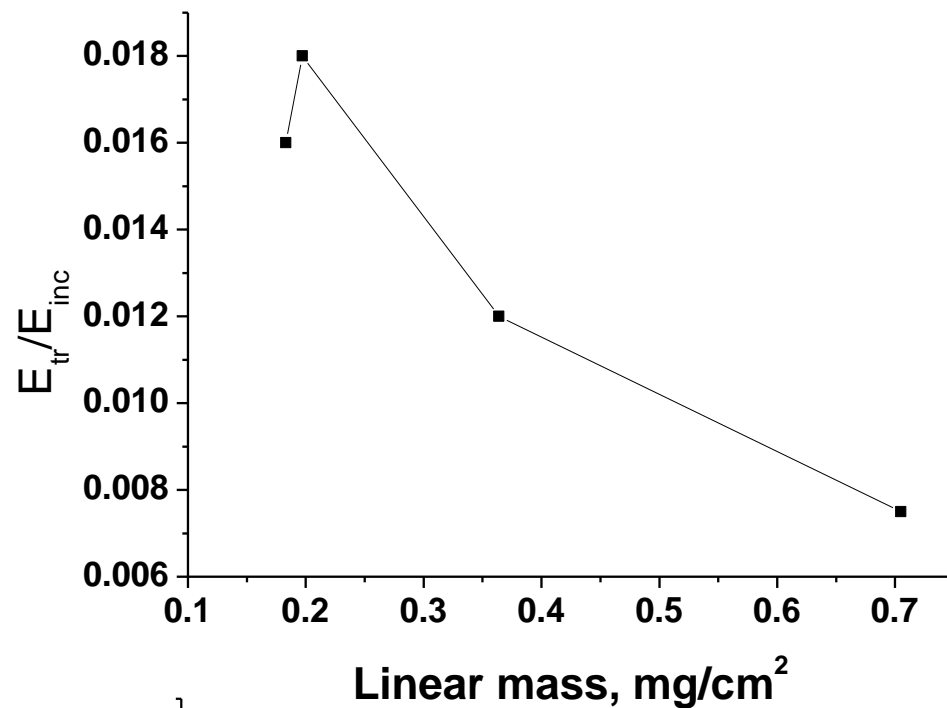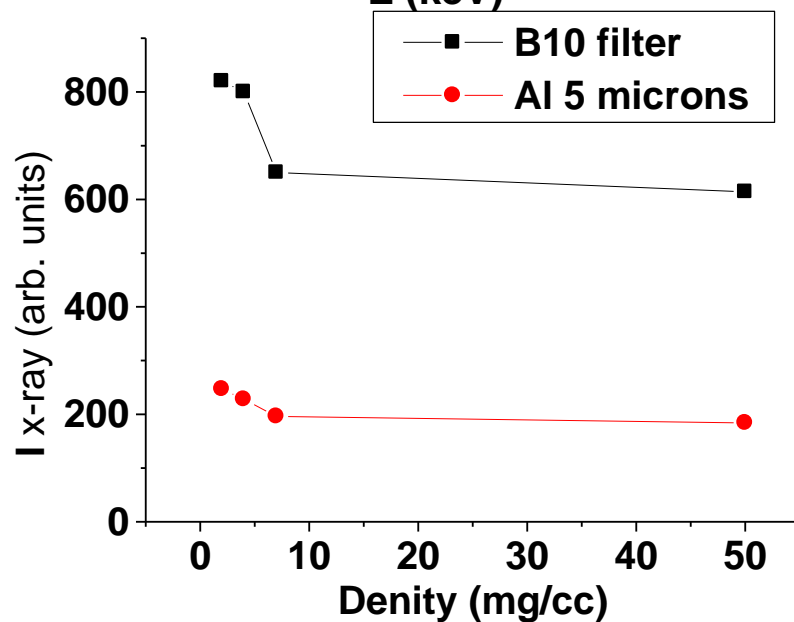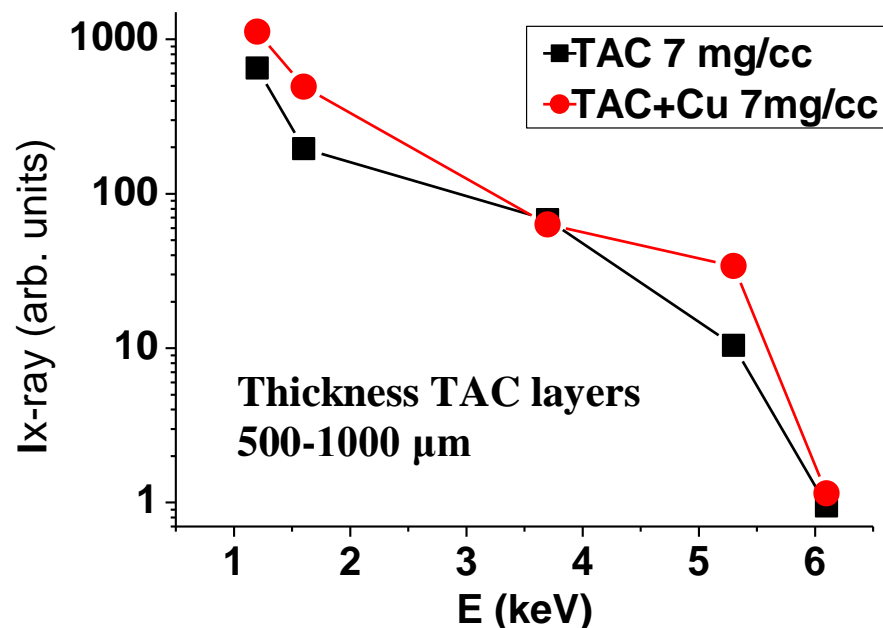## (Low-density TAC and Sn-dust with density 50 mg/cc)

TAC density 4 mg/cc. AFM
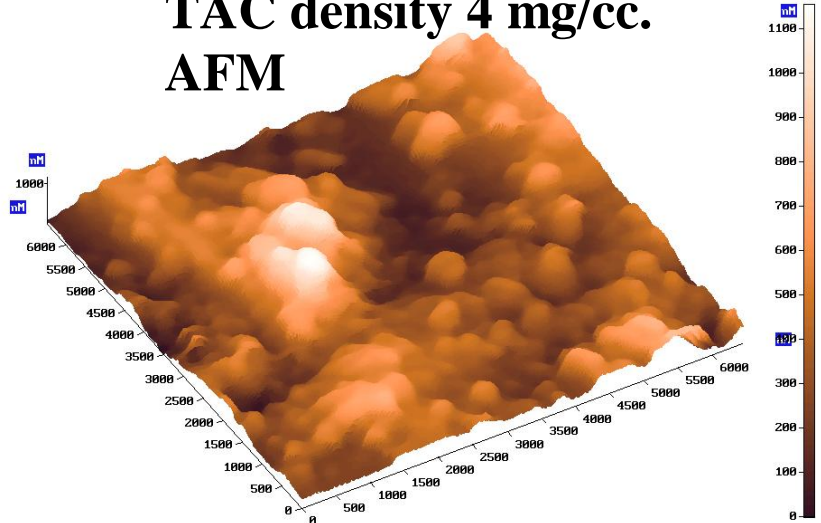
Al-foil on washer

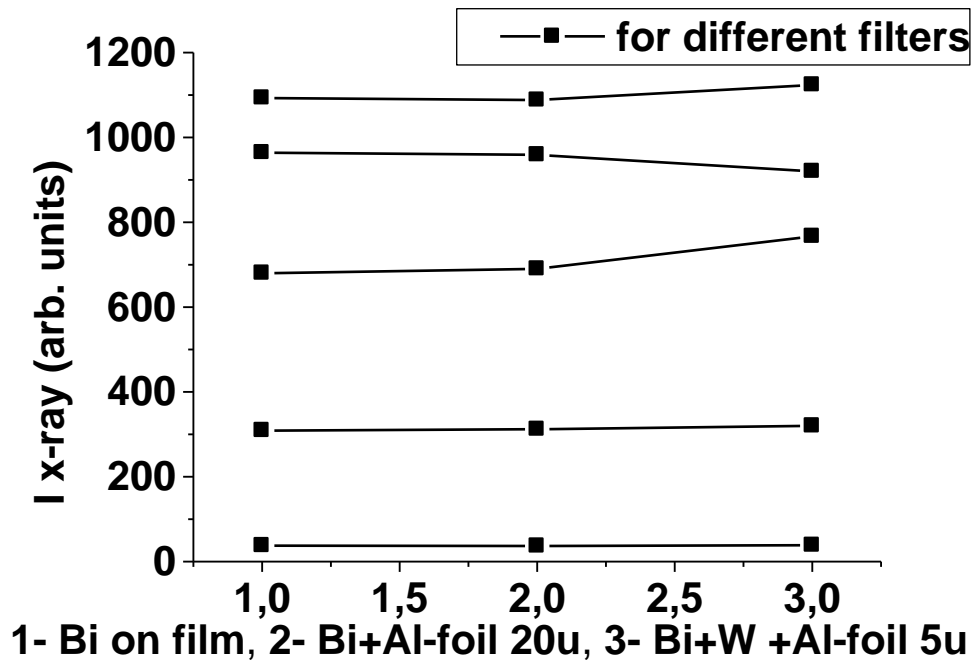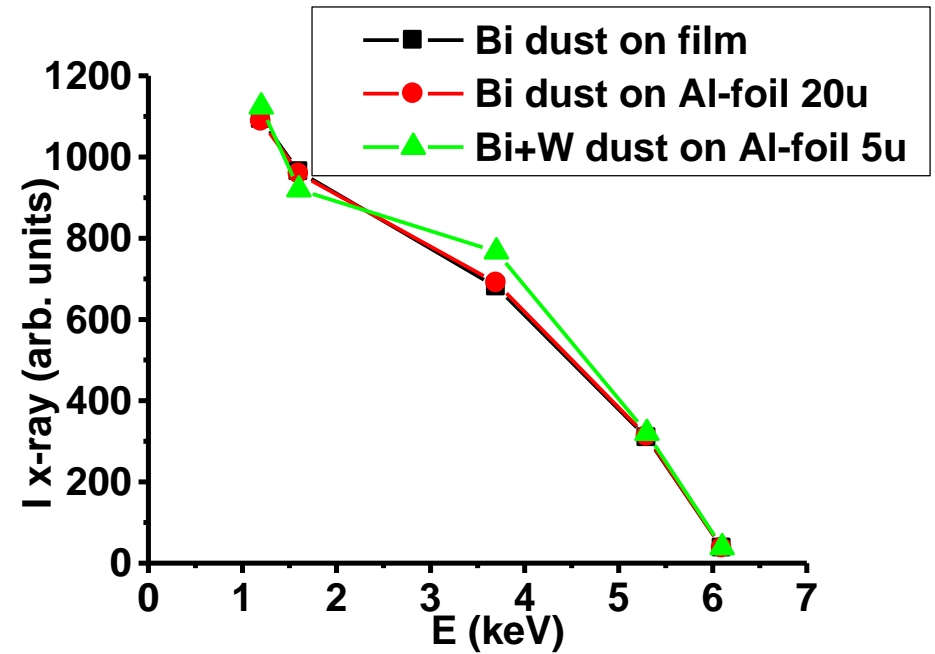SHOT RESULTS (TAC 2009)

RESULTS (TAC 2010)
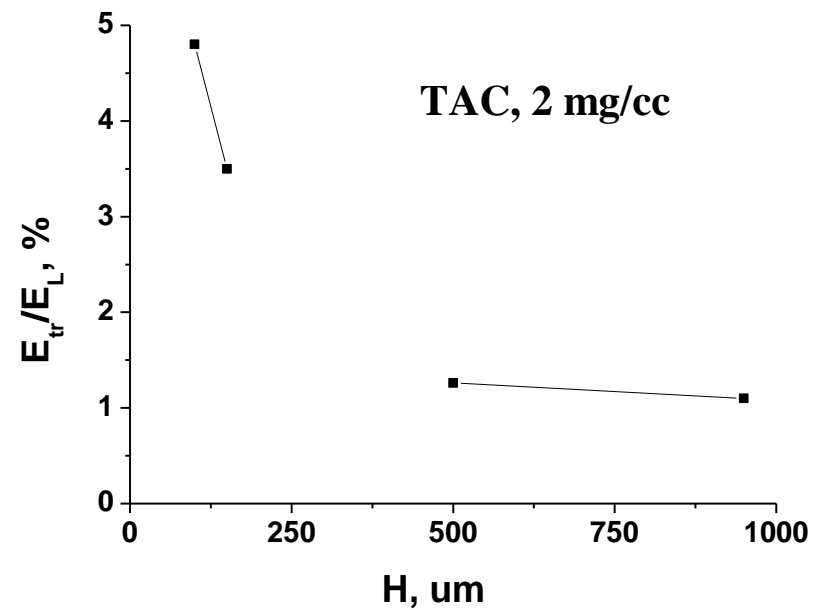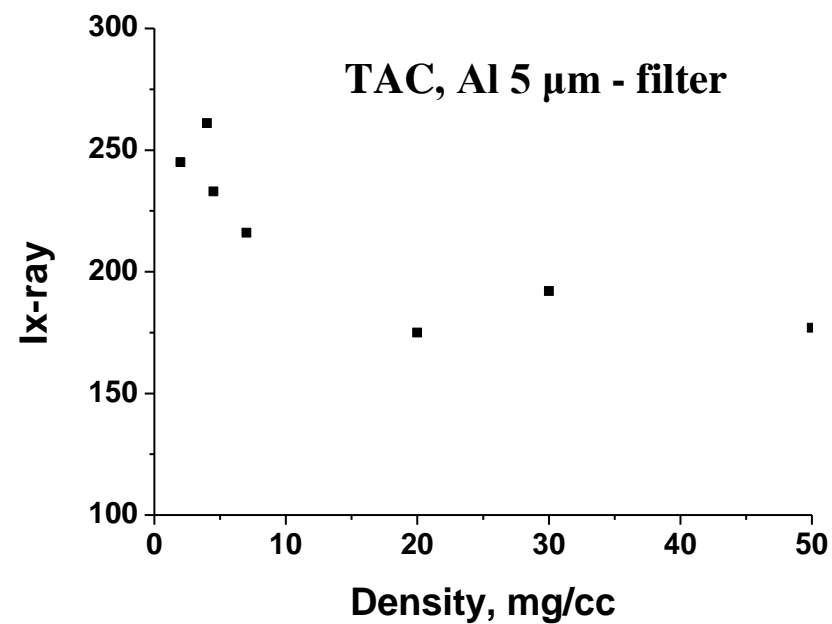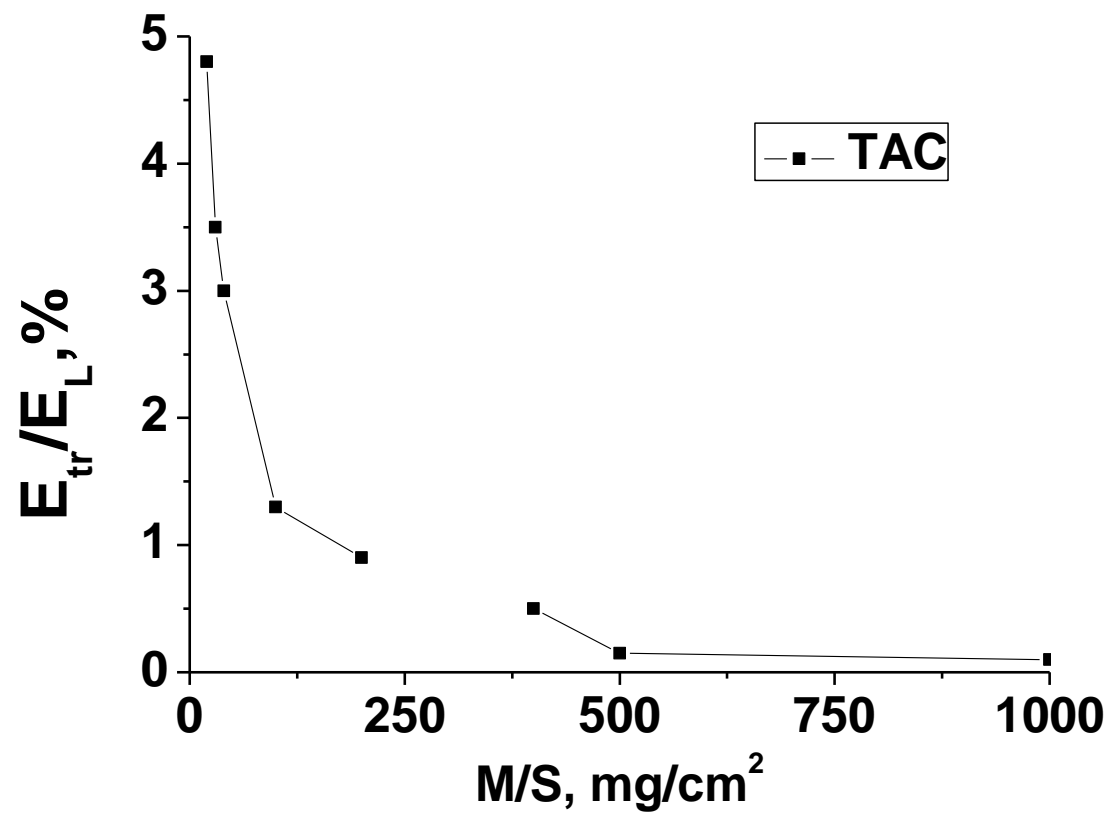
RESULTS (Bi-dust and Bi-metal)

X-ray emission intensity from various detectors dependent on Bi-dust substrates (results 2010).

X-ray emission intensity of Bi-dust on various substrates dependent on detector energy (results 2010).

In the two experimental series (2009 and January-July 2010) reported presently the total of 230 laser shots were done. The data was processed statistically. Each experimental point plotted is averaged over 3-4 to 10-12 laser shots. Results related to *Bi* are highly reliable statistically, there each point is averaged over 8 to 12 shots
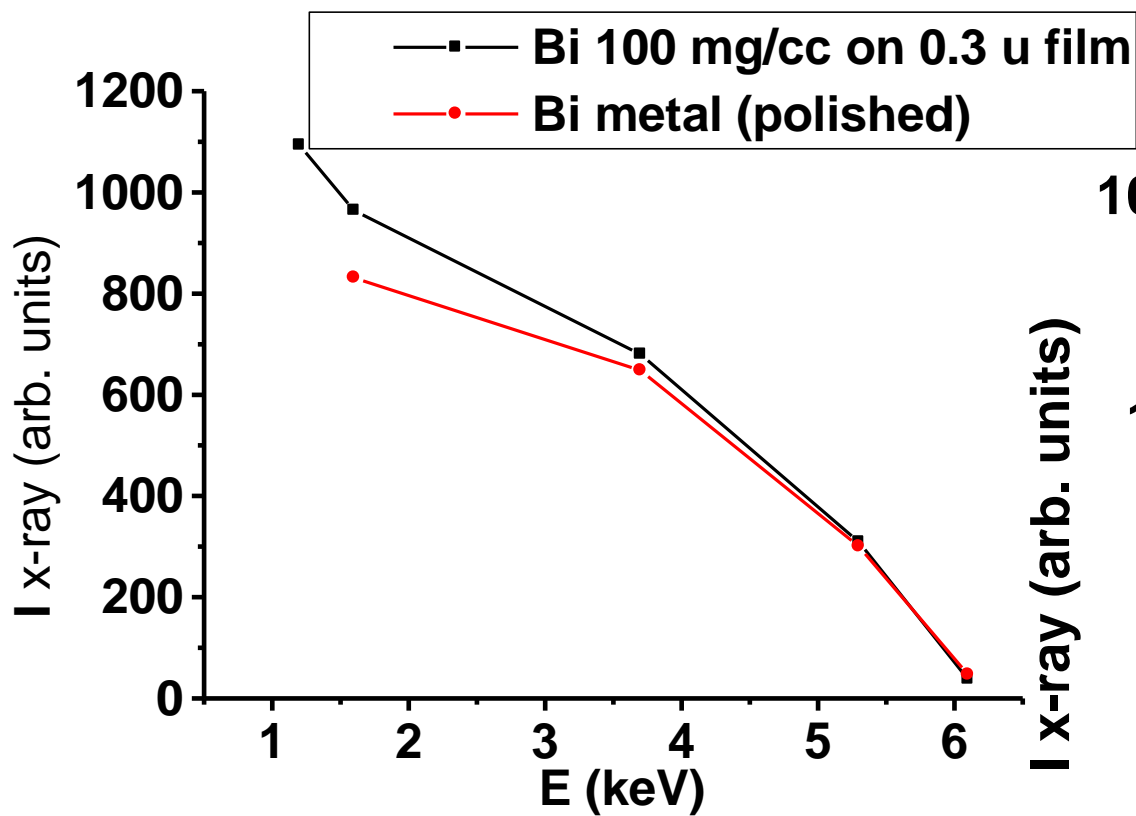
X-ray emission intensity of Bi-dust on polymer film and of Bi metal (polished) dependent on detector energy in ordinal scale and log scale.

SHADOWGRAPHY (TAC)

Al, 2 μm — 4.82 ns

TAC, 4mg/cc 100 μm — 2.92 ns

TAC, 2mg/cc, 100 μm, 2.92 ns

Al, 2 μm — 8.29 ns

TAC, 4mg/cc 100 μm — 6.39 ns

TAC, 2mg/cc, 100 μm, 6.39 ns

TAC, 2mg/cc, 100 μm, 2.92 ns

→

TAC, 2mg/cc, 100 μm, 6.39 ns
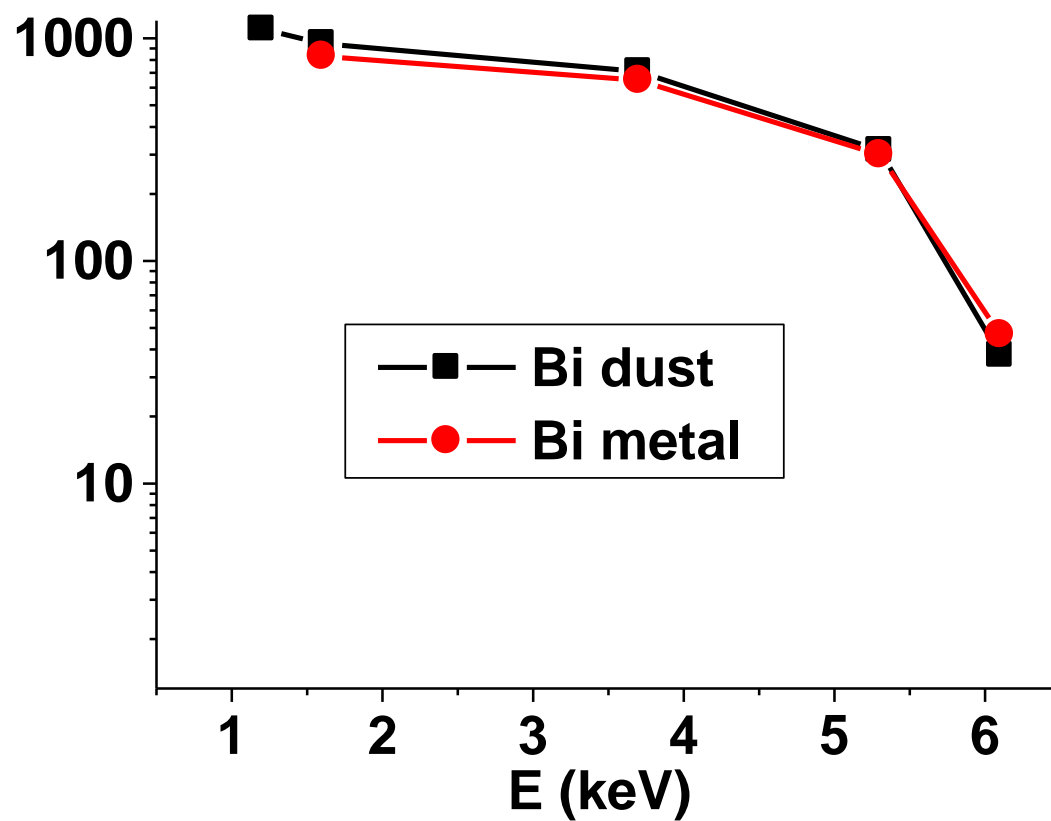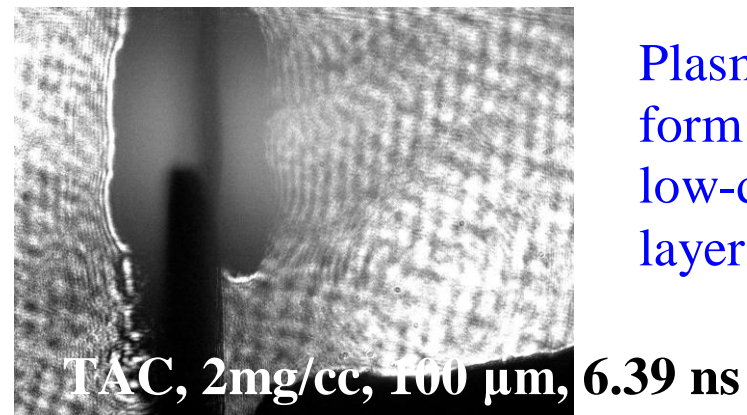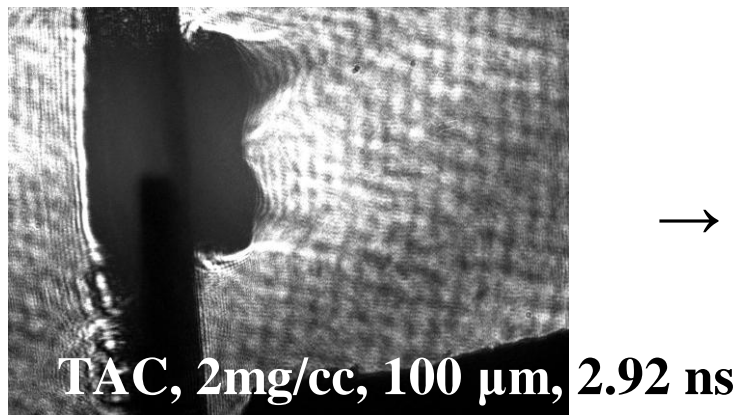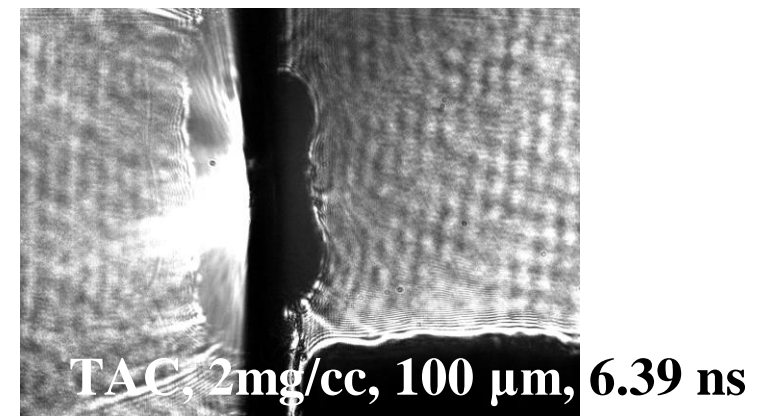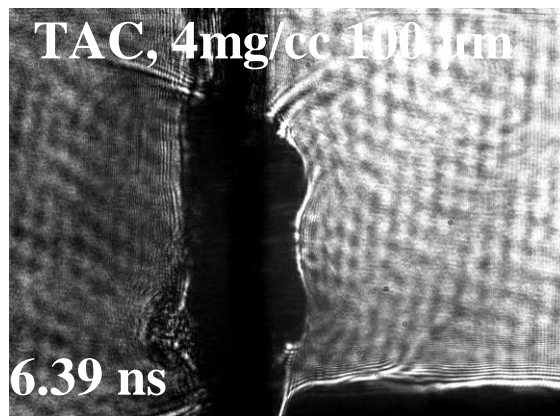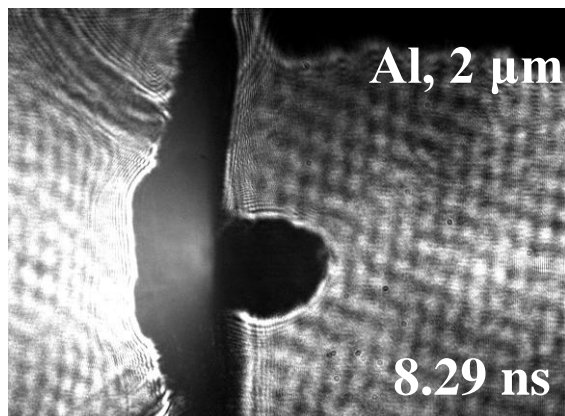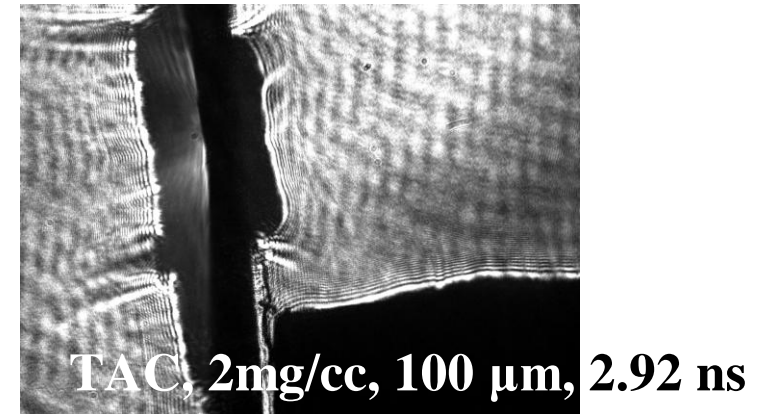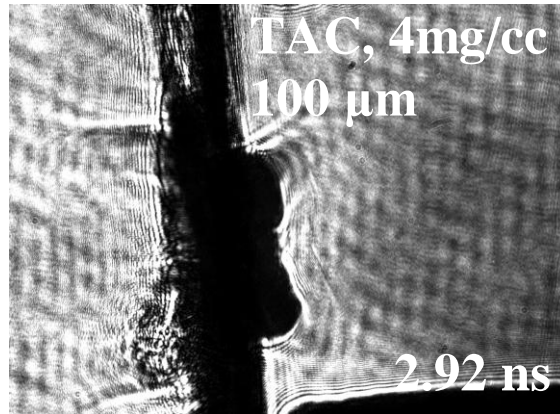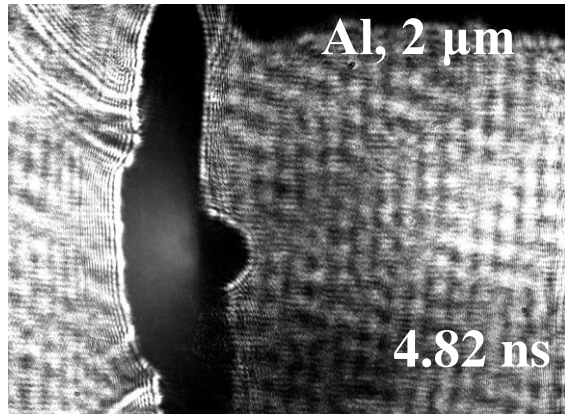
Plasma flow different form from Al-foil and low-density polymer layer

SHADOWGRAPHY (Bi dust and metal)
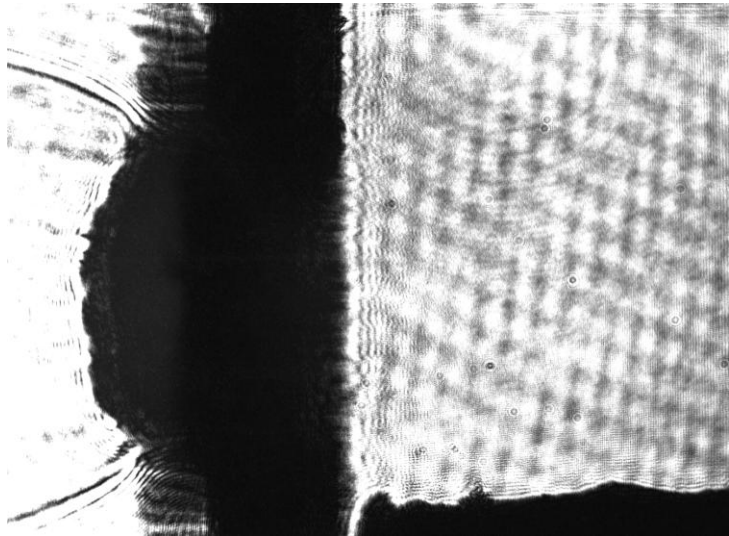
Bi-dust, 100mg/cc, 100 μm   Bi metal, polished   Bi metal, unpolished

Analyzing the published data we can state that our results are close to what can be expected, especially if to take into consideration the non-linear SRS and SBS. We think they contribute to the total measured radiation along the beam direction previously interpreted integrally as " transmission".

For backward scattering similar to the forward scattering the gain coefficients of SRS and SBS are both proportional to laser intensity on the target 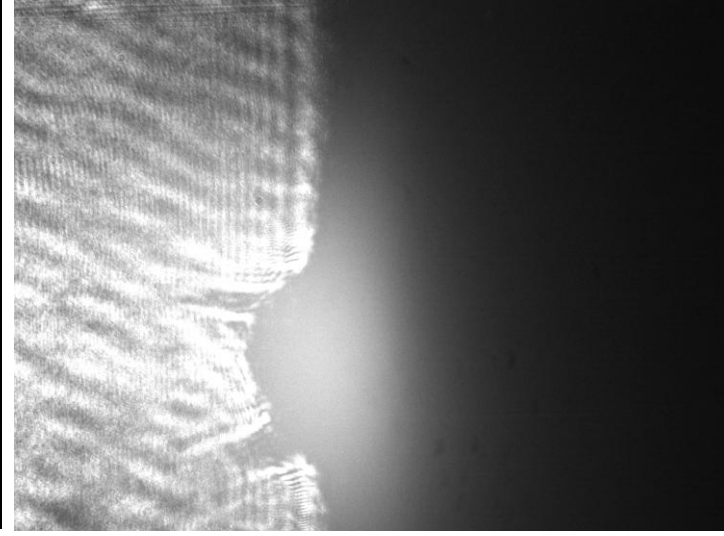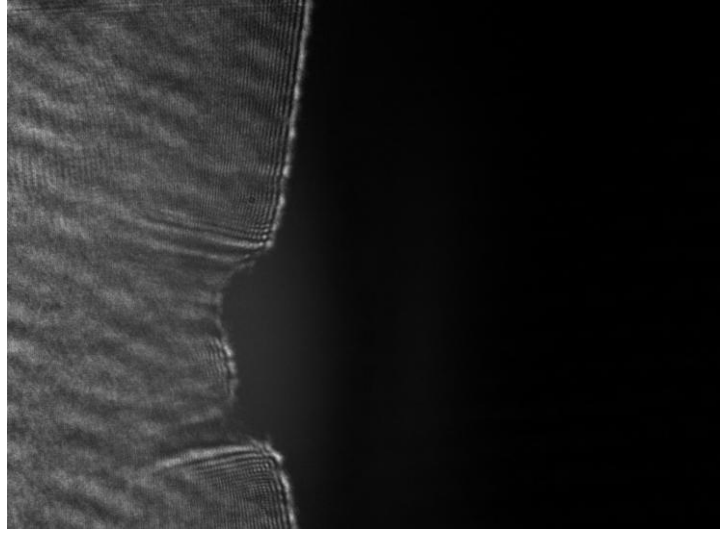(plasma) surface, are similarly dependant on wavelength and on electron plasma density related to the critical plasma density. But temperature dependence differs: $G_{SRS} \sim T_e^{3/2}$, but $G_{SBS} \sim 1/T_e$. Here T_e is **electron** plasma temperature.

Only for thin, less than 0.1 mm layers of target the result is higher than expected by a factor of 2-2.5. This can be attributed to the fact that in the course of the laser pulse duration all the aerogel layer is transformed into undercritical plasma which his transparent to essential part of laser radiation.

CONCLUSION plastic aerogel

Several interesting results were obtained in the experiments on laser beam interaction with various low-density nanostructured targets, laser radiation flux being $\approx 10^{14}$ W/cm^2 and pulse duration 0.5 ns.
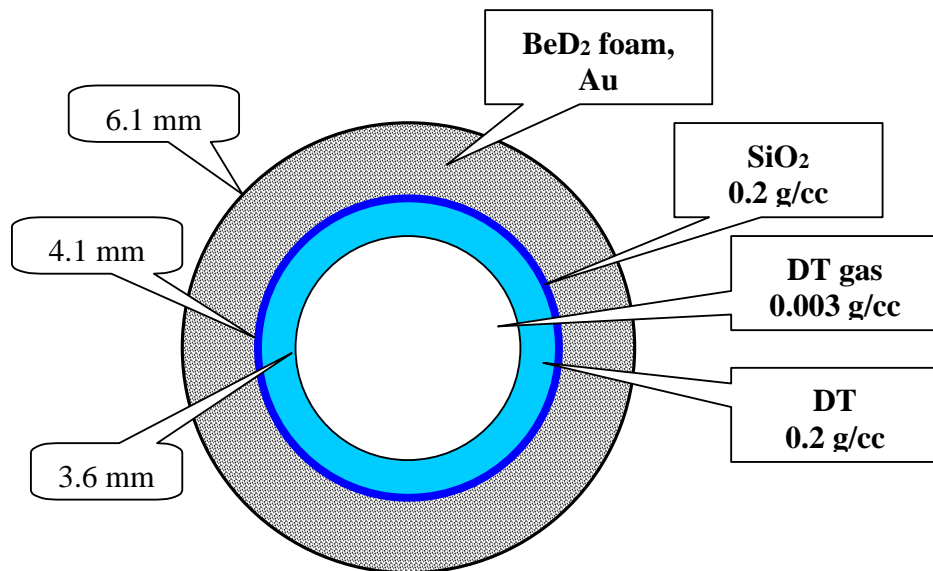
1. The dependencies of reflection, scattering and transmission for the laser light in plasma via the initial density, when target is a special polymer network formed by fibers less than 0.1 micron thick. Reflection is slightly dependent of density, backscattering relative to the incident beam and transmission especially are quite sensitive to plasma density, especially in the region which produces critical or under-critical electron concentration being fully ionized. Higher laser light transmission through the near-critical and under-critical plasma is connected after [8,9] with plasma turbulence slow relaxation. The influence is far more pronounced when part of the polymer is substituted by the copper nanoparticles of 50-100 nm size.

2. The x-ray spectrum emitted from plasma born from the 3-D polymer network of a single-layer target is almost independent of polymer density and of polymer thickness. In the 2-layer target (polymer+*Al*-foil) the spectrum comes out softer. Adding the *Cu*-nanoparticles results in harder x-ray spectrum.

3. Intensity of plasma x-ray emission from polymer aerogel targets weakens across higher density and thicker polymer layer. It could be due to rapid plasma cooling at its movement inside the cooler matter.

4. Shadowgrams for plasma movement from the thick (or dense) polymer network layer (without *Al*-foil from the backside) are double-peak with central valley instead of bell-like shape.

CONCLUSION metal foam

The comparative experiments with plastic aerogels and with metal targets show the difference in plasma behaviour both from solid metal target and from low-density metal layer of nanoparticles approximately 100 mg/cc.

1. The technology routes of metal low-density layers are realized for *Cu, Sn, Sn-and-Mo, Bi, and Bi+W.*
2. The x-ray spectra emitted by plasma of low-density *Bi* are more intensive in the soft part than those of the polished solid metal.Thin *Bi* layer is also quite strong emitter.
3. The intensity of plasma x-ray emission from low density *Bi* is 10-15% higher than that from solid polished *Bi*.
4. The plasma x-ray emission intensity from low-density Bi drops across the layer thickness growth. The effect is similar when at the same polymer layer an Al-foil is used on its rear side
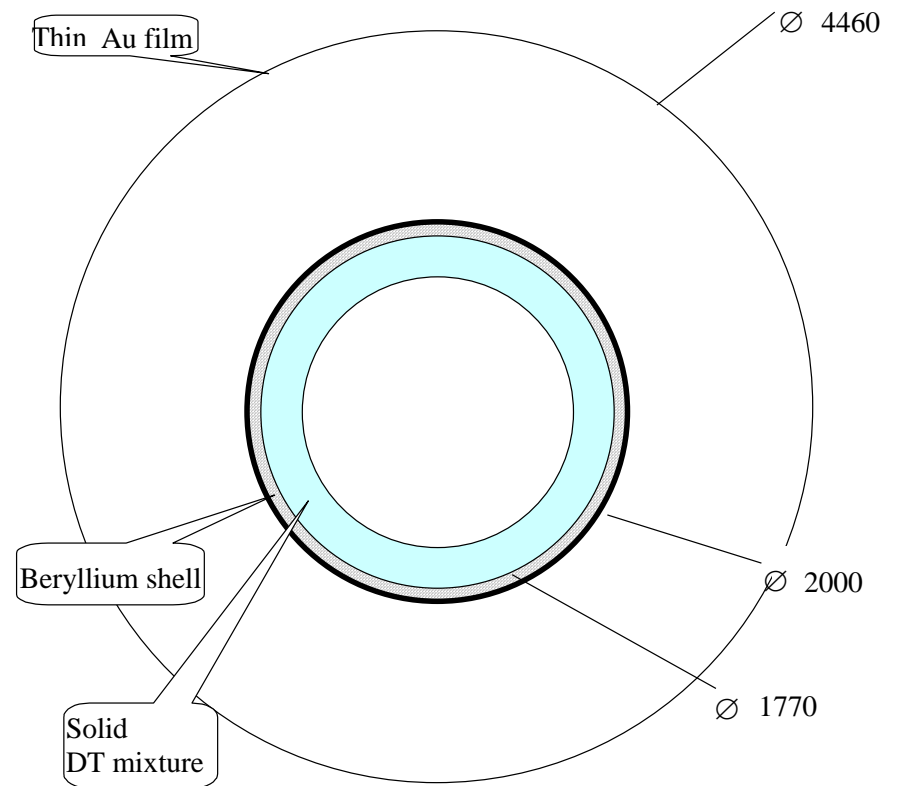
Direct-indirect targets

Left diagram labels:
- BeD$_2$ foam, Au
- SiO$_2$ 0.2 g/cc
- DT gas 0.003 g/cc
- DT 0.2 g/cc
- 6.1 mm
- 4.1 mm
- 3.6 mm

New NIF-scale laser target design with low-density BeD$_2$ (Au) or Be(Au) layer (absorber-converter to x-ray). Left numbers are diameters.

Yu.A.Merkuliev Low density high-Z layer for indirect target converters. Report on China-Russia seminar. May 1993, Chengdu, China.

S.Y.Guskov & Yu.A.Merkuliev. Low density x-ray converter. Quantum electronics (Russian). 2001, pp. 311-318/

Right diagram labels:
- Thin Au film
- Beryllium shell
- Solid DT mixture
- ∅ 4460
- ∅ 2000
- ∅ 1770

Eliezer E., Honrubia J., Velarde G. Direct-indirect target for NIF. Phys. Let., A, 166, 249-252, 1995.

Au-converter thickness is 0.25 µm

Thanks for attention!