EMMI Workshop on Plasma Physics with Intense Ion and Laser beams

Moscow, 14-15 May 2009

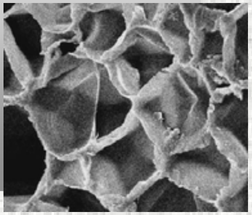
Olga Rosmej,
Plasma Physics, GSI

Nanostructures irradiated by ns and ps PHELIX-laser pulses

Stopping of heavy ions in dense plasma

production of the plasma target for heavy ion interaction using *direct* and *indirect heated low Z foam*

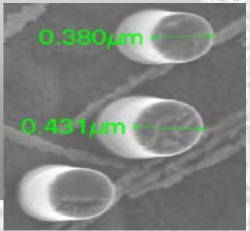
UNILAC(linear accelerator) – area:
PHELIX: E~300J, τ =1-20 ns, I ~ 10^{15} W/cm^2, contrast 10^{-5}



Monochromatic backlighting for HED - experiments

effective generation of Kα-radiation in *high Z nanostructured* targets

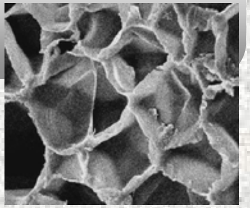
PHELIX-Laser bay :
PHELIX: E= 0.1 -100J, τ ~ 0.7-10 ps, I ~ 10^{16} -10^{19} W/cm^2



Collaborators

- GSI Helmholtzzentrum für Schwerionenforschung
- VNIIEF, Sarov, Russia
- Joint Institute of High Temperature, Moscow, Russia
- Institute Lasers et Plasmas, Bordeaux , France
- Kurchatov Research Center, Moscow, Russia
- Lebedev Physical Institute, Moscow, Russia
- Lawrence Livermore National Laboratory, US
- Institute of Modern Physics, Lanzhou, China

Advantages of nanostructures irradiated with laser beams



- Near 100% laser light absorption
- Smoothing of the laser intensity distribution after propagation in foams
- Higher conversion of laser energy in to the plasma temperature compared to the solid foils
- The last results into the higher ionization degree of the laser produced plasma
- Supersonic ionization mechanism at undercritical target densities
- Slow hydrodynamics of expansion – long living plasma sack

foam structures can be produced with a big variety of properties adjusted to the experimental needs:

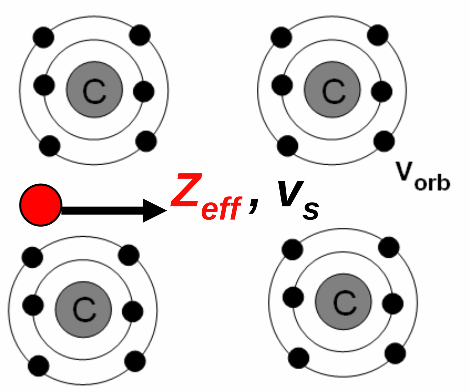
mean densities down to 1/1000 of the solid density.

•withstand temperatures up to 200-600 C keeping the nano- and microstructure

•can be produced with random or regular structures.

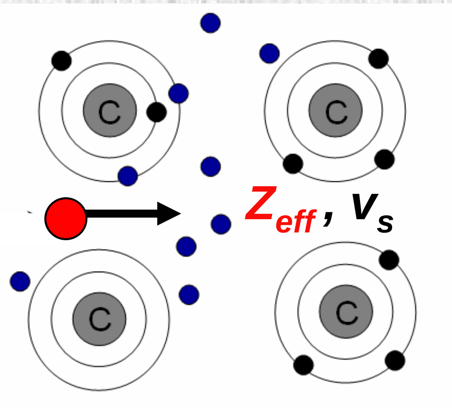
Heavy ion stopping in ionized matter

Heavy ion interaction with laser produced plasma:



Increased energy transfer from the projectile ion to free plasma electrons

Higher projectile ion charge in plasma



Projectile energy loss in partially ionized matter

$$-\frac{dE_S}{dz} = \frac{16\pi a_0^2 I_H^2 Z_{eff}^2}{m_e v_S^2}\left[\underbrace{\sum_{Z=0}^{Z_K}(Z_K - Z)\, n_Z \ln\left(\frac{2m_e v_S^2}{I_Z}\right)}_{\text{bound electrons}} + \underbrace{n_e \ln\left(\frac{2m_e v_S^2}{\hbar\omega_p}\right)}_{\text{free electrons}}\right]$$

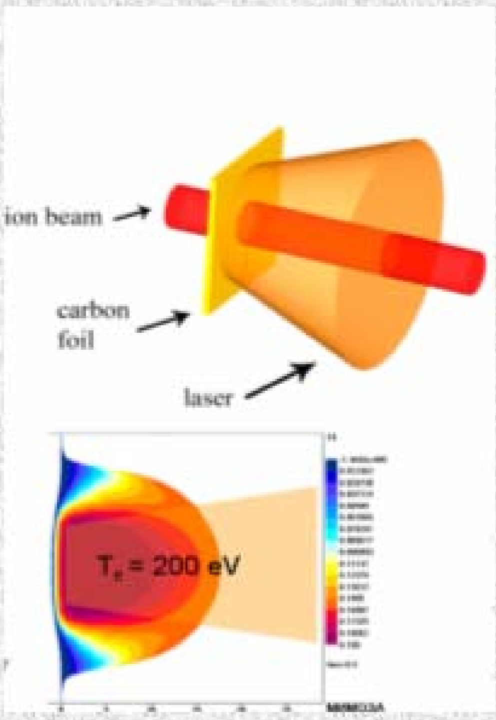
ion stopping in plasma is an important issue e.g. for fast ignition concept

Schemes of the plasma target production

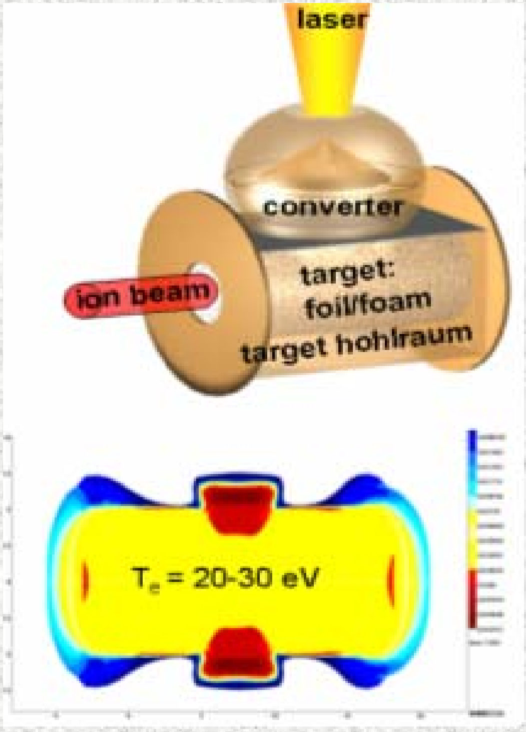
Heating with hohlraum radiation

Direct laser heating

Ideal plasma:
Te~ 200 eV, fully ionized

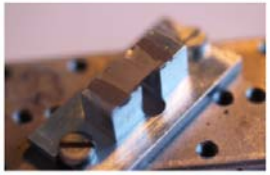


homogeneous plasma:
Te~ 20 eV, partially ionized



Target variety

direct heating

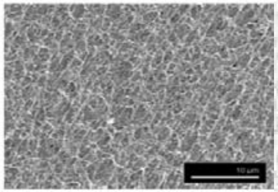


thin C - foil

cryogenic H/D

indirect heating

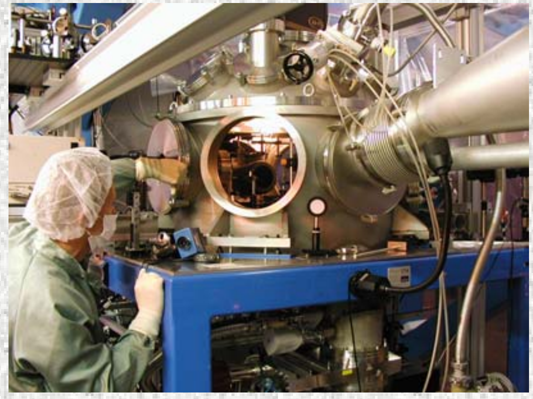
gold hohlraum



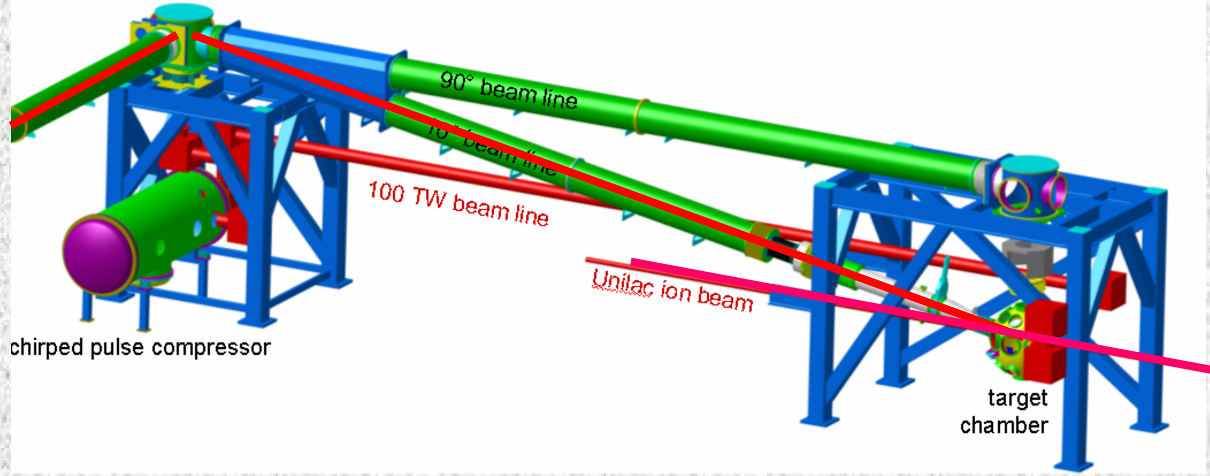
CHO-foams

Laser – Heavy Ion Beam Combined Experiments

Target chamber



PHELIX-laser : 0.5 kJ @ 1-15 ns, 2ω (2010)



Heavy ion beam:
3<Z<92, E=3–13 MeV/u,
RF: 108/36 MHz

Currently: 10° beam line: directly laser driven plasma → energy loss in ideal plasma
2010: 90° beam line: Hohlraum radiation driven plasma → energy loss in non-ideal plasma

Diagnostic methods and instruments

Heavy ion beam :

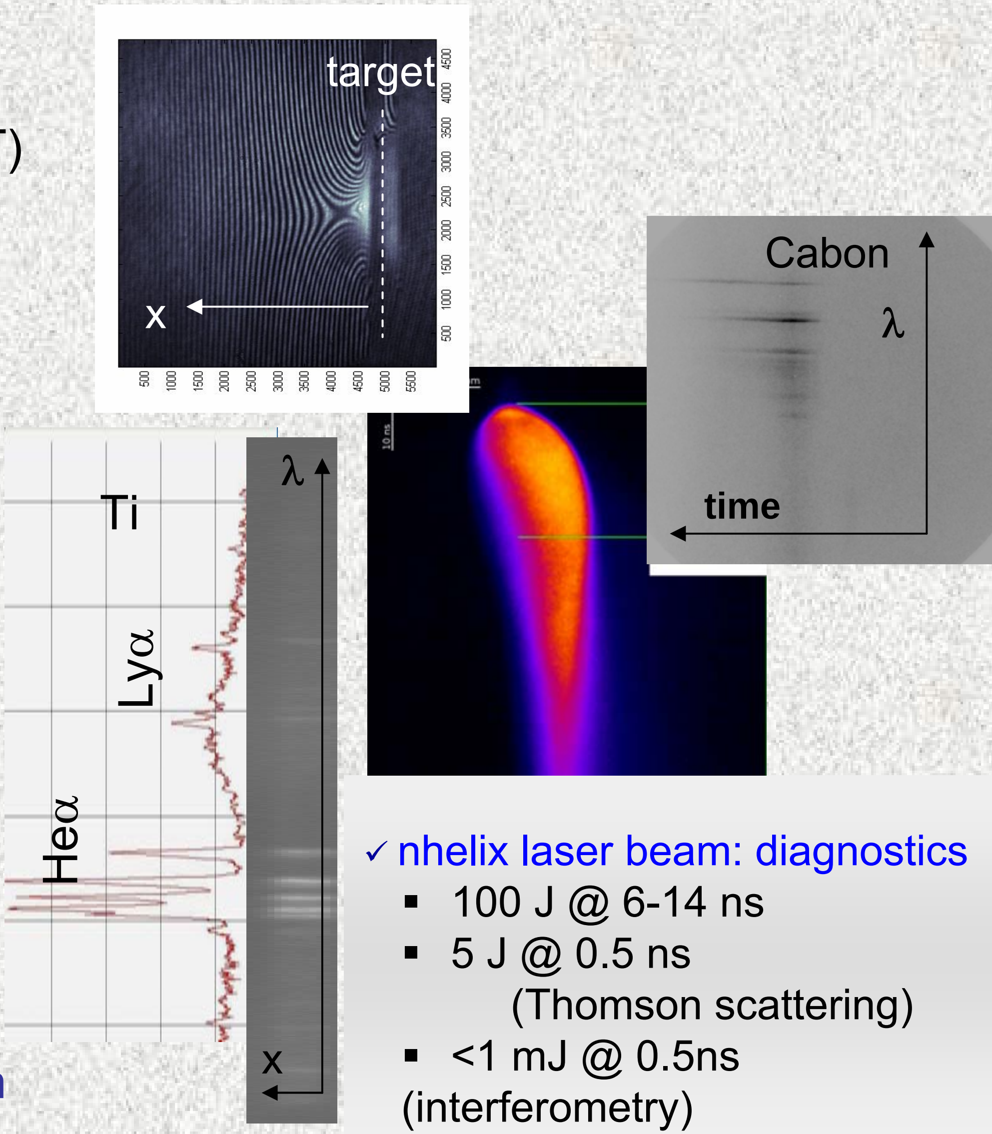
ion energy measurements (TOF)
charge state distribution (Dipole, 1.8 T)

Plasma diagnostics :

laser interferometry →
electron density distribution
X-ray streak →
plasma parameters Te(t), ne(t)
visible streak camera →
plasma expansion velocity, Te
VUV, XUV, X-ray spectrometers→
Te, ne, ionization degree

Laser diagnostics:

calorimeter → total energy
diodes → temporal laser profile
CCD camera → laser spatial distribution



✓ nhelix laser beam: diagnostics

- 100 J @ 6-14 ns
- 5 J @ 0.5 ns (Thomson scattering)
- <1 mJ @ 0.5ns (interferometry)

Problems of the direct laser irradiation:

- 1mm laser spot (1-D expansion) at the target is formed by the phase plate, resulting in strongly inhomogeneous distribution of the laser intensity

- direct irradiation of foils provides fast expending plasma target with strong gradients of plasma parameters

HOMOGENEOUS and CONSTANT parameters of the high density plasma target over 3 ns – the length of the ion bunch

Goal of the project:

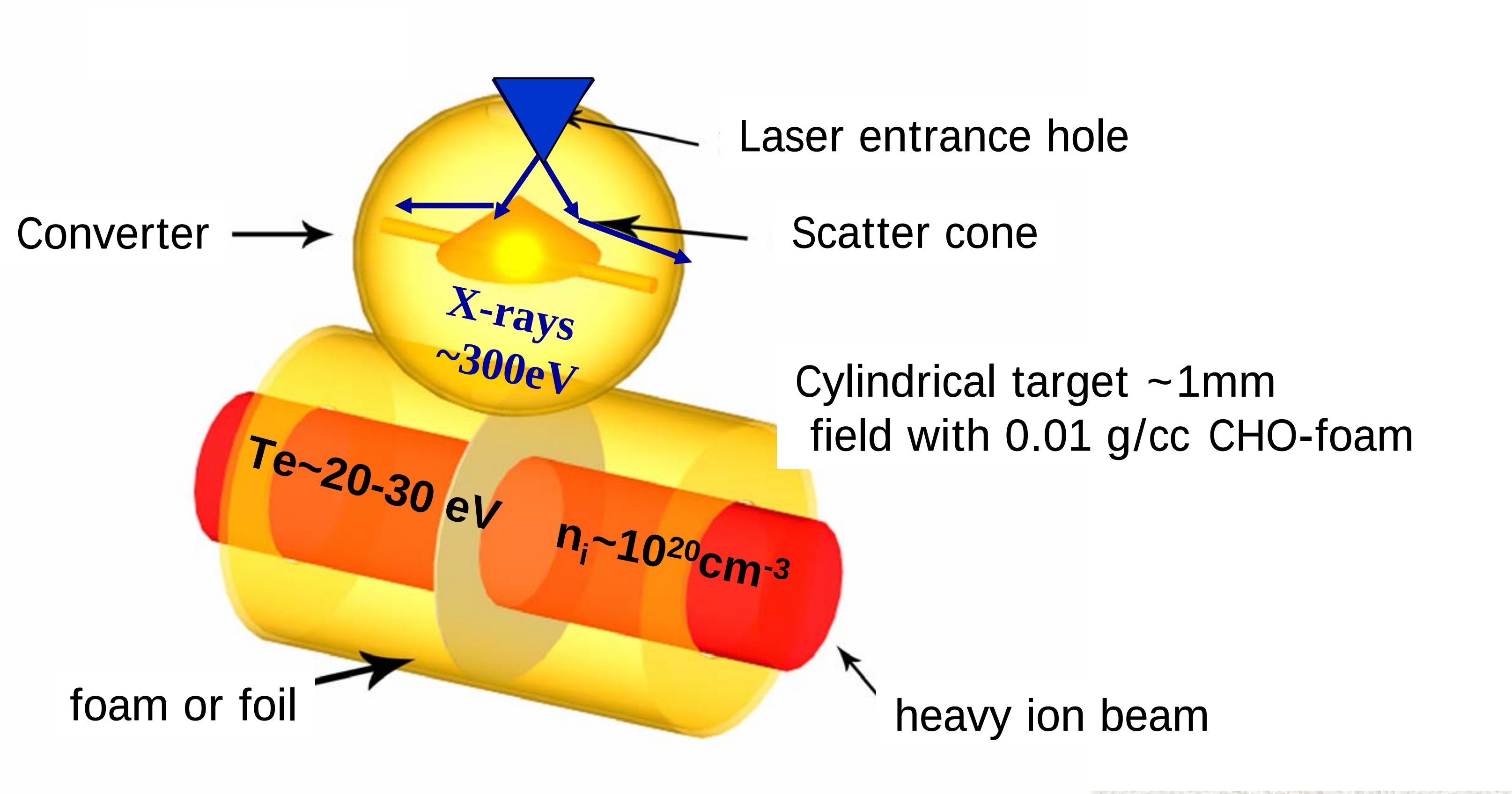
creation of homogeneous long leaving (~ 3 ns) fully or partially ionized plasma of 10^{20}-10^{21} electron density

Approaches:

- Indirect heating using hohlraum radiation
- Direct heating of the low Z foams with undercritical density

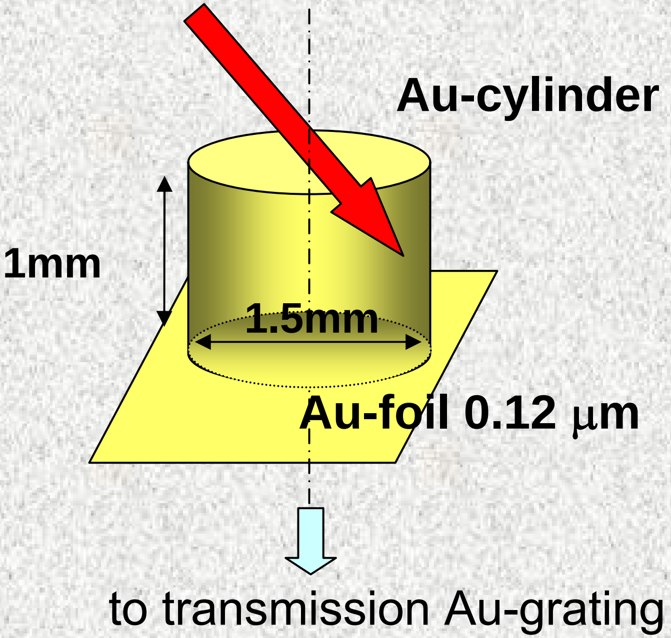
Indirect heating using hohlraum scheme

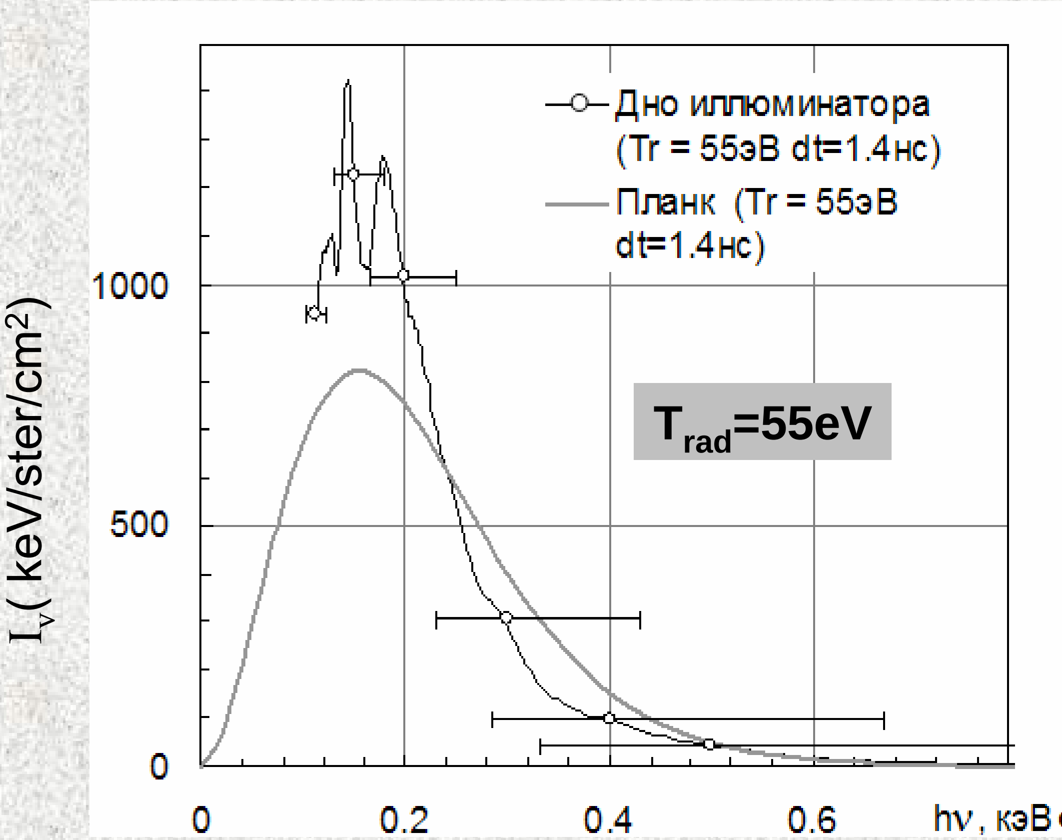
PHELIX: 0.3kJ, 1-3 ns - homogeneous plasma



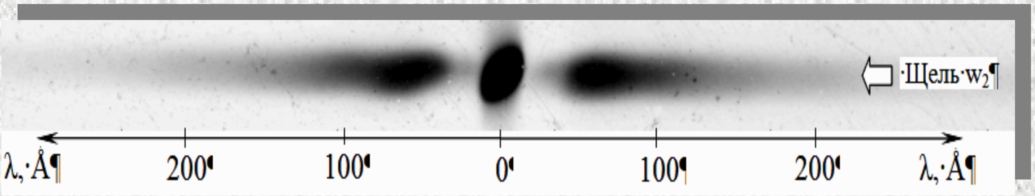
Radiative Temperature of Au-Converter

PHELIX: 250J
1.4 ns, d=200μm
λ=1.056 μm





T_{rad}=55eV



VNIIEF, Sarov
N. Suslov, A. Kunin, N. Zhidkov

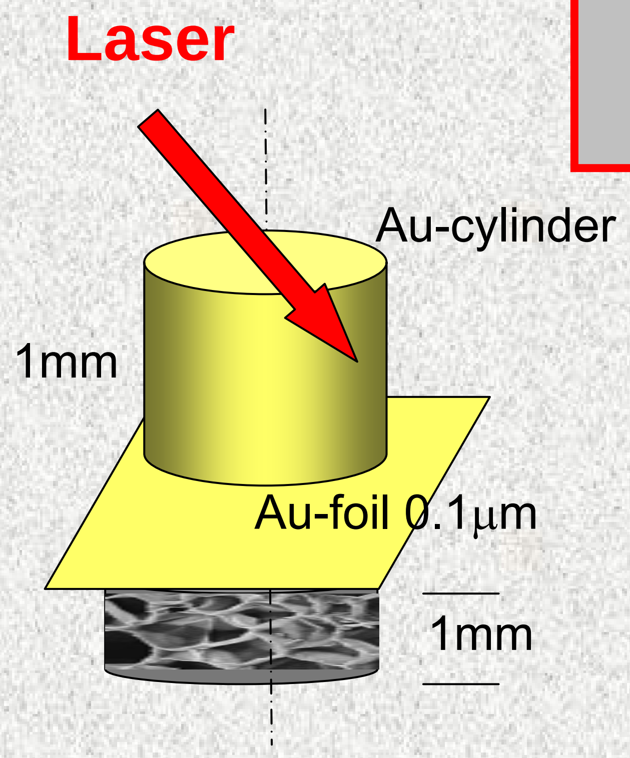
Electron temperature of CHO-foam

PHELIX: 2008

250J; λ**=1.053μm**
$\tau = 1-10$ ns, **d=200μm**

PHELIX: 2010

250J; λ**=0.53 μm**
τ= 1-10 ns, **d=50μm**



CHO-foam 3 mg/cm^3

T_{rad} ~ 55 eV

↓

σT^4~ 10^{12} W/cm^2

↓

T_{foam} ~ 10 eV

T_{rad} ~ 100 eV

↓

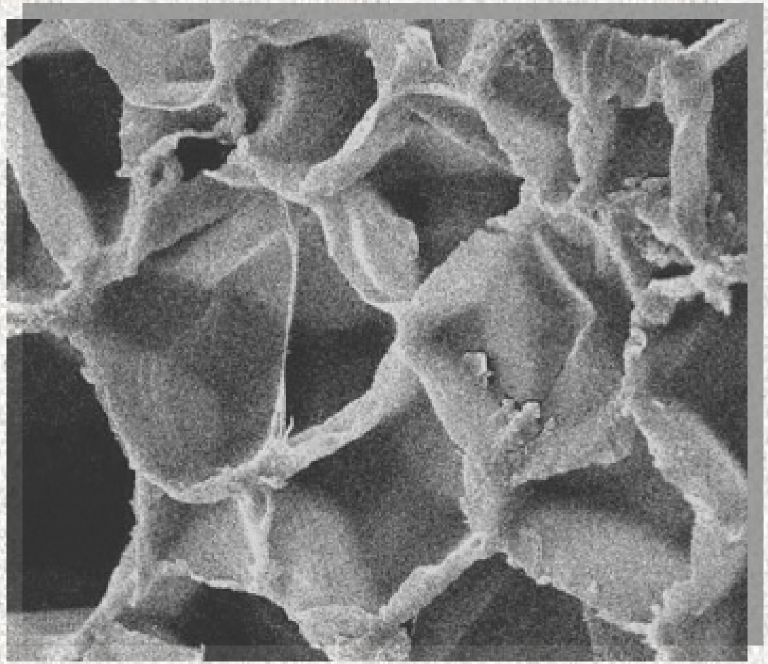
σT^4~ 2 10^{13} W/cm^2

↓

T_{foam} ~ 40-50eV

Experimental proposal P014 September 2009

Direct irradiation of foam targets



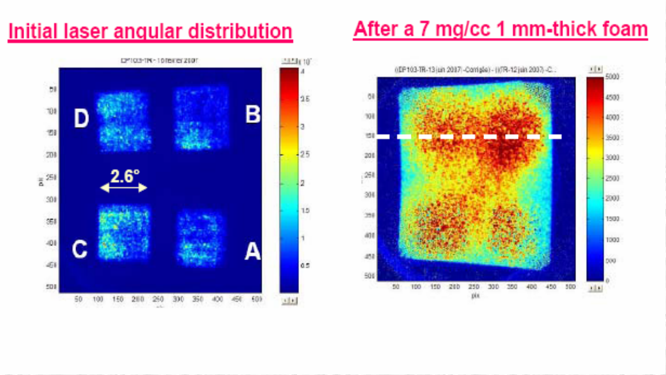
Creation of a long leaving plasma sack

Advantages of foam targets for laser-matter interaction

- **Smoothing of LL intensity distribution at the target**

  M. Dunne et al (PRL 1995)-foam buffer (TRINITI-agar-agar – 1997;

  LIL-TAC-2007:10kJ, 2.7 ns, 3w)

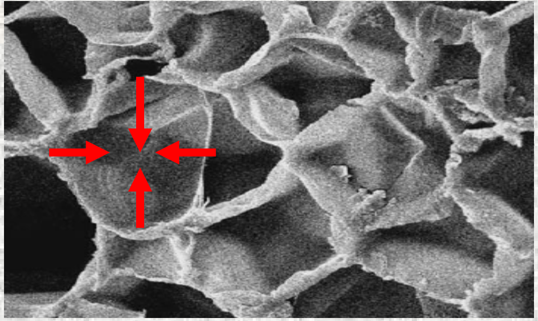


- **High efficiency of the LL conversion in plasma temperature**

  (TRINITI, “Mishen”- increased Ti)

  foils –expansion in to the vacuum

  Foams -expansion in to the pore



- **Supersonic ionization of foams with undercritical density**

  (PALS, LIL)- heating/ionization are faster than expansion

  ionization front velocity in TAC foam irradiated at 10^{14} Wcm^{-2} v~ 1mm/ns

$$mv_i^2 \Rightarrow T_i \Rightarrow T_e$$

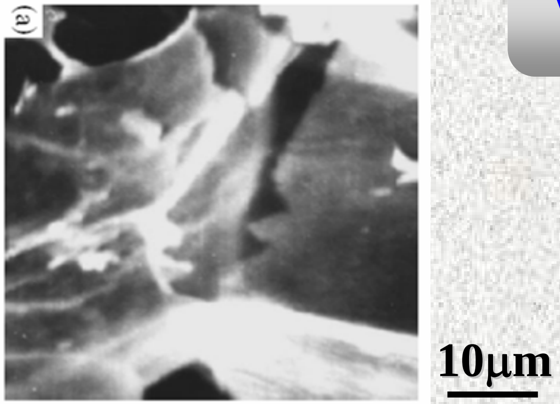
Supersonic ionization

for $\lambda_{las}=1\mu m$ $n_e < 1.e21$ cm-^{3}

TAC($C_6O_8H_{12}$): $\rho_c < 3 mg/cm^3$

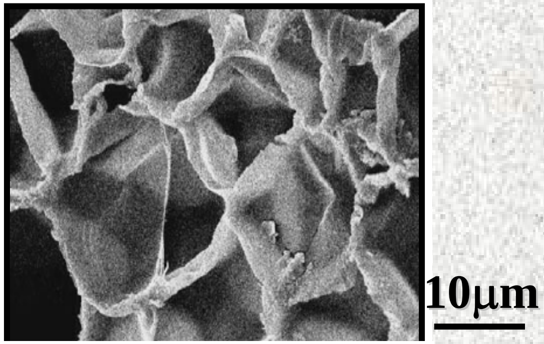
N. Borisenko, LPI

Variety of low Z foam structures



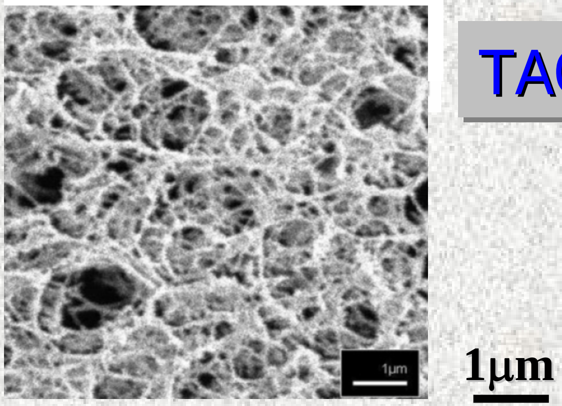
$C_8H_8O_3$ foam (agar-agar) of 1-20 mg/cm^3

Randomly distributed thin fibers
TRINITI, Mishen, VNIIEF-Sarov Iskra 5



Polystyrene $(CH)_n$ 1-20 mg/cm^3

Quasi regular sponge like structure (3D network)
TRINITI, Mishen

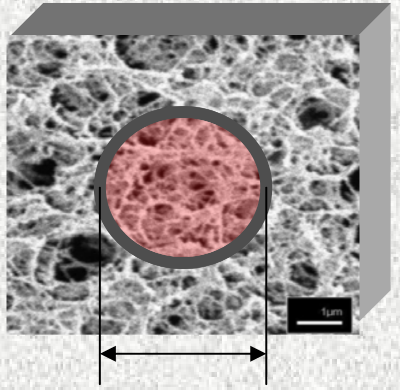


TAC - cellulose triacetate $C_{12}H_{16}O_8$ 1-30 mg/cm^3

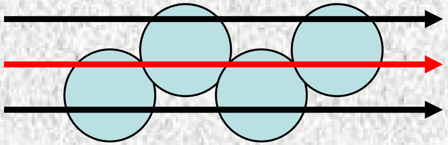
3-D regular network with open cell structure,
The most fine pore structure (~ 1mm)remains
stable up to 220C
PALS, LIL, GSI

Influence of target porosity on the heavy ion energy broadening

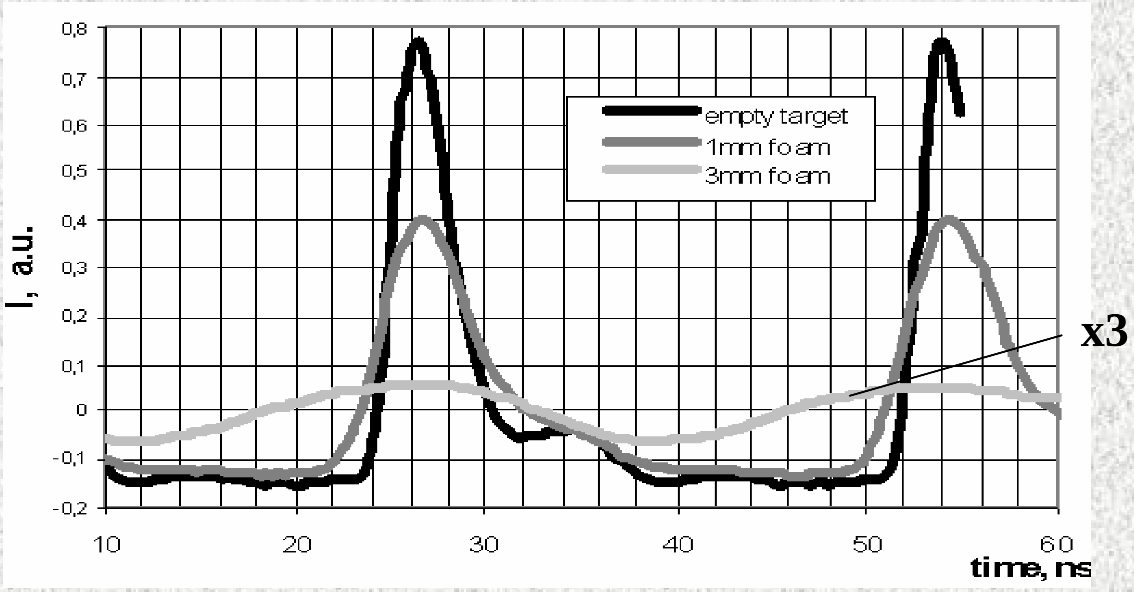
large pore size (agar-agar up to 50 mm)-
different areal density is viewed by ions (0.5- 1mm spot)-
different energy loss- broadening of the ion energy
spectrum – merging of the ion pulsed structure!



Ion beam spot~ 500μm



Agar-agar: ~50 mm
Polystyrene: ~10 mm
TAC: ~ 1mm



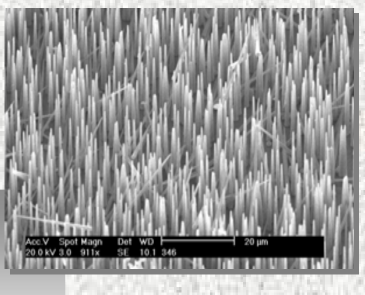
5.9 MeV/u Ar ions energy spectrum after interaction with agar-agar foams of 1 and 3 mm thickness time-off-flight technique with base 4.822 m and 1.196 m

LASERLAB EUROPE

Proposal gsi-phelix001384

“Characterisation of X-Ray Production by Ultra-Intense Picosecond Laserpulses in Nanostructured Targets”

GSI Helmholtzzentrum für Schwerionenforschung GmbH
Institut Lasers et Plasmas, Bordeaux , France
Kurchatov Research Center, Moscow, Russia
Joint Institute of High Temperature, Moscow, Russia
Lawrence Livermore National Laboratory
Institute of Modern Physics, Lanzhou,China



experimental and theoretical study of the
laser interaction with
high Z nanostructures
for the generation of energetic x-ray pulses.

Main Goal: application for HED experiments

Effective production of energetic photons with energies above 20- 30 keV for monochromatic backlighting of mm^3 large high Z targets (Al – Pb) heated by heavy ion beams

Candidates : Ag (21 keV), Sm (38 keV), W(57 keV)

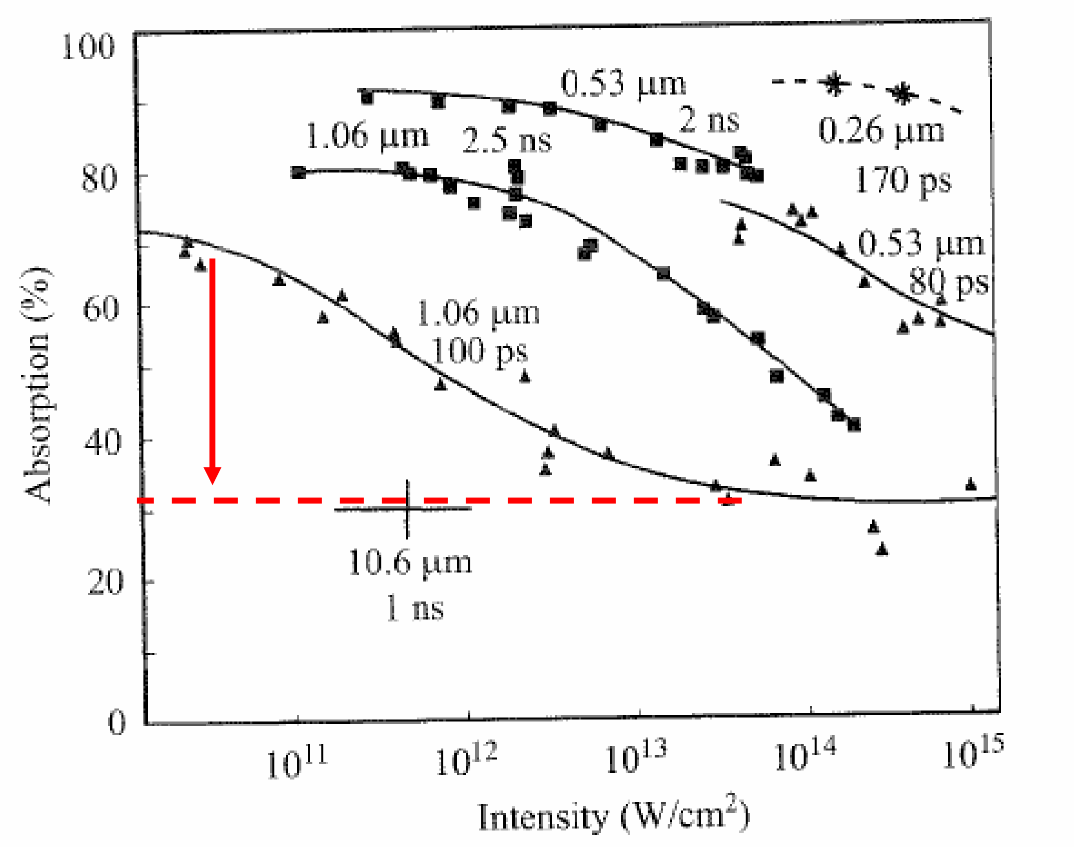
He$_\alpha$, Ly$_\alpha$ generation is not possible (PHELIX)

Effective K$_\alpha$ generation by hot electrons with $T_{hot} \sim 3E_{Ka}$

- maximum cross-section for K-shell ionization by the electron impact

$T_{hot} \sim$ 60-200 keV

Improvement of the laser energy absorption at high intensities



Low absorption of the laser energy at λ=1 μ: 30%
τ=100ps I =10^{14} Wcm^{-2}

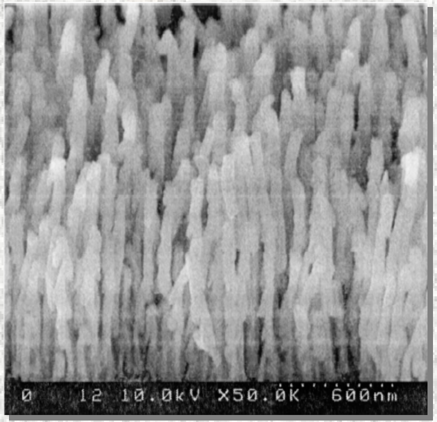
S. Atzeni, J. Meyer-ter-vehn
The Physics of Inertial Fusion

Nanostructures provide near 100% of LL-absorption even at high intensities

Near 100% absorption leads to the increase of soft X-ray yeld

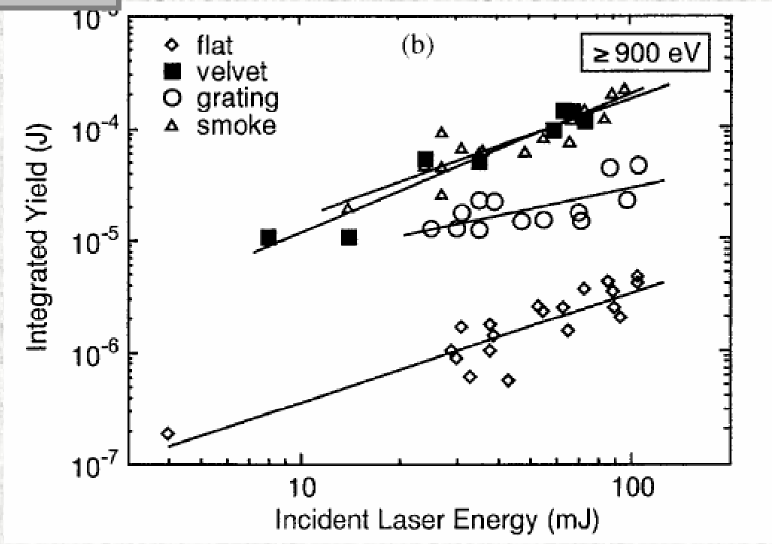
Physical Review Letters , V.84, N. 22, 2000

Ni nanowires 70 nm



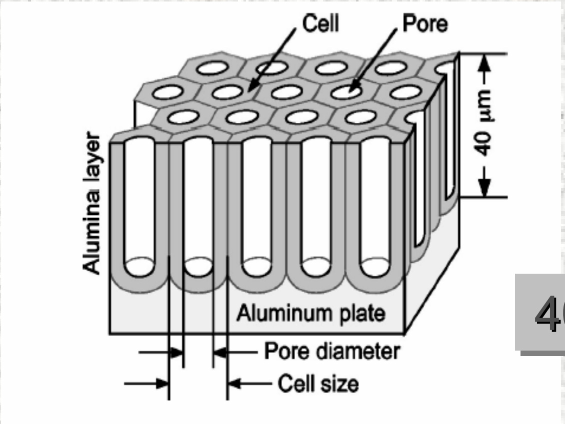
Laser: Nd-glass
1.054 μm, 1 ps,
10^{17} W/cm^2, 10^{10}

50 fold enhancement
hν> 900eV



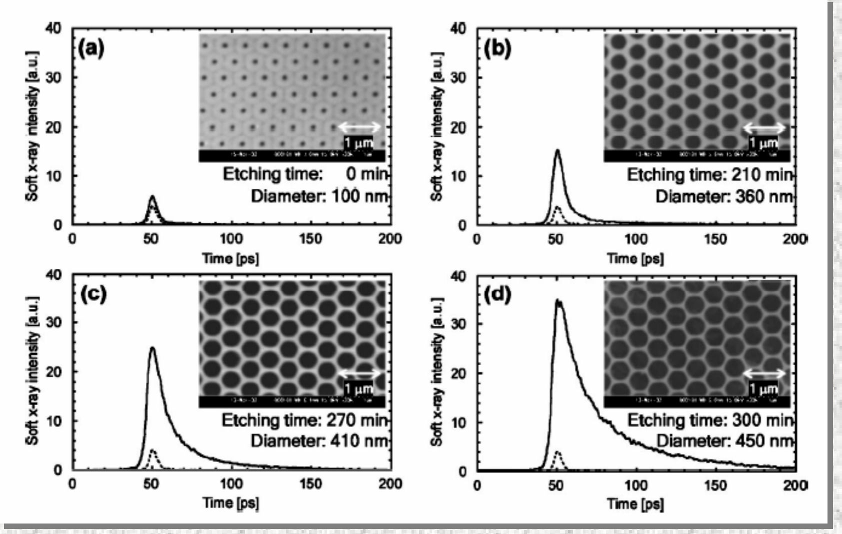
JOURNAL OF APPLIED PHYSICS VOLUME 96, NUMBER 12 15 DECEMBER 2004

Al nanohole-array



Laser: 790nm,
100fs, 10 Hz,
10^{14} W/cm^2, 10^6

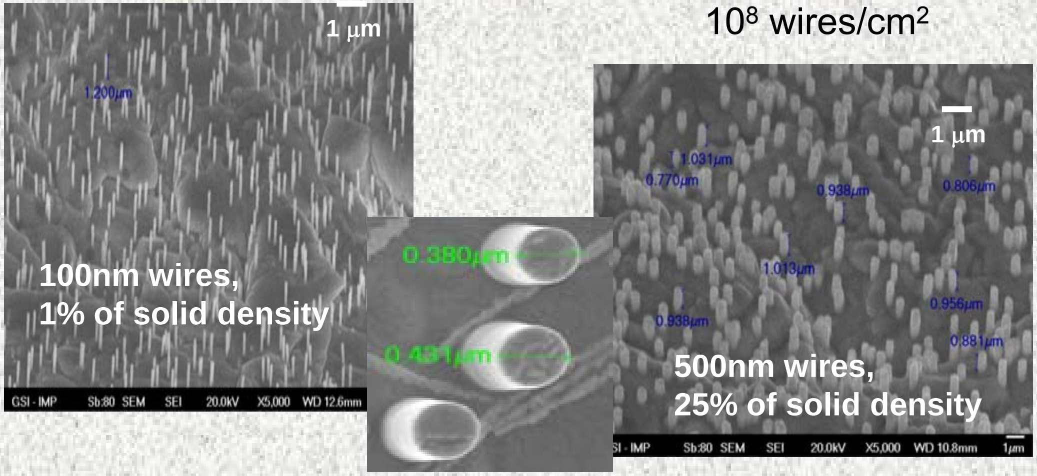
40 fold 0.05-1.5 keV



Cu-target variations

Cu-nano-hairs on the 15 μm Cu layer

Institute of Modern Physics, Langhou:J. Duan, J. Liu, Y. Zhao



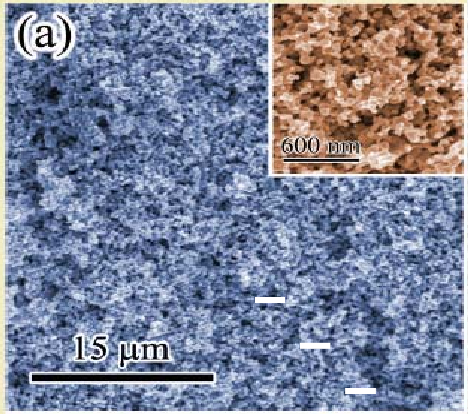
10^8 wires/cm^2

100nm wires,
1% of solid density

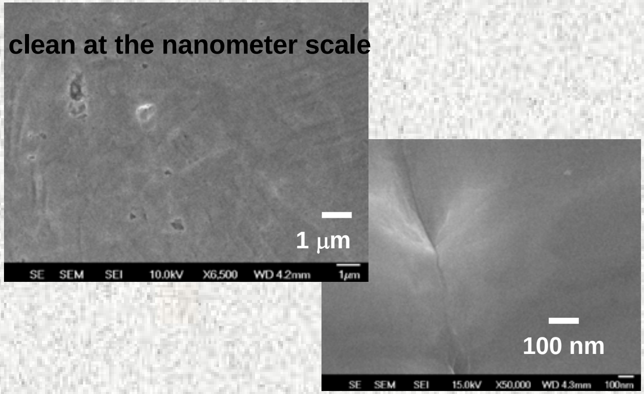
500nm wires,
25% of solid density

7% porous Cu casting-filter method

LLNL, US, A. Hamza,

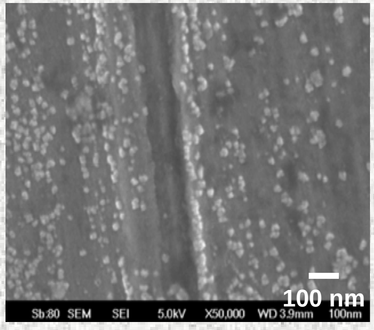


Etched Cu foils (clean surface)

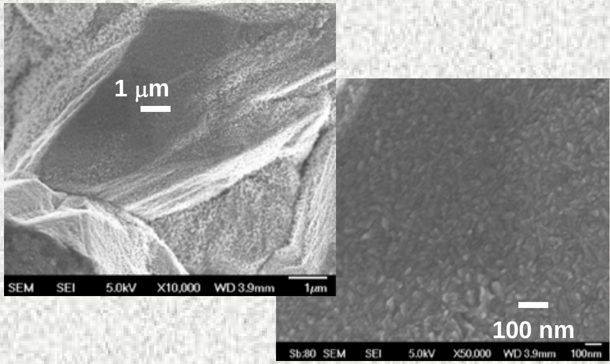


clean at the nanometer scale

Good-fellow quality Cu foils



“old” Cu foils covered with crystalline



Last remarks:

Laser contrast – crucial issue! Currently – 10^{-6}
After contrast improvement (plasma mirror) 10^{-9}-10^{-10}

First results at GSI – Report by E. Kazakov 15.05, 14.40

Thank you for your attantion!

EMMI

IPCP RAS

ITEP Moscow

GSI

JIHT RAS