Laser plasma interaction in nano-particle copper targets

S. Chaurasia[1], D. S. Munda[1], Nitish Kumar[2] , N. Kulkarni*, P. Ayyub[3], N. K. Gupta, L. J. Dhareshwar[1]

1. ***Laser & Neutron Physics Section, Physics Group, Bhabha Atomic research Centre, Mumbai,***

2. Cochin University of Science and Technology, Cochin, Kerala.

3. ***Department of condensed matter physics, Tata Institute of Fundamental Research, Mumbai.***

e-mail –shibu@apsara.barc.gov.in

- Theme of our work on Laser plasma Interaction has been to study several target designs involving composite as well as mixtures of materials of varying density and target structuring over these past few years (Au-Cu alloy, High Z doped polymers, Cu,Au coated with nanop- crystalline particle layers etc.)

- Effect of various laser parameters such as laser wavelength, intensity, pulse duration, different spatial and temporal shapes etc on laser-target coupling has also been studied extensively to achieve maximum x ray conversion efficiency and ion emission.

- A mixed metallic alloy of Au-Cu was observed to yield higher x ray conversion efficiency* and also the ion dynamics were studied**.

* X ray and ion measurements in laser produced plasma from gold-copper alloy targets *S. Chaurasia, D. S. Munda, C. G. Murali, N. K. Gupta and L. J. Dhareshwar, Accepted for publication-J. Appl.Phy.*

** Ion dynamics in laser produced plasmas from mixed high Z targets, *S.Chaurasia*, L. J. Dhareshwar and N.K. Gupta, accepted for publication- Radiation Effects and defects in solids.*

Introduction :

Interaction of intense lasers with nano-particles and clusters has become a subject of intensive study in the recent times. Significant enhancement in soft and hard X-ray emission has been reported by several authors in targets with structured surfaces. Significant enhancement in laser light coupling in plasmas created from copper nano-particle targets using 100-2000 fsec laser pulses at 806nm at intensity 10^{15} to 10^{16} W/cm^2 has been reported.

Extremely energetic (MeV) and highly stripped ions have been produced by Intense laser interaction in noble gas clusters.

Free standing Metal clusters(Ag,Pt) have been also used to generate highly charged and energetic ions. Nano particles embedded within host matrix (glass)

Motivation for our work

What happens at long laser pulse durations- Sub nanosecond (300-800psec), memory of initial laser pulse absorption by nano-particles retained?

What is the difference between free-standing metal clusters and layer of nano particles on bulk material?

Dependence of Laser absorption in nano-particle layers on laser parameters (Energy, pulse duration, polarization, wavelength etc).

In our experiments reported here, we have compared-

solid polished copper targets having a 1μm and 3μm thick layer of copper nano-crystalline particles of about 15nm size with plain polished copper targets.

1. **Ion emission from plasmas-** Ion flux, Ion energy, Ion velocity etc.
2. **X-ray emission in various spectrum range namely soft x-ray (B10 filter > 0.7 keV), harder x-ray (Ti Filter 3.2 to 4.96 keV) and hard x-ray (Ni filter 4.6 to 8.3 keV)**
3. **Effect of Laser field polarization on x-ray and ion emission.**

Experiments

12 J / 500 ps Nd:glass laser operated at

- **Energy-2Joules.**
- **Pulse duration- 300-500 psec.**
- **Intensity-10^{13} -10^{14}W/cm^2**

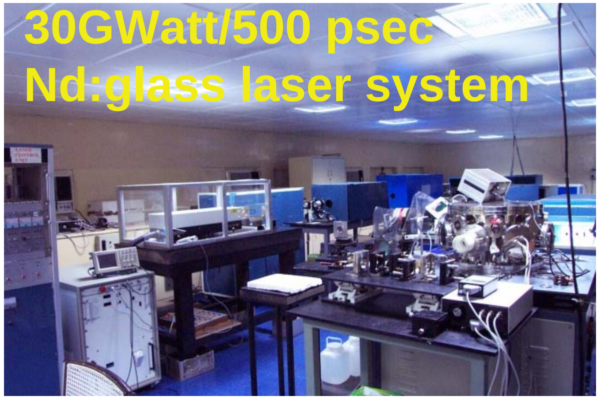
Targets-

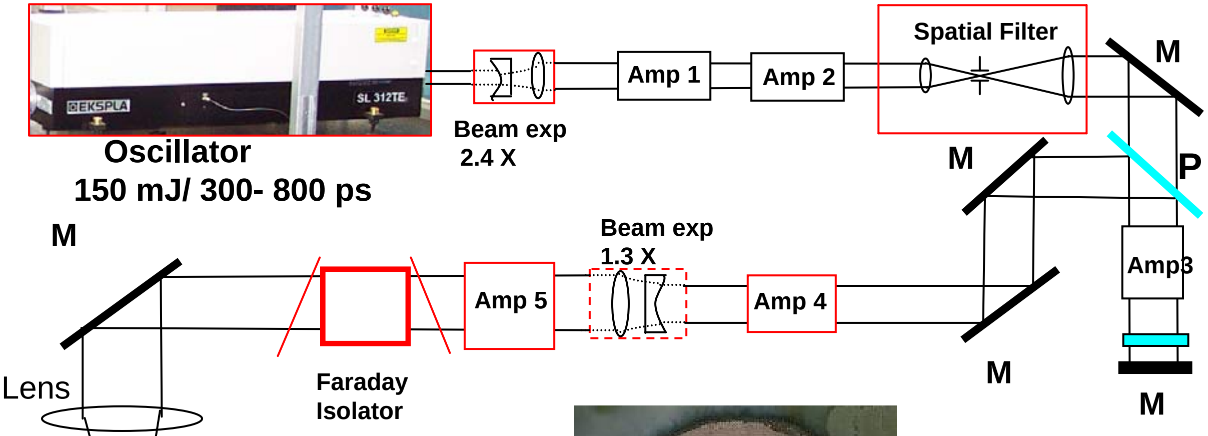
- **Polished copper solid target,**
- **1 µm, 3µm thick coating of copper nano-particles of 15nm size on top of solid target.**

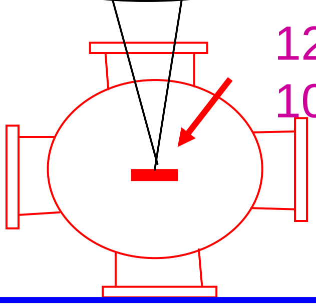
Diagnostics-

1. **Langmuir probe array**
2. **Faraday cup ion collectors**
3. **X-ray semiconductor detector cover with 12 µm titanium (3.2 to 4.96 keV) and 5 µm nickel filter (4.6 to 8.32 keV).**
4. **X-ray vacuum photodiode cover with B10 filter (> 0.7 keV)**

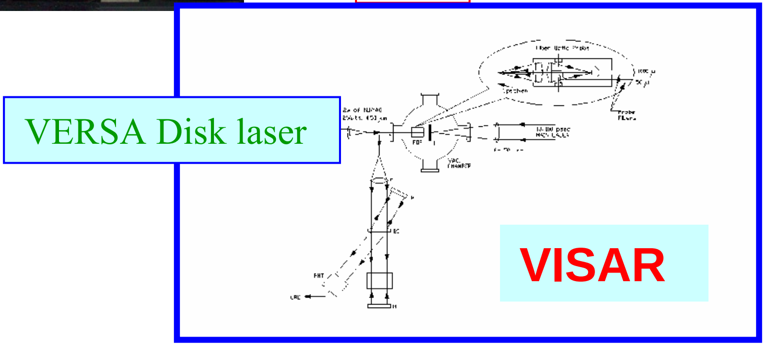
Picosecond laser laboratory


30GWatt/500 psec
Nd:glass laser system





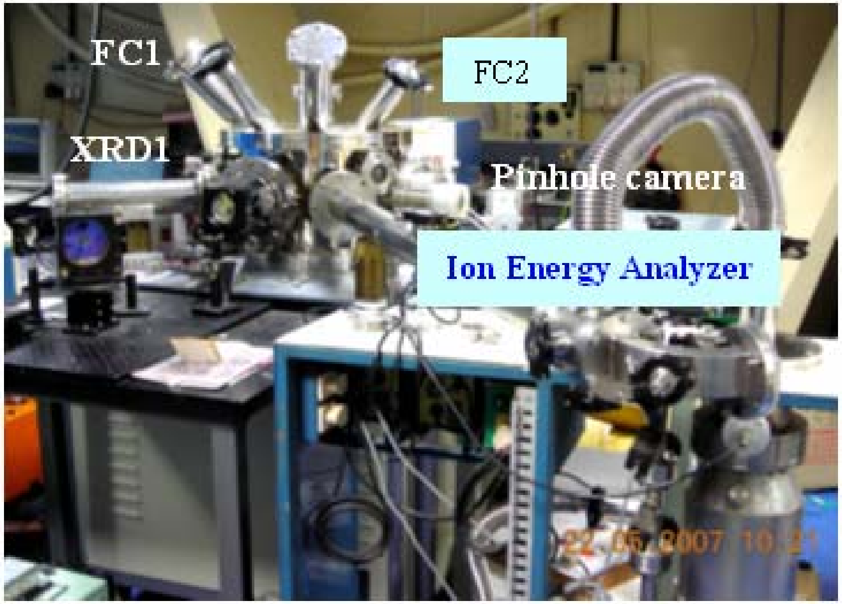
12Joule/500ps
10^{14} W/cm^2

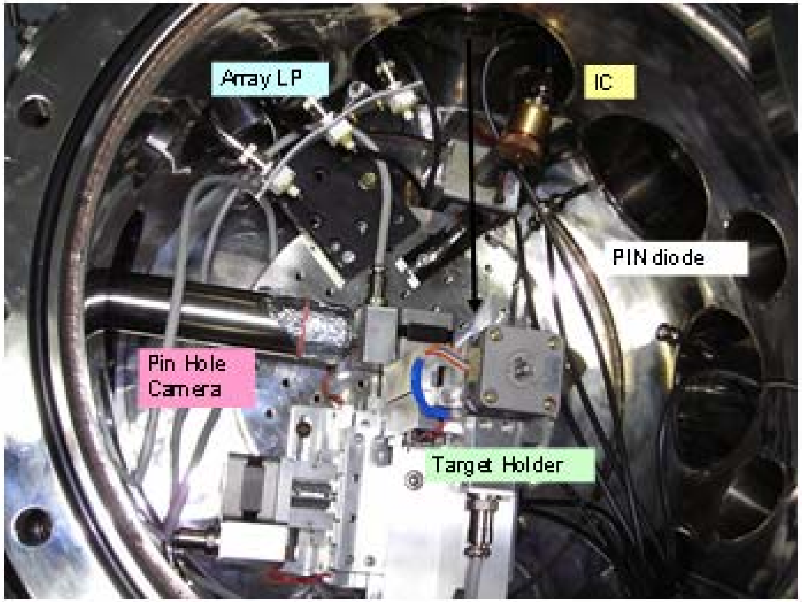


Laser foot print at the final stage

Laser system

Experimental chamber outside view and inside view:





X-ray diagnostics-

- 3 channel X-ray semiconductor detector (quantrad make)
- 2 channel X-ray semiconductor detector (UDT sensor)
- X-ray pinhole camera.
- 7-channel x-ray vacuum biplanar photodoide
- X-ray transmission grating spectrograph
- X-ray crystal spectrograph
- X-ray CCD camera

Ion diagnostics-

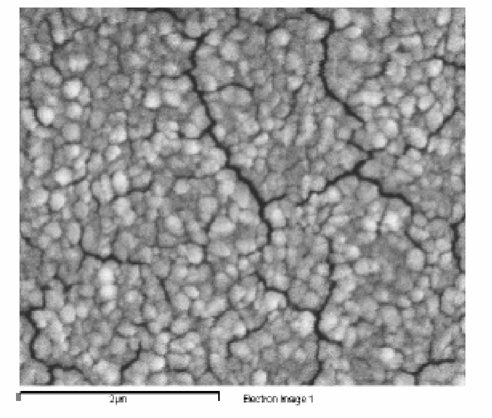
- Langmuir probes
- Ion collectors
- Electrostatic IEA

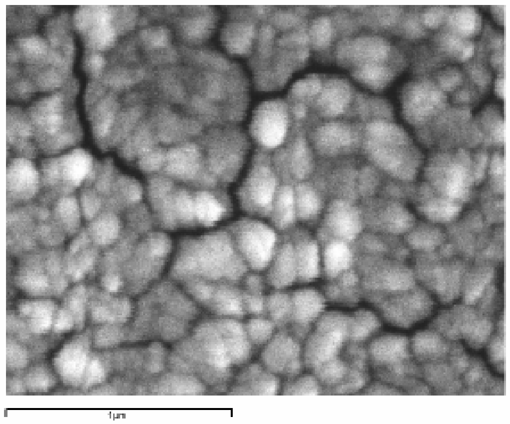
EOS studies –

- Optical streak camera – shock velocity
- VISAR set-up – Particle velocity

Target preparation

Sputter-deposition at relatively high pressures (~20-200mTorr) and low substrate temperatures (~100-300K) is known to produce nanocrystalline films [1]. The average particle size can be controlled by proper choice of sputtering voltage, gas pressure and substrate temperature. In the present case, the nanocrystalline copper sample was prepared by dc magnetron sputtering (at 325V)from a 50 mm dia copper target at 100 mtorr pressure on a bulk copper substrate held at 300 K. The average particle size (as obtained from a masurement of the x-ray diffraction line broadening) was about 15-25 nm.

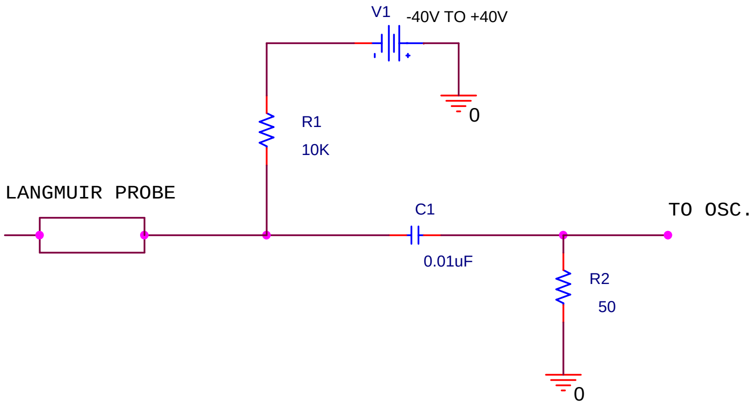


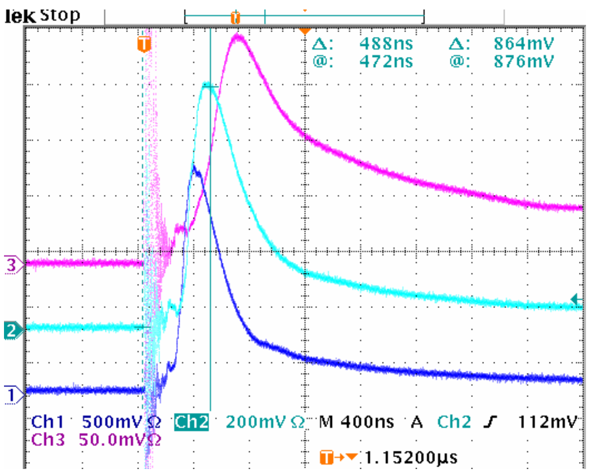


[1]P. Ayyub, R. Chandra, P. Taneja, A. K. Sharma, and R. Pinto, Appl. Phys. A 73, 67 (2001)

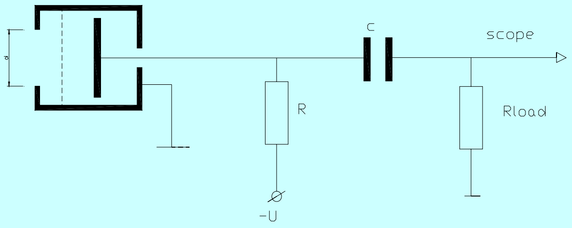
Array of Langmuir Probe

- In our experiment we have used 3 Langmuir probe at different angle (13^{0}, 30^{o} and 45^{o}) biased negatively with -30V.
- The Langmuir probes are cylindrical type with dia 0.5mm and of length 4mm placed inside the vacuum chamber at a distance of 11cm from target.

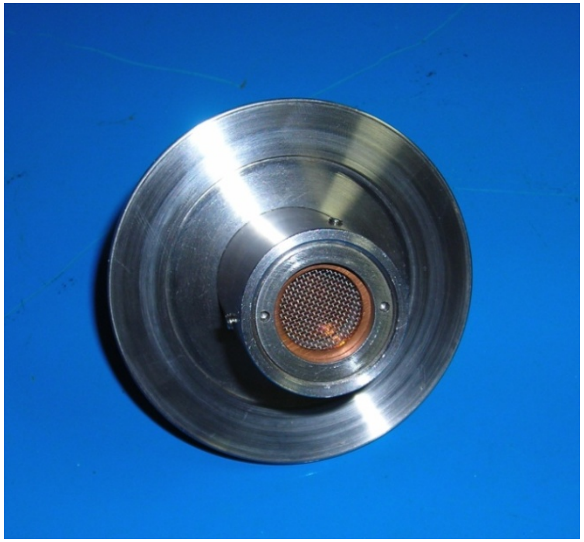




Schematic of Faraday cup (Ion collector)



(a)

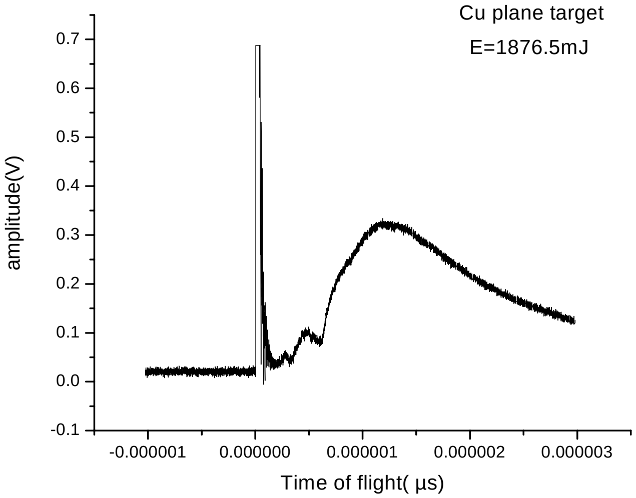


(b)

(a) Schematic of Ion collector,

(b) Photograph of ion collector,

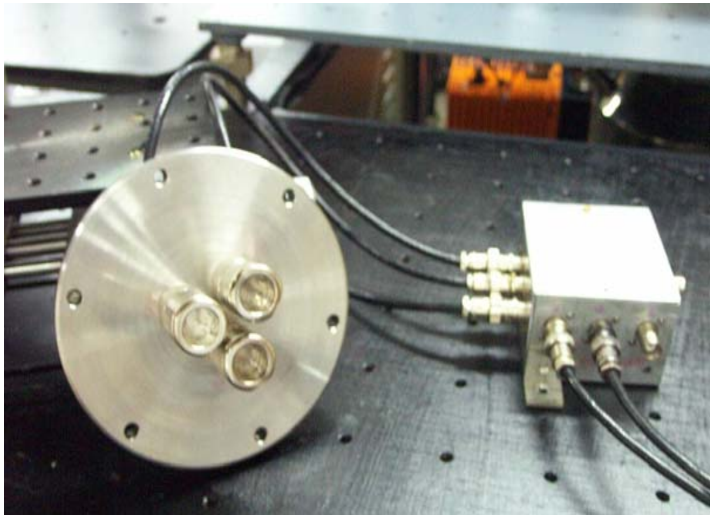
(c) Recorded signal of copper plasma

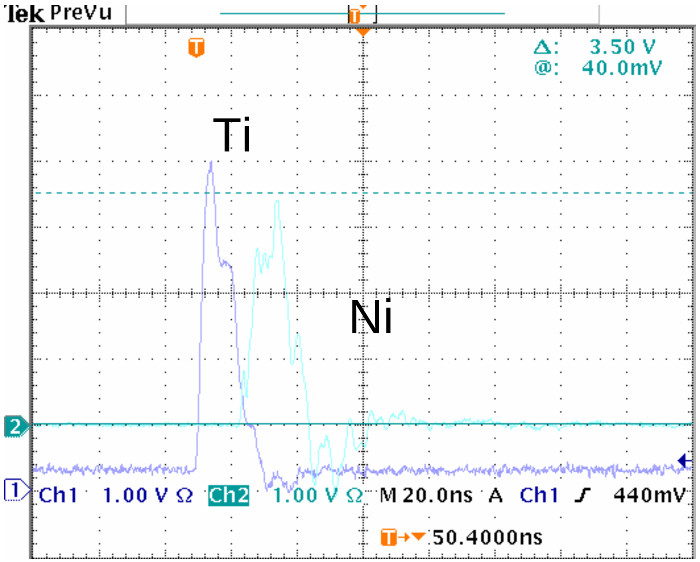


(c)

Three Channel X-ray Detection Head For Diagnostics Of Plasma

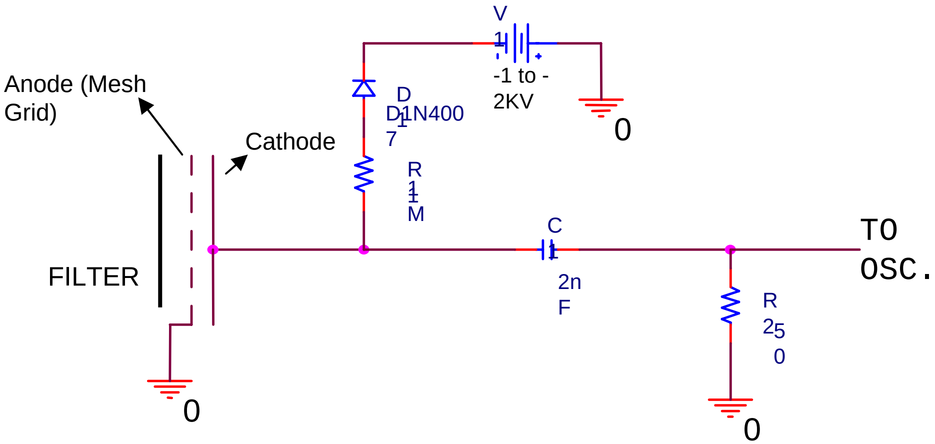
- A compact, three channel noise resistant detection head based on semiconductor detectors (PIN diode, 100PIN250, by Quantrad Corporation, USA) has been built for the diagnostics of the x-ray emission from plasma as shown in fig. a.
- Multi systems detection systems give the possibility of evaluating the level of x-ray emission at different ranges of wavelength.
- The K-edge filter foils (Ni – 5 µm, Ti - 12 µm) are mounted on the filter holder which is held in position 5 mm from the diode in front at the PIN diode by the foil holder supporter.

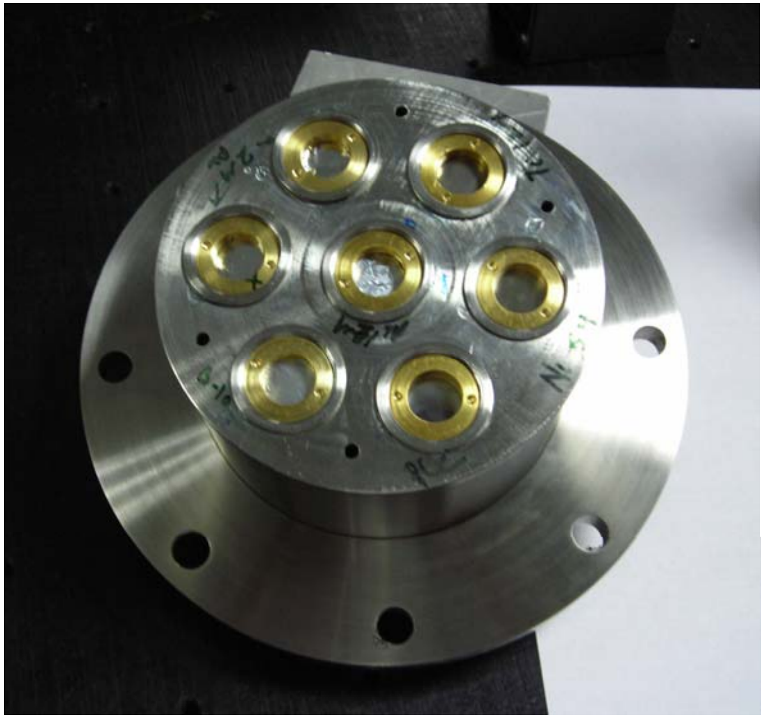


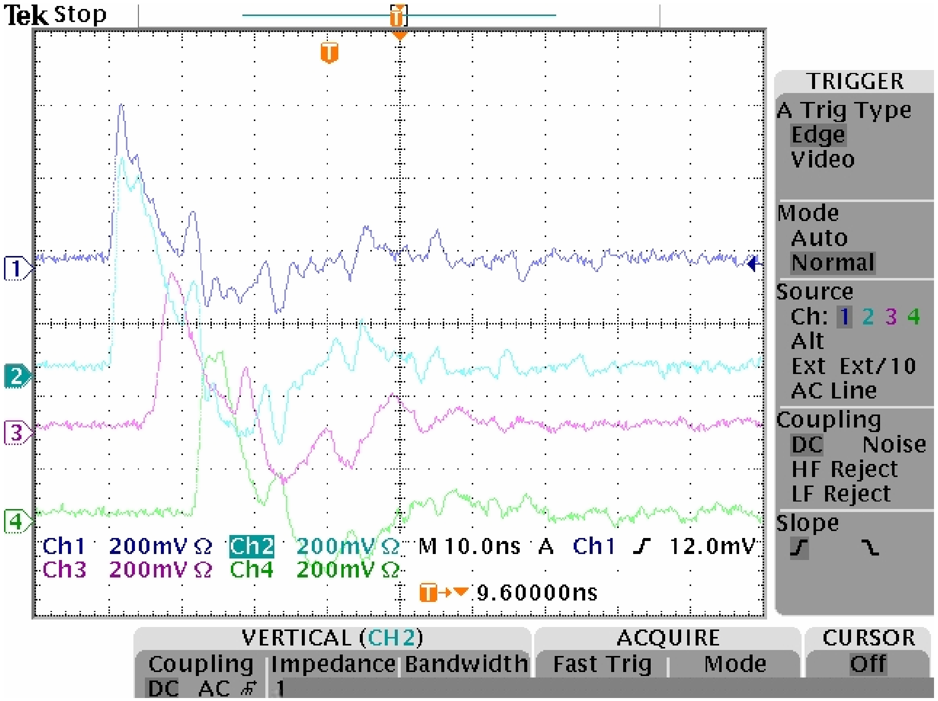


X-ray vacuum photodiode array

- 7 channel,
- 150 ps rise time,
- cover with B10 filter,
- negatively biased at 1kV

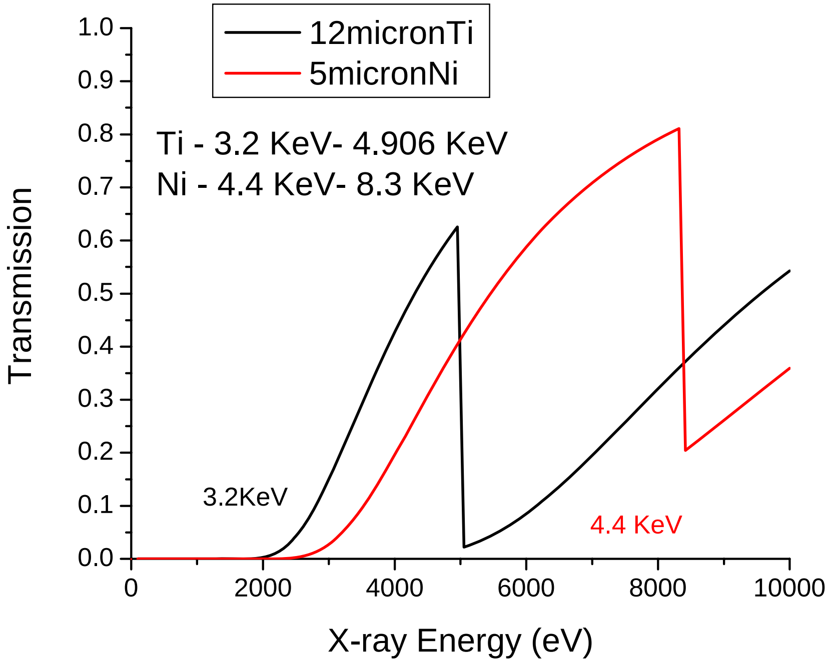


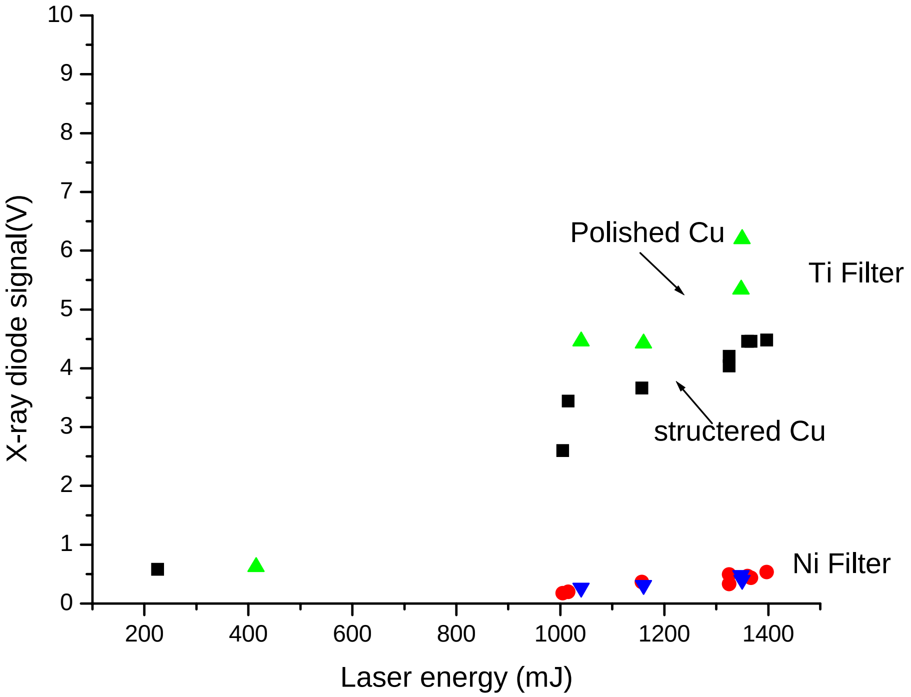




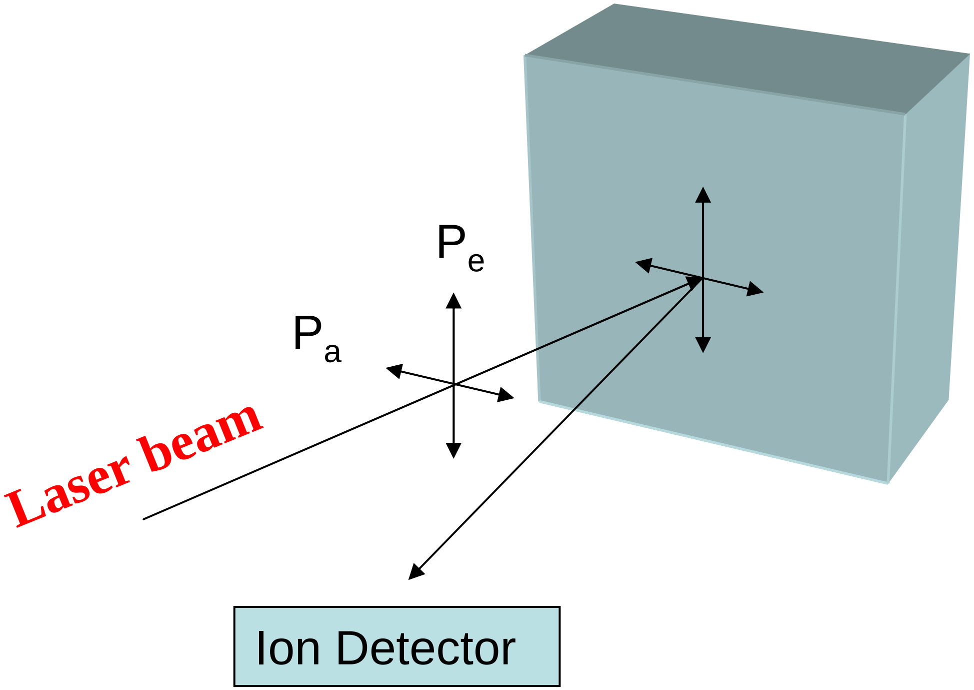
Ch1 200mV Ω Ch2 200mV Ω M 10.0ns A Ch1 ⨍ 12.0mV
Ch3 200mV Ω Ch4 200mV Ω
T→▾ 9.60000ns

X-ray measurement



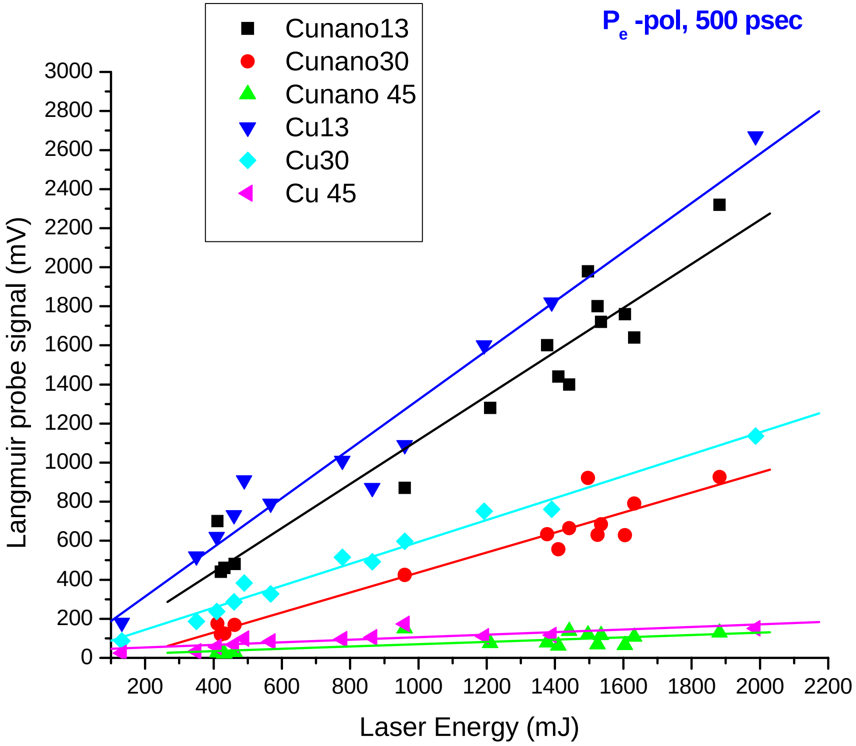


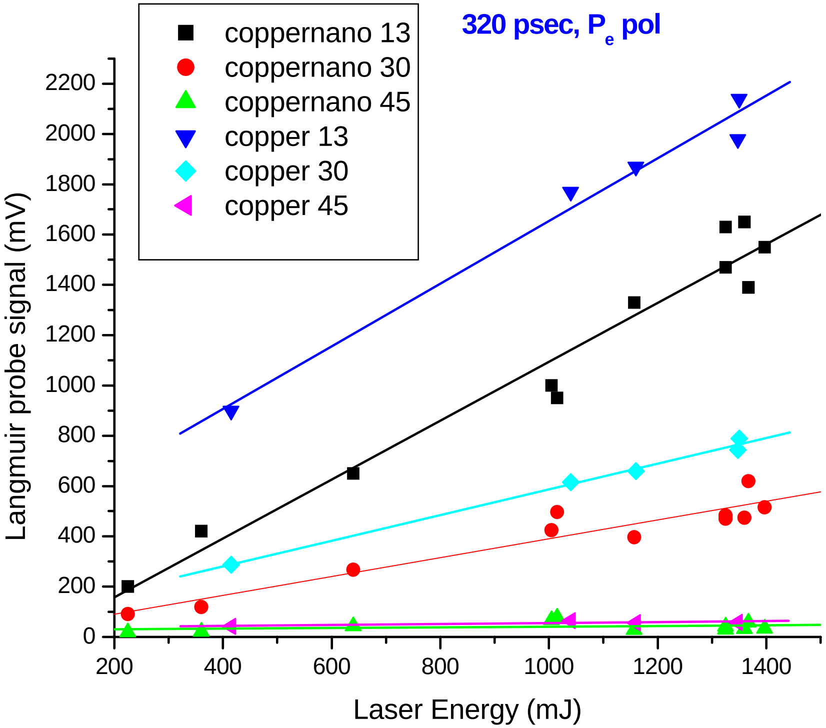
Schematic of the polarization of laser light on normal incident target



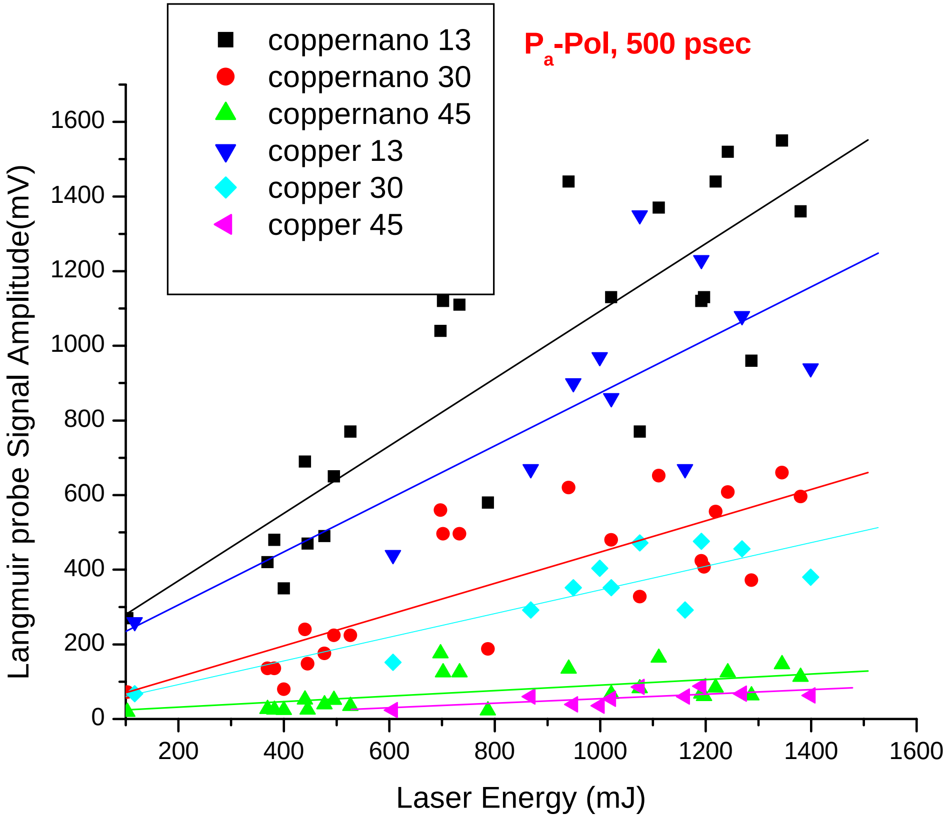
Experimental Results with 1μm thick layer

Ion amplitude variation with P_e – polarized laser energy on copper and nano-copper targets

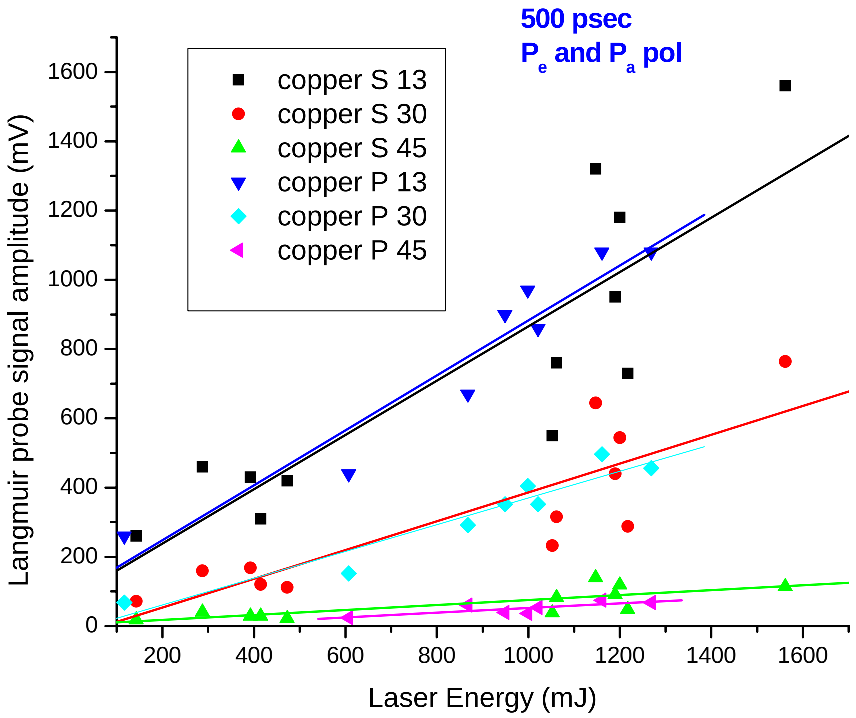


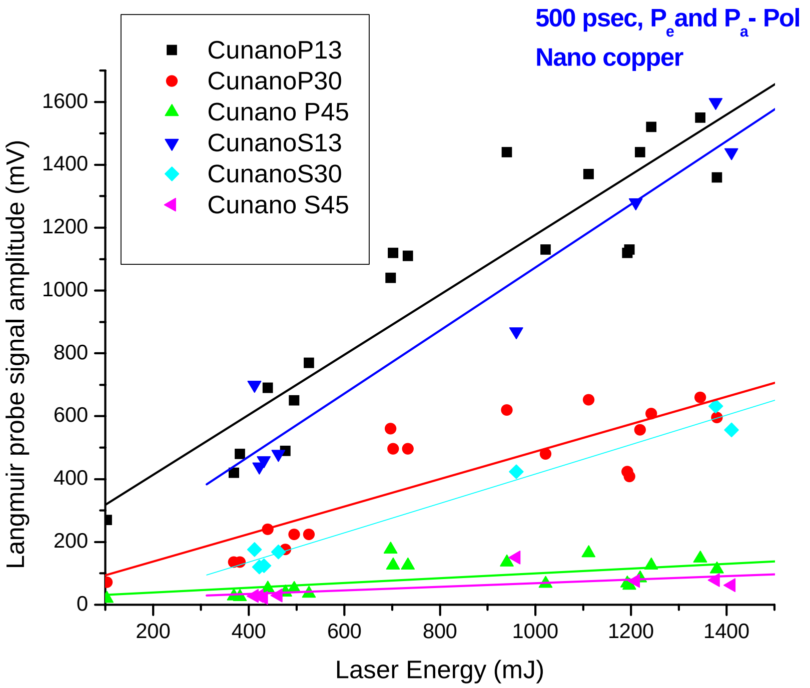


Ion amplitude variation with laser energy for a P_a polarized laser incident on copper and nano-copper targets

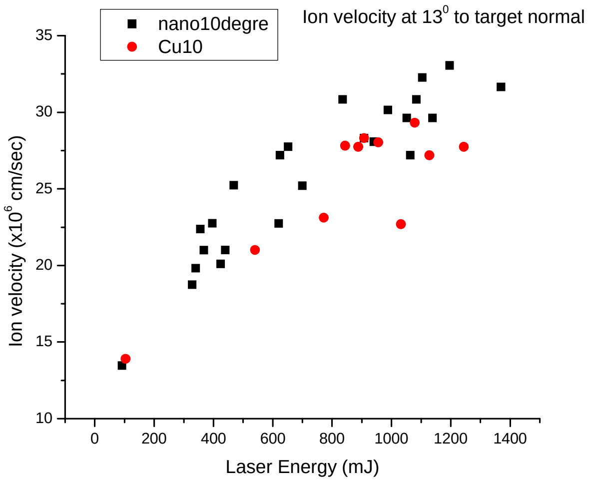


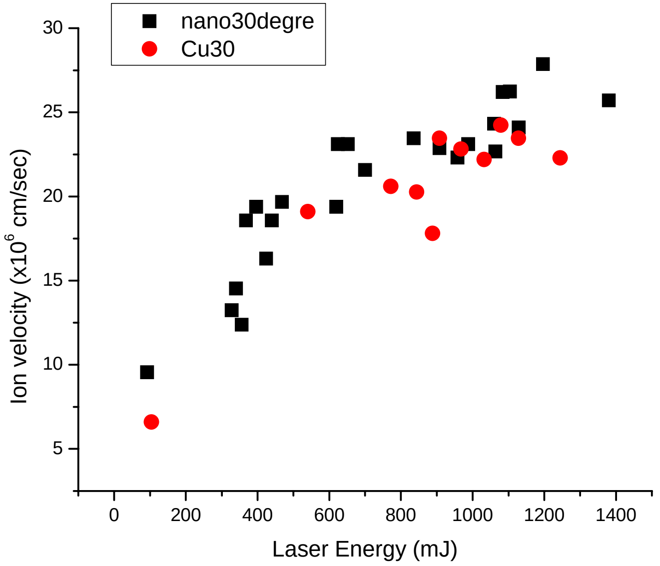
Effect of P_e and P_a polarized laser light on polished copper and nano-copper targets-

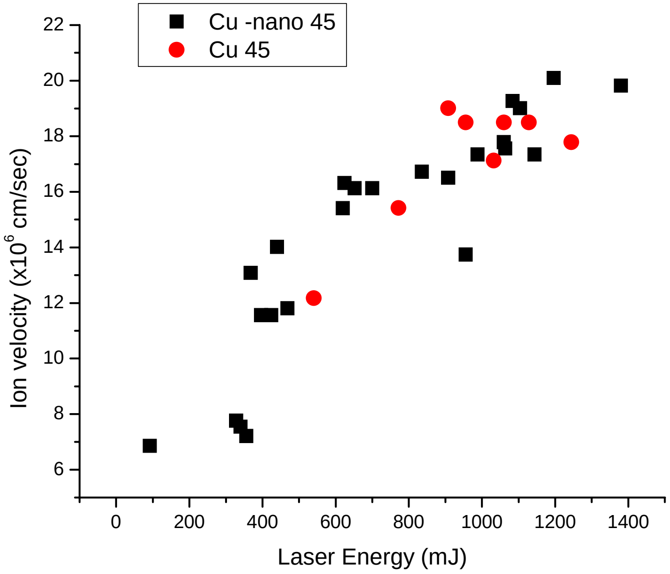




Ion velocity for copper and nano-copper target at three angle as a function of laser energy







Observations:

1. It is observed that the behaviour of plasma generated from copper nano-particle coated target is different from that of plain copper target.

2. The ion flux in case of nano-particle coated copper targets is higher for P_a polarization of the laser pulse as compared to P_e polarization.

3. Nano-particle coated targets show higher ion flux compared to plain copper. The same is observed for ion velocity also.

4. No difference in ion flux ablated between P_a and P_e polarized light for a polished copper target.
5. Laser absorption is higher for a nano-coated surface as compared to a plane polished surface.(because ion velocity is found higher for nano)

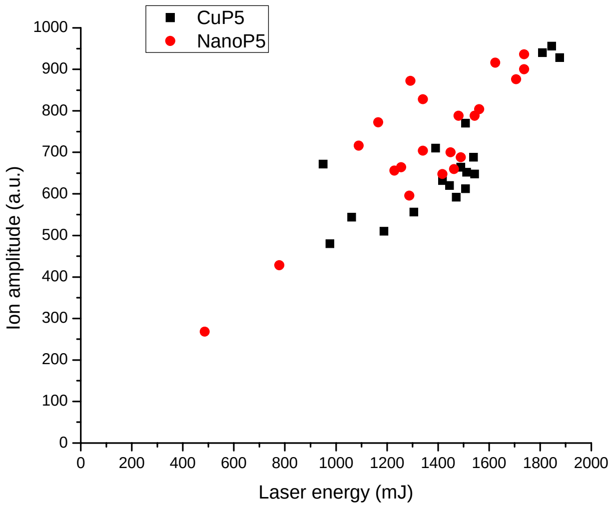
Experiments with 3 micron thick layer of copper nano particle on copper substrate

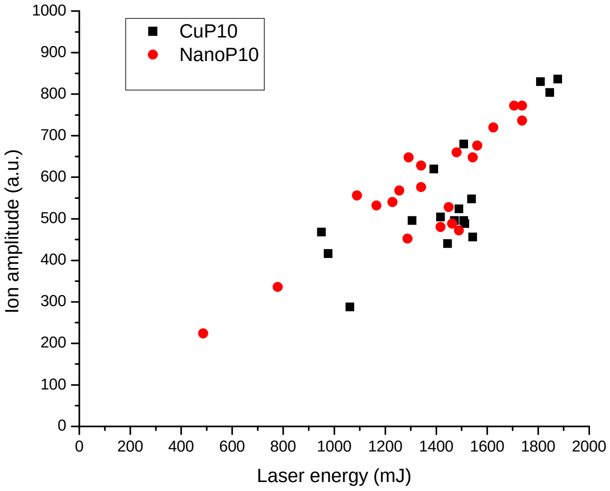
- **In these experiments a copper nano particle layer of 3 micron is coated on copper base.**

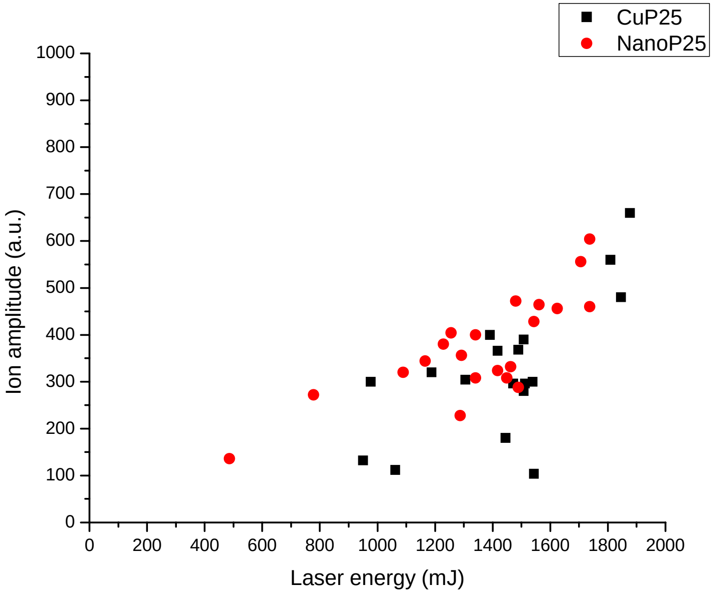
- **For the ion parameter detection an array of Langmuir probes and ion collector used.**

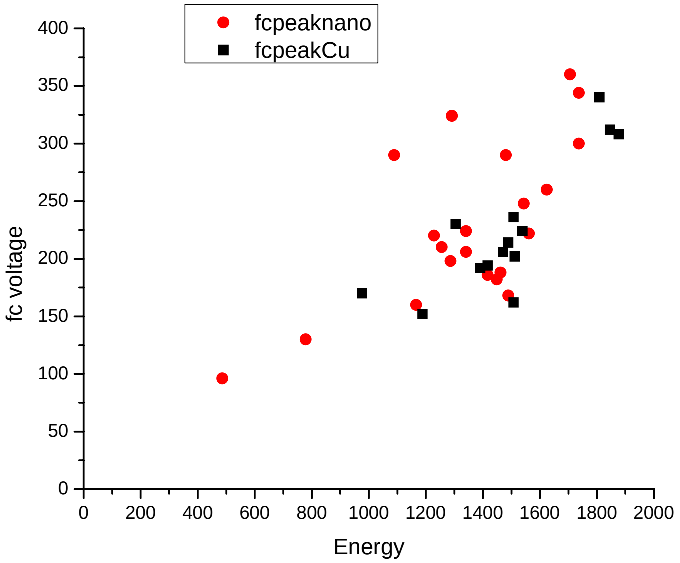
- **For the x-ray detection we have used semiconductor pIn diode cover with titanium filter and indigenously developed x-ray vacuum photodiodes cover with B10 filter (tranmission > 0.7 keV).** ***This B-10 foil had a Polycarbonate base film of thickness 2 µm and had a density of 0.24 mg/cm^2. 80% of this density was due to the thickness of the base film and 20% due to the 0.6µm thick Aluminum coating. From the manufacturer's data, the equivalent thickness of one B-10 foil was calculated as 0.05 mg/cm^2, 0.15mg/cm^2 and 0.0376 mg/cm^2 of aluminium, carbon and oxygen respectively.***

Comparison of copper and nano-copper targets for P_a (p) polarized light

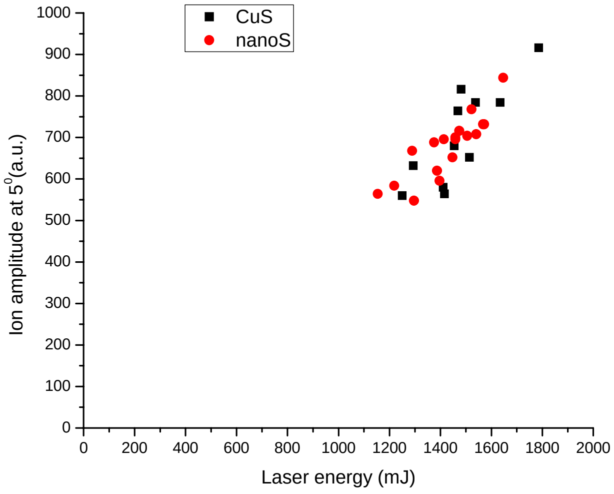


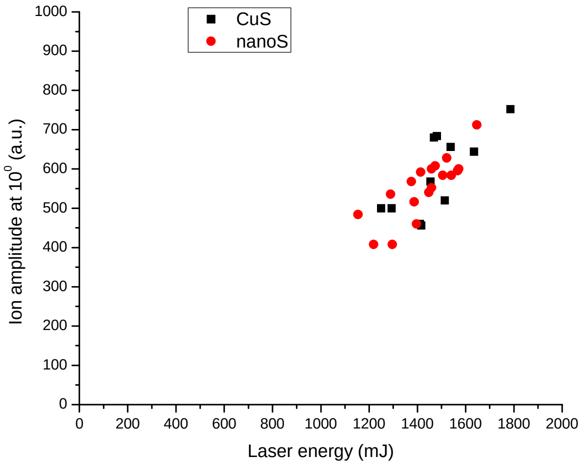


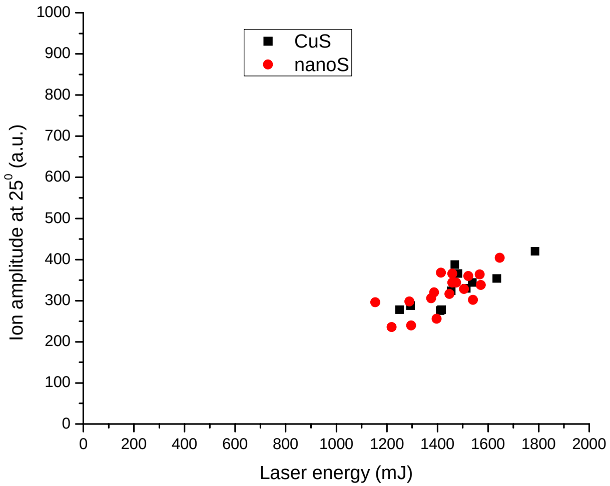


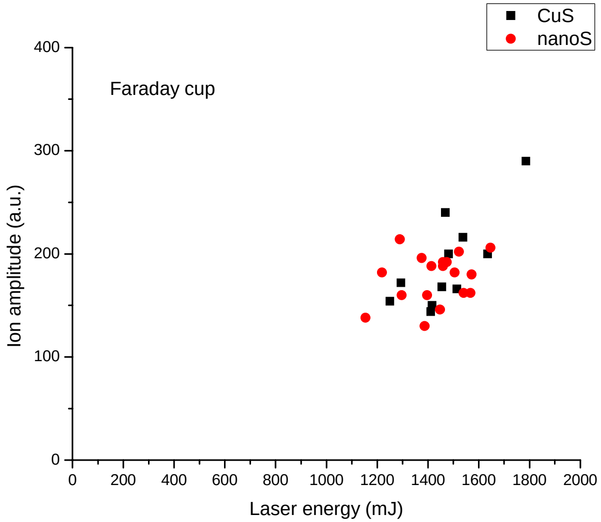


Comparison of copper and nano-copper for P_e (s)polarized light

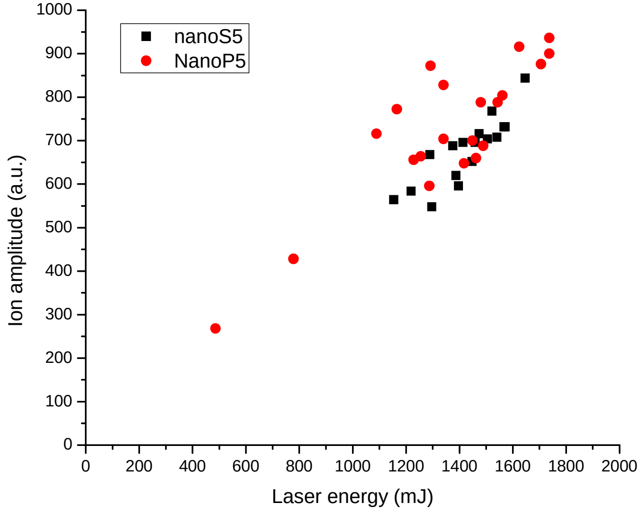


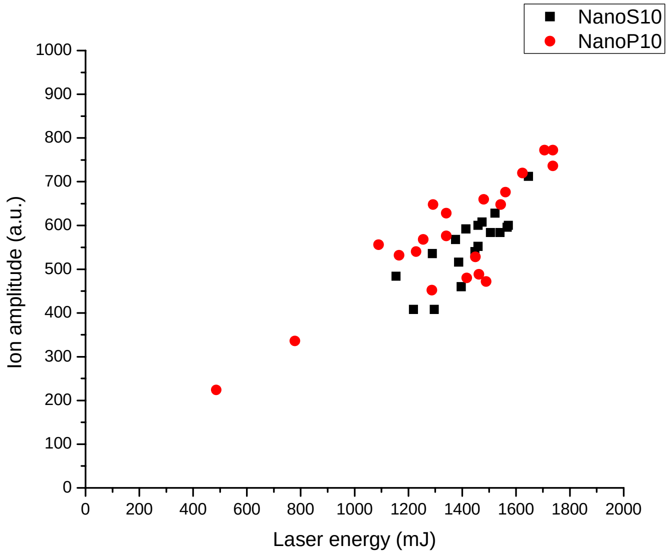


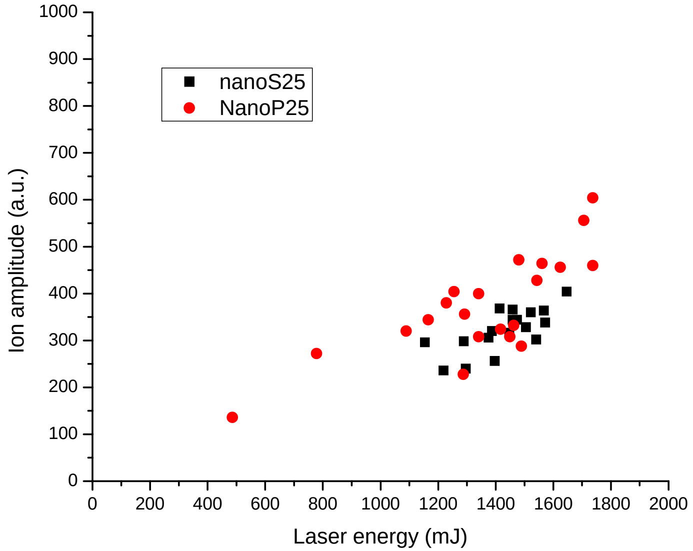


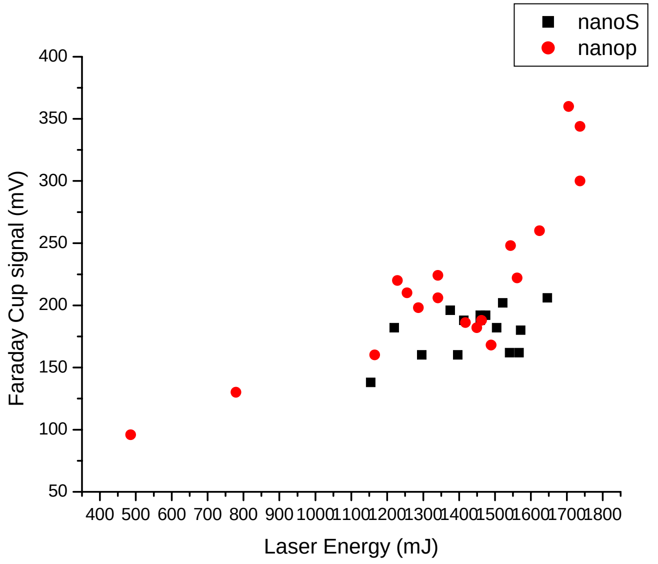


Comparison of nano copper target with P_e (S) and P_a (P) Laser beam

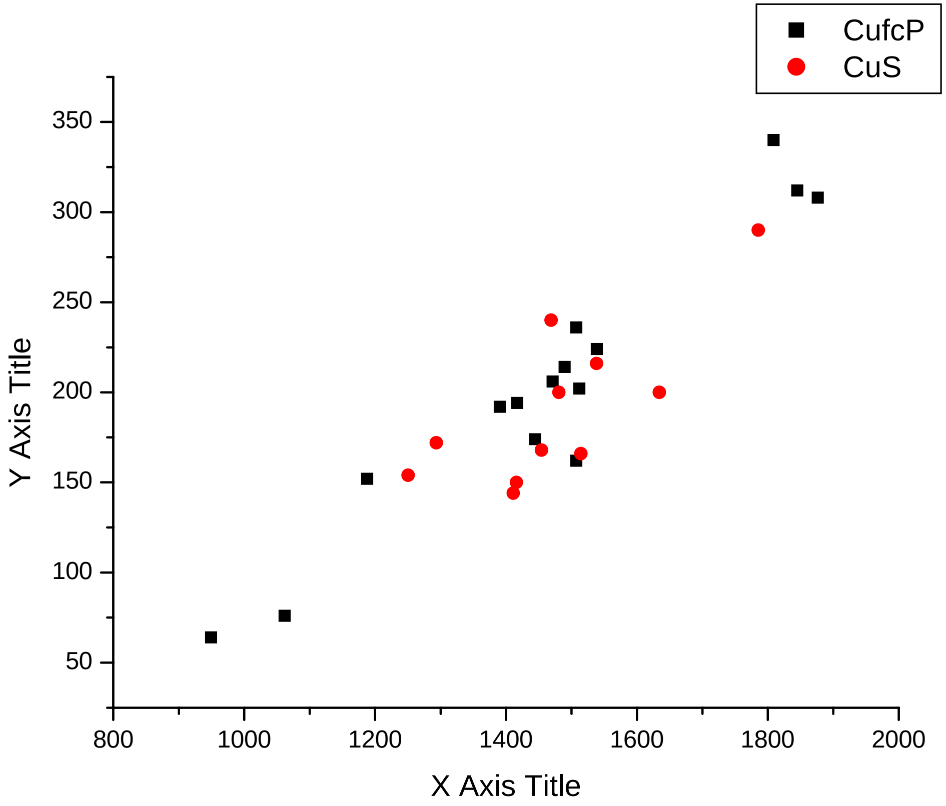




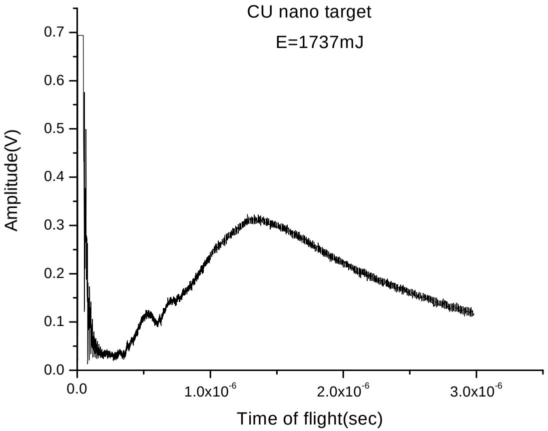


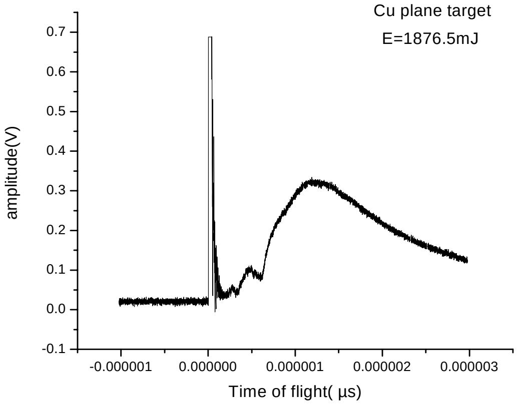


Comparison of copper target with Pe (S) and Pa (P) Laser beam

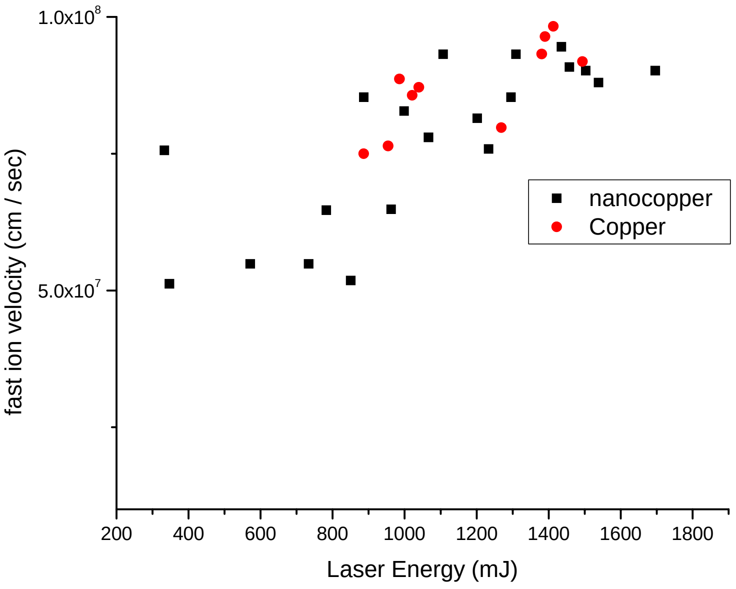


Faraday cup record of copper and nano copper coated plasma

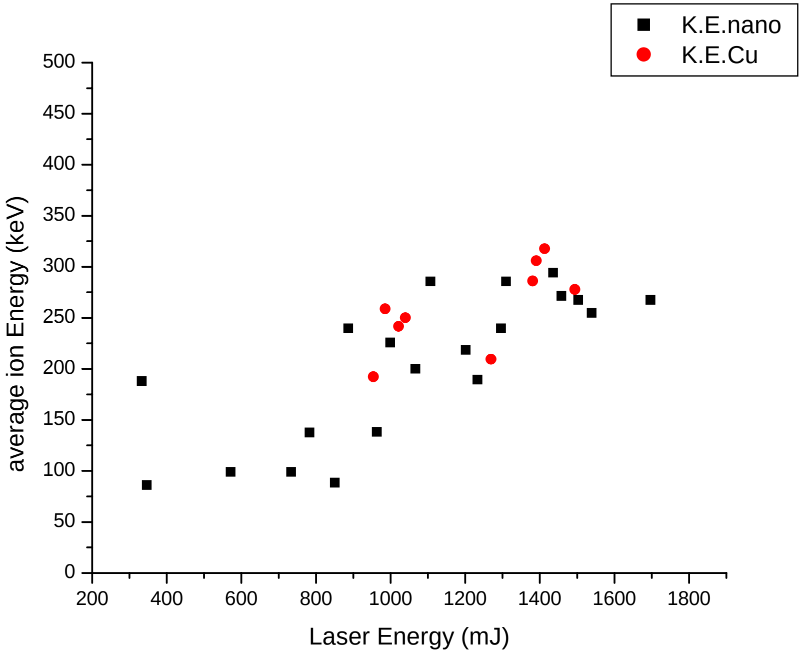




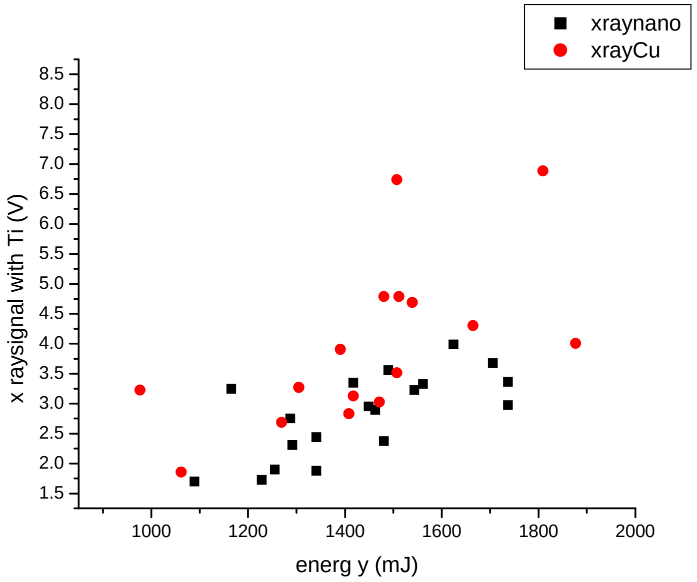
Fast ion velocity Vs Laser energy

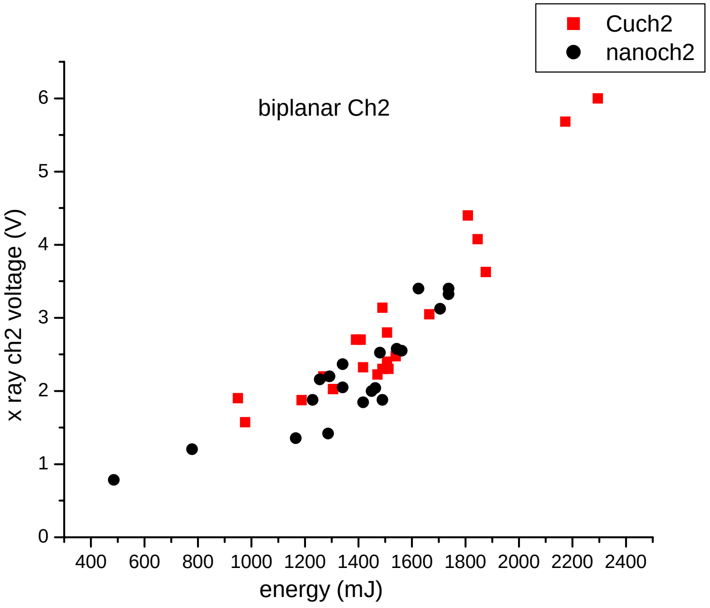


Kinetic energy Vs Laser energy for fast ions



X-ray measurement from copper and nano-copper plasma using x-ray semiconductor diodes covered with Ti filter and x-ray vacuum photodiode covered with B10 filter





Ion current calculation :

- The total ion current reaching to the probe located in streaming plasma is the sum of the ion component Ii and electron component Ie.

$I_i = e\,v\,S\,(1+\gamma/z)\,z\,n_i$ For $V < 0$ ...(1)

$I_e = I_{e0}\exp\,[\,e(V - V_p)/\,kTe]$ For $V\text{-}V_p \le 0$ ...(2)

- Here v is average velocity, S = 2rl is cross-sectional area of the probe; r and l are the radius and the length of the probe respectively, V is applied voltage to probe, V_p is plasma potential, kTe is the plasma temperature. At sufficient negative bias (V <0), in the saturation ion-current regime the electron current $I_e = 0$ and the probe operate as a flat charge collector and the ion current (probe current) at time t can be measured by the expression

$I_i\,(t) = V(t)/\,R_{load}\;[1+\gamma/z]$ ...(3)

- Where V(t) is voltage is the voltage amplitude of the probe signal, R_{load} is load resistance (50Ω) and γ is secondary ion-electron emission coefficient, z is the average charge state. In several experiments the value of the γ/z have been measured and quoted to be varying from 1 to 2. We have considered γ/z = 1 for our calculation

Recent publications

1. "Enhancement of x-ray emission and ion velocity in laser plasmas from gold – copper mixed target"-S.Chaurasia*, D.S.Munda, C.G.Murali, N.K.Gupta and L.J.Dhareshwar, Accepted for publication in J. Appl. Phys.
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Thank you

L. J. Dhareshwar