Joint Experiments on X-ray / Particle Emission from Plasmas Produced by Laser Irradiating Nano Structured Targets

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Abstract The 1st Joint (Host Laboratory) Experiment on laser plasma involving more than twenty scientists from eight countries has been carried out at the Laser and New Materials Laboratory, Faculty of Science, Cairo University, Egypt. It was co-ordinated by the International Atomic Energy Agency (IAEA) and supported through the IAEA and the ICTP (International Centre for Theoretical Physics, Trieste). The main experimental programme was aimed at characterising the possible enhancement of x-ray and particle emission from plasmas produced by laser incidence on nano-structured targets. Laser beams at 1.064 □m of 250 mJ and 532 nm of 165 mJ focused at the target surface using a nanosecond laser type Quantel were used in the present study. In the present experiments nano-copper structures evaporated onto copper bulk disks and nano-gold structures evaporated onto gold ones were used. The thickness of the nano-materials on their bulk material was 1 □m. An ion collector and x-ray semiconductor diode were used to study the ion and x-ray emission, respectively. Both were positioned at the same port at 90^o with respect to the target surface and at 90 cm from the surface in the case of the ion collector and 55 cm in the case of the x-ray detector. These experiments were performed at vacuum pressures of (5 - 8) x 10^{-6} mbar. Comparison of both studies in the case of nano structured targets and bulk targets were performed at different laser fluencies (1x 10^9 – 1x10^{12} W/cm^2) on the target. A 20% increase of the X-ray emission for nano gold with respect to bulk gold was observed, however, the x-ray emission in the of nano copper and copper was the same.

INTRODUCTION

Plasma generated by ultrashort laser pulses with solid target is very important in numerous scientific fields, such as medicine, biology, chemistry, engineering and solid state research, which require X-ray imaging with high spatial and temporal resolution [1], laser ion source for heavy ion accelerator [2], direct ion implantation [3], etc. Such plasmas also offer a great promise as a micro size source of x-rays in areas such as lithography and time resolved diffraction [4-8]. Moreover enhancements of x-ray emission and the factors responsible for these enhancements are of great importance. Previous work reported an impressive progress in enhancement of soft x-ray [9] and hard x-ray [10] using structured surface, viz, gratings [11-12], velvet coatings [13], porous and nano-cylinder [8,12,14] targets. Also, the enhanced x-ray emission implies enhanced hot electron production, which is very important in the field of inertial fusion research [15] and particle acceleration [16].

Recently, a 13-fold enhancement of hard x-ray yield emitted from metal nano-particle-coated solid targets irradiated with 100-fs, 806-nm laser pulses was observed [17]. This work stimulated us to work jointly in studying the x-ray and ion emission from laser irradiated nano-structure targets using this time a nanosecond laser. So, the main experimental program was aimed at characterising the possible enhancement of x-ray and particle emission from plasmas produced by laser beam incidence on nano-structured targets. Beams at 1.064 μm of 250 mJ and 532 nm of 165 mJ focused at the target surface from a nanosecond laser, type Quantel, were used in the study. In the present experiments nano-copper structures evaporated onto copper bulk disks and nano-gold structures evaporated onto gold ones were used. An ion collector and x-ray semiconductor diode were used to study the ion and x-ray emission, respectively.

EXPERIMENTAL SETUP

The present work was performed using the experimental setup shown in Fig. (1). A Q-switched Nd-YAG Brilliant-b laser from Quantel delivering 600 mJ in 6 ns full width half maximum (FWHM) at the fundamental wavelength 1064 nm and 280 mJ in 5 ns FWHM at = 532 nm were used.

The laser intensity at target was varying from 1x109 to 1x1012 W/cm2. The plasma was generated in a spherical vacuum chamber by focusing the laser beam (using a quartz lens of a focal length f1 = 50 cm) at 45o to the target surface. The chamber was equipped with four ports in the mid plan and the measurements were carried out under the pressure of (5 - 8)× 10-6 mbar obtained by an Alcatel turbo molecular pump.

A semiconductor x-ray detector, type AXUV 100 and an ion collector were used for the measurements of the intensity of the x-ray and ion emission.

The x-ray detector was filtered with the use of 3-μm Al filter giving the main (soft) energy range of sensitivity before the edge of attenuation at about 1-1.56keV (cut-off at att. 1/e). In some cases a thicker filter was used to check the existence of hard x-ray component (in the range of 3-6 keV). The x-ray detector was placed normal to the target and at a distance of 55 cm from the target surface. It operated without bias.

The ion collector was placed normal to the target and at a distance of 90 cm from the target surface. It was biased at -100 volt.

In the present experiments nano-copper structures evaporated onto copper bulk disks and nano-gold structures evaporated onto gold targets were used. The thickness of the nano-materials on their bulk material was 1 m.

The comparison of both studies in the case of nano-structured targets and bulk targets were performed at different laser fluencies (1x 109 – 1x1012 W/cm2). The experiments are made for two different harmonics (first and the second one).

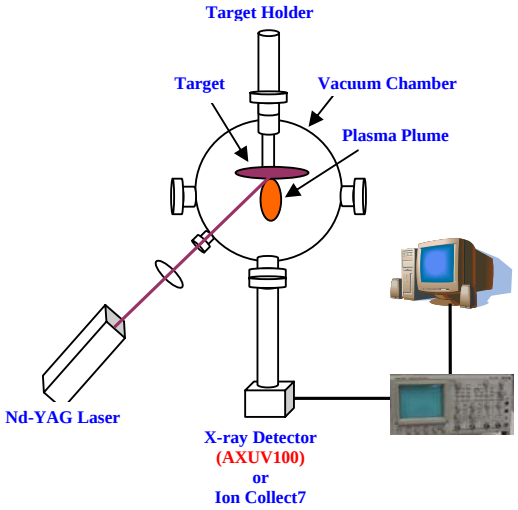


FIGURE 1. Experimental Setup

RESULTS AND DISCUSSIONS

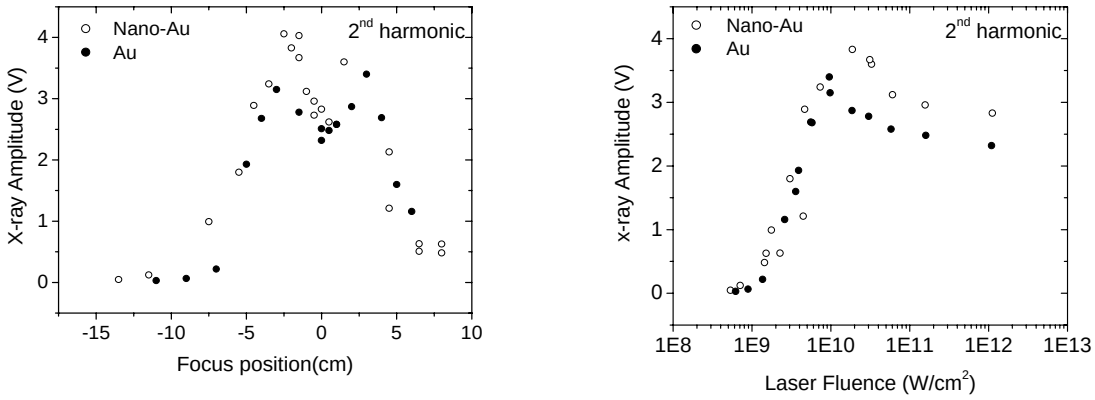
Results of x-ray measurements are presented twofold as a function of focus position and as a function of laser fluence, see fig. 2 and 3. The results reveal that the soft x-ray emission generally increases as we move towards the best focus position.

However, close to the best focus position, there is a sharp dip in the x-ray emission. This effect is for both harmonics, see fig. (2a), fig (2c), and fig. (3a), excluding cooper, the first harmonics.

Also, it is clear from the graph that x-ray flux is higher for high Z (Au) target and the sharp dip is more pronounced in the case of gold. X-ray emission from the copper and nano-copper is the same. In the case of nano-gold the x-ray emission is 20% higher than that from the solid gold.

This indicates that absorption of laser light in the case of the target coated with nano particles is higher and it results in enhancement of x-rays.

(a) **(b)**



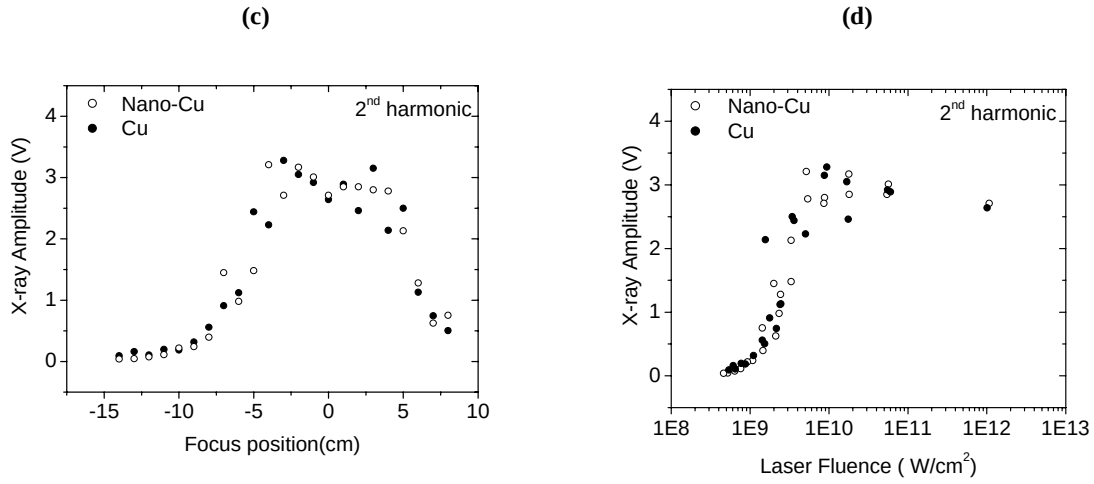


FIGURE 2. Presents the soft x-ray emission using the 2nd harmonic laser beam at □ =532 nm for two different types target a, b for gold c, d for copper.

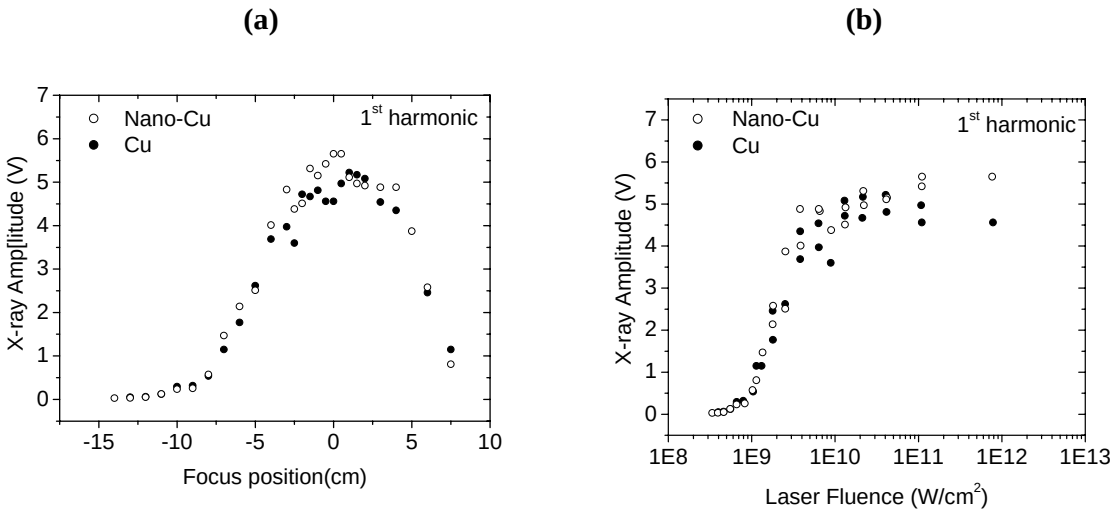


FIGURE 3. Presents the soft x-ray emission using the 1st harmonic laser beam at λ =1.06 μm for copper targets.

In the case of the second harmonic , around 15- 20% increase of the soft X-ray emission for nano gold with respect to bulk gold was observed, as shown in fig (2b), however, the x-ray emission in the case of nano-copper and pure copper was the same for both harmonics, as it is shown in fig (2d) and fig.(3b).

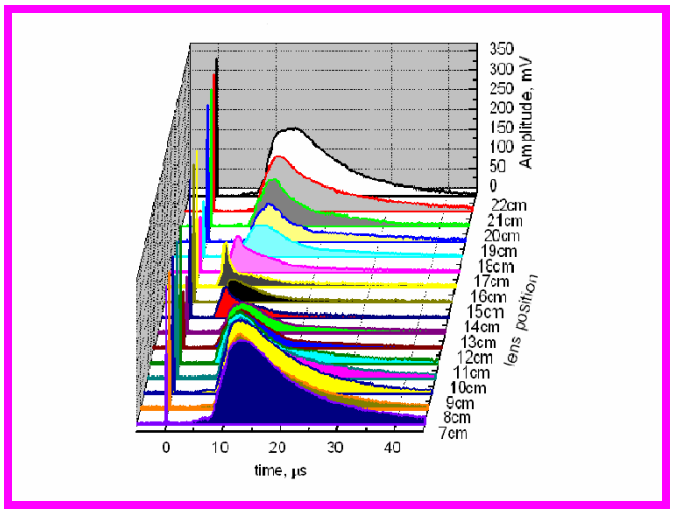


FIGURE 4. An example of the ion emission signal detected by the ion collector for different focusing position.

Fig 4 presents an example of the detected ion signal at different focusing positions; however it shows no fast ions are observed and hard x-ray signal is neglected. Moreover Fig. 5 shows the x-ray and ion emission with different focusing position and for different types of targets. However the experiments show that, the ion flux (amplitude) is seen to decrease sharply at the best focus position. From Fig. 4 it is clear that away from the best focus the total number of ions (i.e., area under the curve) is bigger and when shifting close to the best focus it becomes minimal. At the same time, the peak of the collector signal is shifting towards the shorter times. This indicates the higher velocity and hence the higher kinetic energy of ions. Fig. 5 also shows that at the best focus, the peak of ion amplitude (peak of ion current) is the lowest and ion velocity (kinetic energy) is maximal. This implies that when we move towards the best focus, the total kinetic energy of ions increases but then the total number of ions is smaller. We did not observe any fast ion components at increased intensity (when being closer to the best focus) and hard x-ray component was then also negligible. This indicates that at this intensity no nonlinear processes could start.

Basing on the time of flight (TOF) method, ion velocity was obtained and it shows the velocity increases towards the best focus, as shown in fig. (6).

For the understanding of the nature of the laser beam interaction with the bulk material and their nanostructure, SEM scans of craters were measured. From fig. 7, it is clear that the material removal from cooper target is higher than the one from the gold target. This can also be seen in fig5 that the ion amplitude peaks are higher for copper than the ones for gold at same laser fluency.

CONCLUSIONS

From the above observation it is clear that the maximum soft x-ray emission is off the best focus position which is in agreement with the model developed by G. J. Tallents [18]. There is no enhancement in x-ray emission observed in the case of nano copper coated target than the solid copper where as 20% enhancement was observed in the case of gold nano-coated target than solid target. There was no fast ion components seen and hard x-rays were negligible. Moreover, it is clear that the flux of x-ray radiation fully reflects the amount and temperature of electrons present in the plasma produced. The higher the plasma temperature, the higher energy of photons emitted from the plasma. As the total x-ray flux is determined by the electron concentration, it is volume dependent (it depends on the focus spot diameter). The amount of fast electrons produced, increases with ILλ2. At higher laser intensities, the presence of non-linear processes in the preformed plasma may significantly increase the temperature of the fast electrons and, therefore, mainly the hard components of x-ray radiation and fast ion emission

are produced that does not happen in low-energy nanosecond experiments.Laser intensity was not sufficient to start non-linear processes and hence there were no signals of fast ions (of high charge states) and hard x-rays. The minimum in ion amplitude and soft x-ray at the best focus shows that the volume effect is dominant at low intensity laser produced plasma. Moreover, as shown in fig 6, the ion emission in the case of nanostructure and the bulk material, was the same in the case of using 1-μm nano-layers. More experiments are needed to determine fully the influence of the layer on x-ray and ion emission.

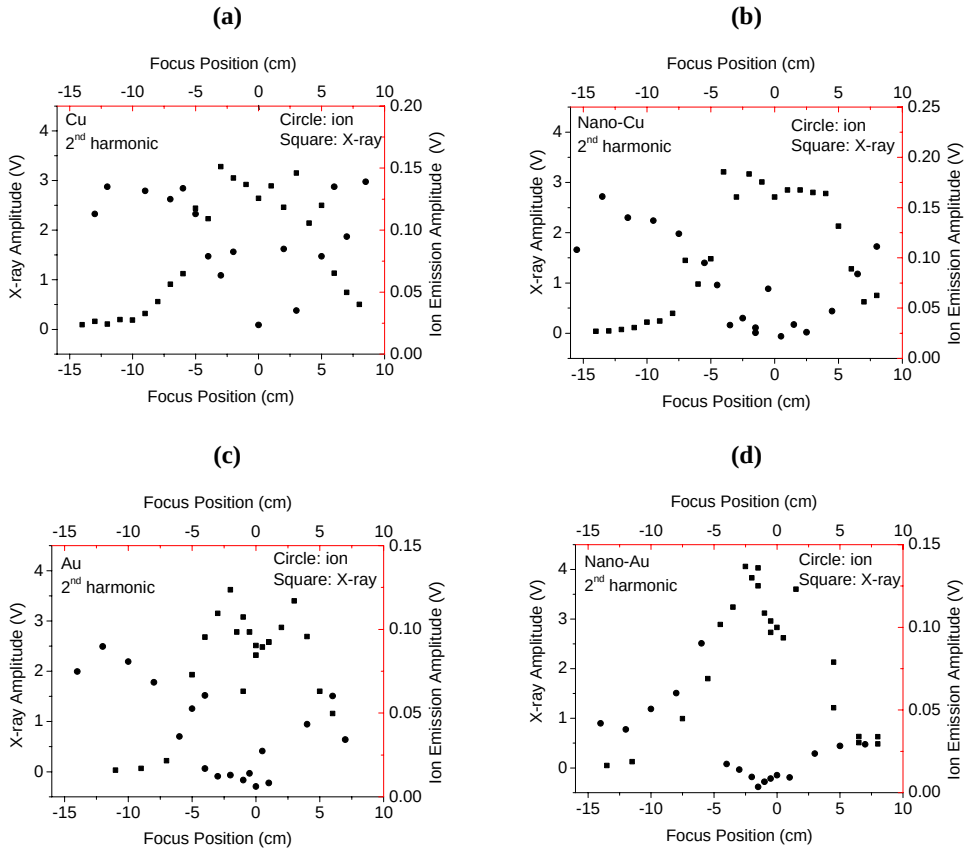


FIGURE 5. X-ray and ion emission at different focusing positions and for different types of targets, measured by the use of 2nd harmonics laser beam.

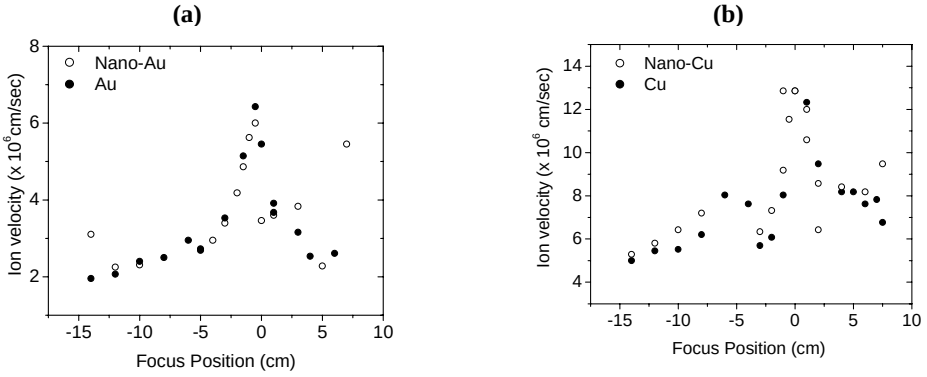


FIGURE 6. The ion velocity at different focusing positions for a) gold, b) copper targets covered with nanostructures.

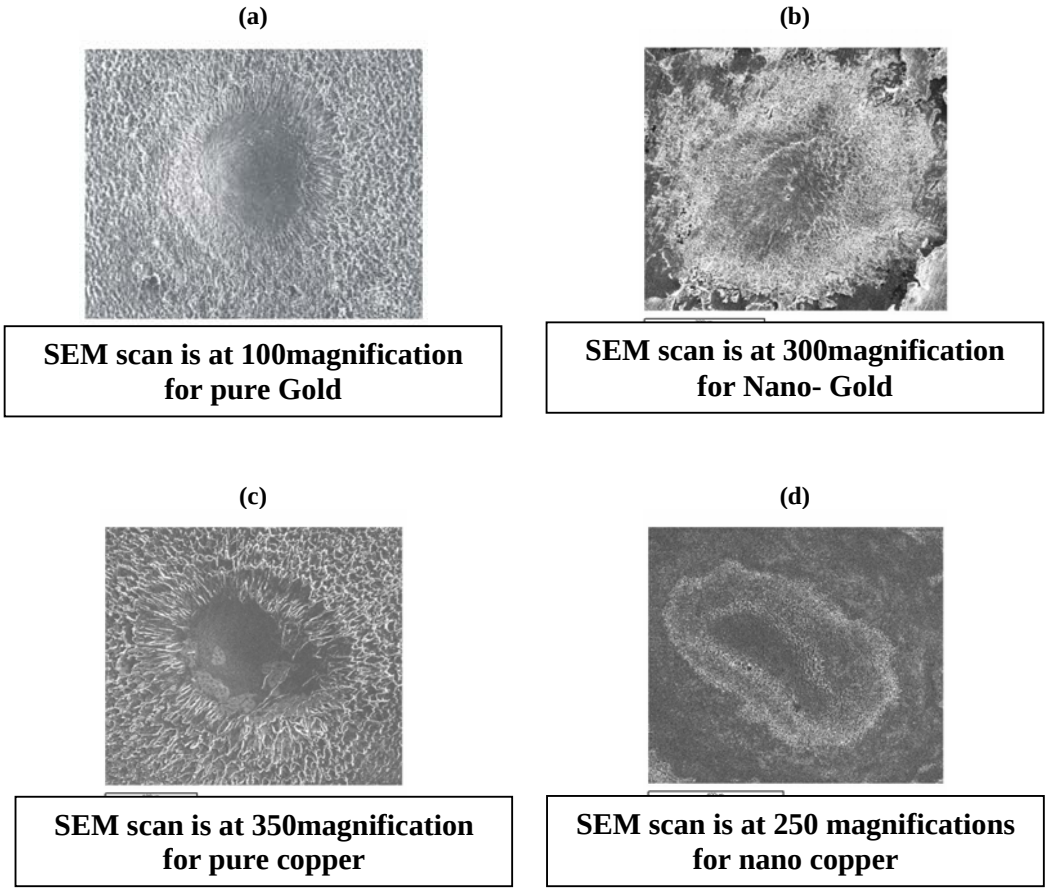


FIGURE 7. SEM scans for gold and copper targets and it nanostructure at best focus positions

ACKNOWLEDGEMENT

Authors wish to thank Prof. P. Ayyub of Tata Institute of Fundamental Research, Mumbai, India for the preparation of nano particle coated targets and perform the SEM scans of targets

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