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Enhancement of KeV X-rays and ions emission from cocktail (Cu +Au) target irradiated with sub-nanosecond Nd:Glass Laser

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Abstract:

It is well known that by mixing of two high Z materials such as- Au-Sm and Au-Gd and U-Au-Dy it is possible to obtain an enhancement of Rosseland mean opacity as compared to either of the two elements in the mixture, increasing the overall coupling efficiency between the laser and target. Such cocktail targets have been widely advocated for the use of inner wall of the Hohlraum cavities used in ICF. In this paper we report the characteristics of X-ray and ion emissions from Au, Cu and the optimum mixture 0.43Au+0.57Cu. Plasma was produced with an Nd:Glass laser focused to intensity in the range 10^{13} to 10^{14} W/cm^2. A 2 to 10 fold enhancement in X-ray emission from the Au+Cu mixed target was observed as compared pure copper and gold targets respectively in the different spectral regions observed. Ion velocity is also observed to be higher. This can be an indication towards a higher plasma temperature leading to an enhanced laser absorption in mixed targets.

Introduction:

There has been a substantial work on the optimization of laser-plasma X-ray sources using various laser parameters like wavelength, pulse duration, laser intensity and also target materials[1]. A high laser to X-ray conversion efficiency has been a primary objective in the pursuit of these applications. In recent past, cocktail targets (mix of two or more high Z materials) have been widely advocated for enhancing the X-ray emission. Various combinations of elements such as- Au-Gd, Au-Sm, Au-Nd, Au-Cu etc has been proposed[2-4]. It is also well known that in applications of X-ray backlighting of dense plasmas, an intense and efficient multi KeV X-ray sources in the wavelength range of few Å is needed[5].

In this paper we present a comparative experimental study of X-ray and ion emission from pure gold, copper with a mixed target of atomic composition 0.43Au+0.57Cu in the wavelength range of 1.5 to 3.9 Å, using a sub-nanosecond laser pulse.

2. Experiments:

In these experiments a single shot 2Joule/500psec Nd:glass laser pulse (λ=1.06µm) was used with intensity on target in the range $8x10^{12}$ -$5x10^{13}$ W/ cm^2 . The experimental schematic is shown in Fig.1. The Au-Copper alloy targets were prepared by taking the right proportion of pure gold and oxygen free-high conductivity copper pieces and melting them together in an

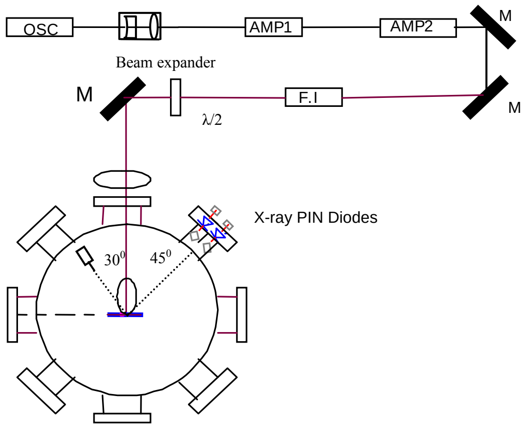

Fig.1. Experimental Set-up.

inductively coupled electric furnace in a ceramic crucible. The alloy thus prepared was rolled to a uniform thickness of 2 mm and surface was polished. Pure copper and gold polished targets were also used for comparison. X-ray emission from the laser produced plasma was measured at 45^0 with respect to target normal at a distance of 26cms, using two silicon x-ray p-I-n diode (make Quantrad250 PIN 100- with an active area of 100 mm^2, rise time less than 3 nsec and sensitivity 0.2C/J) biased at -300V. K-edge x-ray filter foils used were- 12µm thick titanium (transmission range2.5 to 3.9 Å) and 5µm thick Nickel (transmission range 1.5 to 2.87 Å). This specific spectral region was chosen since it is often used in X-ray backlighting of dense plasmas which are relevant to Inertial confinement fusion[6]. The peak of X-ray signal height was used to compare the X-ray emission from different targets. Ion characteristics measurement was done using a Langmuir probes (diameter of 0.5mm and of length 4mm)biased negatively at -30V. The probes were placed at an angle of 30^0 with respect to target normal and at a distance of 12cm from target.

3.Results and Discussions: The details of the hydrodynamics simulations of the laser plasma interaction is given in Ref.7, where the atomic processes considered are the collisional ionization, three body recombination, radiative recombination, and die-electronic recombination. The opacities and emmissivity are obtained by adding the bound-bound, bound-free and free-free contributions. For the case of mixtures, the bound-bound and bound-free contributions to opacities are obtained as weighted average.

The x-ray signal amplitude versus laser energy for gold, copper and mixed target for 12 µm Ti and 5 µm Ni filters are shown in Fig.2 (a) and (b) respectively. In these figures x-ray signal are expressed in Volts. It is observed from these figures that for an incident laser energy of 1.5 J, there was a 9 fold and 1.8 fold enhancement in X-ray emission from the Au+Cu mixed target as compared pure copper and gold targets respectively in the spectral region 2.5Å- 3.9Å; 6 fold and 1.5 fold increase respectively in the spectral region 1.5Å-2.87Å. It is clear from these figures that the slope of the plot for mixed target is higher as compared to pure copper and gold in both spectral ranges. The enhancement in x-ray signal is because of increase of opacity for the mixture. It is also noted that the enhancement in the x-ray emission increases with laser energy in our experimental range.

Spatial profiles for ion temperature and plasma density at various times for laser energy of 0.2J and 2J obtained by numerical simulations are shown in Fig.3. We observe that the ion temperature of most part of the coronal region which is mainly responsible for the emission of X rays is around 100 eV for 0.2 J laser while it is about 500 eV for 2J. Considering the ion temperature to be 100eV, the bound-bound and bound-free contribution to opacity was calculated at a representative density of 0.03 g/cc which are shown in Fig.4. In this two figure, in the wavelength region of 1.0Å-2.0Å, we note that the bound-free opacity is clearly higher for Au-Cu mixed target as compared to either pure gold or copper.

Further, between 2Å-5Å the opacity for the mixed target follows that of copper though for pure gold it is lower. Hence, combining these two observations we can clearly say that the Rosseland mean (integrated opacity) of Au-Cu target should be higher compared to either pure gold or copper in the experimental spectral region of 1.5Å -3.9Å. This increase is higher with increasing temperature. In fact, we have integrated the data over our experimental range of 1.5Å -3.9Å. Ion velocity for Copper, Au-Cu mixed and gold targets measured at various laser energies with a Langmuir Probe placed at 30^0 with respect to target normal are shown in Fig.5. The ablation velocity or ion velocity for copper targets should have been the highest considering it to be having the

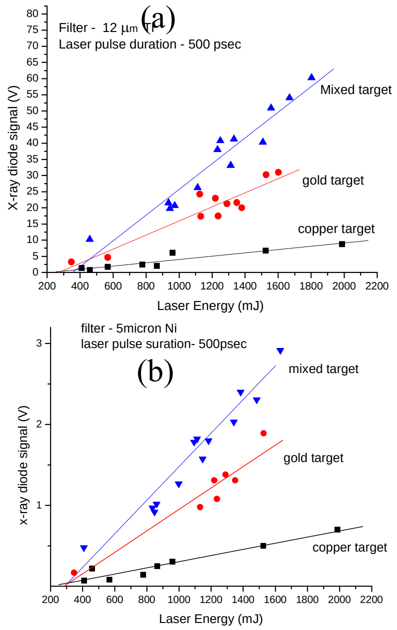

Fig. 2. –X- ray emission as a function of Laser energy for the two pin diodes.(a)-Nickel filter (b)-Titanium filter

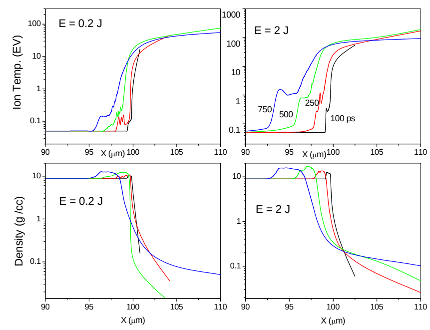

Fig.3: Spatial profiles of ion temperature and density for laser energy 0.2 Joule and 2 Joules.

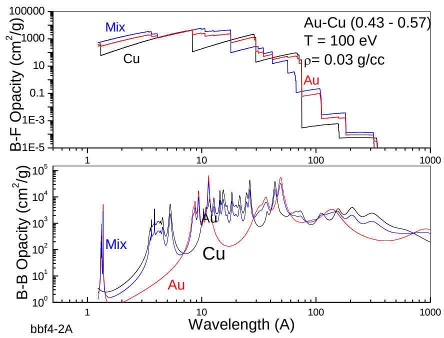

Fig. 4 Bound-Free and Bound-bound opacity of the plasma at a temperature of 100eV and plasma density of 0.03g/cc for copper (—), gold (—) and Au-Cu (—) Mixed targets.

lowest mass and lowest for gold targets having the highest atomic mass. The average ion velocity for the mixed targets should have been somewhat in between. However, it is seen that the average ion velocity in case of the mixed target is almost similar to copper at lower laser energy, but, increases to about 1.12 times higher as compared to copper and almost 1.4 times compared to gold at 1.5J. This result thus shows a higher than expected ion velocity in Au-Cu mixed targets. This observation in turn implies that ion temperature in Au-Cu mixed target is higher than in either gold or copper targets. Ion measurements also thus support our result that a higher ion temperature is attained in an Au-Cu mixed target leading to higher X-ray emission.

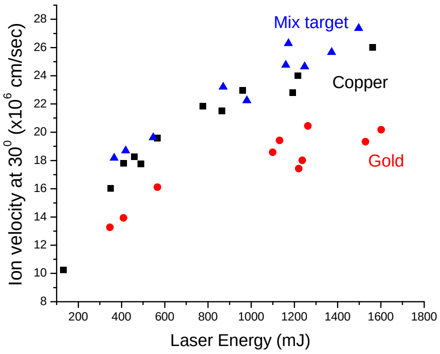

Fig. 5. Ion velocity as a function of laser energy for copper (■), Gold (●) and Au-Cu Mix (▲) targets.

5. Conclusions:

An extreme enhancement of X-ray emission from laser plasmas from a mixed alloy of gold and copper of an atomic composition of Au0.43+Cu0.57 has been reported in a narrow spectral region of 1.5Å to 3.9Å. The enhancement is 6 to 9 folds compared to copper and 1.5 to 1.8 times compared to pure gold target. These observations have been explained on the basis of an enhanced bound-bound and bound-free opacity of the plasma in the spectral region under consideration. There is an increase in ion velocity at higher laser energy also.

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