X-ray emission from Au-Sm alloy target irradiated with high power sub nanosecond laser

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Abstract: The hohlraum cavity is generally made out of gold (Au) and recently it has been shown that laser-target coupling efficiency can be increased by using cocktail or mixed targets such as gold-samarium (Au-Sm). We report here results of experiments performed on Au-Sm alloy in various spectral regions for various compositions. In these experiments, a 12 Joule/500ps Nd:glass laser has been used. It is observed that the soft x-ray emission in the spectral region 0.7 -1.56 keV is enhanced by about 40-50% by using a composition of Au:Sm::3:7 as compared to pure Au. However, in case of hard x-ray emission (3.2 -5 keV), there is a reduction in x-ray emission from Au-Sm target as compared to pure gold. This behaviour, that enhancement occurs in soft x-rays in the case of mixed Au-Sm targets is desirable in the ICF scheme.

I. Introduction:

X-ray emission from laser produced plasmas is intensively studied as a radiation source for use in microlithography [1], microscopy [2], stimulated XUV generation [3] and inertial confinement fusion [4]. For indirect drive inertial confinement fusion, it is desirable to minimize the amount of x-ray energy absorbed by the hohlraum walls (usually constructed of Au) while maximizing the amount of x-ray energy absorbed by the ICF capsule. Several materials have been used for hohlraum cavity with the aim of increasing the coupling efficiency of the laser target. Computational simulations indicate that the energy lost into the hohlraum walls in National Ignition facility (NIF) ignition target could be reduced by a significant amount when the Au was replaced by a cocktail target consisting of mixture of two or more high Z- elements [5]. The Rosseland mean opacity [6] is used to describe radiation transport in optically thick materials when the matter and radiation are in thermodynamic equilibrium. It is defined as a weighted harmonic mean of the energy dependent opacity:

\[
K_f = \frac{1}{\int_{0}^{\infty} (\partial B_\nu / \partial T) d\nu} \int_{0}^{\infty} \left( \frac{\partial B_\nu}{\partial T} \right) d\nu
\]

Here \( T \) is the radiation and material temperature, \( B_\nu \) is the blackbody spectrum, and \( k_\nu \) is the frequency-dependent opacity. The basic idea of using mixtures of two or three high Z materials is that regions of the x-ray spectrum for which Au opacity is relatively low can be “filled in” by mixing Au with complementary materials having a relatively high opacity in these spectral regions or in other words, such blending of materials results in the high opacity regions complement low opacity regions of the original material (Au). Typically the hohlraum cavities made of pure Au are heated to a temperature of
about 200-300 eV. There are significant windows in the opacity at energies around peak of black body spectrum and the mean opacity is dominated by the regions of low opacity in the frequency-dependent opacity. Various combinations of elements such as gold-gadolinium (Au-Gd), gold-Samarium (Au-Sm), gold-Neodymium(Au-Nd),Gold-copper(Au-Cu) etc have been proposed [7-9]. Experiments have been done with Au-Cu alloy which exhibit enhancement of soft x-ray [10], and hard x-ray [11] emission. Ion dynamics of Au-Cu alloy also has been studied along with individual Au and Cu [12] and shows that increase of plasma temperature in the case Au-Cu alloy.

In this paper, we present a comparative experimental study of x rays emitted from pure gold and a mixture of Samarium gold target, in the two ranges of wavelength- 0.7 to 1.56 keV, where Sm is having peak absorption and 3.2- 5 keV where Au is having peak absorption band.

II. Experimental set-up: The experiments were performed with our home built Nd:glass laser system ($\lambda$=1.06µm) which is capable of producing 12 J energy per pulse[13]. The laser system used consists of a commercial oscillator (100mJ/300-800 psec) followed by two 19 mm x 300 mm Nd:Glass amplifiers pumped by six xenon filled flash lamps, two 38 mm x 300 mm and one 50 mm x 300 mm Nd:Glass amplifiers pumped by twelve xenon filled flash lamps each, a spatial filter to smoothen spatial non-uniformity and an optical relay to beam expansion. Spatial filter is placed in between second and third stage of the chain and an optical relay system is placed between fourth and fifth amplifier stage. And two Faraday Isolator to protect any back reflection which can cause damage to the optics and laser oscillator. The laser system was operated in a single shot mode with maximum energy up to 10 J per pulse and pulse duration of 500 psec. The schematic of laser system is shown in figure 1. A $\lambda/2$ wave plate is used at the end of laser chain to rotate the polarization of the laser beam according to experimental requirements. The mirrors M3, M4 and M5 are used to generate optical delay in beam which is required in some experiments for the synchronization of laser beam with diagnostics. High power laser is focused with $f/5$ lens in a chamber evacuated to $4\times10^{-5}$ mbar of the intensity of the order of $10^{13}$ to $2 \times 10^{14}$ W/cm². Laser was incident normal to the target. Silicon semiconductor diodes (XUV100, by UDT sensor) were used for x-ray flux measurement. To measure the soft x-rays, the AXUV detector is covered with a B10 filter (transmission >0.9 keV) was placed at an angle (θ = 45°, φ = 55°) with respect to target normal at a distance of 40 cm and other AXUV diode was covered with 2 μm Al filter (transmission (0.7-1.56 keV and >2.1 keV) was placed at angle (θ = 45°, φ = 80°) with respect to target normal at a distance of 36.2 cm. where θ is the angle between the target normal and detector in vertical plane and φ is angle between target normal and the detector in horizontal plane. For harder x-ray measurements, a detector covered with 12 μm Ti filter (transmission 3.2 -4.96 keV) was placed at 45° and at a distance of 65 cm. The diode detectors are operated in a time

![Figure 1. Schematic of experimental set-up for measurement of x-ray emission from Au-Sm alloy.](image-url)
integrated mode. The details of the diodes detectors are described elsewhere [14]. The Au and Sm as well as Au-Sm mixed targets were prepared by using powders containing micro particles. These powders were compressed using a polymeric binder to form Au, Sm and Au-Sm pellets of different compositions. The half inch diameter pellets were made by applying two ton weight to the appropriate mixtures of Au and Sm powders, containing 100 micro liters of aqueous 2% polyvinyl alcohol solution as binder per gram of the metal powder mixture. This method could easily provide the pellets of almost any required composition with reasonable structural stability could be obtained by this method. Pure gold and pure samarium pellets as well as pellets with Au : Sm atomic weight ratios of 3:7, 5:5 were used in the experiments.

III. Results and discussion:

Numerical simulation in support of this experiment has been done. Numerical simulations of laser plasma interaction experiments involve the absorption of laser light by target, its conversion into x-rays and its redistribution by multiple absorption and re-emission, and finally the hydrodynamics of the laser produced plasma. The two requirements for these simulations are computations of the frequency dependent radiation opacities and radiation hydrodynamics. Radiation opacity as a function of x-ray photon energy in the range of our experiments is shown in figure 2. It is seen that the opacity for the gold and samarium show their complementarities i.e peak of one coincides with the valleys of the other. The spectrum of Sm consists of two peaks due to M-shell and N-shell transitions corresponding to photon energies- 1.1-1.6KeV and 0.2-0.6KeV respectively. The N-shell band emission of gold at about 0.8KeV falls in between the two, thus blending the opacity spectrum. Thus it is expected that the Rosseland mean opacity of the mixture should be greater than the individual Rosseland means leading to enhance x-ray emission. This is confirmed by our simulations. In figure 3 we show the Rosseland mean for the mixture as a function of gold fraction. Opacity is calculated for the entire spectrum. The plasma density is 0.1 g/cc and temperature is 200 eV. The mean is normalized to the pure gold value. Square marker points in this figure are the values taken from the paper of Wang, MacFarlane and Orzechowski [15]. Our results slightly over predict the Rosseland mean of the mixture as compared to Wang et al. (1997). However, at higher temperatures, the trend changes and our model under predict the mixture means. It is evident that the opacity is maximized for a mixture having a composition between 0.5 to 0.7 fractional density of Au.

The x-ray emission from the pure Au, pure Sm and various composition of Au-Sm targets were experimentally studied by using three AXUV detectors covered with x-ray filter foils- 2 μm Aluminum foil, B10 foil and the 12 μm thick Titanium foil. X-ray transmission through these filters is shown in Fig.4. The x-ray emission as function laser energy for the above filters are shown respectively in Fig. 5, 6 and 7. Fig. 5 shows x-ray emission in the spectral window 0.7 – 1.56 keV and above 2.1 keV. The x-ray yield is seen to increase with addition of Sm to Au, as compared to pure Au. Soft x-ray yield measured with B 10 foil is shown in Fig. 6. It is observed that the difference in x-ray yield in Au-Sm compared to pure Au is higher with the detector covered with B10 filter than with the Al filter. This can be explained on the basis that when the Al filter is used over the detector, x-ray transmission starts after 0.7 keV where Gold is also having a strong peak and hence difference in Au-Sm and Au could be reduced. However, while a B10 filter foil is used on the detector, transmission starts from 0.9 KeV, the gold peak reduces and the dominating Samarium peak is present. Therefore, this can result in a substantial increase of x-ray emission when Sm is mixed with Au as compared to pure Au, as
observed in Fig.6. For example, ratio of x-ray signal $I_\text{X}(\text{Au-Sm})/I_\text{X}(\text{Au}) = 2$ for B 10 filter and is 1.5 when an Al filter is used. In both cases the laser energy is fixed at 9 J. However, in case of hard x-rays (3.2-4.96 KeV) detected using the Ti filter, as shown in Fig.5, Au shows a higher x-ray yield than all the compositions of Au-Sm. This observation is expected as seen from Fig.2, where it is clearly seen that Au has a strong emission in the range 3-5 KeV as compared to Sm. Fig.3 shows a lower opacity for Sm as compared to Au. This is opposite of what we observe in experiment, where pure Sm exhibits a higher x-ray emission for all three filters. This can be explained due to the fact that all filters cut off the strong x-ray emission of Au in the energy range <0.9 KeV and measures the strong emission band of Sm between 1-2.0 KeV.

Figure 2. Radiation opacity as a function of photon energy for gold and samarium at representative temperature and density.

Figure 3. Rosseland mean opacity as a function of fraction of gold in mixture at a temperature 200 eV and density 0.1 gm/cc.

Figure 4. Transmission curves of 2 µm Aluminum, B 10 and 12 µm Titanium filters used in experiments.

Figure 5. X-ray intensity with laser intensity measured with AXUV diodes covered with Al filter for various compositions of gold and samarium.
Conclusion: The studies on the x-ray emission from Au, Sm and Au-Sm mixture with various compositions have been studied with a high power sub-nanosecond Nd: glass laser capable of producing focused intensity of the order of 10¹⁴W/cm². It is observed that the soft x-ray emission in the spectral region 0.7 - 1.56 keV is enhanced by about 40-50% and there is almost a 100% enhancement for x-ray emission at >0.9 keV (B10 foil filter), by using a composition of Au:Sm:: 3:7 as compared to pure Au. However, in case of hard x-ray emission (3.2 - 5 keV), there is a reduction in x-ray emission from Au-Sm target as compared to pure gold. This behaviour, that enhancement occurs in soft x-rays in the case of mixed Au-Sm targets is desirable in the ICF scheme. Enhancement in the hard x-rays may not be beneficial, which may result in ICF target pre-heat. The experimental results are consistent with the theoretical estimates of the radiation opacities in the energy range of our experiments.

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