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K-α Radiography at 20-100 keV Using Short-Pulse Lasers *

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Abstract. X-ray radiography is an important tool for diagnosing and imaging planar and convergent hydrodynamics phenomena for laser experiments. Until now, hydrodynamics experiments at Omega and NIF utilize $E_{x\text{-}ray} < 9$ keV backlighter x-rays emitted by thermal plasmas. However, future experiments will need to diagnose larger and denser targets and will require x-ray probes of energies from 20-100 keV and possibly up to 1 MeV. Hard K-α x-ray photons can be created through high-energy electron interactions in the target material after irradiation by petawatt-class high-intensity-short-pulse lasers with $>10^{17}$ W/cm^2. We have performed several experiments on the JanUSP, and the Vulcan 100TW, and Vulcan Petawatt lasers to understand K-α sources and to test radiography concepts. 1-D radiography using an edge-on foil and 2-D radiography using buried wires and cone-fiber targets were tested. We find that 1-D thin edge-on foils can have imaging resolution better than 10 μm. Micro volume targets produce bright sources with measured conversion efficiency from laser energy to x-ray photons of $\sim 1\text{x}10^{-5}$. This level of conversion may not be enough for 2-D point projection radiography. A comparison of our experimental measurements of small volume sources with the LSP/PIC simulation show similar K-α creation profiles but discrepancy in absolute yields.

1. INTRODUCTION

There are many new classes of laser experiments planned at NIF or Omega-EP that involve larger and denser targets than the ones used for previous experiments. Such research includes the study of

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material strength and EOS under high pressure, mid to high Z capsule implosion experiments, and studies of high ρR cores for the double-shell experiments. These experiments need x-ray backlighter energies of 20-100 keV for diagnosing and imaging laser induced implosions. An efficient high-energy x-ray radiography source can be created using an ultra-high-intensity laser, which produces high-energy non-thermal x-rays from interactions between relativistic electrons and cold target atoms. These electrons produce K-α fluorescence emission in any mid-to-high Z solid, and these 20-100 keV x-rays can be used as semi-mono energetic backlight sources for radiography. The construction of a multi-kJ, 1-10 ps Petawatt laser is planned for high-energy x-ray radiography applications at NIF and Omega-EP.

However, we do not currently have a firm understanding or a model that predicts K-α x-ray source parameters for experimental conditions of interest. Previous [1-4] K-α generation experiments utilized low energy lasers that created a low intensity and fluence environment. A few experiments with the Nova Petawatt laser[5-6] were able to reach 1×10^{19} W/cm^2 but K-α studies were limited to lower Z materials (Mo K-α at 17.5 keV). In particular, the physics of relativistic electron generation and propagation affecting K-α production when transitioning from sub-ps low fluence conditions used in current experiments to the tens-of-ps high fluence conditions envisioned for NIF remains unexplored. While studying physics issues such as x-ray conversion efficiencies, source sizes, spectral bandwidths, and dependencies on laser intensities and target thickness, we are trying to optimize the source towards workable high-energy radiography levels.

2. K-α SOURCE SIZE

The required spatial resolution for the next-generation laser experiments is better than 10 μm. If we want to apply point projection imaging, we will need an x-ray source smaller than 10 μm. Our initial measurements performed at the RAL petawatt and JanUSP lasers, however, show that the typical K-α source size is ~60 μm [7] even though the actual laser spot size is < 10 μm. Fig. 1 shows a pinhole

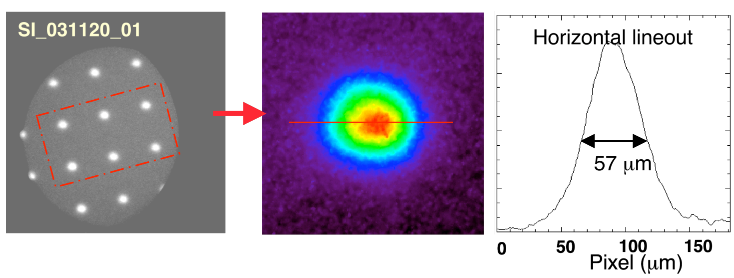

Fig 1. 22 keV Ka source size measured bya pinhole array

image of the 22 keV Ag K-α source from the Vulcan petawatt laser where the measured FWHM of the x-ray spot size is 57 μm. The x-ray sizes are considerably larger than the laser spot size of <10 μm, due to the large spreading of the relativistic electrons. As a demonstration, we also performed a point projection radiograph of a 3 mm outer diameter, 25 μm thick Au hohlraum and knife-edge radiography. The spatial resolution of these images is ~60 μm as measured from their edges. This result implies that high resolution imaging using a simple thick foil cannot be achieved.

3. HIGH RESOLUTION 40 keV 1-D RADIOGRAPHY USING THIN EDGE-ON FOIL

Higher spatial resolution can be achieved if we can confine the x-ray radiation in a small volume that is smaller than our desired spatial resolution. As a first attempt, we tested a 1-D radiography concept that uses a very thin (<10 μm) and small (100x100 μm) Samarium foil as the laser target and custom made Ta resolution slits as the radiography object.. These experiments were performed using the short pulse petawatt laser at Rutherford Appleton Laboratory, UK. A schematic of the experimental setup

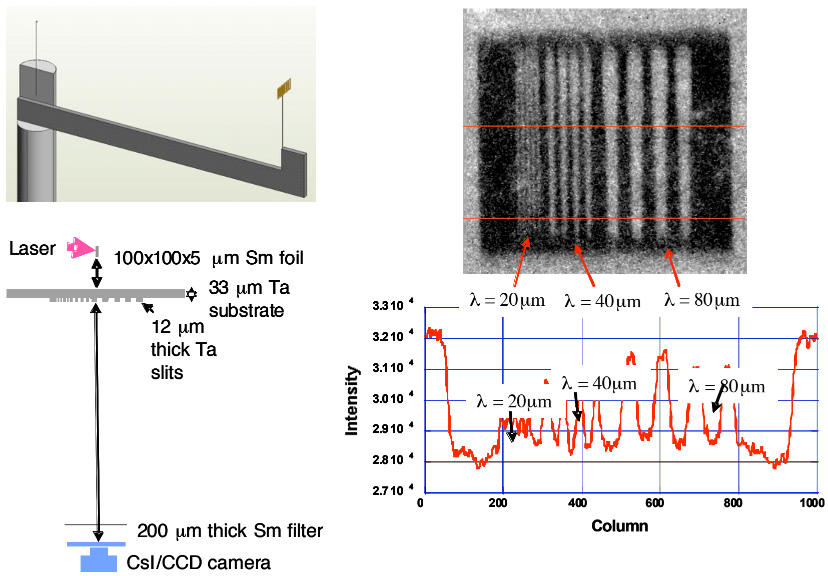

Fig 2. Experimental setup of 40 keV 1-D radiography and resulting radiography image of a Ta resolution slits.

is shown in Fig 2. The laser energy on the target was 65 J with an intensity of 6 x 10^{18} W/cm^2. The imaging detector was a CCD camera that has a CsI(Tl doped) scintillator glued onto the CCD. The resulting image is shown in the second panel of Fig 2. For the 1-D analysis we average the intensity values along the slit direction; the resulting lineout is shown below the image. Similar analysis was done for different detectors and different radiography targets. From this data we found that the MTF is ~0.2 for the 20 μm period patterns. When we optimize the configuration of the laser, target and the detector we expect to easily achieve an MTF greater than 0.5 for the 20 μm period features in the NIF or Omega-EP experiments.

4. MICRO VOLUME TARGETS FOR 2-D POINT PROJECTION RADIOGRAPHY

Extending our observation that high energy x-ray sources can be confined within the target volume, we made many small wire targets buried in different geometric shapes to create a small point source for 2-D radiography. The tested geometries were a 100 μm Cu wire embedded in an Al substrate, a cone with a wire tip, a flag stalk, and a V-shaped Al substrate with a wire end. One example of Cu Kα crystal imaging of these targets is shown in Fig 3. From this data we see that the Kα emission is mainly from the initial hot electron interaction region. This implies that shorter wires will not degrade the total yield of Kα photons enabling us to create a small point source. We also had the HOPG spectrometer and a single photon counting camera for these targets. By combining their data sets, we observed that the smaller volume targets are generating a brighter source and the variation of total Kα yield from different geometric shapes is within a factor of 2.

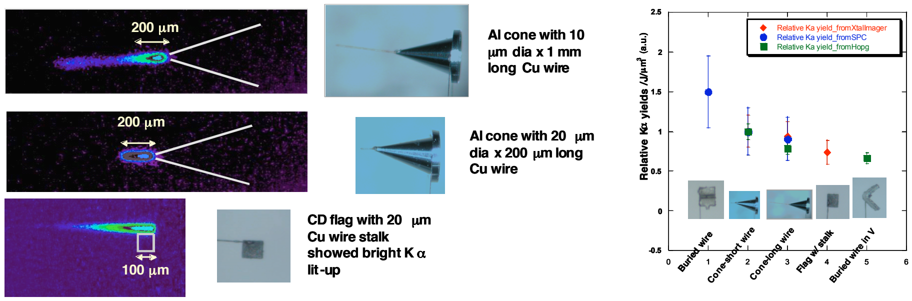

Fig 3. Cu K-α crystal images of cone/wire and flag targets (left). Right panel shows the relative K-α yields for various micro volume sources.

We also measured the absolute Kα yield using the single photon counting camera data. From this absolute yield, we estimate the conversion efficiency from the laser energy to Kα photons for the short cone/wire target to be $1x10^{-5}$. While we still need to understand the laser coupling efficiency, hot electron conversion efficiency, and radiation transport issues from all these different shapes, $1x10^{-5}$ level is too low for 2-D radiography to have 10 µm resolution for the NIF experiment. We are now investigating options to make more efficient targets.

5. LSP/PIC Simulation

In order to understand the physics issues associated with short-pulse high-intensity laser interactions in a small volume, we began to utilize integrated modeling. The integration is done by combining outputs from Lasnex for hydrodynamics, Explicit PIC (Z-3) for laser plasma interactions, Implicit PIC

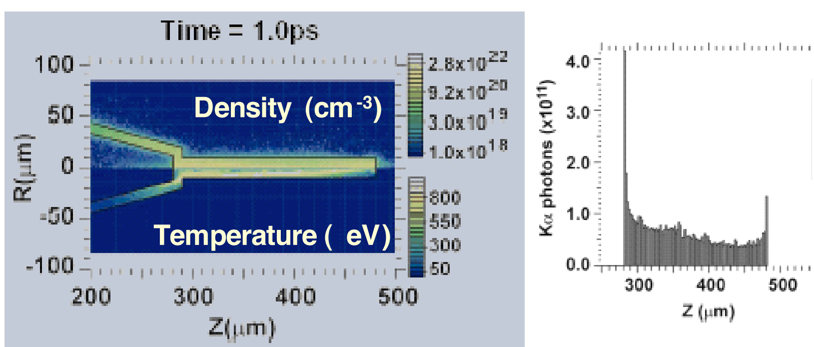

Fig 4.LSP/PIC simulation of cone/fiber target

(LSP) for electron transport, and FLYCHK for NLTE atomic physics, DRAT for radiation line transport. Figure 4 is the results from LSP simulation for the cone/wire target that we tested as a micro source target. The density and temperature profiles qualitatively follow the same as our data; however, the K-α absolute yield and the spatial distribution is ~a factor of 10 different. We plan to further enhance our modeling capability so that we can utilize its output to optimize and understand radiography targets.

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