poor utilization of available power which results in lower guiding velocity. Focussed super continuum beam is not suitable for guiding biological objects because the extended spectral range leads to concern about absorption induced damage. Laser Bio-Medical Applications and Instrumentation Division of RRCAT has shown that an aspheric holographic optical element (axilens), which combines the long depth of focus of axicons and the good light collection efficiency of a spherical lens, can lead to significant enhancement in the guiding distance without much compromise on the guiding velocity.

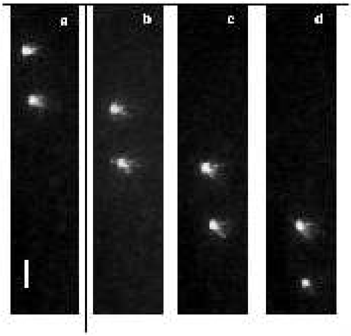

Fig.L.15.1. Guiding of two 6 µm PS microspheres inside the focal region of a holographic axilens. The laser beam direction appears as from top to bottom. The microspheres were imaged using the laser light scattered by them. With the optics used, the size of the image of the particles on the camera was ~ 16 µm. Successive frames are separated in time by 4 s. Scale bar is 45 µm long.

A holographic axilens was generated by applying an appropriate phase hologram pattern on a spatial light modulator (SLM, LCR-2500 Holoeye Photonics). The output of a 532 nm, cw laser source (Verdi, Coherent Inc) was focussed using this axilens onto a glass cuvette containing ~ 6 µm polystyrene (PS) spheres suspended in aqueous medium. The sample was imaged using a combination of a 10X microscope objective and a CCD camera. Fig.L.15.1 shows guiding of two PS microspheres. The bright spots correspond to the laser light scattered by the microspheres. Fig.L.15.2 shows the measured variation of guiding velocities along the direction of the transport of the particles when a holographic axilens or a spherical lens of identical focal length (~ 200 mm) were used to focus the beam. The beam powers (~100 mW) was also kept same for this experiment. Compared to the use of a spherical lens, a factor of ~ 2.5 larger guiding distances was achieved using the axilens. Although the peak guiding velocity was ~ 35 % less with axilens, the guiding velocity was more uniform over the distance of transport. The observed guiding distance (~ 10 mm) using axilens is significantly longer than that reported previously (~ 3 mm).

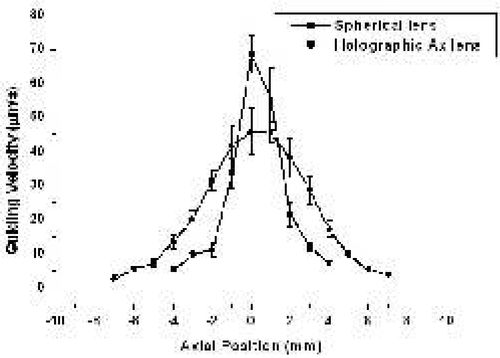

Fig.L.15.2. The guiding velocities vs axial position plot inside the focal region of a holographic axilens and a spherical lens.

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L.16 : Narrow band x-ray emission in the water-window spectral region

X-ray sources in the water-window region (23–44 Å) are of particular interest for imaging of live biological samples with high contrast, as in this range, the water present in the sample offers very little absorption to the radiation compared to the other major constituents like carbon. Laser produced plasmas, on account of their high peak brightness, can provide sufficient exposure in a single radiation pulse of short duration (nanosecond or smaller). This facilitates imaging of the sample in a single shot which is advantageous as it prevents any degradation to resolution due to motion blurring, as well as radiation induced structural changes in the sample which manifest over a longer time scale.

Laser irradiated gas and liquid jets have been used to produce narrow band line emission in the water-window spectral region, and they are accompanied by little or no plasma-debris. However they have rather poor conversion of laser energy to x-rays. On the other hand, the use of high-Z solid targets and short wavelength lasers as the driver for producing a laser-plasma x-ray source of high conversion efficiency is well established. More recently, novel targets have been explored such as nanostructure targets and mix-Z targets for enhancement of the x-ray emission. A debris-free x-ray radiation in the water-window spectral region can be obtained from these plasmas by using them along with either multi-layer x-ray mirror or narrow band x-ray filters. Free-standing x-ray filters will have the advantages of a simple geometry and they are available with good transmission (≥10 %) over a narrow spectral band. X-ray imaging using broad-band radiation within the water-window spectral region may also lead to a poor contrast and a lower resolution in the recorded image. This may even forbid precise quantitative analysis of the recorded x-ray images. It is therefore desirable that an x-ray source in the water-window range should have a narrow spectrum for live sample imaging.

At Laser Plasma Division of RRCAT, a narrow band x-ray source in the water window spectral range at 25 Å $\pm$ 1 Å (i.e. 24 – 26 Å), has been made. The source was produced by focussing second harmonic of a glass laser (4J, 3ns) to an intensity of ~ 10^{13} W/cm^2 on a 50-50 (atomic fraction) copper-gold mix-Z target, filtered through a 0.4 µm aluminium / 0.9 µm vanadium free-standing x-ray filter. It provides a high transmission over a narrow spectral band starting from λ ~ 24 Å (corresponding to the L-edges of vanadium) with a peak transmission of ~ 9.4 %. A typical x-ray spectrum from gold-copper mix-Z plasma, transmitted through this filter is shown in Fig.L.16.1. The purpose of using mix-Z target was that these targets are very good soft x-ray converters [J.A.Chakera et al, *Appl. Phys. Letters* 83, 27, 2003]. The x-ray spectrum and the energy flux were measured at two angles viz. 45° and 85° from the target normal using a transmission grating spectrograph and calibrated xuv p-i-n diodes. The angular distribution of the radiation intensity is usually fitted to a form $I_\theta = I_o \cos^n\theta$, where I_o is the intensity in the direction of the target normal, θ is the angle between the direction of observation and the target normal, and 'n' is the scaling exponent whose value lies in the range $0 < n < 1$. In our case, a scaling exponent of 0.23 was obtained. From this value of the scaling exponent, the x-ray conversion of the plasma in the 24 -26 Å spectral range, integrated over full solid angle, turns out to be ~ 4.9 %. An x-ray yield of ~ 3 mJ /sr is observed in the direction of 45° from the target normal in the narrow spectral range of 24 -26 Å. This x-ray flux is sufficient for single shot x-ray imaging of live biological samples with high contrast. [For more details, please see : J. A. Chakera, S. R. Kumbhare, P. A. Naik, and P. D. Gupta, *Applied Phys. B 86, 510, 2007*].

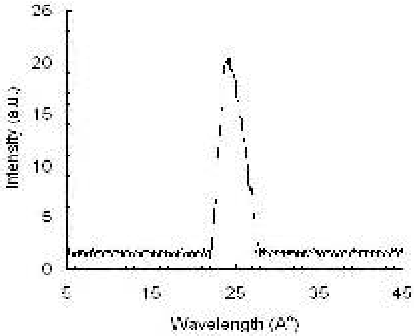

Fig.L.16.1 : A typical x-ray spectrum from gold-copper mix-Z plasma, transmitted through the narrow band filter

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L.17 : Sub-MeV bremsstrahlung x-ray emission from intense laser-plasma interaction

Ultrashort duration terawatt laser pulses when focussed to an intensity > 10^{18} W/cm^2 interact with matter to produce high energy electrons with energies beyond MeV. The high energy electrons produced from solid targets may result in production of intense hard x-rays via bremsstrahlung process and high energetic particles through secondary interactions. Owing to the unique features of these sources, they may be used for applications in both basic sciences and technology. Although these sources are interesting, they also pose potential threat of radiation hazard to the experimentalists routinely working with such laser systems. In the context of both the applications and radiation hazard, it is imperative to have knowledge of the radiation dose and its angular distribution outside the interaction chamber. Moreover, it is desirable to identify and characterize all sources of radiation to take necessary safety measures.

Laser Plasma Division of RRCAT has carried out detailed measurements of the radiation dose produced due to the interaction of Ti:sapphire laser pulses (45 fs, 150 mJ) focussed on a solid planar copper target at a laser intensity of 1.3×10^{18} W/cm^2. The schematic of the experiment is shown in Fig.L.17.1.

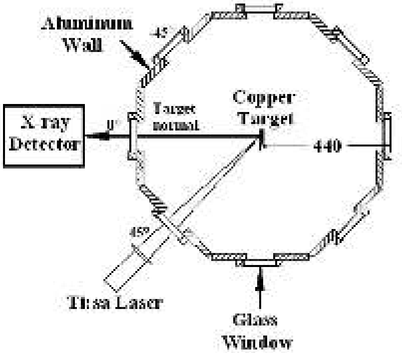

Fig.L.17.1 : Schematic of the experimental setup

In the present experimental conditions, fast electrons with temperature of ~200 keV can be produced along the target normal direction by the process of resonance excitation of plasma wave and wave breaking. Initially, the fast electrons escape the interaction region along the target normal direction leaving behind intense space charge fields which then pull back the remaining outgoing fast electrons in to the target resulting in bremsstrahlung hard x-rays. Hard x-rays with energy ≥ 40 keV can pass through the 10 mm glass windows distributed at 22.5° angular intervals in the laser incident plane. The dose due to this hard x-ray radiation was measured with radiation detector (Victoreen, 450 P) outside