L.4: Short pulse laser based K-α x-ray source for time resolved x-ray diffraction

The K-α radiation produced by the interaction of ultra-short, ultra-intense laser pulses has been a subject of considerable importance for potential applications in studying the time evolution relevant to material science, or as a backlighter source for probing high density matter. The x-ray line radiation of photon energy 1–8 keV is more suitable as probe for backlighting of materials for optimal contrast as well as for time resolved x-ray diffraction studies. The efficiency of the emitted K-α radiation is determined by the energy distribution of the hot electron in the plasma and their propagation into the target. This, in turn, depends on parameters such as laser beam intensity, laser pulse duration, pre-pulse level, wavelength, polarization, and the angle of incidence.

Recently, a study on the optimization of a laser generated x-ray source of ultra-short duration K-α line radiation has been carried out at the Laser Plasma Division of RRCAT. The source was created by the interaction of pulses from a Ti: sapphire laser system (10 TW, 45 fs, 10 Hz) with a solid target surface. The x-ray yield was optimized (at a fixed laser fluence ~ 3.8×10^{4} J-cm^{-2}) with the laser pulse duration. The latter was varied by changing the distance between the compressor gratings. It showed a maximum at laser pulse duration of 740 fs, 420 fs, 350 and 250 fs for Mg (1.3 keV), Ti (4.5 keV), Fe (6.4 keV) and Cu (8.05 keV) targets respectively. The measured spectra were identical for both positive and negative chirp, indicating that the K-α generation process does not depend on the laser pulse shape. The laser to x-ray energy conversion efficiency for various targets is shown in Fig. L.4.1. The highest conversion efficiency of 3.2×10^{-5} was estimated for Ti K-α. For Fe K-α, it was 2.7x10^{-}5, whereas for Mg K-α, it was only 1.2×10^{-5}. The lower x-ray conversion efficiency for Mg Kα- is due to lower fluorescence yield. The smaller conversion for Cu (1.85×10^{-5}) is attributed to the requirement of much higher energy for K-shell excitation of high-Z materials.

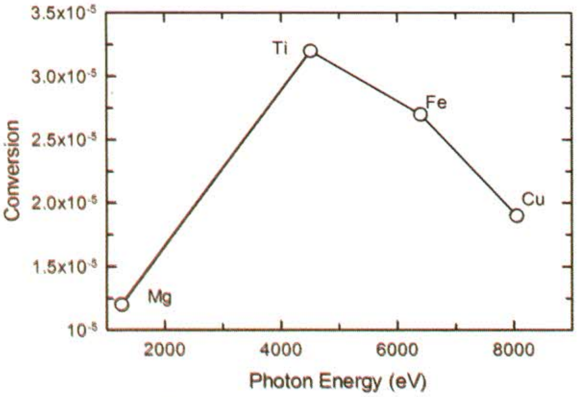

Fig. L.4.1: The highest K-α x-ray conversion efficiency η_x for Mg, Ti, Fe, and Cu, for a fixed laser fluence

As an application, the x-ray source was used for measurement of shock-wave profiles in a silicon crystal by time resolved x-ray diffraction, using Ti K-α x-ray line radiation as the probe pulse. A part of the stretched pulse (800 nm, 200 ps) was used as pump to irradiate a 500 μm thick flat Si (111) crystal sample at an intensity of 6 GW/cm^{2}. The remaining pulse created the Ti K-α x-ray pulse, which was used as the probe pulse. The time delay between the pump laser pulse and the probe x-ray pulse was adjusted by an optical delay line. Fig. L.4.2 shows the variation of the broadening of the Ti K-α line with the time delay between the pump and the probe pulse. It is observed that the diffraction pattern broadens with increasing delay to reach a maximum. Thereafter, the K-α_1 width decreases and comes close to the pristine (undisturbed) value.

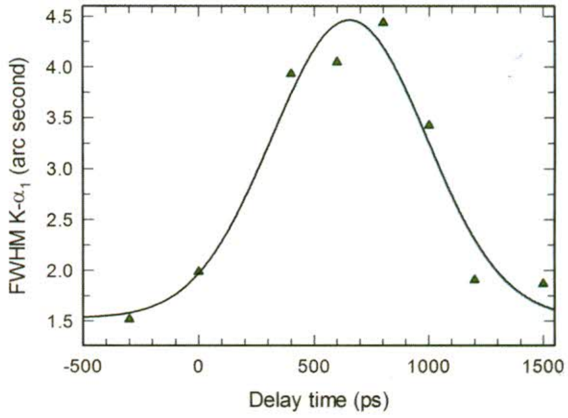

Fig. L.4.2. Variation of the FWHM of the Ti K-α_1 line radiation as function of the delay between the pump and the probe pulse.

It can be seen that maximum broadening occurs at 650 ps, which corresponds to the time when the shock wave propagating through the sample reaches the x-ray penetration depth. The reduction in the broadening of the K-α peak is either due to the reduction in the compression wave pressure within the penetration depth of the probe x-rays in the sample, or due to the passing of the shock wave beyond the maximum probe depth inside the crystal. The performance of the x-ray source for measurement of shock-wave profiles in a silicon crystal demonstrates the capability to perform high resolution time resolved studies using a tabletop setup.

For more details, please refer to V. Arora et al., AIP Advances 4, 047106 (2014).

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