A K-alpha Imaging Crystal diagnostic for CLF

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Introduction

Laser interactions with matter are routinely diagnosed by measuring K-alpha x-rays emitted from plasma sources. Spherically curved imaging crystals combined with an x-ray detector (usually either image plate or x-ray sensitive CCD's) are one way of detecting the number and position k-alpha x-rays from within plasmas. This is an extremely useful method for collecting information on plasma conditions such as electron transport in plasma[1,2,3].

The CLF identified a gap in this area of x-ray diagnostics and has now developed an imaging K-alpha diagnostic including a crystal analyser and specific mount for deployment to high power laser experiments. This enhances the suite of available x-ray diagnostics and enables support of experiments in this area where previously this was unavailable. This article reports on the design and characterization of the resulting system

Diagnostic design

The k-alpha imaging system developed consists of a spherically curved quartz crystal, 21-31 lattice structure and radius of curvature of 380mm. It has a lattice spacing of 1.541Å and at close to normal incident angle is ideal for imaging 1st order Cu K-alpha 8keV x-rays. These crystal properties were chosen to fit in with current crystals that some of our user community already have that have been successfully deployed on experiments at CLF facilities.

The system to allow alignment of the crystal consists of a crystal mount and an x,y,z drivable stage. Fig. 1 shows 3D CAD image of the crystal mount. The mount is designed to hold the central point of the crystal over the centre of the tip & tilt axes. There is a front surface lip against which the crystal substrate buts up to giving precise location (and re-location) of the crystal inside the mount. This assembly attaches on to an x,y,z drive via location dowels and has bolt holes for clamping that are also compatible with other equipment for cases where this may be required.

Tip & tilt adjustment is delivered using pico motors[4] that can be manually or electrically driven and either with, or separately from, target area drive systems giving flexibility for alignment purposes.

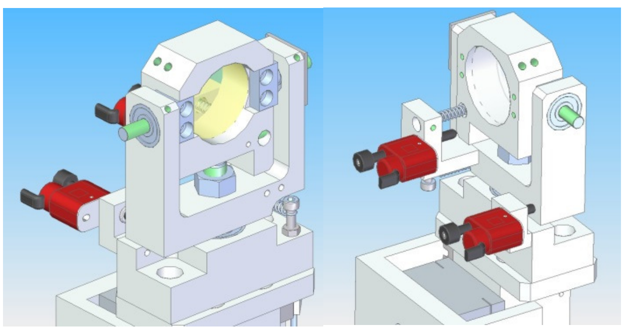

Fig. 1 3D views of the crystal mount, front and back, showing where the crystal sits against a location lip (shown in yellow).

Characterisation – Set-up

Checks that the crystal and its mount would perform to expected specification were required – both to verify the crystal works as required and also that the mount could be evaluated and any improvements identified. To test this the TAW facility was used to deliver ~100J, 10ps pulses to 20µm thick Cu targets, with a focal spot of ~4-6 microns in order to generate Cu k-alpha x-rays at 8.048KeV. TR type image plate was used as the detector. Fig 2 shows the set-up of the interaction.

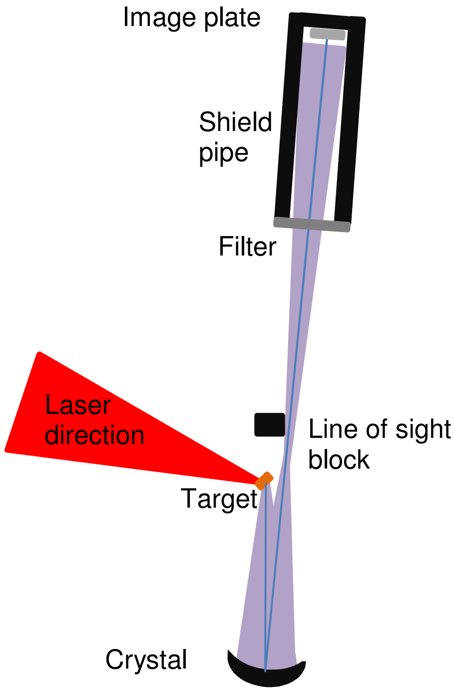

Fig. 2 Crystal imager set-up schematic. The crystal was located 204.7mm from target, the image was located 2313.25mm from the crystal.

The crystal needed to be set to the correct angle to diffract the Cu K-alpha signal and be aligned to give an image of the interaction point where the x-rays are generated. This is aligned optically initially.

To align this system a <1mW 532nm laser was used to set the image axis, crystal height and bragg angle. The crystal was set at a distance of 204.7mm from target and 2313.25mm from crystal to image plate – positions determined in part by the physical locations of the interaction chamber ports and equipment needed to hold the detector (TR image plate). This enabled a large magnification x11.3 and also put the image in a position where the image plate could be installed on the outside of the interaction chamber. The bragg angle was set to 88.7 degrees to enable imaging of Cu K-alpha radiation at 8.048 keV in first order. The large bragg angle means that the crystal is imaging nearly on axis which is very helpful for minimizing spherical and other aberrations[5].

A shielding tube, filtration and a line of sight block were installed to reduce the impact of background x-rays on the signal coming from the crystal imager. In this case at least, these were essential as the signal could not be seen without them. The crystal was protected from debris by a piece of 23µm thick mylar. Fig 3 shows the actual set-up.

Targets were set-up to be irradiated at an incident angle of 29 degrees to enable x-rays to be collected from the back surface of the target. Images of the x-ray source from the target were taken as an initial investigation with the time available.

Characterisation – Results

Initial analysis has been carried out to verify that the crystal can be used for Cu K-alpha imaging in the first instance. Details of its efficiency and absolute resolution are planned for future investigation.

Fig 4 shows an example of an image obtained from x-rays emitted from the back surface of the target. The size of this image is 440 microns wide x 610 microns tall on the image plate. Taking into account the angle subtended from the target onto the crystal (45 degrees) and the magnification (11.3), the actual width of the signal works out at 54 x 54 microns ±5 microns.

An offset between the x-ray and optical image positions can exist for spherically bent crystals due to slight changes in the lattice spacing layers that occurs during crystal manufacture[6]. This is offset different for each crystal and was measured to be 7.15 ± 0.8mrad for the crystal used in this case.

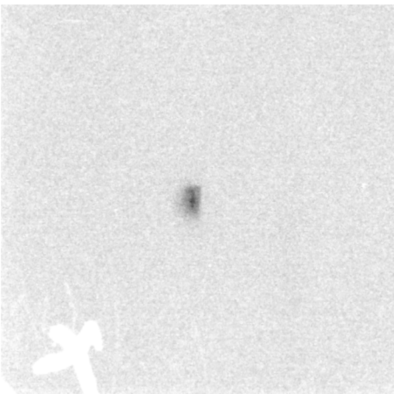

Fig. 4 Image of Cu K-alpha emission from rear surface of 20µm thick Cu target, ~250 x 350 pixels

The mount designed for the crystal has been assessed.. Repositioning testing shows that relocates stably onto the x.y.z it was used with the output image from the input line off the crystal to output did not move, over the distances in this case, when the mount was removed and replaced and number of times. The crystal locates easily inside the mount, the lip engineered in giving a good referencing point. Sensitivity of the pico motors is adjustable to a variety of set levels when driven electrically. Speed ranges are available for macro and micro motion with a minimum step motion of 30nm (0.6mrad). Overall when used the mount was robust and performed well.

Conclusions

CLF have designed and characterized a new k-alpha imaging diagnostic as a prototype. The diagnostic has been evaluated and a few modifications suggested for the future to enhance the design of the mount. A second mount is to be produced to enable two of these diagnostics to be available to CLF community users enhancing the suite of x-ray diagnostics available.

The crystal itself has been shown to work at the x-ray energy of interest and its bragg offset measured. Further examination is planned to ascertain the crystal efficiency and resolution.

References

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