Ni-like Mo X-ray lasing on Astra

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Introduction

The grazing incidence pumping scheme has been a major advance in the development of X-ray lasers since its initial demonstration of saturation in 2005 [1]. This technique uses the main heating beam at a grazing angle from the target surface, to allow energy deposition at the gain region [2]. This has reduced the energy required to pump the laser from many ten's of joules, to allow saturated lasing pumped by <1J of energy on target. Such small pump laser energies can enable industrial and other uses of short wavelength lasers not possible with expensive 4th generation light sources.

We report measurements of the saturated output of the Ni-like Mo X-ray laser on Astra and discuss the optimum pumping conditions.

Experimental Arrangement

This experiment took place on the Astra facility at the Rutherford Appleton Laboratory. A 60/40 beam splitter was employed to split the Astra beam into two paths, with the energy in favour of the long pulse. The background pulse was of duration ~500ps with peak irradiance on target of ~6×10^{11}W/cm^2 for a 4mm line focus. The short pulse was of ~240fs duration, with ~5×10^{14}W/cm^2 peak irradiance for the same 4mm line focus. The long pulse line focus was created by a spherical lens/cylindrical lens combination, whilst the short pulse was focused to a line using an on-axis parabolic mirror with a focal length of 76.2cm. These two beams were then overlapped on the target to produce a line focus of ~4mm × 50µm.

The targets used in this experiment were solid slabs of Mo of 1mm thickness and of various lengths. The primary diagnostic used was an imaging flat-field spectrometer with a 1200 lines/mm aperiodically ruled grating to image the X-ray laser onto a CCD or streak camera. The Axis-photonique streak camera, with a KI photocathode, giving a temporal resolution of <1ps was used in this experiment to measure the temporal output of the laser. The spectrometer recorded the second order diffraction with a CCD when the streak camera detector was in use. A gold mirror was placed within the body of the spectrometer, after the grating, in order to reflect the second order lasing lines to the CCD camera. This arrangement enabled both time resolved and time integrated X-ray laser output to be simultaneously measured. A crossed-slit camera was used to monitor the line focus length, uniformity and the overlapping between the two pulses. This then allowed adjustments to be made to the lenses and parabola to ensure good overlapping of the pulses.

Results

In order to optimize the energy output of the Mo X-ray laser, a number of parameter scans were undertaken. Grazing angles on target of 14°, 17° and 20° were investigated. At these grazing incidence angles, scans of target length were carried out, along with measurements of the optimum delay between the long pulse and short pulse.

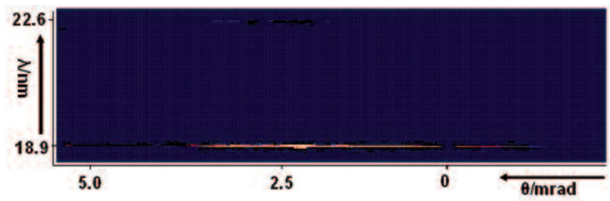

Figure 1. Flat-field spectrometer image showing the 18.9nm 4d-4p lasing line of Mo. Also visible is the second 4f-4d lasing line at 22.6nm.

The flat-field spectrometer showed strong lasing from the 4d-4p line of Mo with the weaker, second 4f-4d lasing line also visible. Figure 1a shows a typical image of the 18.9nm lasing line, with the second lasing line at 22.6nm. Typical divergence angles at full width half maximum were ~3-7mrad with pointing angle of ~2-9mrad. Figure 2 shows the output from the second order spectrometer, taken from the same shot as figure 1. Whilst the first order flat-field CCD detector was in use, it allowed a calibration to be made between the two orders.

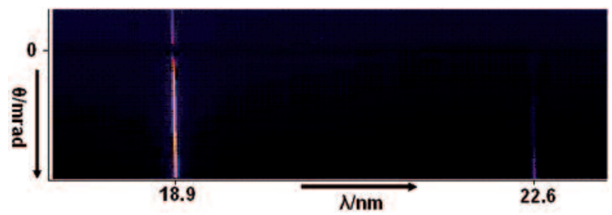

Figure 2. An image from the second order flat-field spectrometer, which clearly shows both the 18.9nm and the 22.6nm lasing lines of Mo.

The X-ray emission produced along the line focus was monitored by the crossed-slit camera. Figure 3 shows the long pulse line focus emission for a parabola grazing angle of 14°. From figure 3 it is possible to see that the intensity along the line focus was not uniform, which was a problem suffered throughout the experiment. However, it was seen that sufficiently uniform irradiation along the line focus could be achieved when a target shorter than the line focus was used, so that both ends of the line focus overlapped the target.

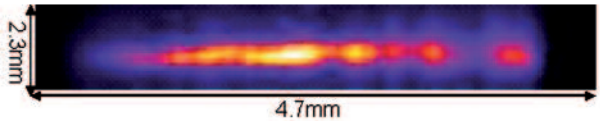

Figure 3. Image taken from the crossed-slit camera of the long pulse line focus for a grazing angle of 14°. This line focus has dimensions 3.2mm × 50µm.

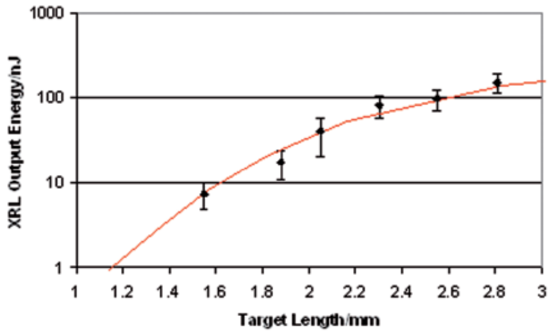

Figure 4. Points show the variation of the X-ray laser output with target length for a fixed delay of 673ps. The curve is a plot of the Linford fit which gives g_0=59cm^{-1} for a grazing angle of 17°.

Figure 4 shows a plot of the variation of X-ray laser energy output with target length for a grazing incidence angle of 17°. The long pulse/short pulse delay used for this scan was 673ps, which is ~optimum delay, and this gave an energy output of ~150nJ for a target length of 2.8mm. The curve fitted to the plot is the condition for saturation by Pert [3] and Casperson [4] using the Linford approximation [5]. The fit shows that the laser was operating into saturation, with a small signal gain coefficient g_0=59cm^{-1}.

A comprehensive scan of the pre-pulse to main pulse time separation was also undertaken for each of the grazing angles at varying target lengths. Figure 5 shows the average output for delays ranging from -73ps up to 823ps between the arrival of the long pulse and the short pulse on target for a target length of 2.5mm and 17° grazing angle. For this particular configuration, the optimum delay is shown to be ≈600ps. From other analysis, the optimum delay seems reasonably constant for other target and parabola configurations.

From our analysis of the various target length scans and delay scans, it was established that the 17° parabola grazing angle was our optimum, although all angles lased into saturation.

A series of measurements of the temporal output of the X-ray laser were taken with the Axis streak camera coupled to detect the first order flat-field spectrometer output. The Mo X-ray laser was seen to have a pulse duration of 3.0-3.5ps, which appeared to be consistent for the various pumping conditions. Figure 6 shows the output from the streak camera, from a 17° parabola angle and a 673ps delay between pulses.

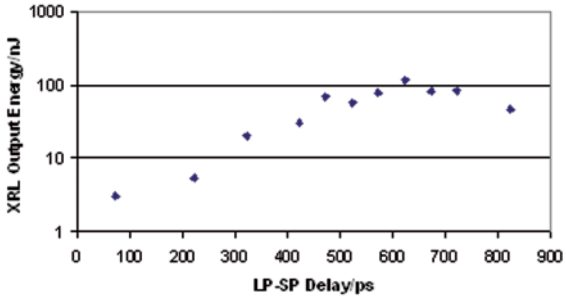

Figure 5. Variations of the total X-ray laser output with delay between the long pulse heating beam and the short pulse for 2.5mm target length and 17° grazing angle.

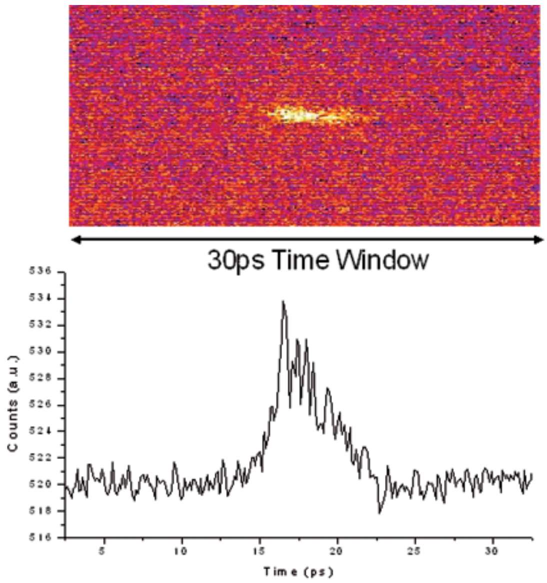

Figure 6. Temporal output of the X-ray laser recorded by the Axis-photonique streak camera.

Conclusions

Ni-like Mo X-ray lasing pumped by the grazing incidence scheme has been demonstrated under the conditions of the Astra laser system. Optimum pump conditions have been examined and discussed, and lasing has been shown to operate into saturation. These measurements have shown that the optimum grazing angle is 17°, with an optimum long-pulse/short-pulse delay of 623ps. Pulse duration measurements were also obtained and the X-ray laser has been shown to operate with a duration of ~3ps.

References

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