Astra Gemini compact plasma mirror system

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Introduction

In order to access ultrathin (submicron) targets with Astra Gemini at intensities greater than 10^{20} W/cm^2, a contrast (ratio of peak laser intensity to the amplified spontaneous emission (A.S.E.) pedestal or pre-pulses) of greater than 10^{10} is required in order to prevent laser modification of the target prior to the arrival of the peak of the laser pulse. The inherent contrast of Astra Gemini at present is 10^6-10^7 and so a system is required to improve this property by around 4 orders of magnitude. In order to achieve this, a plasma mirror system was designed for use inside the Gemini interaction chamber and this report describes its design and implementation on the recent ion acceleration experiment.

Plasma mirror system

Self-induced plasma shuttering, commonly referred to as a plasma mirror, can be used to enhance the contrast of a laser pulse at the expense of the energy delivered to target. During the rapid ionisation of a material, the release of electrons gives rise to overdense plasma with a reflectivity close to unity, regardless of the material's initial properties. Therefore, by focussing onto a glass substrate with a tailored anti-reflection coating so that ionisation only occurs on the rising edge of the main pulse the preceding ASE and any pre-pulses will be reduced in the reflected beam, resulting in an enhanced contrast as shown in Figure 1.

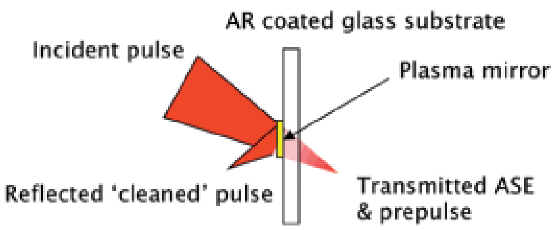

Figure 1. Schematic of single plasma mirror setup.

The laser intensity incident on the plasma mirror is chosen by adjusting the size of the focal spot on the glass. The ideal operating intensity depends on the initial laser pulse profile and identifying it requires measurement of the reflected beam energy and also the reflected beam quality. By operating the plasma mirror at a higher intensity the reflectivity (and hence the energy throughput) is maximised since an earlier 'switch on' time allows more of the main pulse to be reflected. However, switching on the plasma mirror earlier means that the plasma surface will have longer to expand before it reflects the peak of the main pulse. The expanding plasma disturbs the initial substrate flatness and causes the beam to scatter instead of being perfectly specularly reflected.

The optimum condition to operate the plasma mirror with negligible distortion of the reflected beam is found when the condition [1] $c_s \Delta t < \lambda_{laser}$ is met, where c_s is the sound speed and Δt is the time from ionisation to the peak of the main pulse. In this case the laser beam will not resolve any modulations in the surface of the expanding plasma and so reflection will remain specular. Previous characterization of plasma mirror systems have found an optimum intensity of ~1×10^{16} W/cm^2 which gives a reflectivity of >65% while retaining the spatial quality of the beam [1,2].

Design of the Astra Gemini plasma mirror system

Design specification of the Astra Gemini plasma mirror system:-

- Must fit into the Gemini interaction chamber and take up as little volume as possible
- Must provide the option to the experimenter of using 0, 1 or 2 plasma mirrors
- Must maintain the Gemini repetition rate of 1 shot every 1 minute
- Must be able to take >50 shots before having to change the plasma mirror(s)
- Must allow for diagnostics to monitor the output beam from the system (i.e. energy, pointing, focusability)

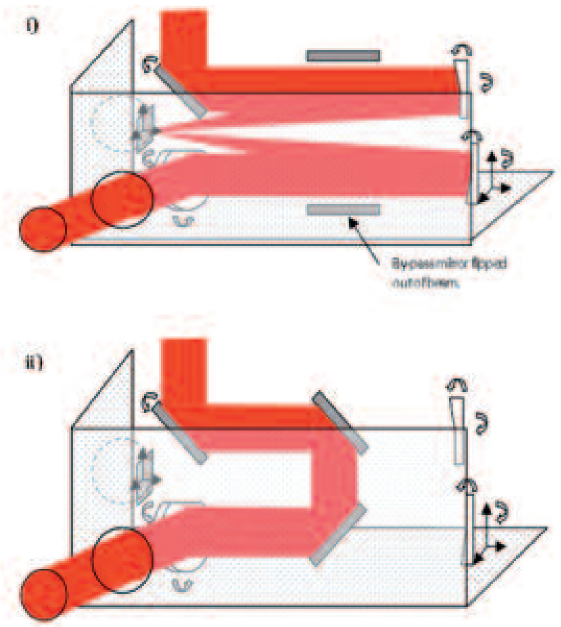

Figure 2. Schematic of the Astra Gemini plasma mirror system design. (i) The beam is routed via plasma mirrors which consist of either one plasma mirror at near normal incidence or two mirrors at ~40°. (ii) Plasma mirror system by-passed for high energy, lower contrast shots.

Plasma mirror characterisation

At the beginning of the ion acceleration experiment in Gemini the double plasma mirror setup was characterised in order to achieve the $>10^{10}$ contrast required.

A permanent diagnostic was set up to monitor the far-field of the output beam from the plasma mirror system. This had to be modified in order to reduce B-integral effects in the transmissive optics and air breakdown at the focus of a lens (see Figure 3). The far-field at the output of the plasma mirror system was then compared to the input far-field. Together with measurements of the output energy (made with a calorimeter) the optimum conditions for operation of the double plasma mirror system could then be determined.

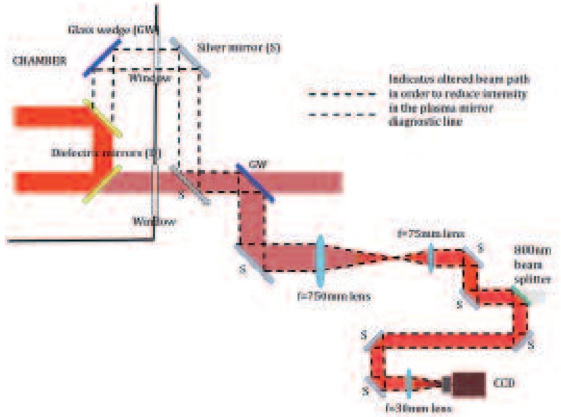

Figure 3. Schematic of the leakage taken for the plasma mirror far field diagnostic; the dotted line path indicates the altered beam path.

Calibration shots were first taken using the by-pass mirrors to give the calorimeter value for ~100% transmission. The double plasma mirrors were then set up in the configuration expected to give the optimum results and the input energy was varied to alter the intensity on the plasma mirrors. The energy incident on the first plasma mirror was varied over the range of 0.7-12.4 J giving an intensity variation on the first plasma mirror in the range of 3×10^{14} and 5×10^{15} W/cm^2. Measurements of the area of the burn marks on the plasma mirrors allowed the intensity on the first plasma mirror to be calculated (see figure 4).

Figure 5 shows that the plasma mirror throughput increases with intensity initially as more of the main pulse is reflected, before levelling out to a maximum value of 48±5%. This gives the reflectivity of each mirror as ~69% which is consistent with previous work.

The far-field images showed that at the highest intensity the reflected beam still focused to a near diffraction limited spot (see figure 6).

The cold reflectivity of the double plasma mirrors was measured to be 5×10^{-5} (0.7% for each mirror) which should correlate with the level of contrast enhancement for full power shots.

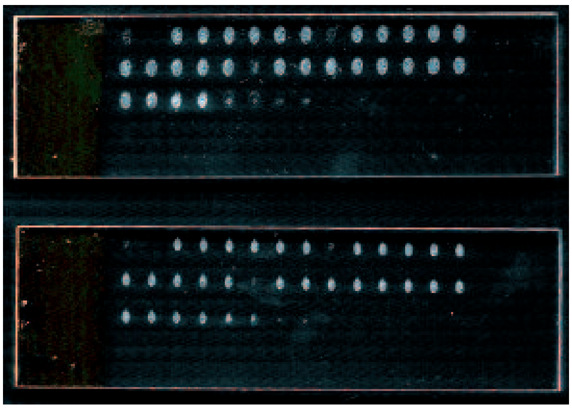

Figure 4. Image of used plasma mirrors; the first plasma mirror is shown in the top half of the image (ellipse spot size 2×3 mm) and the second plasma mirror is in the bottom half (ellipse size 1×2 mm).

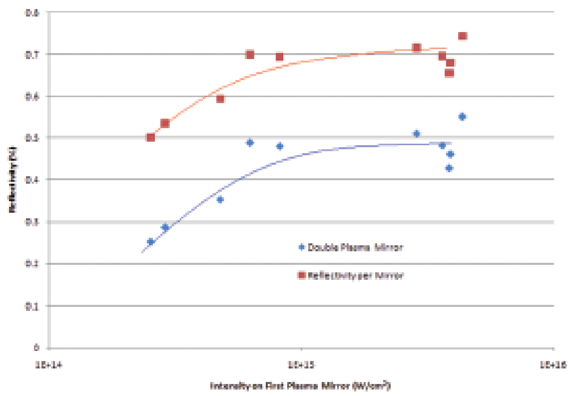

Figure 5. Energy throughput from the double plasma mirror system at varying incident intensities on the first plasma mirror.

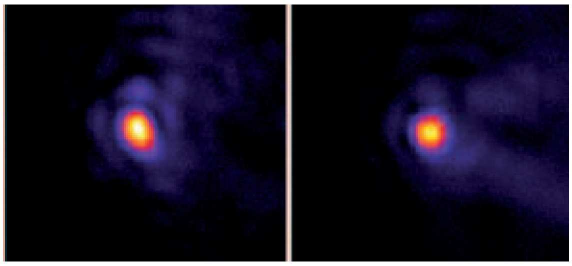

Figure 6. (Left) Low intensity (no plasma) output far-field from the plasma mirror system. (Right) Typical high intensity output far field image of the plasma mirror system.

Conclusions

A plasma mirror system was designed, installed and commissioned for use in the Astra Gemini interaction area which allows for the use of 0, 1 or 2 plasma mirrors for contrast enhancement.

The double plasma mirror setup was characterised and used on a successful ion acceleration experiment giving a resulting contrast of $>10^9$ in a 6 J pulse. This allowed sub-micron targets to be shot at high intensities ($\sim 10^{21}$ W/cm^2).

Future work will include measuring the contrast of the output pulses with an autocorrelation and the full characterisation of the single plasma mirror setup.

References

1. B. Dromey *et al*., *Rev. Sci. Instrum*. **75**, 645 (2004).
2. Ch. Ziener, P. S. Foster *et al*., *J. Appl. Phys*. **93**, 768 (2003).
3. Lévy et al., Opt. Lett. 32, 310-312 (2007).
4. M. J. V. Streeter *et al*., CLF Annual Report 2008-2009.