Redesign of Gemini Double Plasma Mirror System

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Introduction

The inherent contrast of the Gemini laser system is too low to shoot the thinnest targets needed for many experiments, and therefore a double plasma mirror (PM) system is employed to give the required contrast enhancement. This article describes some recent engineering improvements made during a redesign of that system. Readers interested in the performance of the plasma mirror system are directed instead to ref [1].

Plasma mirrors

Plasma mirrors (PMs) are routinely used in the CLF to improve the contrast of laser pulses. They achieve this contrast enhancement by exploiting the rapid change in reflectivity that can occur when a material is ionised. The PMs themselves are simply glass substrates with an anti-reflection coating for the wavelength of operation. The substrate is positioned in a focusing beam, at a point where the leading edge of the main pulse will be intense enough to surpass the ionisation threshold of the surface, but the intensity of any prepulses or ASE emission will not. In this configuration, any light incident on the substrate before the arrival of the main pulse, is efficiently transmitted through the substrate, and lost from the system. Conversely, any light that arrives after ionisation has been initiated by the leading edge of the main pulse will be efficiently reflected from the mirror-like plasma and, ultimately, propagated to target. The reflectivity of the substrate prior to ionisation is typically <1%, whereas the reflectivity of a newly formed plasma surface can approach 100%, meaning that contrast enhancement of 10^2 per PM is easily achievable. A more detailed description of the mechanism is available in the literature [1,2]

Description of previous Gemini PM system

An obvious position for the placement of PMs is just before target in the focusing beam. However, as PMs are frequently used in experiments with low F# focusing geometry, there is limited space and, typically, if used in this way the PM is incorporated into the target assembly to be replaced and re-aligned after each shot. This is suitable for low rep rate lasers such as Vulcan, where the chamber is generally cycled after each shot but, to take advantage of the high shot rate which is one of the key features of Gemini, a different approach is necessary.

In order to implement PMs on Gemini, a dedicated, recollimating, double-plasma-mirror system was developed[1]. A schematic of the optical arrangement is shown in Figure 1. After entering the system, the beam is directed by a turning mirror (M1) to an F7 OAP (OAP1), which focuses the beam towards the first PM substrate (PM1). The beam is incident on this substrate shortly before it reaches focus, is reflected, and then passes through focus before reflecting off the second PM substrate (PM2). Finally, the expanding beam is collected and recollimated by a second F7 OAP (OAP2) and directed out of the system by the final turning mirror (M2). With the OAPs properly optimised and aligned, the beam exits the system with no degradation to its focusability. Figure 1 also shows the bypass system, consisting of two mirrors (BP1 & BP2) designed to rotate into position (dashed rectangles) to direct the beam to the output line without interacting with the PMs. This is equivalent to removing the PM system from the beamline, and allows users to observe the effect of the PMs on beam quality and focusability, and gives an option to easily compare data with and without improved contrast or to access higher energies at lower contrasts.

The PM substrates themselves are mounted on translation stages to be moved between shots to expose a fresh part of the surface to the beam. This requires precise alignment of the substrates to ensure they translate parallel to the substrate surface in both dimensions. This requires the mounting of either a dial gauge, or a chromatic confocal sensor to measure the variation in surface position as the translation stages are moved.

Issues with previous plasma mirror system

The original PM system was design was commissioned in 2008, the limitations of the facility at the time dictated that the design be as compact as possible in order to minimise the system footprint in the Gemini chamber. This resulted in a number of compromises in the implementation where conservation of space had to be prioritised over ease of use. Several problematic features can be seen in the schematic.

First, the system had to be designed in a ‘vertical’ orientation (meaning that, in Figure 1, OAP1 is positioned vertically above OAP2). This gives the smallest footprint, but comes with the obvious difficulties of working with optics on a vertical surface.

Second, the system needed to be positioned in the corner of the chamber, so as to not impinge on useful space in the chamber. This limited the options for incoming and outgoing beams, making necessary the large turning mirrors in the vicinity of the PM substrates, resulting in a very cramped working area

Third, the space constraints necessitated that the bypass system consist of mirrors that were rotated into position, limiting the accuracy to which they could be removed and reinserted and

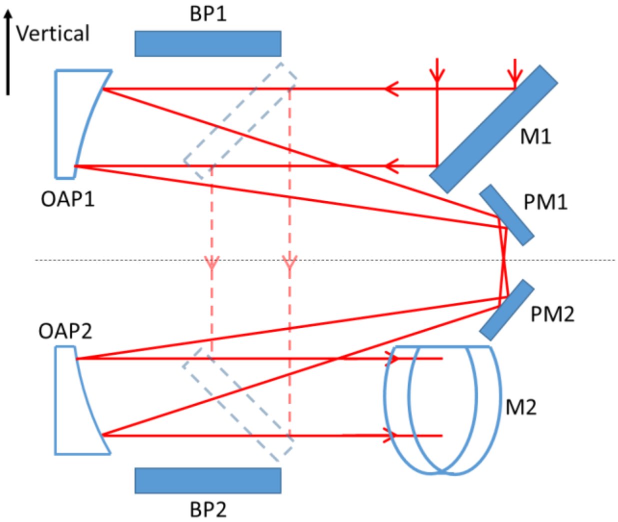

Figure 1. Schematic showing a side elevation view of the previous Gemini plasma mirror system

making adjustments to mirror position impossible.

Fourth, the limited space led to the use of non-standard mirror substrates, which makes the sourcing of replacements slow and costly.

Finally, the compactness of the system, and the bespoke nature of the engineering, meant that modification or correction to the system, or changes in alignment, were extremely difficult to implement.

Redesign of the plasma mirror system

Since the original design, the space constraints driving these design choices have been eased due to engineering innovations in TA3. The first is the ‘Item’ framework that has been installed in the main chamber. This is constructed from extruded aluminium struts (referred to by its brand name, ‘Item’) that provide flexible mounting options near the roof of the chamber. This allows two-level beamlines to be set-up with ease so that space can be much more efficiently used within the chamber. The second is the now routine use of large extension chambers in TA3. Multiple extension chambers may be attached at the same time, with each one increasing the chamber footprint by over 20%. The additional space that these improvements have made available provided the opportunity to redesign the PM system.

The redesign has focused on improving the practical implementation of the PM system, and has retained the original optical design. Therefore, no changes to the performance of the PM system will be reported, however users may find the details of changes made to the practical implementation, detailed here, helpful in the planning of future experiments

New Layout

The newly designed system is shown in Figure 2. The orientation of the system is now horizontal, making general alignment tasks significantly more straight-forward. The footprint of the whole assembly is approximately 650 mm by 1300 mm and can fit on a breadboard in a standard TA3 extension chamber. The horizontal orientation allows more flexibility in the addition of alignment aids and monitors on an ‘as-needed’ basis, and will allow further developments to be implemented with relative ease

With the system mounted in an extension chamber, it is natural to arrange the input and output beams as shown in Figure 2, entering and exiting the system without the need for the additional turning mirrors. This greatly improves access to the plasma mirrors during alignment and allows more space for mounting hardware to hold and manipulate and monitor the PM substrates.

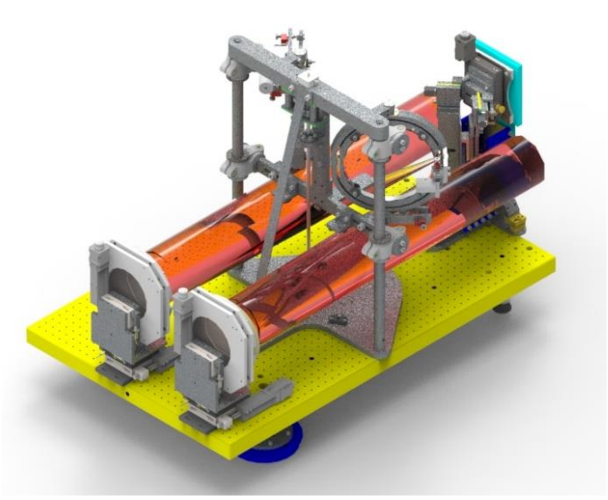

Figure 2. CAD render of the new Gemini plasma mirror system, shown mounted on a standard extension chamber breadboard

Bypass

The additional space has also allowed for significant improvement to the bypass system. The bypass mirrors are now translated vertically out of the beam and, when re-inserted, are located with kinematic bases to improve repeatability. Both mounts have motorised actuators, meaning any NF or FF misalignments can be easily corrected. The horizontal separation can be manually adjusted to match the mirror to the beam position.

In the main chamber, there may be some concern that this design may interfere with upper level beamlines but in the extension chambers, where the system is intended to be used, this is not normally an issue.

Parabola Mounts

The OAPs are now mounted on Thorlabs LNR stages, allowing 50 mm of motorised travel in each axis. Since the system is mounted on a horizontal breadboard, the stages can be easily repositioned, giving access to set-ups far from the intended design. The OAP mounts have manual actuators for pitch and yaw, with access to the mounts greatly improved.

Plasma Mirror Substrate Mount

The PM substrates are mounted on a central column. The column is mounted on lockable, kinematic bases, and can therefore be easily removed for adjustment if needed. The PM substrates are mounted on separate horizontal translation stages to allow independent horizontal rastering of each substrate, but share a common vertical translation stage. The angle of each substrate can be independently adjusted to ensure the parallelism of substrate surface to the translation stages. It was observed in operation that the motion of the vertical translation stage is not perfectly straight, and the surface may move by 2-3 microns over the full range of vertical travel. This is within the spot size and Rayleigh range of the F7 parabolas, and so does not impact the final focus of the beam. The horizontal separation of the substrates can be manually adjusted so that the beam size on each substrate can be independently chosen.

Debris Shields

New debris shields were designed which have both fine angular and translation adjustment. This allows for accurate positioning of the debris shield parallel to the PM substrate surface. These are easily mounted on kinematic bases to allow simplified removal and reinsertion.

Conclusions

The original plasma mirror system in Gemini had several serious issues which were dictated by space constraints in TA3 at the time of its design. Due to engineering improvements and innovations in TA3, to increase both the volume of the Gemini target chamber and the efficiency with which that volume can be used, it has been possible to allocate more space to the plasma mirror setup. This was taken as an opportunity to redesign the system to exploit the additional space and eliminate the main issues faced by users.

References

1. M. J. V. Streeter, CLF Annual Report 2008-2009, p225
2. B. Dromey, Review of Scientific Instruments **75**, p645 (2004)