Progress on positioning of solid targets for Gemini

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Introduction

When conducting experiments using the Gemini laser the highest intensity is achieved using the *f*/2 parabola which focusses to a spot radius ($1/e^2$) of 1.6μm with a corresponding Rayleigh range of 10μm. We have developed techniques [1 - 6] for positioning of targets within the high intensity region (i.e. with of order 1 micron accuracy) but currently with certain limitations.

Our routine method of positioning is to image the rear surface of the target to ensure that it is in the same plane as the focal spot of the laser. This employs a microscope objective which acts as both the lens to image the focal spot and the focussing optic for the target backlighter [1]. In the previous CLF Annual Report [4] we discussed the performance of our standard camera arrangement. With the simplest target conditions of normal incidence and a rough rear surface, a puck of targets can be mapped in about 20 minutes to obtain a grid of motor (*xyz*) positions. Even accounting for the camera being moved out of the way for each laser shot, this enables 1 shot per minute which is sufficient for current Gemini solid target experiments.

However, for most experiments there is a complicating factor to the target alignment which causes large delays to this procedure. The most common problem is a lack of structure on the rear surface of the target which makes it impossible to bring it into focus. Best focus is also difficult to judge when the target is non-normal because only the central stripe of the image will be in focus rather than the whole screen.

Here we report how we have refined earlier versions of the focal spot camera to address some of these issues. We also discuss the characterization of some of the motors that we have available for fine positioning.

Improved focal spot and target camera

The design of the camera is shown in Fig. 1. The image is formed by a 50x magnification, long working distance (13mm) infinity corrected microscope objective followed by a tube lens of focal length 200mm. Because the objective is infinity corrected there is a parallel light beam between its exit and the tube lens and so additional optics can be introduced without distorting the image [7]. The maximum spacing that can be used between the two lenses without vignetting can be calculated from the properties of the system and in our case is 109 mm.

We send the beam through three 50% reflectivity beamsplitters. The first provides a transmitted beam that is imaged onto a wavefront sensor for optimization of the adaptive optic (see C. D. Gregory *et al*., also in this CLF Annual Report). The second and third allow the injection of an LED light source and a fibre coupled laser, both at the same wavelength (800nm) as Gemini. These are focused by the objective, illuminating the rear surface of the target so that we can bring it into sharp focus in the same plane as the laser focus. The LED diverges and uniformly fills the camera chip giving very clear images which usually show a lot of fine structure. The laser beam is collimated and focuses tightly on the target. This gives a bright spot on the camera either by direct reflection for a normal incidence target, or by imaging of scattered light if the target is at an angle.

With the high magnification necessary to view the focal spot it can be difficult to carry out the initial alignment. For this reason we have added a 10x magnification microscope objective to the second beamsplitter. The system is designed such that the field of view can be shifted from 50x to 10x magnification with a single mouse click and the camera maintains good focus.

The whole set up is rigidly connected on a single metal plate and connected with lens tubes and cage system rods. This is then mounted on a large 3 way motion stage to ensure that the camera can be driven well out of the beam path on the shot.

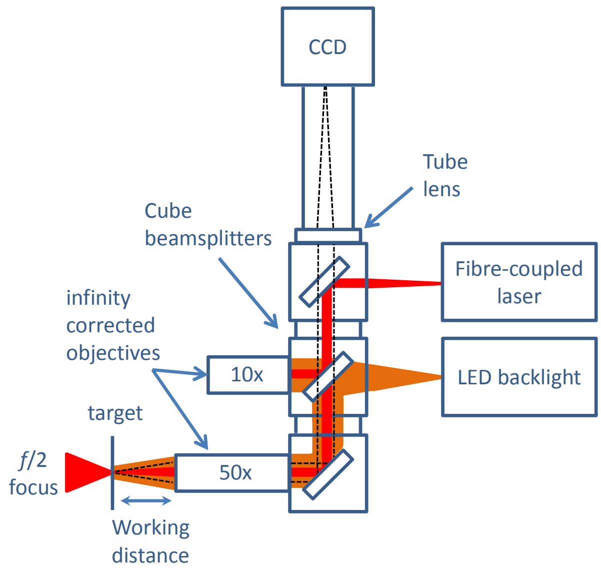

Figure 1. Camera arrangement used for focal spot measurement and target positioning.

Demonstration of the camera system

LED illumination of a structured target

The simplest case of alignment is when the target has easily visible structure on the rear and is at normal incidence to the main laser. After imaging the focal spot of the laser, the target is brought into view and translated in the *z* direction until surface features are seen in sharp focus as shown in Fig. 2(a). The LED provides a uniform backlighter over the whole field of view. Here the target material is coated onto the back of a silicon target wheel with 300 μm holes [6]. The entire hole can be seen because the magnification in this case was low (10x). When the target is angled as in Fig. 2(b) the alignment is more challenging but is still possible because features in the centre of the image remain in focus while those at the edges become blurred. The outline of the hole can still be seen vaguely if the contrast of the image is enhanced.

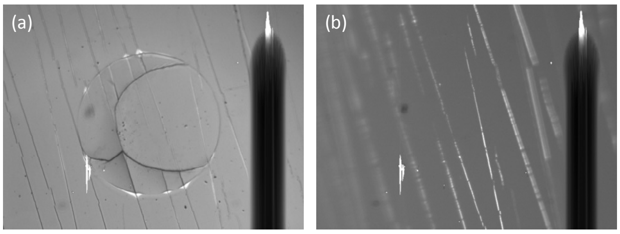

Figure 2. LED illumination of the rear of (a) normal incidence target and (b) angled target.

Targets without visible features

Many of the targets used on Gemini experiments do not have such features on the rear surface. Two examples are ultrathin carbon foils (~10 nm thickness) and polished silicon. The desirable property of having a clean back surface comes with the disadvantage of being very difficult to bring into focus. We can see this in the images shown in Fig. 3. (Here the backlighting is non-uniform because it is provided by bright laser light rather than the LED). With a 50 nm carbon foil (Fig. 3(a)) it is easy to see features whereas the 10 nm foil (Fig. 3(b)) has fewer blemishes. In fact in a real experiment with more careful target handling often no features at all are seen in the field of view of the 50x microscope.

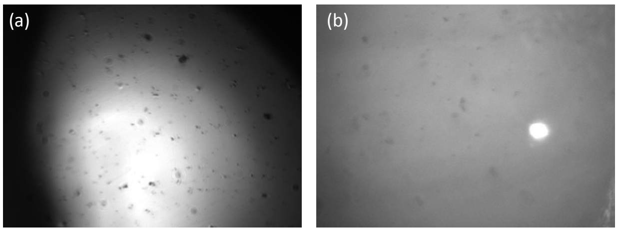

Figure 3. Images of the rear of (a) 50 nm carbon foil and (b) 10 nm carbon foil.

This problem can be solved with the addition of a focusing laser beam to the system [1, 2]. If the target is at normal incidence the beam is directly reflected and gives a very bright focal spot on the camera. This can be seen in Fig. 3(b), however the spot here is saturated. Figure 4 shows the alignment beam from a 10 nm carbon foil at normal incidence as it is moved through focus in 1 micron steps. It is possible to pick out the best focal spot within about 2 µm, which is adequate for positioning on Gemini. Further examples are shown in Fig. 5 where each image shows a 3 micron step size. The technique works well on (a) 10 nm and (b) 50 nm carbon foils and on (c) silicon targets (although the silicon imaging here is saturated).

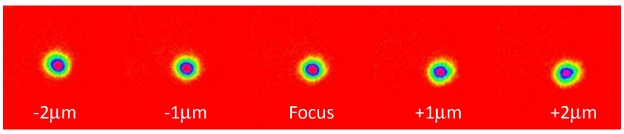

Figure 4. The focal spot of the laser on the rear of a 10 nm carbon foil as the target is moved in 1 micron steps.

If the target is angled the objective picks up scattered light and still focuses on the camera but in a poorer quality spot. Preliminary scans at 45 degrees are shown in Fig. 5 for (d) a 50 nm carbon foil and (e) a silicon wafer. Although inelegant, it is feasible to use retro systems with bad focusing by matching the shape of the beam profile each shot, but we need further investigation to determine whether it can be done in this case. An alternative solution would be to place an alignment marker at the top and bottom of each target. This would be visible on the LED and then a middle *xyz* position could be determined.

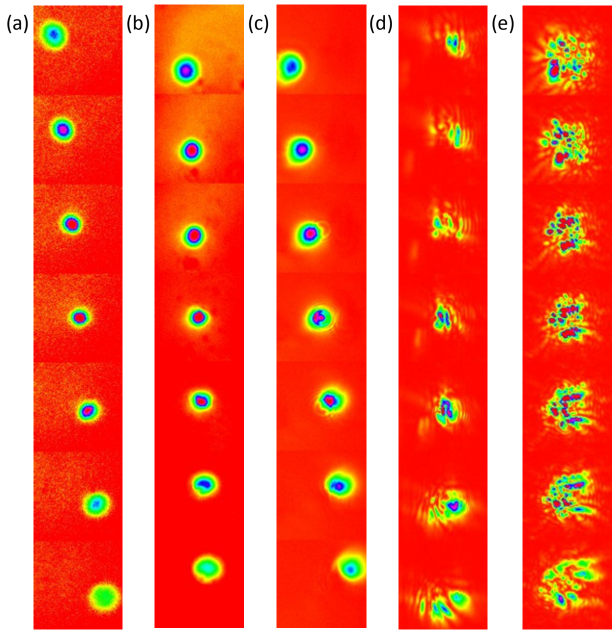

Figure 5. Images of the rear surface laser as the target is scanned through focus. Normal incidence: (a) 10 nm carbon, (b) 50 nm carbon, (c) silicon wafer. 45 degree angled: (d) 50 nm carbon, (e) silicon wafer.

Dual magnification imaging of targets

A useful feature we have added to the camera system is a 10x objective for larger field of view imaging. This is mounted next to the 50x objective (or above, depending on experimental layout) and the switch can be made by translating a stepper motor between two set positions with a single mouse click. A demonstration is displayed in Fig. 6 where we have imaged a resolution grid with the two objectives. The motor motion takes only a few seconds and the image remains in focus. We also show here a 10 nm carbon foil. The 10x magnification image (Fig. 6(c)) is ideal for assessing the quality of the target and ensuring that the laser is not focused on a wrinkle or a blemish. Moving then to the 50x image (Fig. 6(d)) the user can accurately position using either the LED or the backlighter laser.

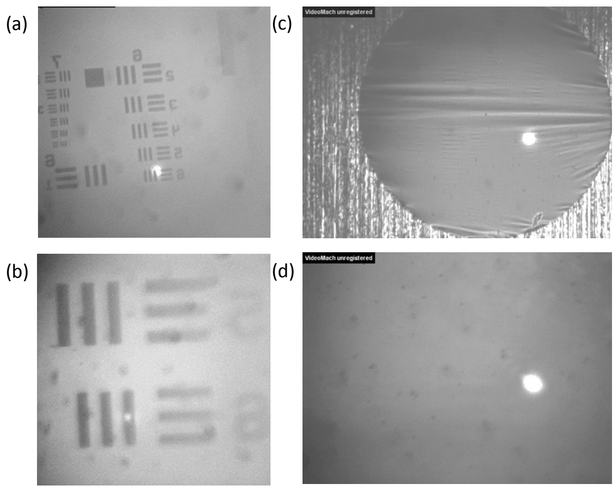

Figure 6. Images of a resolution grid with (a) 10x and (b) 50x magnification. Images of a 10 nm carbon foil with (c) 10x and (d) 50x magnification.

A point to note is that it is very difficult to produce ultrathin foils consistently as can be seen by the non-uniformity of the surface in Fig. 6(c). The Target Fabrication group are currently working on novel production methods for solving this issue but at present we need to take this into account. It means that the targets cannot be raster scanned blindly through the puck, even if we are confident that each target centre is in focus. Rather we may need to pick an *xy* position on each target and note the corresponding *z* position. As long as all motorized motions are on encoded stages, this can still be performed in advance for each target wheel in order to maximize the shot rate while the laser is available.

Characterization of motor stages

A critical aspect of effective target positioning is the choice of the target stage. We require large and rapid motions in the *x* and *y* direction to be able to step around the array but highly accurate motion in the *z* direction to be able to locate the target within the few micron Rayleigh range of the laser.

We have tested various stages for this purpose using a commercial chromatic confocal point sensor [8] to determine the position of a stage with sub-micron accuracy.

602 servo motor xyz stage

The 602 model is a standard CLF 50mm *xyz* stage which uses magnescale encoders to provide position readout. The *x* and *y* servo motors can easily be replaced with faster (but less sensitive) versions when using an array target. We verified that a slow motor can provide micron accuracy as shown in Fig. 7(a) where the magnescale readout is plotted against that of the confocal sensor. The main disadvantage of the 602 is that the magnescales are delicate and often suffer from faults during the experiment. Also the motors do not operate in closed loop and so the operator still must drive to the next position rather than being able to move in a single mouse click or automated way as one can with stepper motors. An upgrade of the drive system is planned to incorporate the encoder to enable closed loop operation of servo motors.

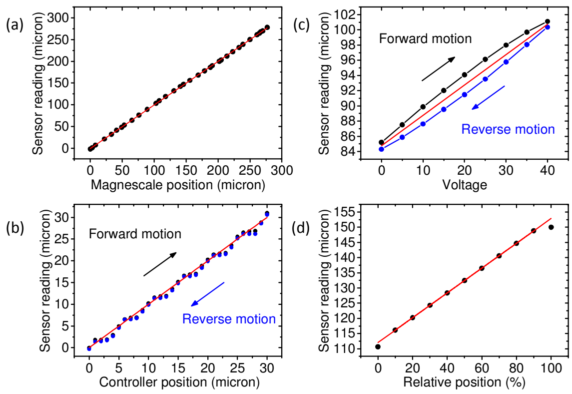

Figure 7. Characterization of available motorized stages. (a) mount position encoded with magnescale (b) large stepper stage without encoder (c) open loop piezoelectric motors (d) closed loop piezoelectric motor.

Large motion stepper motors

The alternative to a 602 stage is to use 50 mm travel stepper motors. These are more bulky but allow rapid movement to a specified position, ideal when using arrays of targets. Our test results from this stage are shown in Fig. 7(b). In this case the motor was driven using the hardware and software provided by the manufacturer. As can be seen from the plot, the motor does not respond to each command to move 1 micron, limiting the minimum reliable motion to 5 microns. This motor is designed to be used with a micro-stepping controller and in that case should be able to achieve a minimum incremental movement <0.05 µm. We have noticed that when we use the CLF drive system software we suffer significant hysteresis that is not seen with the supplied controller. This can be solved by integrating encoders attached to the stages into the drive logic. Until this is completed these large motors are not appropriate for fine (<5 µm) motion control.

Piezoelectric motors

Very fine motion control can be achieved using motors driven by the piezoelectric effect. The positioning resolution is typically of order 10's nanometers and they are designed to fit into a standard stage as a replacement to a manual actuator. Because of this accuracy the motors are extremely slow so they are only suitable for fine tuning after a larger motion stage has brought the target close to focus (within a couple of µm). The piezo motors we commonly use do not have encoders meaning that this fine tuning needs to be done for each target just before the shot. This is acceptable as long as the positioning method is rapid. To be able to step a target using pre-recorded positions requires encoded picomotors but these are expensive and have not been tested in the harsh environment close to the target of a full power shot.

We tested the positioning accuracy of a piezoelectric motor combined with a strain gauge reader for closed loop operation. The results are shown in Fig. 7 for (c) open and (d) closed loop operation. In open loop the motor exhibits distinctive hysteresis behaviour typical of piezo motors [9] peaking at about 2 µm in the middle of the motion. In closed loop the motor performance is excellent (apart from at the extremes of the motion) giving us sub-micron accuracy over a range of 25 µm.

Conclusions

The challenge of rapid target positioning with micron accuracy requires high quality motors and a consistent methodology. We have improved the design of the focal spot camera to allow matched 10x and 50x magnification and rear illumination by LED. We have added a focused laser so that targets can still be positioned when there is a lack of visible structure on the surface. Using a confocal point sensor, we have characterized some of our existing motor stages. Some refinements of the drive control system are required to achieve micron accuracy with large motion (50mm) stepper motors. Piezoelectric motors offer a suitable alternative but have not been fully tested under experimental conditions.

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