The Problem with Silicon

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Introduction

Precise alignment of laser targets, to within Rayleigh range of experiment focusing optics, can usually be achieved by retro imaging[1]. This involves collecting light that scatters off a target from an alignment beam, re-imaging it, and setting the image to be at its smallest size when the target is at the focus of the alignment beam. This has become the standard way to make sure that targets are at focus on experiments using the Vulcan High Power Laser Facility and is relied upon to guarantee the highest intensity is present on target. The precision needs to be within the Rayleigh range (30 µm) for the F#3 focusing optics that are used.

Silicon targets are now regularly used in plasma interactions for their lattice structure and resistivity properties[2]. Silicon also however presents alignment procedure issues with retro-imaging. This is due to highly polished, flat surfaces and high transmission to the laser light employed (1053nm) at alignment beam intensities (mW). This polished surface means that they do not diffusely reflect giving a very low scatter signal, rendering retro imaging very difficult to achieve.

Coating the targets with a layer of a metal such as Silver or Aluminium can help, but does not result in a surface that scatters light enough and is still very hard to use. This is mainly due to the coating following the silicon surface, being very good at specular reflection and very poor at diffuse reflection. Therefore very little light ends up being collected by the retro imaging system and the result is extremely dim to the point of being un-usable.

Coating the surface can also be an issue due to changing the physics environment of the target to be shot so a solution that avoids additional materials in the interaction zone of the target being present would be more optimal.

In this report a method and results to mitigate these issues is presented.

Solutions

Targets used in this example are 3mm x 3mm x 225µm thick Silicon 111 squares cut from a wafer. Their surface is flat and mirror like.

In this case the physics required that the surface of the target at the interaction point, surrounding area and the back surface remained flat. A slight roughing up of the target front surface was tried and seen to not work well enough to give a good scatter at the interaction point. In any case this was not useful to preserve the physics conditions being investigated. Coating with Aluminium or Silver did not work well enough either partly due to the geometry of the experiment in place, as well as it producing a mirror surface rather than any scattering. Also tried was a method to add a material that would scatter highly and diffusely to the top and bottom of the silicon. In the case tried it was 100µm wide 4µm thick Al hand cut and glued on to the surface. This method, although for retro-imaging did work, is very time consuming and too variable in the results to make it a useful method when producing high numbers of targets.

A new method has therefore been tried that doesn't add any other material to the target itself. A roughened strip at the top and at the bottom of the target surface was made using "sand" blasting. This results in a surface rough enough to diffusely scatter but not eroded so much that it makes a large thickness difference from the front surface. The aim being that this would enable retro imaging to take place in these two positions. Any small offsets on focus position (within Rayleigh range) could be used to locate the target position required at the central region that is too specular and transparent to see directly.

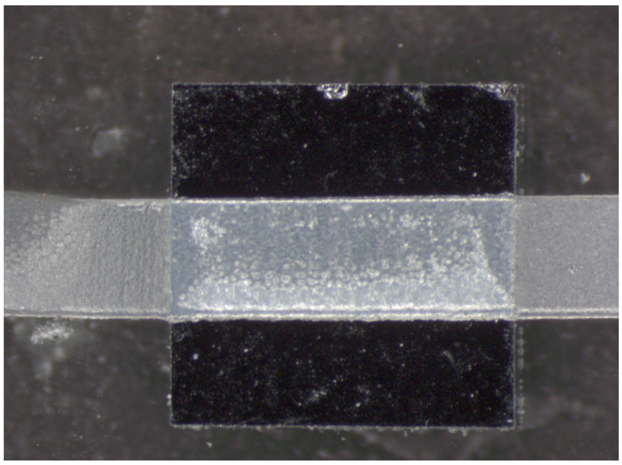

Fig 1 Silicon target prepared with a central mask to enable top and bottom to be eroded

The initial test of this involved masking a 2 mm central strip of the front surface of a silicon target leaving two 500µm stripes one at the top one at the bottom. See Fig 1.

The remaining area was sand-blasted for a couple of seconds to rough up the top and bottom areas to enable it to scatter light. The "sand" is Aluminium Oxide particles of average size 60µm diameter used with a backing pressure of 3.5 - 4 bar. The result of this was then characterised to see the depth change and roughness achieved. This is important as if the depth eroded is significantly similar to, or more than the Rayleigh length of our laser focus in the target area (30µm in this case), then this may not have been easily usable as each individual target would have to be specifically characterised, adding to time required to produce and align them. If the depths are wholly within Rayleigh range this issue can be eliminated.

This first test target was mounted on a standard post and wire stalk, set up in position for retro imaging and then shot (in Target Area West with a 1053nm, 2ps, 100J laser pulse).

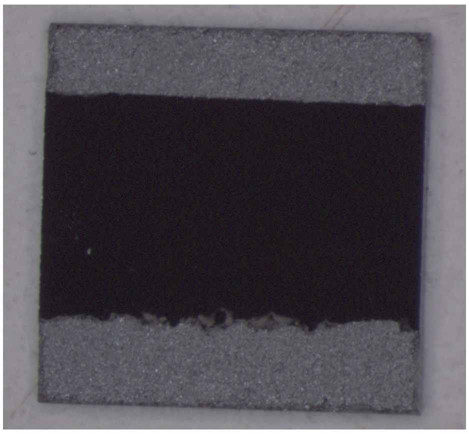

Fig 2 Silicon target after sandblasting.

Results

The picture Fig 2 shows what the silicon target looks like with a sandblasted strip top and bottom.

Characterisation of this target showed that the erosion depth was of the order 20 ±5µm deep along the length for a first attempt of sandblasting.

This target was then shot successfully, since an easily visible and usable retro-image could be formed. This method was then employed on a larger number of targets - a microscope slide with a batch of targets all masked along their centres were blasted together (see Fig 3). Also the time that the sand blasting was employed for this was reduced slightly to see if this would improve the likelihood of the depth staying within the Rayleigh range of 30 µm. Fig 4 shows the 3d profile that was achieved and this gives a peak to valley in this image is 13.24µm. Fig 5 shows a sample eroded area with peak to valley profile of 15.7µm and a surface roughness of 2.05µm The original surface of the silicon has a rougness or 7Å (Fig 6). Data figures are from Veeco interferometric measurements.

Sandblasting of batches of targets enables a fast production turn around. The reduced erosion depth due to shorter time of blasting to reliably keep well below 30 microns has been very successful.

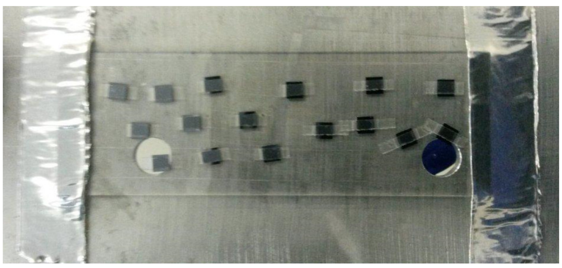

Fig 3 a batch of targets prepared for being sandblasted..

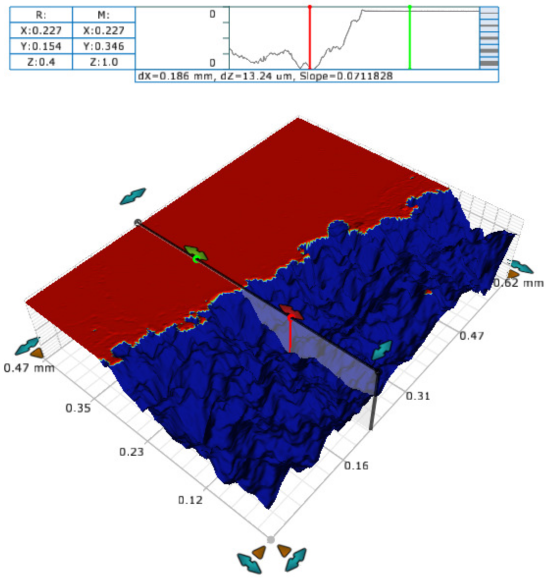

Fig 4 Silicon target sample area from eroded and non eroded sections, 3d image data.

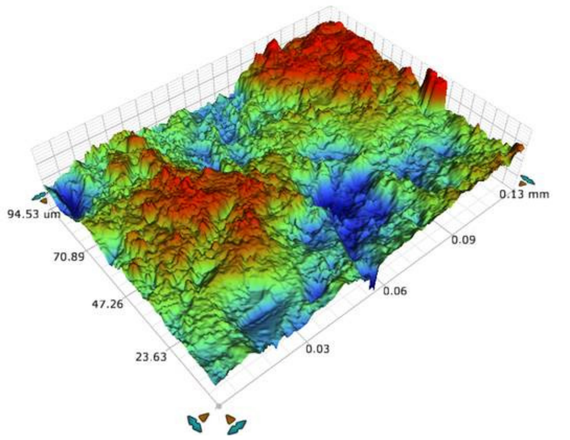

Fig 5 3D profile of a sandblasted section of silicon target. The surface roughness was measured to be 2.05µm and peak to valley depth erosion of 15.7µm

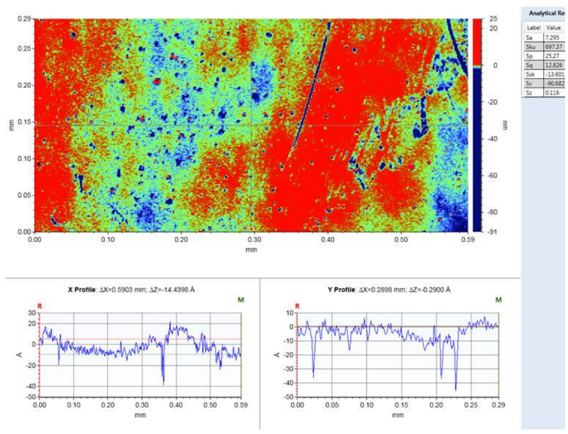

Fig 6 surface of untouched silicon with a surface roughness of 7.3Å

Conclusions

Conclusions of the tests so far show that sandblasting of the silicon surface is very successful in the circumstances it was used. The target was a large enough initial area that some of it could be used for an alignment strip top and bottom. The sandblasted area has enabled a much improved scatter signal compared to that of flat polished silicon. The retro imaging system captured enough light from this to enable a useful retro image to be formed allowing targets to be accurately positioned to within the Rayleigh range of the F#3 parabola focus. This is also a quick technique for production and characterisation purposes.

The success of this technique had a huge impact on the experiment on which these targets were used. The ability to install and immediately pump the interaction chamber with the knowledge that these targets can be reliably aligned, without prior procedure, saved a minimum of 30 minutes of each pump cycle and a massive increase in data shot rate.

This was a first attempt at a new technique. Investigation to gain a deeper understanding of the roughness limits vs sand grain size, pressure, time of blasting or other variables available may be of interest for future work for target surface modification.

References

1. D. Carroll CLF annual report 2011-2012 “An imaging system for accurate target positioning for fast focusing geometries”
2. D.McLellan et al PRL 113 185001 (2014)