Target characterisation and pre-alignment for the HAMS high throughput targetry system

Contact *sam.astbury@stfc.ac.uk*

Sam Astbury[1], Chris Spindloe[1], Nicola Booth[1], Martin Tolley[1], Chris Gregory[1], Elliot Bryce[1], Shah Karim[2]

Central Laser Facility, Rutherford Appleton Laboratory, Harwell Oxford, Chilton, Didcot, Oxon, OX11 0QX

Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, Nottingham, NG7 2QL

Introduction

With the recent development of ultra intense, high repetition rate lasers offering experimental access and limited access time per experiment, it is crucial that a significant number of shots are taken on laser targets to ensure an acceptably large and reliable dataset is gathered. Experiments using debrisless targets such as gas jets tend to make better use of the high repetition rates that laser facilities can offer, however, the use of solid targets poses the issue of having to reload targets regularly and replace pellicles which requires cycling of the vacuum system which can take a great deal of time. This issue can be mitigated somewhat with the use of a target wheel, however, unless all targets are aligned within the Rayleigh range of the laser, it can be cumbersome to use.

The Central Laser Facility (CLF) have designed a High Accuracy Microtarget Supply (HAMS) system which couples MEMS-based target production, a six degrees of freedom programmable alignment stage and long-distance interferometric target measurement. The integrated technology allows for several hundred targets to be etched onto eight silicon wafer segments, mounted onto a precisely machined wheel mount and moved remotely into position. The interferometer gives a z-correction which is input to the hexapod and moves the target precisely into focus of the beam. The target is shot, the wheel is rotated to the next target, and the process is repeated for all targets on each wafer segment on the wheel.

Characterisation of the wafer targets and pre-alignment prior to loading the wheel into the target chamber is necessary to ensure that the targets are of the correct thickness following the etching process, the individual wafer arc alignment is concentric about the axis of the wheel, and wafer-wafer z displacement is sufficiently small to be within the measuring range of the interferometer (~100 µm).

Figure 1. Etched HAMS silicon wafer segment with three rows of 100nm thick Si_3N_4 target apertures each comprising 44 targets.

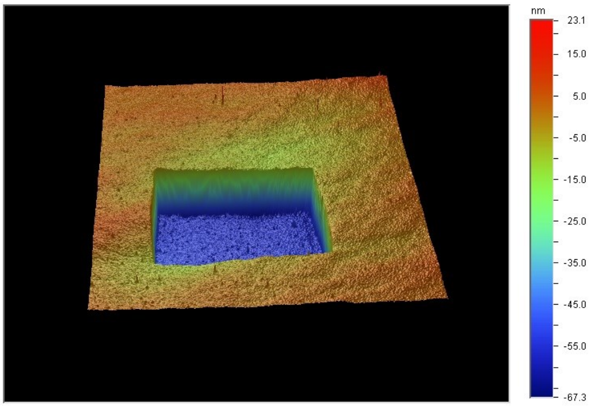

Figure 2. 3D white light interferometric topography of Si_3N_4 surface across 350 µm square target aperture.

Target roughness characterisation

For the research phase of the HAMS system 100 nm silicon nitride was used as the target material which was coated onto four-inch silicon wafers. A photomask comprising eight arc-segments each with two or three rows of 350 µm target apertures was designed to pattern onto the wafers and was subsequently etched (Figure 1)

The silicon nitride coatings were characterised using a Wyko NT9300 white light interferometer to establish the film deviation over the aperture. It needs to be as flat as possible to ensure reproducibility and is important for ion acceleration experiments in the TNSA regime in which ions propagate normal to the target surface (Figure 2).

As can be seen in Figure 2 the surface roughness across the silicon nitride is <10nm which is optically flat on the scale of the laser focus and well within the measuring range of the interferometer to be used for in-situ focal alignment.

Interface wheel characterisation

The wafer segments are mounted on a precision-machined ceramic interface wheel (Figure 3) which needs to be machined as flat as possible in the XY plane so that when the wafer segments are mounted there is a minimal z variance from segment to segment.

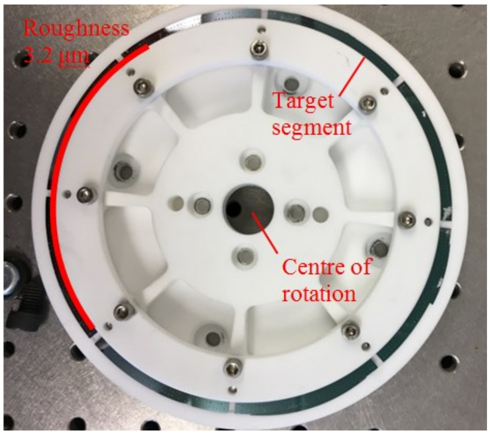

Figure 3. Interface wheel mounted with target segments.

The roundness of the interface wheel, specifically on the face aligning with the inner diameter of the segments, must also be precise enough to ensure concentricity of the segments about the rotational axis of the wheel.

For future experimental access on the Gemini laser at CLF alignments are specified to be within a Rayleigh range of ±4 µm and so the maximum peak to valley surface roughness R_t must not exceed this value.

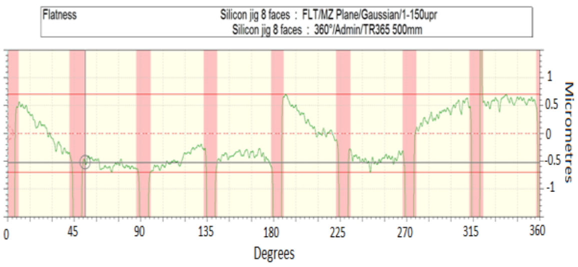

Figure 4. Surface metrology of the ceramic interface wheel over each of the eight target segment mounting slots.

The data obtained from the surface metrology of the interface wheel (Figure 4) gives an R_t of 1.4 µm which falls well within the specification for the system. The roundness of the interface wheel along the segment mounting face was measured as 3.2 µm using a rotational scanning probe, falling within the specification of 10 µm and ensuring that given an ideally round target segment there will be minimal x and y target-to-target deviation about the centre of rotation of the interface wheel.

Segment alignment characterisation

After ensuring the target thickness, interface wheel surface roughness and roundness were sufficient, characterisation of the target segment alignment was necessary. Depending on the etching method of the wafers the edges of the silicon wafer can be slightly jagged. (A wet etching process, although cheaper, can leave a jagged edge if the etched feature does not run parallel to the crystal plane.) Such jaggedness posed a potential issue with the mounting of the inner edge of the segment against the aligning face of the interface wheel.

The target segments were loaded onto the interface wheel and characterised on an OGP SmartScope coordinate measuring machine (CMM) to measure their concentricity about the centrepoint of the interface wheel.

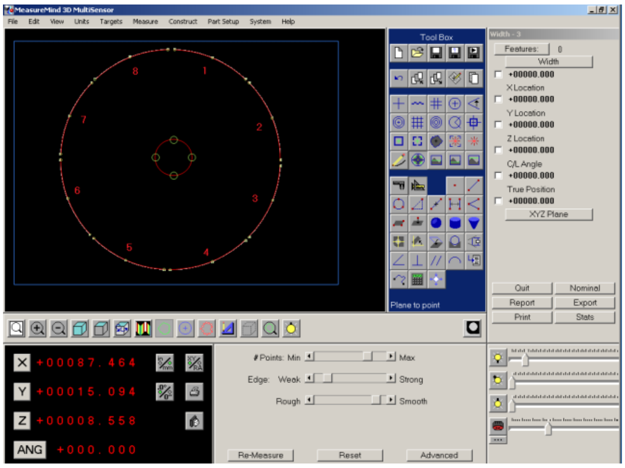

Figure 5. CMM characterisation of the target wheel and wafer segments. Green lines indicate measured features and red lines indicate constructed features inferred from measurements.

Figure 5 shows the characterisation method of the concentricity of the targets relative to the target wheel. It was achieved by mapping the four holes surrounding the centre of the interface wheel and constructing a circle passing through the centrepoints of each hole, the centre of which gave the centrepoint of the interface wheel. Then the two outer and central target apertures of each wafer segment were mapped and an arc constructed passing through each of the three apertures. Consequently the centres of rotation of each wafer segment could be inferred the offsets of which, compared to the calculated centre of the interface wheel, are shown in Figure 6.

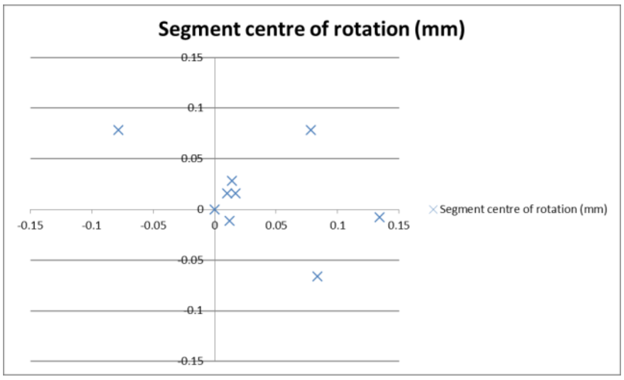

Figure 6. Centrepoints of rotation for each of the eight target segments mounted onto the interface wheel.

The centrepoints of rotation of the segments varied within ±130 µm about the rotational axis of the wheel which can be accounted to user error during the manual assembly of the segments onto the wheel. However, over the 61.5mm rotational radius of the outer target arc, the x and y drift is smaller than that of the target aperture diameter (350um) and so over 360° all targets were within the 5 µm spot size of Gemini laser. For a given centre-of-rotation offset in x and y for each wafer segment the correction in position in x and y for a given angular rotation of the wheel could be calculated using the following equations (1 & 2).

$$\text{x-offset root coordinate} = \tag{1}$$

$$\frac{2x_{off}\left(1+\frac{\tan(90-\vartheta)}{\tan(\vartheta)}\right) \pm \sqrt{\left(2x_{off}\left(1+\frac{\tan(90-\vartheta)}{\tan(\vartheta)}\right)\right)^2 - 4\left(1+\frac{1}{tan^2\vartheta}\right)\left(-r_{targ}{}^2 + x_{off}{}^2 tan^2(90-\vartheta)\right)}}{2\left(1+\frac{1}{tan^2\vartheta}\right)}$$

$$\boldsymbol{y-offset\ root\ coordinate} = \tag{2}$$

$$\sqrt{\boldsymbol{r_{targ}}^2 - \left(\boldsymbol{x_{offsetrootcoord}} - \boldsymbol{x_{off}}\right)^2} - \boldsymbol{y_{off}}$$

Where x_{off} is the x-coordinate for the offset centre of rotation of the wafer, y_{off} is the y-coordinate for the offset centre of rotation, ϑ is the angle rotated between targets, r_{targ} is the target arc radius, taken from the photomask (61.5mm for the outer target ring). The x and y-offset root coordinates give the position of the target aperture given the angle rotated about the interface wheel. The difference between these coordinates is then manually corrected after rotation to ensure the laser spot is in the centre of the target aperture.

Empirical testing of segment alignment was performed using a Precitec chromatic confocal sensor which also gave the target to target displacement in z as the wheel was rotated along each wafer segment.

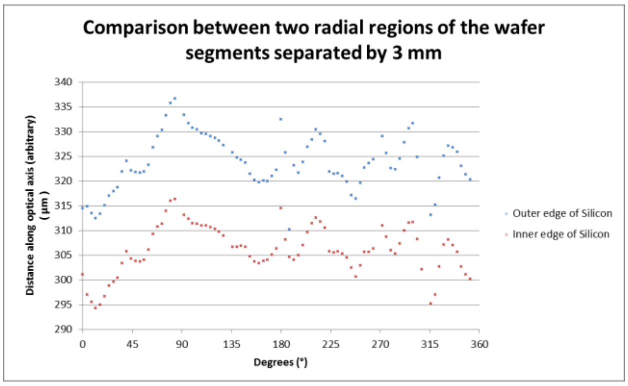

Figure 7. Chromatic confocal displacement results across two radial regions of the target wafer segments showing the change in z position over 360˚.

The results from the chromatic confocal sensor measurements (Figure 7) showed that the segments varied by ±10 µm along the focal axis. It can also be seen that there is a tilt in the wafer from the inner to the outer diameter which is apparent due to the shift in displacement between the two radial regions.

Further experimentation into the issue showed the cause to be a combination of particulates (namely silicon dust) trapped underneath the segment and also the mounting clamp not holding the segments tightly enough.

Conclusions:

The surface quality of the silicon nitride targets used for the HAMS wafer target material has been measured to a surface roughness less than 10 nm which is flat enough a) for TNSA ion acceleration and b) to obtain an interference fringe pattern required for interferometric measurement of the target to bring it into the laser focal position.

Surface metrology of the interface wheel upon which the target wafer segments are mounted gave a peak to trough flatness of 1.4 µm which is within the 4 µm Rayleigh range of the Gemini laser. The roundness of the interface wheel along the inner diameter mounting face was measured as 3.2 µm using a rotational scanning probe which is within the tolerance of 10 µm.

Confocal chromatic displacement measurements indicate that the alignment of the wafer segments to the wall of the interface wheel accounts for a ±10 µm variance over the eight wafer segments (well within the measurement range of the interferometer to be installed onto the system) and is due to non-uniform clamping force and particulates between the segment and interface wheel bowing the silicon wafer.

A method for calculating the misalignment offset corrections on rotation of the interface wheel is shown through use of a CMM upon assembly of the interface wheel which will prove necessary when shooting targets of sufficiently small diameter.

Future Work:

The current procedure for pre-characterisation of the target segments on the CMM is a manual process. When the HAMS system develops into a routinely used microtarget source the pre-characterisation will need to be a more automated process. Programming work into writing a measurement recipe on the CMM has been proposed to be able to completely characterise the alignment of the wafer segments on the interface wheel with minimal user input.

The Target Fabrication Group at CLF will continue to progress its work with Deep Reactive Ion Etching (DRIE) which allows etching of silicon wafers without the limitations of grain boundary constraints arising in wet etching. DRIE processing allows for smooth curved patterns in target segments alleviating concentricity alignment issues between the interface wheel wall and inner diameter of the segments.

Integration of the long measurement range interferometer will allow for a reliable in situ measurement method to establish a z-correction from target to target and feedback automatically into the hexapod for live adjustment as well as EPICS integration.