

Batch Production of Micron-scale Backlighter Targets.

Contact Graham.Arthur@ScitechPrecision.com

Graham Arthur

Scitech Precision Ltd., Rutherford Appleton Laboratory,
Harwell Oxford, Chilton, Didcot, Oxon, OX11 0QX

Christopher Spindloe and Martin Tolley

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

Introduction

High power laser experiments typically require of a number of high specification target components. One such example of this is where an experimental package is diagnosed by a secondary target interaction that is designed for x-ray or proton imaging depending on the experimental requirement and the target composition. In this paper we report on the fabrication of x-ray backlighting targets.

The generation of x-ray probe beams for diagnostic use in high power laser science is well known and has been in use for many years. It is commonly achieved by the laser irradiation of a high-Z metallic target positioned behind a pinhole and close to the primary target. These backlighter targets have had typical dimensions of several 10s of microns in diameter. As a consequence the source size from these is relatively large and hence the resolution of the x-ray probe beam is limited. There has, therefore, been a drive to fabricate backlighter targets with significantly smaller dimensions to create probe beams with greater resolution.

In addition, the pulse repetition rate of current and future high power laser systems is increasing and this, in turn, leads to an increase in the numbers of targets required. Traditionally laser targets, including backlighters, have been fabricated using conventional machining, coarse etching processes and hand assembly which allow targets to be produced in quantities of 10s to low 100s, but this will no longer be able to satisfy demand in both quantities and dimensions/tolerances for the future.

We describe the mass production of micron-scale, micro-wire backlighter targets using Micro-Electro-Mechanical System (MEMS) fabrication techniques. These techniques are a development of the fabrication methods using in the semiconductor industry and use industry standard silicon wafers as the basic substrate. In the same way that integrated circuits (ICs) are manufactured in very large numbers, it is possible to batch-produce micro-wire backlighter targets on silicon wafers with numbers in the 1000s, even for short production runs.

Backlighter Target Design

Conventional backlighter targets

A conventional backlighter target design typically consists of a high-Z metallic source behind a pinhole. The example shown in Figures 1 and 2 is a design used on the Orion laser [1] and consists of a 400 μ m diameter x 0.5 μ m thick titanium micro-dot on a 2mm square x 50 μ m thick CH film. This is mounted 0.5mm behind a 5mm square x 50 μ m thick tantalum pinhole which has a 10 μ m CH coating on all surfaces.

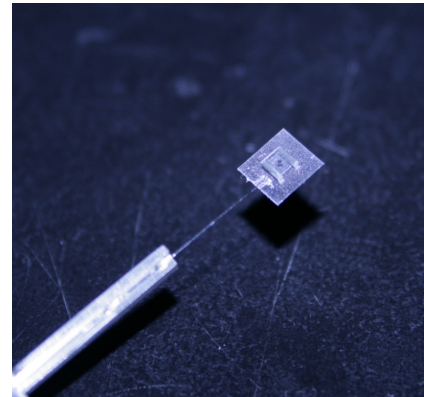


Figure 1. Conventional backlighter target consisting of a titanium micro-dot on a CH film and mounted behind a tantalum pinhole

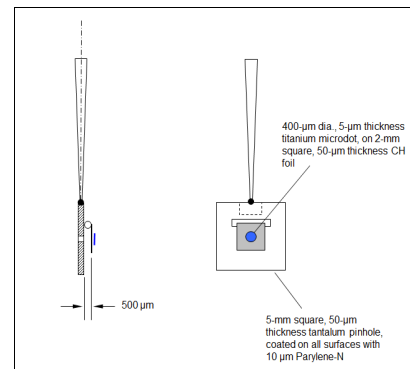


Figure 2. Schematic of the conventional backlighter target shown in Figure 1

Micron-scale backlighter targets

The micron-scale backlighter target, as described here, is a markedly different design to that seen in Figures 1 and 2. It consists of a square-sectioned micro-wire with dimensions of a few μ m square x a few tens of μ m in length, as shown in schematic form in Figure 3.

This micro-wire is supported on a low-Z, CH membrane with a thickness of 1 μ m. This membrane is, in turn, mounted on a Y-shaped support formed from the remainder of the silicon wafer substrate after the manufacturing processes.

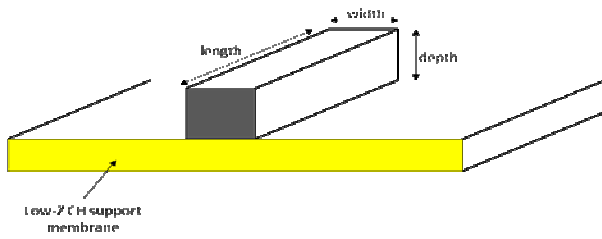


Figure 3. Schematic form of the micron-scale backlighter target (Width and depth are a few μm , whilst length may be 10s to 100s μm .)

Initial micron-scale backlighter target design

The computer aided design (CAD) drawing for the initial design is shown in Figure 4. The drawing shows a 100mm diameter silicon wafer substrate with the CH membranes having dimensions of 1mm x 1mm which are located on a pitch of 1.25mm x 1.25mm, giving approximately 1900 targets. The zoomed-in section of Figure 4 shows this in more detail. Also seen on the drawing are diagnostic trenches and alignment marks for use during the fabrication process.

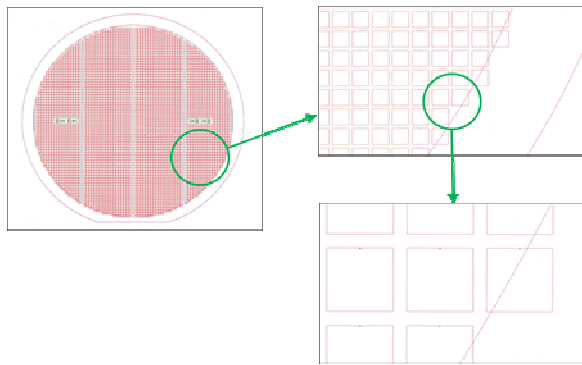


Figure 4. CAD drawing of the 100mm silicon wafer with approximately 1900 targets. The zoomed-in sections show the individual targets in more detail.

Design for first production run

Prior to the first production run, it was decided to change the design by increasing the CH membrane area to measure 2mm x 1mm to allow easier access to the backlighter for both the laser beam and the alignment optics. The CAD drawing for a single target is shown in Figure 5. Alignment arrows are included in the design to allow the target to be more easily located and positioned when in the target chamber.

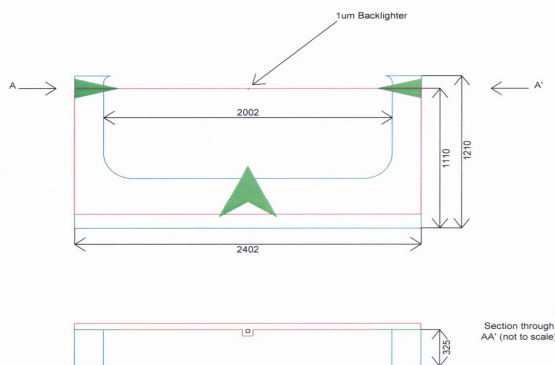


Figure 5. CAD drawing for the first production run of the micron-scale backlighter target. The backlighter is found at the intersection of the vertical and horizontal arrows.

MEMS-based manufacture

These manufacturing technologies offer the opportunity to fabricate targets with significantly smaller dimensions than previously achieved, and with much finer tolerances. Unless requested otherwise, the substrates for this type of target fabrication are usually silicon wafers which are typically 100mm in diameter, have a thickness of 300-500 microns and are flat from edge to edge on the micron scale. MEMS microfabrication techniques are based upon three basic processes: deposition, patterning and etching, and are described briefly below.

Deposition

Generally this capability includes sputter-coating, thermal evaporation, chemical vapour deposition, thermal oxide growth and spin/dip coating. Consequently it is possible to deposit precisely controlled films of metals, dielectrics and polymers.

Etching

These processes may be either dry etching or wet etching. In the former, a plasma containing highly reactive species (e.g. fluorine, chlorine) is generated which etches the substrate and/or previously deposited thin films. In the latter, the substrate and its coatings are immersed in a solution which is selected to etch the required layer, whilst leaving the other layers unaffected.

Patterning

This is the key process and uses either optical or e-beams tools to pattern a thin film of photo- or e-beam sensitive material known as a resist which has previously been applied to the substrate by spin or dip coating. The exposed and developed resist film is then used as a protective stencil through which deposition or etching can take place, thereby transferring the pattern into the substrate or its coatings.

Optical lithography uses photomasks to define the patterns. Masks usually comprise of an extremely flat quartz plate with the pattern defined on one side of that plate in a 100nm layer of chromium. In cases where only low resolution is required a photomask defined on an acetate sheet by high resolution inkjet printing may be used to reduce costs, but are prone to greater wear and tear with repeated use and can suffer from excessive thermal expansion in poorly controlled processing environments.

Electron beam lithography is utilised to define the highest resolution features and uses an e-beam tool which takes the device CAD files (converted into an appropriate format) and uses them to steer the e-beam on the surface of the resist and hence to directly write the required pattern which is then developed prior to use in the next process step.

These basic processes are repeated as often as required, and in a pre-determined order until the final structures are created.

Fabrication

The basic process steps are shown in schematic form in Figure 6. This figure shows the processing in cross-section and focuses on a single target. The patterning processes are able to align the various steps with sub-micron accuracy so that it is relatively straightforward to ensure that the micro-wire is positioned at the edge of the CH membrane, as required – and as shown later in Figure 11. Although the processing appears relatively complicated when compared with conventional target manufacture and utilises sophisticated processing tools, it should be remembered that the process is able to provide micro-wire backlighter targets with sub-micron tolerances and at the

fabrication rate of ~1900 targets per wafer, which was not previously possible.

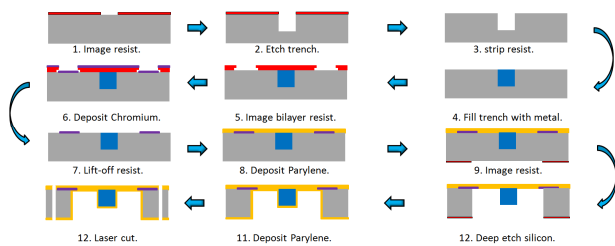


Figure 6. Basic process steps for the manufacture of the micro-scale backlighter targets.

Results

Figures 7 to 12 show the backlighter targets at various stages in the fabrication process. Figure 7 and 8 show the etched trenches (cf. Figure 6 – step 2) whilst Figures 9 and 10 show a wafer after trench filling (cf. Figure 6 – step 4). Figure 10 is an atomic force microscope (AFM) image and demonstrates that the surface of the filled trench is flat to better than 45nm. Figure 11 is following the resist lift-off process (cf. Figure 6 – step 7) and Figure 12 is a finished target (cf. Figure 6 – step 12).

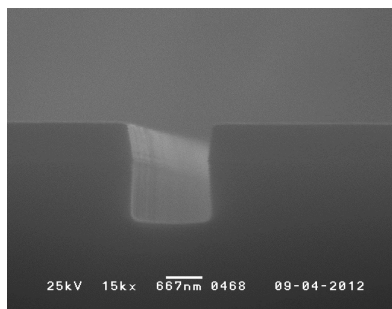


Figure 7. 1µm etched trench in silicon before resist is removed.

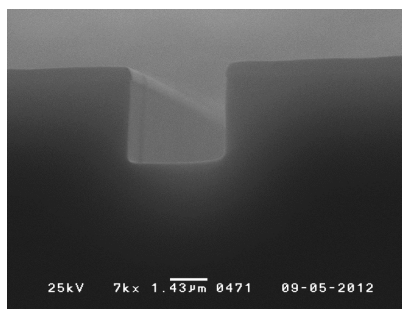


Figure 8. 3µm etched trench in silicon before the resist is removed.



Figure 9. Optical image of filled 1µm x 1µm x 10µm trench.

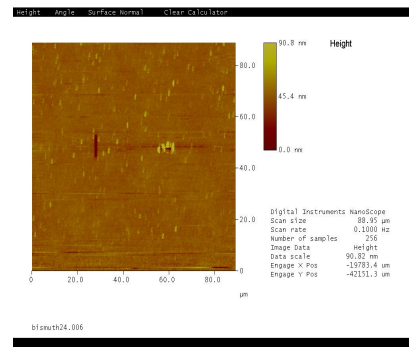


Figure 10. AFM image of a filled 1µm x 1µm x 10µm trench. The filled surface has a flatness of better than 45nm.

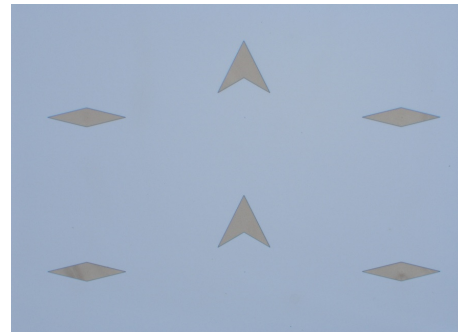


Figure 11. Wider area of the silicon wafer after the lift-off process, showing the Cr alignment arrows.



Figure 12. Edge of the CH membrane with a 3µm x 3µm x 10µm target at the edge and ready for use.

Conclusions

In conclusion, we have successfully manufactured micron-scale backlighter targets with three different cross-sectional dimensions: 1µm x 1µm, 3µm x 3µm and 5µm x 5µm. They were manufactured using MEMS-based fabrication techniques which are suitable for scaling-up to produce batches of up to a few 10s of wafers, using the currently available equipment. Each wafer potentially provides 1000 – 2000 targets and therefore a batch production of (say) 20 wafers could yield up to 40,000 micro-scale backlighter targets.

1. Hopps N, Danson C, Duffield S, Egan D, Elsmere S, Girling M, Harvey E, Hillier D, Norman M, Parker S, Treadwell P, Winter D, and Bett T. 'Overview of laser systems for the Orion facility at the AWE', Applied Optics, 52, 15, 3597-3601 (2013)