MEMS Fabrication of Silicon Microwire Targets.

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Abstract. Micro- and nano-structured surfaces can lead to increased absorption of incident laser pulses in high power laser experiments. Here we describe how MEMS (Micro-Electro-Mechanical System) manufacturing techniques (in this case, optical lithography, and deep silicon etching), have been used to create surface structured (“microwire”) laser targets consisting of 15um tall, regular arrays of 2um or 3um wide silicon microcolumns for a recent experimental campaign using the Vulcan laser at Rutherford Appleton Laboratory (RAL).

1. Introduction.
Recent high power laser experiments such as those described in [1] and [2] have shown that micro- and nano-structured surfaces can lead to an increase in the absorption of the incident laser pulses. There are a number of ways such a surface may be manufactured but one of the best routes is to use MEMS-based fabrication techniques to create regular arrays of closed-packed micron-scale pillars (microwires), which behave in the desired way. Some alternative methods (e.g. laser heating or electroplating) are able to create microwire targets of the correct dimensions and microwire densities but with a more random placement of wires within the target areas, whereas the chosen route allows pillars, grating or similar structures to be defined over specific areas which are both highly uniform and scalable. Other MEMS processes including wet etching [3] have been used elsewhere to create silicon micro-needles of similar dimensions for other applications such as drug delivery, but these have typically been pointed needles rather than the close-packed, square-topped, vertical-sidewalled pillars specifically requested for the experiments at RAL.

This paper describes the basic processes of MEMS-based fabrication and continues by outlining the process steps required to manufacture these arrays which consist of 2um or 3um microwires each over an area measuring approximately 500um x 500um per target. The microwire arrays were successfully created and have been used in a recent experimental campaign [4].

2. MEMS-based manufacture.
The MEMS-based manufacture uses technologies originally developed from those found in the semiconductor manufacturing industry. 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. Crystal orientation is normally <100> unless specifically requested otherwise. For target manufacture, wafer doping type is not normally customer-specified. MEMS microfabrication techniques are based upon the three basic processes outlined below:
2.1. Deposition.
This 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.

2.2. Etching.
This 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 through a protective masking layer. In the latter, the substrate and its coatings are immersed in a solution which is chosen to etch the required layer, whilst leaving the masking and other layers unaffected.

2.3. Pattern transfer.
This is the key process and, depending upon the dimensions required for the laser target, uses either optical, e-beam, or nanoimprint tools to pattern a thin film of 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 and/or its coatings.

Optical lithography uses ultraviolet (uv) light passing through photomasks to define the patterns in an optical resist. Resolution is limited by the wavelength of the light and for laser target-making this is usually restricted to about 0.5-1 micron.

For the highest resolution features, electron beam lithography is used. Here an electron beam focused down to a nanometre-scale spot is driven across the surface of the resist to directly expose (“write”) the pattern.

Nanoimprint lithography (NIL) uses a previously made stamp which is pressed into the resist layer. Application of heat or uv light retains the topography of the stamp in the resist thereby transferring the pattern. The stamp is also made using lithographic and etching processes. This method can achieve resolutions in the nanometre scale and is particularly attractive for mass production when compared to e-beam lithography.

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

3. Target Specification.
Figure 1 shows the dimensional specification of the microwire target, whilst Figure 2 shows how this is realized as a practical laser target. The target mount is a 2mm x 7mm x 350um piece of silicon with the microwire array 2mm from one end. The trench around the target allows it to be easily separated from the silicon wafer as it is only secured with a small tab at the other end following fabrication and can be simply “snapped out” and bonded to a standard support structure.

![Figure 1. Basic target specifications.](image)
4. Target Fabrication.

Figure 3 shows the microfabrication steps, in cross-section, using a silicon-on-insulator (SOI) wafer as it is being processed. This wafer has a 20μm thick silicon device layer and a 325μm thick silicon handle (support) layer, separated by a 1μm oxide layer, which acts as an etch-stop layer during the processing. Optical lithography using a Karl Süss MA-6/BA6 mask aligner was used throughout to define the structures which have a minimum feature size of 2μm. Silicon etch was carried out using an STS deep reactive ion etch (DRIE) system and the oxide removal using an Oxford Instruments System 90 reactive ion etch (RIE) tool.

The process steps were as follows: Step (1) is the initial lithographic step which images the array of pillars into a 1.5μm resist film on the device layer. Step (2) is the first deep silicon etch, creating the pillars in the device layer. Following a resist strip, step (4) is the next lithographic step which images the cavities and separating trenches into a 7μm resist film on the handle wafer side. Step (5) is the second, deep silicon etch, from the underside, which stops at the oxide etch-stop layer. After another resist strip, step (7) uses a laser cutting tool to cut through the oxide and device layer, leaving each target array held in place by the small tab (see §3). Step (8) is a manual “snap-out” of the individual target arrays, as required. Step (9) is an oxide strip, using RIE, to remove the etch-stop layer prior to manual bonding of the target onto a standard support structure which is then placed in the target chamber.
5. Results.
Following the process steps described above, 60 x 60 arrays of 2um and 3um microwires were successfully manufactured. Figures 4 to 6 show the microwire arrays during manufacture and inspection. The layout on the wafer meant that more than 100 target arrays were processed per wafer and, as only a fraction of the total available were required for this experimental campaign, high yield was not an issue and was not specifically measured. It does, however, demonstrate the potential for mass production if a similar type of target is required in the future.

Figure 4. Optical image of the photoresist pattern of the 2um pillars before etching. This corresponds to Figure 3, Step 1.

Figure 5. SEM image of 3um pillars after deep silicon etch viewed at 30°. This corresponds to Figure 3, Step 3.
Figure 6. Wyko white light interferometer scan of the 2um microwire arrays which had a finished depth of 9-10um. The 3um versions had a finished depth of 13-14um.

6. Conclusions.
We have demonstrated the successful manufacture of microwire array targets with both 3um and 2um critical dimensions in 500um x 500um areas. Both types have now been used in a recent experimental campaign[4]. Further optimisation of the manufacturing processes could lead to improved targets of this type (e.g. narrower and/or taller microwires), should they be required for future experiments.

7. References.
1. Dimitri Khaghani et al. “Enhancing laser-driven proton acceleration by using micro-pillar arrays at high drive energy” Sci. Rep. 2017, 7: 11366.
2. Purvis MA, et al. Relativistic plasma nanophotonics for ultrahigh energy density physics. Nature Photonics. 2013;7:796–800. doi: 10.1038/nphoton.2013.217.
3. N. Wilke, A. Mulcahy, S.-R. Ye, A. Morrissey Tyndall “Process optimization and characterization of silicon microneedles fabricated by wet etch technology” Microelectronics Journal 36 (2005) 650–656.
4. "A bright laser-driven X-ray and particle source using microstructured silicon targets" submitted to Nature Physics.