Vertically aligned nanowire arrays as laser targets

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Introduction

Vertically aligned nanowire arrays have become a more prevalent type of target for high-powered laser experiments in recent years and have garnered interest due to their applicability to various fields[1]. They can be formed by a variety of methods depending on the materials used for the nanowires and substrate and exhibit interesting properties under the influence of a high-powered laser pulse[2,3]. The “forest” of nanowires has been shown to increase plasma yields and allow the laser to penetrate deeper into the sample because the wires are able to propagate the pulse deeper into the sample[3]. The effect allows a greater absorption of the pulse and has shown nanowire arrays to be competitive with foam targets for some applications. The method described in this paper was to electrochemically form nano-porous aluminium oxide templates and subsequently electrodeposit the desired metals within the pores, using nickel nanowires as the proof of concept before moving onto other metals.

Surface quality/roughness

The smoothness of the aluminium substrate (foil) prior to anodization is very important in obtaining a well-ordered porous template[1]. Defects in the surface, such as the grooves caused by the rolling of the foil, can create a preferential pathway down to the conductive aluminium through the non-conductive alumina layer (this is the mechanism the drives pore formation). This can cause pore formation that does not conform to the ideal honeycomb arrangement that is usually expected and desired for its consistent interpore spacing. The foil samples were treated with different polishing methods and compared to the unpolished foil using surface profilometry to create line scans and map scans of the samples.

The line scan data showed mechanical polishing and electropolishing to be the best techniques of those tested for producing a smooth surface, however, the mechanical polishing removed too much material and induced some “ordered” roughness, much like the unpolished foil.

Anodization/pore formation

Anodization involves an electrochemical reaction at the surface of an aluminium substrate to form an oxide barrier layer using an acidic electrolyte (in this case oxalic acid). By varying the conditions it was possible to create a porous alumina membrane layered on top of the aluminium with controllable parameters[1,3,4] (pore diameter, spacing and depth). Calibration curves were developed for pore dimensions resulting from altering different anodization conditions for voltage and pore widening time within certain limits.

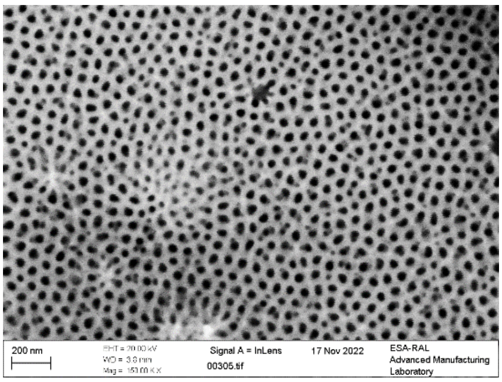

Figure 1: Nano-porous template made by 2-step anodization

The general trends were determined with pore diameter and spacing increasing with voltage, and depth increasing with anodization time.

A 2-step anodization process was used to improve the pore ordering: etching away the oxide from the first anodization process and forming pores within the remaining indentations.

An ideal arrangement is a hexagonally ordered[1,3] honeycomb of pores visible under SEM across the surface of the substrate. Good results in terms of consistent pore spacing and diameter were achieved and, while the hexagonal arrangement could still be improved (likely to occur with increased voltages), the templates formed were of sufficient quality to make well-ordered, vertically-aligned metal nanowire arrays.

The pores were imaged using an SEM and analysed using the pixel-counting software ImageJ as well as through a programme developed in-house to count the pores and measure the diameters. Measurements were also recorded manually as a comparison. A fast Fourier transform was also used to determine whether the hexagonal pattern was arising in the template.

Nanowire deposition

Once the procedure for forming the templates had been consolidated, experiments were carried out to ensure that electrodeposition of nickel nanowires worked as anticipated. Nickel nanowire arrays were able to be formed with a high success rate. The deposition process was performed using a nickel sulphate and boric acid electrolyte and required a reverse-pulse waveform. This was needed to keep the oxide layer thin enough within the pores so that the reaction could occur at the conductive metal layer at the bottom of the pores.

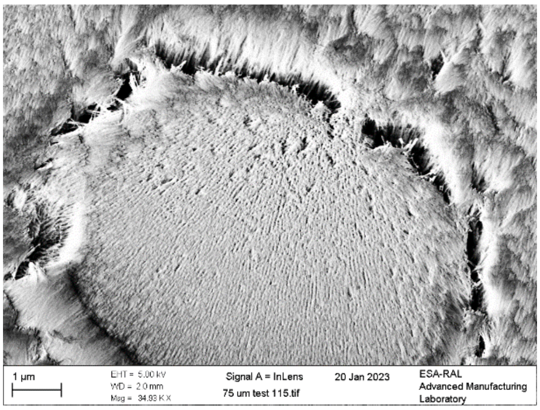

Figure 2: Nanowire array from 2-step anodized template

Nanowire analysis

The nanowires are analysed in a similar way to the porous templates using SEM imaging and pixel counting software to determine the nanowire lengths. The diameters and spacings of the wires mirror those of the pores they are deposited in. Some problems that were observed in the wire arrays is that the nanowires can clump together due to a high aspect ratio[2] and their proximity which allowed the attractive forces between them to pull them together. This could be solved by increasing the interpore distance or wire diameter, or by decreasing the wire lengths. The wire diameter is dependent on pore diameter and length is dependent on deposition time.

Nanowire Targets for the University of York

The targets were shot at the ILIL in Pisa, Italy. Early results indicate that it was possible to see Optical Transition Radiation (OTR) from the rear of the targets and also ion and x-ray data was collected. Of particular interest will be reflectivity data which will give us an idea of any absorption increase due to the nanowires. This will be analysed by the user group in the coming months. This represents the first occasion of CLF producing vertically aligned nanowire arrays to be used as targets for a high-powered laser experiment.

Other materials and future work

The next steps in this project will be to investigate electrodepositing other metals to form nanowire arrays, as well as to further examine the conditions required to alter the dimensions and spacing in the porous templates. Additional tests to assess how higher voltages affect the pore ordering and dimensions will also be conducted to allow for greater tuneability of nanowire arrays to be provided.

Conclusions

Good results were achieved, with consistent porous templates and nanowire arrays being synthesised. Additionally the investigation into using other metals for the nanowire arrays has begun starting with copper. A degree of tuneability has also been achieved for wire diameter, length and spacing by altering the anodization and deposition conditions in the synthesis of the arrays. This should allow for nanowire arrays to be delivered according to the specification of users within specified limits.

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