

*Delimit, label and calculate the domain size areas for aluminum and titanium nanoporous structures using image processing techniques*

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1-Objective:

The aim of the present study is to develop an image processing software that provides the degree of organization of nano-arrays consisting of hexagonally ordered arrays of nanopores of anodic aluminum oxide (AAO) and anodic titanium oxide (ATO) [Figs. 1(a) and (b)] based on the analyses of digital Scanning Electron Microscopy (SEM) images.

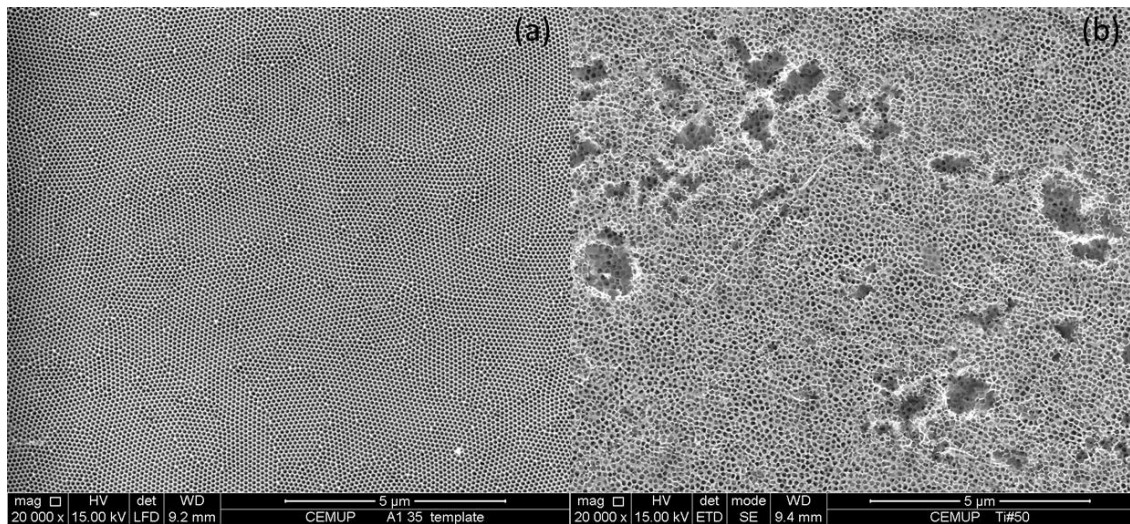


Figure 1- AAO (a) and ATO (b) top view SEM images.

2-State of the art:

The oxidation of metallic foils of aluminum or titanium can result in the formation of a network of dense nanopores [Figs. 1(a,b) and Fig. 2]. The characteristic parameters that are controllable by operating conditions are the pore diameter ( $D_p$ ), interpore distance ( $D_{int}$ ), wall thickness ( $W$ ), porosity and pore density (Fig. 2). In these periodic arrays, the ideal arrangement is represented by a hexagonal structure. However, the arrangement of the NTs is often disturbed by defects and grain boundaries.

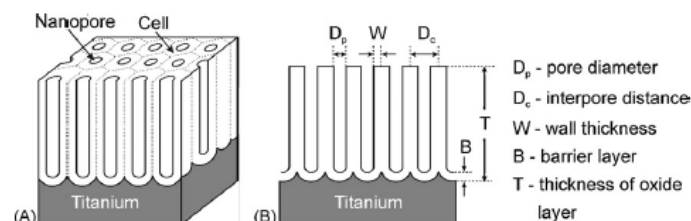


Figure 2- pore rearrangement process occurring on the surface and resulting in a network close-packed pores [1].

The pore arrangement was previously studied using fast Fourier transforms (FFTs) [1, 2]. The image analysis software WSxM [3] and ImageJ [4] can then be employed to calculate and analyze the 2D FFTs of these images.

a) Example of AAO FFT analyses:

To provide a systematic route to evaluate the organization and quality of the nanoporous surfaces, we can perform a detailed FFT analysis of the SEM image. For a single domain region, the FFT evidences the hexagonal symmetry of the pattern. A line profile of the FFT pattern [Fig. 3] shows eight distinct peaks, stressing the long-range order of the structure. In addition, the size distribution of the nanopores distance is seen as the displacement of the central frequencies of the FFT peaks, allowing us to obtain an average of the lattice parameter.

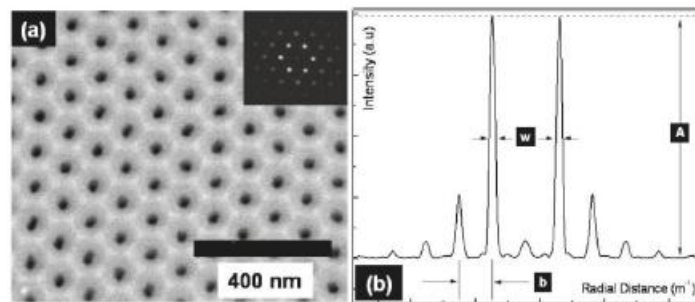


Figure 3 - FFT analysis of the AAO SEM image [4].

b) Average domain size analyses:

A domain size is an area with arrays of hexagonally arranged cells. This ideal pore arrangement regularity is often disturbed by defects and the grain boundaries of the starting metal (Al or Ti). The calculation of these organized areas has been made for the AAO case [5] using home-made software. Numerical image treatment (Fig. 4) of these pictures shows that size of the ordered domains (false colors).

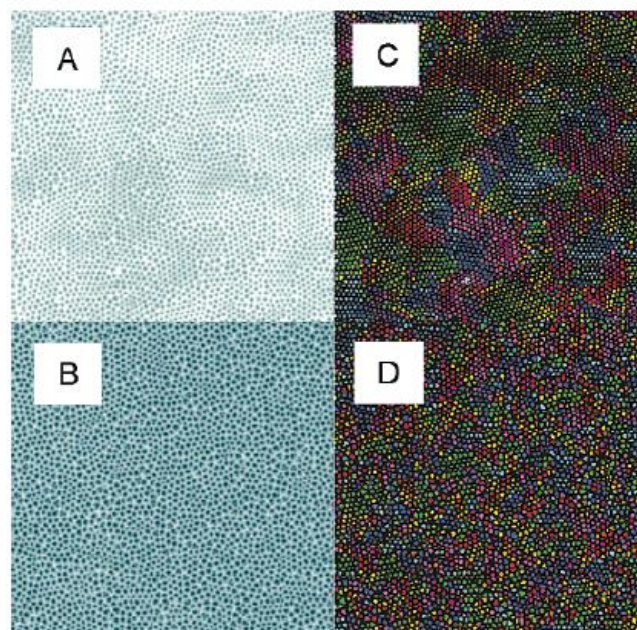
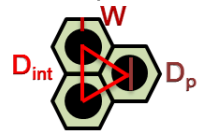


Figure 4 – Average domains size analysis of the AAO SEM image [5].

### 3-Statement of the problem:

The project goal is to develop an *image processing software* with the ability of delimit, label and calculate the domain size areas for aluminum and titanium nanoporous structures. The top view SEM images for the aluminum case display the structure features with a good contrast relating, which is an advantage for the image processing code. However, in the case of titanium, such contrast does not exist in the SEM images. Since the top of such nanoporous is highly damage the organization evaluation has to be made in the SEM images from the nanoporous bottom (Fig. 5).

AAO approach (top-view)



ATO approach (bottom-view)

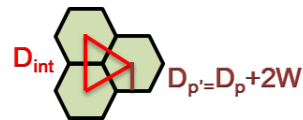


Figure 5- Two approaches for the aluminum (AAO) and titanium (ATO) arrays arrangement evaluation.

Since the problem increases in complexity, as far as we know, very little attention has been paid to the analysis of arrangement of nanotubes in ordered arrays of titanium nanopores. To carry out the delimitation and calculation of such domains size areas, we have to evaluate the titanium nanopores arrays considering that the array arrangement is represented by a hexagonal array and that the cell individual shape exhibits a hexagonal shape (Fig. 6).

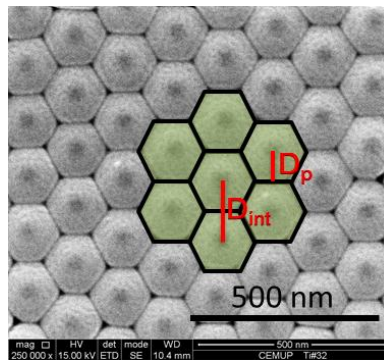


Figure 6- SEM image from ATO arrays arrangement evaluation (bottom view): the ATO arrays arrangement is hexagonal as well their shape.

The objective is then also to obtain software able to delimit and calculate the domain size areas in such titanium hexagonal structures. Figure 7 shows an example of the targeting software result for the SEM images analyze.

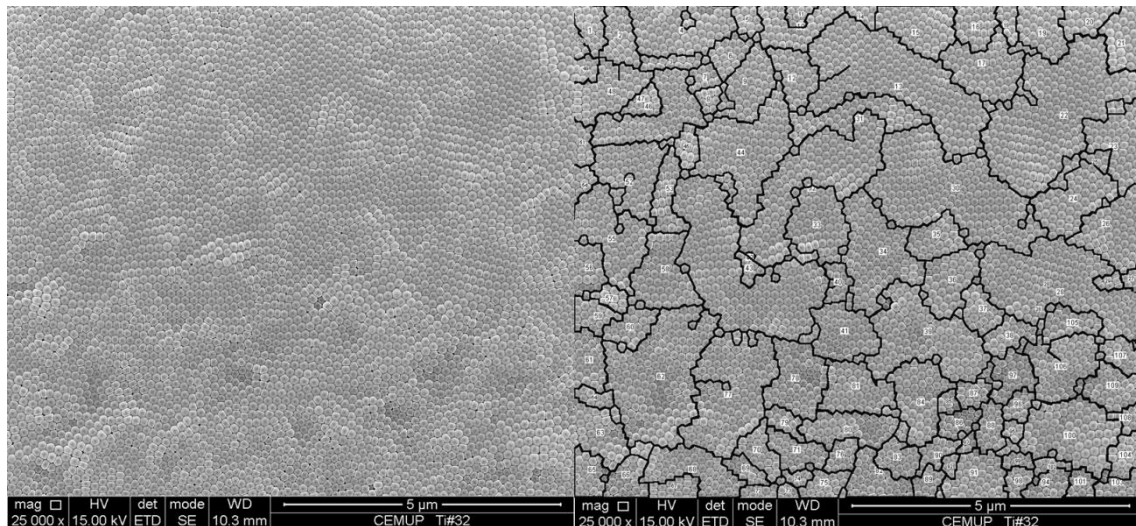


Figure 7: SEM image from the Nts bottom before (left) and after (right) the average domains size areas delimitation and calculation.

### References:

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