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YST035 - TWO-STEP ANODIZATION APPROACH FOR FABRICATING NANOPOROUS ALUMINA ON ALUMINUM HOLLOW TUBES

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ABSTRACT

This study reports the fabrication of nanoporous anodic aluminum oxide (AAO) layers on both the inner and outer surfaces of aluminum (Al) hollow tubes using a modified two-step anodization process. Unlike conventional AAO synthesis performed on planar or single-surface cylindrical substrates, the present method enables simultaneous anodization of concave and convex surfaces within a single system. The novelty of this work lies in the dual-surface anodization approach for hollow tubular substrates, achieving hexagonal nanoporous morphology across geometrically distinct surfaces without requiring separate processing steps. This method expands the applicability of AAO beyond traditional planar templates, offering a scalable route for complex 3D architectures. The resulting dual-surface AAO tubes hold significant potential for advanced applications, including multifunctional membranes, high-surface-area catalytic supports, and fluidic devices where inside–outside accessibility is critical. Their large surface area, high pore uniformity, and robust structure make them suitable for separation processes, sensing platforms, and energy storage devices. By enabling efficient and uniform anodization of both internal and external surfaces, this research provides a pathway for integrating AAO into next-generation tubular devices, offering enhanced performance in chemical, environmental, and biomedical applications.

Keywords – two-step anodization, AAO nanoporous structure, hollow tube

INTRODUCTION

The fabrication of AAO has progressed markedly, moving from its origins on conventional flat aluminum foils to more intricate forms such as aluminum wires, and, more recently, to 3D architectures like hollow Al tubes [1, 2]. This evolution is driven by the growing demand for high-surface-area nanostructures in cutting-edge technological applications. AAO is widely valued for its highly ordered nanoporous structure, chemical inertness, adjustable pore dimensions, and excellent thermal and mechanical stability, making it a versatile platform for use in nanotechnology, electronics, biosensing, and energy storage [3, 4].

Despite these advantages, AAO synthesis on planar aluminum foils presents notable limitations. Achieving pore distribution over large surface areas remains challenging, and the active surface is restricted to a single exposed side, constraining the total available functional area. By contrast, transitioning to 3D substrates such as hollow aluminum tubes enables the simultaneous use of both inner and outer surfaces, significantly increasing the effective surface area. This expanded geometry not only enhances material utilization but also opens opportunities for innovative device designs and multifunctional applications.

OBJECTIVE

This study aims to develop and optimize a two-step anodization process for fabricating nanoporous anodic aluminum oxide (AAO) on both the inner and outer surfaces of hollow aluminum tubes. The specific objectives are to:

i. Establish a reliable two-step anodization procedure capable of producing uniform, self-ordered nanopores on concave (inner) and convex (outer) surfaces simultaneously.

ii. Investigate the influence of anodization parameters, particularly voltage and time on pore morphology, oxide thickness, and structural uniformity across both surfaces.

METHODOLOGY

The fabrication of nanoporous AAO was fabricated on hollow aluminum tubes using a two-step anodization process in a custom-built etching cell [5]. Prior to anodization, the aluminum substrate was sonicated in acetone to remove surface contaminants. In the first anodization step, the exposed surfaces of the tube were immersed in an acidic electrolyte maintained at a constant temperature and subjected to a fixed voltage for one hour. The resulting oxide layer was then dissolved by immersing the tube in an etching solution for two hours, revealing a textured aluminum surface that served as a template for the subsequent anodization. The second anodization was performed under identical voltage and temperature conditions but with an extended duration to produce the final ordered nanoporous AAO layer. The surface morphology and cross-sectional structure of the AAO layers were examined using field emission scanning electron microscopy (FESEM) operated at an accelerating voltage of 5.0 kV and a working distance of 4–8 mm to achieve optimal image resolution. Quantitative analysis of pore structure and dimensions was performed using ImageJ software on the acquired FESEM micrographs.

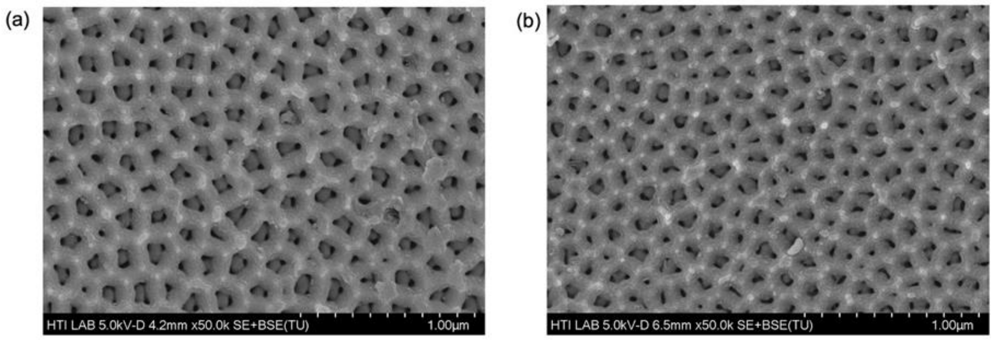

Figure 2 Top-view FESEM images of AAO on the (a) convex and (b) concave surfaces of the Al tube anodized at 80 V for 6 hours.

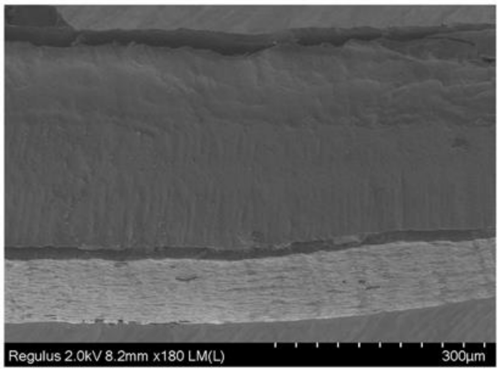

Figure 3 Cross-section of the Al hollow tube with two layers of AAO sandwiching the Al substrate.

RESULTS AND DISCUSSION

The top-view FESEM images of the AAO at 50,000× and cross-section at 180× magnification is shown in Figure 2(a) and (b), respectively. The convex surfaces exhibit an average pore sizes 80nm while the concave surfaces reported a slightly lower pore sizes, around 70nm. This variation arises from the different electrochemical conditions on the tube's inner and outer surfaces [6]. The outer surface, being more directly exposed to the electrolyte, is subjected to a stronger electric field during anodization. This intensified local field accelerates pore growth and leads to the development of larger pores. Conversely, the inner surface, which is partially enclosed and less exposed within the hollow structure, experiences a weaker electric field, producing smaller pores. A similar pattern is observed for the interpore distance, where the outer AAO layer consistently exhibits larger spacing than the inner AAO layer. Figure 3 shows the cross-section Al hollow tube with well attached layers of AAO between the Al substrate. The average thickness of outer and inner AAO layer were measured to be 17μm and 12μm, respectively. The anodization time shows a linear relationship with the AAO thickness [7], indicating a proportional increase in thickness with longer anodization times.

CONCLUSION

A dual-surface AAO layer was successfully formed on the hollow aluminum tube, confirming the feasibility of this fabrication approach. The results highlight its potential for a wide range of applications, including gas separation, sensing, energy storage, and serving as a template for the synthesis of various nanostructures.

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