The Development of Anodic Aluminum Oxide Based Micro-channel Plate for Large-area Photo-detector.

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The Development of Anodic Aluminum Oxide Based Micro-channel Plate for Large-area Photo-detector

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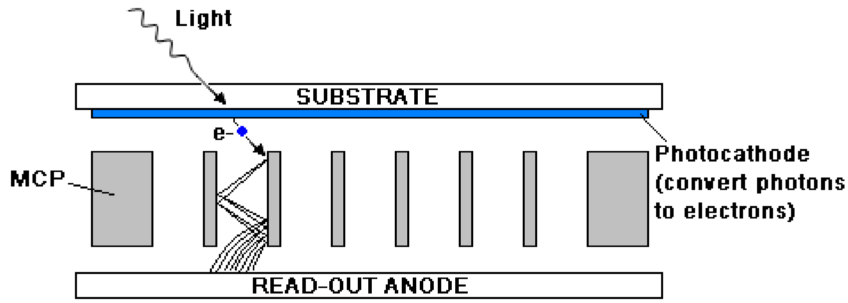
ABSTRACT

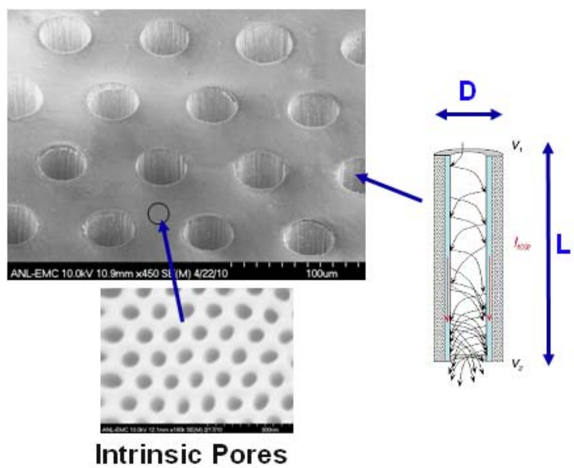
Anodized Aluminum Oxide (AAO) based micro-channel plates (MCP) are fabricated in order to develop economical large-area photodetectors. Commercially available glass capillary array has a limitation to reach channel diameter below ~10 microns. However, smaller channel diameter is desired for better spatial and fast timing resolution. AAO based MCP is a good candidate to produce channel diameter less than 10 um by taking advantage of the nano-scale intrinsic pores during etching process. In this study, various channel diameters are fabricated with use of lithographic patterning techniques and wet etching; and characterized with optical, atomic force, and scanning electron microscopies. The channel diameter, channel length and related aspect ratio, as well as the open area are varied in order to maximize the MCP photon amplification.

INTRODUCTION

Photo-detector based on photomultiplier tube (PMT) is indeed a remarkable device with extreme sensitivity, high gain and high quantum efficiency [1]. However, conventional PMT has multiple discrete dynodes for secondary electron amplification. Assembly of discrete parts is expensive and not easy to build up for a large-scale device. Microchannel plate (MCP) is a plane device composed of delicately fabricated micron-size channel array. When the channel inner walls are coated with material that enhances the secondary electron emission, each channel behaves as an individual PMT and the MCP serves as a relatively large area photomultiplier device [2-5]. Conceptually, an array of MCPs will constitute a truly large area detector desired for high energy physics and astrophysics application. The main show stopper is the cost of MCP. Therefore, there is a need to develop large area and economical MCPs. Figure 1(a) shows a schematic drawing of a MCP based PMT. Short channel length of MCP gives markedly fast timing resolution and micron-scale pore diameters result in high spatial resolution [6]. Commercially available MCP amplification stage is made of glass capillary that is fabricated by drawing glass fibers, slicing and etching hollow fiber cores chemically. However, glass capillary MCP has technical limitation to make smaller channel diameters. The possible range of optical fiber diameter is from 2 to 40 microns [7]. As the fiber diameter decreases, the fabrication becomes more difficult and the cost becomes more expensive. In addition to its high cost, the mechanical strength is also a concern for large-scale device application. Smaller diameter channels are required to enhance temporal and spatial resolution further.



(a)



(b)

Figure 1. (a) Schematic of MCP-PMT (b) SEM image of AAO based MCP. Open area ratio of this MCP is 22.7%. Small picture on the bottom is the magnified image showing the intrinsic nanopores in AAO.

AAO has several attractive advantages. Due to vertically aligned intrinsic nano-scale pores (Fig 1(b)), AAO can be etched to create micro-channels with high aspect ratio (length/diameter). The intrinsic nanopore diameter from 20-300 nm also allows MCP channels to be much smaller than the current 2 microns limit. However, direct anodization does not work well to prepare AAO intrinsic pores with diameters from 350 nm to ~1,000 nm. To work in this pore size region, one needs to apply very high anodization potential (much larger than 200 V DC). The resulting pore array in this region is disordered. The Al sheet is also easily burnt under such high potentials. In order to avoid these difficulties and develop a new fabrication process, we applied direct laser writer patterning/photolithography to prepare patterned large pores with diameter from 4 to 40 microns. We have developed AAO based MCP as an alternative to the commercial glass MCP.

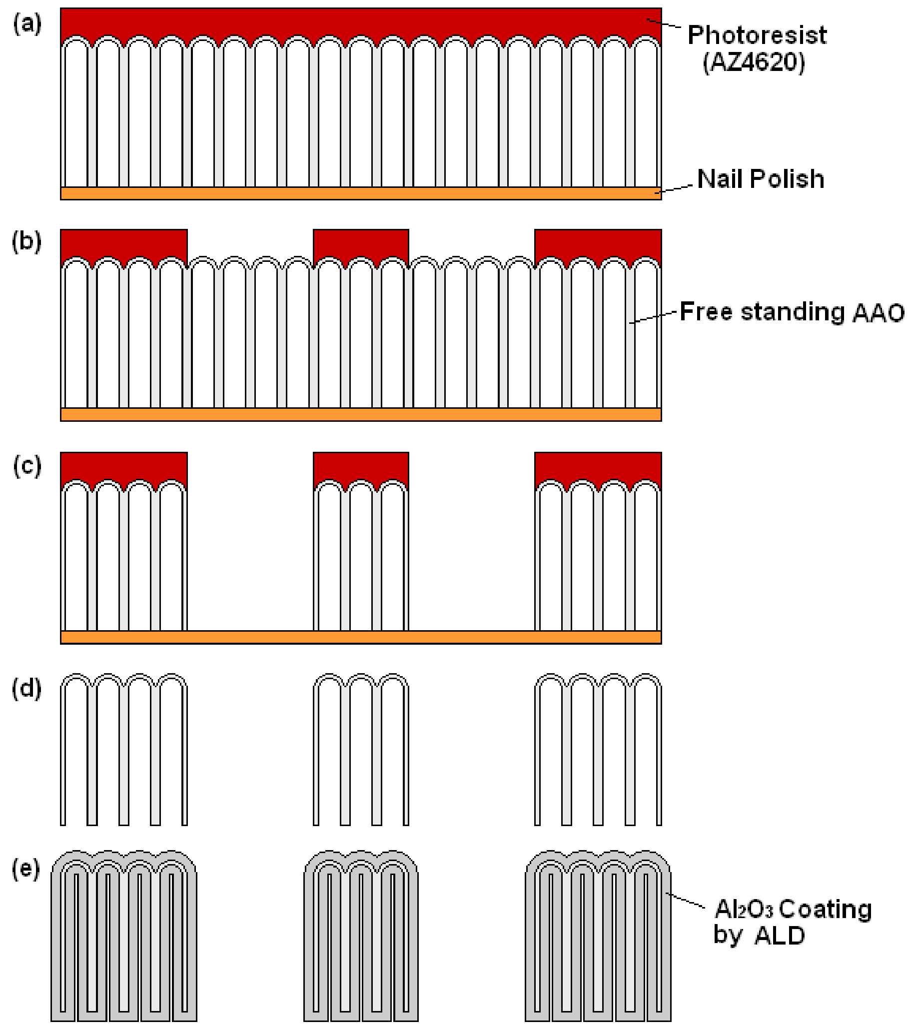


Figure 2. Fabrication procedure of AAO based MCP (a) Photoresist (AZ4620) was coated on the barrier layer. AAO pores are protected by nail polish. (b) Micro-channels pattern are developed. (c) Wet etching in 5% H_3PO_4 at room temperature. (d) All protective polymers are removed. (e) Al_2O_3 was coated by Atomic Layer Deposition (ALD) to enhance mechanical strength of AAO based MCP.

EXPERIMENT

An annealed aluminum sheet of 99.99% purity was purchased from ESPI metals. Surface of aluminum was degreased with acetone for 10mins, rinsed in DI water and dried at room temperature. Electropolishing was conducted by applying low voltage of 10 V for 30 mins at 3 ^{o}C. Al sheet was used as an anode and Pt sheet was used as a counter electrode. The electrolyte was composed of 1:10 volume ratio mixture of perchloric acid and ethyl alcohol (analytical reagent). Aluminum was anodized in 0.3M oxalic acid at 3 ^{o}C by applying a 40V potential. Two-step anodization process was carried out to ensure better AAO film. Non-uniform AAO layer from the first anodization was removed by etching in 6 wt% phosphoric and 1.8 wt% chromic acid solution at 60-80 ^{o}C for 3 hours. The second anodization was carried out for 120 hrs to grow a 200 um thick AAO film. Aluminum was removed without damaging the porous alumina layer to prepare a free standing AAO membrane. A 0.1 M $CuCl_2$/HCl (37wt%) in 4:1 volume ratio solution was used. The photoresist (AZ4620) was spin-coated with 3000 rpm for 30 secs on the barrier layer of the free standing AAO, and the other side of the AAO film was protected with use of nail polish. The thickness of photoresist was 7 um. Direct laser writer was used for photolithography. Micro-channels were etched in 5 wt% phosphoric acid at room temperature for 20 hours (Fig 2(c)). SEM images were taken with use of Hitachi S4700.

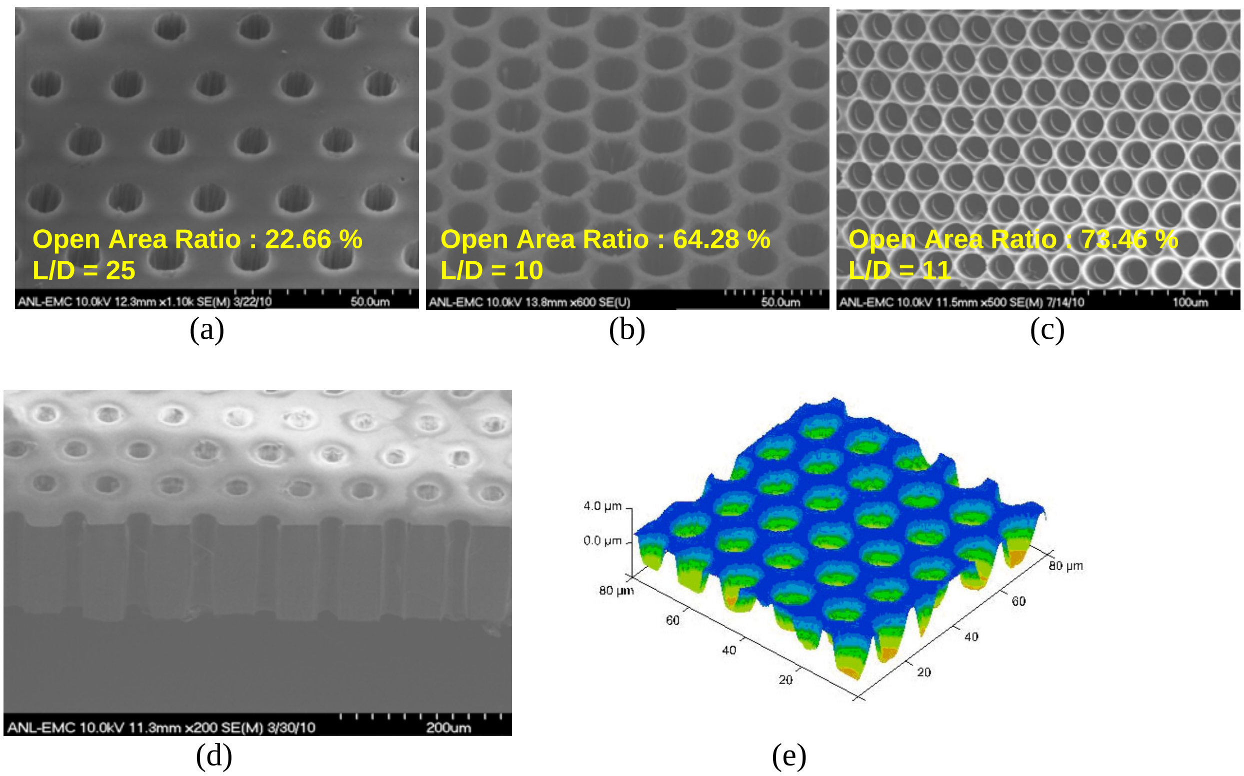
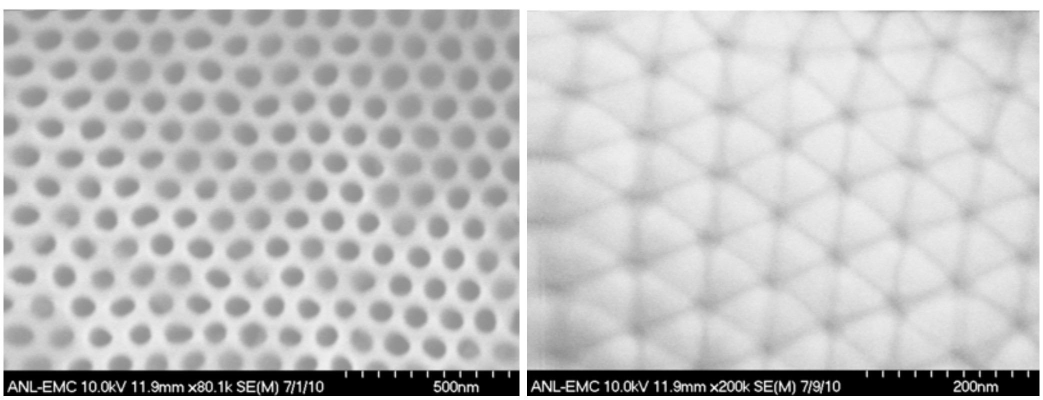


Figure 3. SEM images of micro-channel plates. (a)-(c) AAO based MCPs with various open area ratios and aspect ratios. (d) Cross-section of an AAO based MCP. (e) A 3D AFM image of an AAO based MCP with 80×80 μm^2 scan showing 10 μ pore diameter and 15 μ pore-to-pore distances.

DISCUSSION

Figure 1(b) is the SEM images of a micro-channel plate fabricated by laser writer/photolithography and wet etching. The imaged AAO MCP has 40um channel diameter with 22.7 % of open area ratio. Electron amplification gain would be determined by channel aspect ratio (L/D: where D is the channel diameter and L the channel length). The bottom image in Figure 1(b) is magnified from the top image showing intrinsic pores in the micro-channel plate. These intrinsic pores are advantageous for etching to gain high aspect ratio since etching solution can penetrate into these nano-scale intrinsic pores to help the etching process. Photolithography has been done on the open pore side of AAO for most of the AAO based devices [8,9]. However, the open pore side of AAO tends to be rough and requires an additional top layer in order to prevent photoresist from penetrating into the nanopores. In this study, photolithography was conducted on the barrier layer (Figure 2). Fabrication steps were reduced and simplified. Surface roughness of barrier layer is approximately 30~40 nm. AZ4620 photoresist has very high viscosity and will smooth out the surface roughness. Open area ratio of the AAO based MCP can be easily adjusted by designing different mask patterns. Therefore, AAO MCP can provide flexibility to adjust spatial and temporal resolution of detection devices. Wet etching is a very delicate procedure for the fabrication of AAO based MCPs. Time and temperature must be controlled very carefully. Etching rate is roughly 10um/hr at room temperature in a 5% H_3PO_4 solution.

The AAO based MCP has been studied previously by other groups [10-12] , however, optimal open area ratio has not been achieved. Figure 3(a)-(b) are the examples of AAO MCPs with various open area ratios and aspect ratios. Cross-section of AAO MCP is shown in Figure 3(d). AAO MCP in Figure 3(c) has nearly the maximum possible open area ratio at ~73%. However, AAO based MCP with maximum open area ratio would be fragile and must be handled with great care. We have also applied atomic layer deposition (ALD) technique to strengthen the mechanical hardness of the AAO MCPs. To fill the intrinsic pores, one requires an ALD coating with thickness up to half of the pore diameter. When intrinsic pores are significantly narrowed or blocked, the secondary electrons are not expected to travel through the narrowed intrinsic pore pathways. Here, entire MCP plate is coated with a 60nm of alumina layer by ALD to block the 60 nm intrinsic pores. Based on other ALD studies, the process is expected to make the inner surface of micro-channels walls smoother.[13] A smoother channel wall make the MCP behavior more predictable through calculations and simulations. Figure 4(a) and (b) are the intrinsic pores of AAO MCP before and after Al_2O_3 ALD deposition.



(a) (b)

Figure 4. (a) Intrinsic pores of AAO MCP showing 60 nm pore diameter; (b) AAO based MCP after Al_2O_3 layer deposition through ALD showing narrowed or blocked intrinsic pores.

CONCLUSIONS

We have fabricated AAO based MCPs with various channel diameters and aspect ratios for development of large-area photodetectors. Other potential application areas would be inexpensive and more precise positron emission tomography (PET) scanner in medical imaging, dual readout calorimeters, particle detectors in high-energy physics and gamma-ray telescope camera scanners for transportation security, etc. The new AAO based material only serves as the first step toward a working MCP. In order to prepare a working photodetector, the AAO substrate will be further coated with an emissive layer to enhance the secondary electron emission. Parallel efforts in making photocathode, electronic signal processing, as well as the mechanical assembly, are on-going. In this work, we demonstrated AAO based MCPs with aspect ratios up to 25 and open area reaching 73%.

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