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High Quality Colored Wind Chimes by Anodization on Aluminum Alloy

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***Abstract*—**In this paper, we used a high-quality anodization technique to make a colored wind chime with a nano-tube structure anodic film, which controls the length-to-diameter ratio of an aluminum rod and controls the oxide film structure on the surface of the aluminum rod by an anodizing method. The research experiment used hard anodization to grow a controllable thickness of anodic film on an aluminum alloy surface. The hard anodization film has high hardness, high insulation, high-temperature resistance, good corrosion resistance, colors, and mass production properties that can be further applied to transportation, electronic products, biomedical fields, or energy industry applications. This study also provides in-depth research and a detailed discussion of the related process of aluminum alloy surface hard anodizing, including pre-anodization, anodization, and post-anodization. The experiment parameters of anodization include using a mixed acid solution of sulfuric acid and oxalic acid as an anodization electrolyte and controlling the temperature, time, current density, and final voltage to obtain the anodic film. In the results of the experiments, the properties of the anodic film, including thickness, hardness, insulation, and corrosion characteristics, the microstructure of the anode film were measured, and the hard anodization efficiency was calculated. Thereby it can obtain different transmission speeds of sound in the aluminum rod. And, different audio sounds can present on the aluminum rod. Another feature of the present experiment result is the use of the anodizing method and dyeing method, laser engraving patterning and electrophoresis method to make good-quality colored aluminum wind chimes.

***Keywords*—**Anodization, aluminum, wind chime, nano-tube.

I. Introduction

ALUMINUM products are used in commercial and consumer products, such as electronic components, household appliances and cooking utensils, car parts and sports equipment, aviation, petroleum, defense industries [1]-[3]. The surface of aluminum products can be polished or anodized to increase added value. Since aluminum is lightweight, highly process able, and highly thermally conductive, it is used in a wide range of industries such as the home appliance industry and the automotive industry. However, aluminum is very soft and is not suitable for practical use. Therefore, the surface of aluminum products is usually anodize forming a protect film that exhibits good characteristics such as hardness, corrosion resistance, abrasion resistance, adhesion, uniformity, and coloring [4]-[7]. In the prior technologies, anodization generally has the main purpose of surface decoration or corrosion resistance. However, in the high technologies, the characteristics of film thickness, anti-voltage value, surface roughness, surface color and hardness of the hard anodized film have been strict requirements.

The anodization solution processing line is a chemical solution which is free of heavy metal pollution and non-toxic. A new generation anode processing line with filter function will be set up in production line before the waste liquid is discharged. In addition, the smoke generated in the process can be collected by the exhaust fan and the activated carbon net. Therefore, a new generation of anodization process is actually pollution-free production line.

Anodization of hard-anodization and structure anodic film are application for daily life and industry products. The Hard-anodization is for building materials, transport, military industry, semiconductor equipment, medical equipment, home appliances, sports equipment, environmental protection, kitchen and bathroom equipment. And, the structural anodic film is for semiconductor components, research units, biomedical industry, drug release, energy industry, air and water filtration.

An orderly nono-tube structure of an anodic film which is called anodic aluminum oxide (AAO) by anodization and chemical etching process achieving. The pore size of AAO can be controlled in 10 nm, 50 nm, 90 nm, and (d) 300 nm (Fig. 1). Because AAO has better mechanical properties than TiO_2 nano-tube (NT), the AAO morphology can be controlled easily than TiO_2 NT. For example, AAO pore diameter, length, and pore density can be controlled in the range of 10-500 nm, 0.1-200 µm, and 10^8-10^{12} tube/cm^2, respectively. According to our previous AAO fabrication experience [8], [9], a two-step anodization process can obtain a better nanotube array of membrane than a single step anodization.

In this paper, we propose a colored wind chime with an anodized film structure. The anodizing method is used to control the oxide film structure on the surface of the 6061 Al alloy to modulate the transmission behavior of sound on the surface of 6061 Al alloy wind chimes rods. Using this anodizing technology. A colored wind chime was made using aluminum sheets, rods, and rings. Further, the laser engraving method, the anodized dyeing method, and the electrophoretic dyeing

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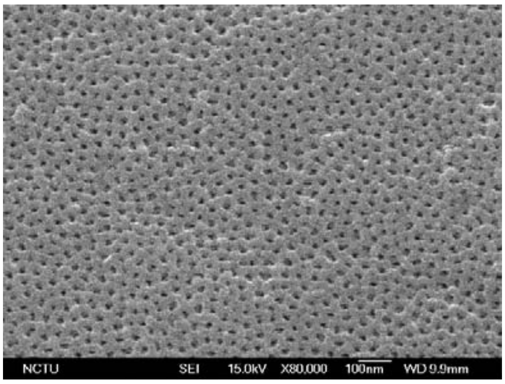
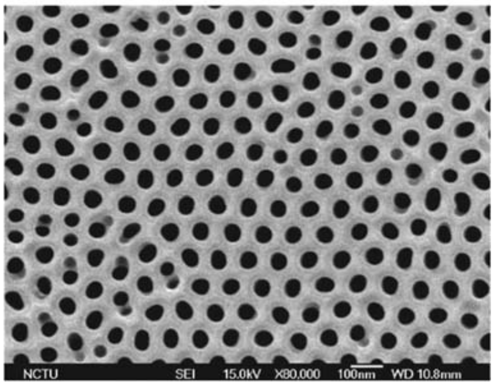
method can be used to customize special patterned colored wind chimes.



(a)



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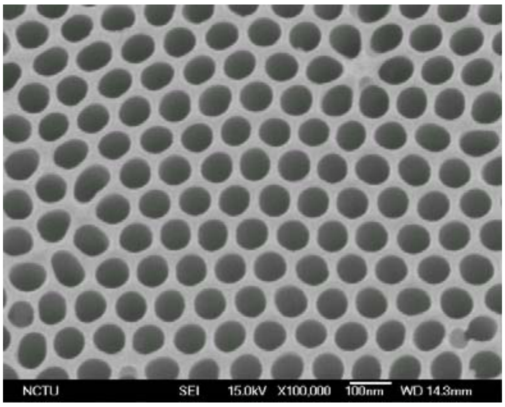
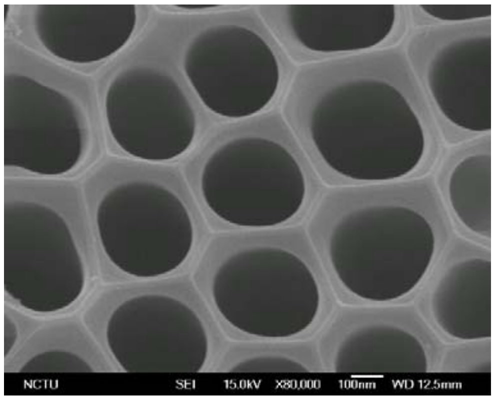


(c)



(d)

Fig. 1 SEM images of Al_2O_3 NTs film with various pore sizes of (a) 10 nm, (b) 50 nm, (c) 90 nm, and (d) 300 nm

The innovations of this process are: (1) the use of anodizing methods to produce colored aluminum (rods, tubes) wind chimes, (2) controlling the microstructure of aluminum anodized films to modulate the audio frequency of sound on aluminum, (3) control the appearance geometry (length-to-diameter ratio) of the aluminum material to change the sound transmission behavior on the aluminum material, (4) use the laser engraving process to customize the characters and patterns on the surface of the wind chimes, (5) use the electrophoresis method to color the text and patterns on the surface of the wind chimes.

II. Experimental Process

The 6061 aluminum tube, rod, and sheet were anodized in the sulfuric acid solution and various colors were dyed in the dye solution. The wind chimes were assembled using coloring anodic aluminum tube, rod, and sheet. The anodization process included (1) mechanical grinding using # 1200 SiC paper, (2) chemical polishing using phosphoric acid, (3) plowing using NH4F solution, (4) anodization using sulfuric acid, (5) dying using dyes, and (6) sealing using boiling water. The surface pretreatment before anodization can control the surface roughness in shining or blush effect. The surface roughness values through sand blasting, chemical polishing, grinding, and anodization are shown in Table I. The aluminum surface through sand blasting has the largest roughness of Ra = 2.38 μm and the surface present to blush property. On the other hand, the aluminum surface through Sand paper grinding has the lowest roughness of Ra = 0.12 μm and the surface present to shining property.

TABLE I
THE ROUGHNESS VALUE OF 6061 ALUMINUM ALLOY AFTER DIFFERENT SURFACE PRETREATMENT

Surface treatment	Roughness (R_a, μm)
Sand blasting	2.38
Sand blasting + Chemical polishing	1.64
Sand blasting + Chemical polishing +anodization	1.83
Sand paper grinding	0.12
Sand paper grinding + Chemical polishing	0.47
Sand paper grinding + Chemical polishing + anodization	0.37
Sand paper grinding + plowing	0.27
Sand paper grinding + plowing + Chemical polishing	0.31
Sand paper grinding + plowing + hard anodization	0.65

The anodization process is controlled by the operation conditions, such as electrolyte composition, current-voltage curve style, temperature, current density, time, final voltage, and anodization efficiency, The detailed operating parameters that affect the quality of hard anodic treatment include: electrolyte composition (wt.%), current-voltage curve style, temperature (ºC), current density (A/dm^2), time (min), final voltage (V), efficiency (η,%). The evaluation of anodization film quality at least includes film thickness (μm), surface color (L, a, b values), surface roughness (R_a, μm), withstand voltage value (V), hardness (HV), and microstructure. In this experimental process, precise control over anodization efficiency was achieved by regulating key parameters such as the anodization time, temperature, and current density.

III. Results and Discussions

Anodizing on an aluminum surface converts a portion of the metal surface into metal oxide, forming a metal oxide layer. Anodized metal surfaces provide greater resistance to corrosion and wear. Anodized metal surfaces are also available to obtain cosmetic effects. For example, the porosity of the metal oxide layer produced by anodization is used to absorb dyes, thereby imparting color to the anodized metal surface. There is a continuing need for surface treatments or combinations of surface treatments to produce new products for metal surfaces. The surface of metal parts or articles can be treated to produce products with different properties and improve the surface quality.

Fig. 1 shows the color of the anodic film produced by 6061 aluminum alloy under different current densities (1~12 A/dm^2) at 22 ºC in 10 vol.% H_2SO_4 anodizing solution. Among them, the anodic film is transparent when the current density is in 1~2 A/dm^2, in, the anode film is brown color (3 ~5 A/dm^2), the anode film is dark brown color (6~7A /dm^2), the anode film is black color (9~10 A/dm^2), the anode film is black, but there are local white burn marks (11~12 A/dm^2).

According to Fig. 2 results, Table II shows detailed data of the experiment parameters of anodization including current density, final voltage, efficiency, and hardness. The film properties of experimental film thickness, theoretical film thickness, efficiency, and hardness can therefore be measured. Depended on the film color, final voltage, and hardness, the anodic films can be classified to mild anodization with current density of 0.5~2.0 A/dm^2, semi-hard anodization with current density of 3.0~6.0 A/dm^2, hard anodization with current density of 7.0~8.0 A/dm^2, and burring anodization with current density of 9.0~12.0 A/dm^2. The results also show that when the current density is small, the experimental thickness of the anodic film is close to the theoretical thickness; but, as the current density increases, the experimental thickness is significantly different from the theoretical thickness. The mild anodization has a higher anodic efficiency (52~90%) compared to the hard anodic efficiency (55~56). However, the hard anodization film has the higher hardness of 359 HV 1.0 compared to the mild and semi-hard anodization films. For the burring type anodization film, the final voltage value was reduced from 50V to 40V; the thickness of the film greatly changed between 65~108 μm, and the hardness value also decreased with the increase of the current density. The biggest difference between hard anodic film and burring anodic film is that the hard anodic film has a stable and high hardness value, stable final voltage, and constant film thickness.

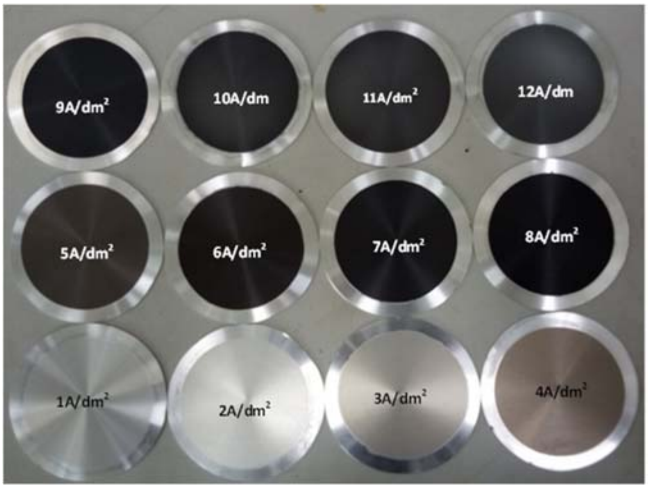


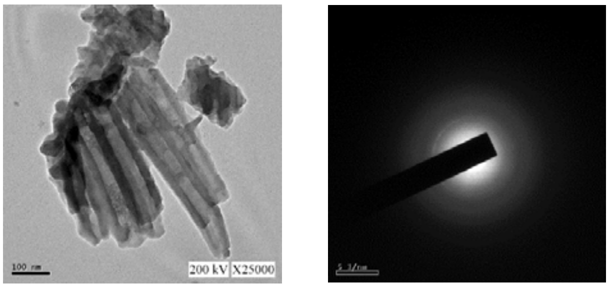
Fig. 2 The images of 6061 aluminum alloy after anodization under the conditions of 1~12 A/dm^2, 50 cm^2, 22 ºC, 2 0 min

TABLE II
The Efficiency and Hardness of Anodic Film through Various Anodization Conditions Process

No.	Type	Current density (A/dm^2)	Final voltage (V)	Efficiency (%)	Hardness ($HV_{1.0}$)
A1	Mild	0.56	7	90	142
A2	Mild	0.8	8	73	148
A3	Mild	1	12	71	163
A4	Mild	2	17	52	185
A5	Semi	3	20	54	196
A6	Semi	4	22	52	197
A7	Semi	5	24	53	255
A8	Semi	6	27	56	312
A9	Hard	7	30	55	335
A10	Hard	8	43	56	359
A11	Burning	9	50→40	54~61	329
A12	Burning	10	50→40	56~65	292
A13	Burning	11	50→40	53~62	189
A14	Burning	12	50→40	59~67	168

When aluminum is placed in a specific electrolyte and the anodic parameters are controlled, the formed oxide film has a regular cell or NT structure. When aluminum is anodized, an aluminum hydroxide anode film is formed on the surface. The anodic film grows upward with hexagonal holes at the beginning. The interface between the end of the NT and the aluminum substrate forms a hemisphere barrier layer. The tube size of diameter, the density of the tube, the thickness of the tube wall, and the length of the tube depend on the anodic parameters.

Fig. 4 shows a TEM micrograph of 6061 aluminum alloy anodized film; (a) multiple anodic nanotubes with a tube density of 108-9 tubes/cm^2; the diameter is between 240 nm to 280 nm, the inner diameter of the tube is between 70~90 nm, (b) amorphous diffraction point. 6061 is a precipitation-hardened (Mg_2Si) aluminum alloy. Fig. 2 also shows the NT has similar grain boundaries or micro-cracks. This microstructure contributes to the brittle property observed when the aluminum substrate is removed, revealing individual anode films.



(a) (b)

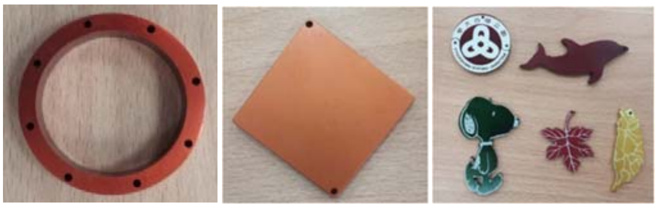
Fig. 3 TEM (a) image and (b) diffraction pattern of 6061aluminum alloy anodization film

Based on the anodization process and suitable experimental parameter controlling, we used this technology to make a colored wind chime. The parts of the colored wind chime include the upper charm, hanging tag, hanging wire, perforated ring, wind chime stick, bumper, lower rocker. Among the parts, the hanging tag, perforated ring, wind chime stick, bumper, and lower rocker can be made of colored anodization aluminum. Fig. 3 depicts the colored wind chimes made of 6061 aluminum alloy and anodization process; (a) colored wind chimes, (b) colored rods, (c) colored ring, (d) colored plate, (e) colored pendant. The colored pendant can further be customized with a specific logo or pattern.

IV. Summary

This study aimed to determine optimal conditions by exploring various operating parameters during the anodizing process. Parameters under investigation include electrolyte composition, current-voltage curve style, temperature, current density, time, final voltage, efficiency, and power. The research delves into the anodizing parameters, and explaining the anodized reaction mechanism, and evaluation of the anode film quality. In order to improve the quality of anodized film and minimizing the future production cost in the industry, this research focused on the experimental parameter control (final voltage, temperature, current density, time) and subsequent calculation and measurement of 6061 aluminum alloy anodization film property (hardness, efficiency, film thickness, surface roughness). Utilizing optimal anodization operation conditions, we used the anodization process to create a high-quality colored wind chime. The fabrication process involved various steps including annealing stress relief of the aluminum alloy substrate, surface grinding, surface polishing, anodizing, dyeing, sealing, surface polishing, laser engraving, and electrophoresis.

(a) (b)



(c) (d) (e)

Fig. 4 Colored wind chimes made of 6061 aluminum alloy and anodization process; (a) colored wind chimes, (b) colored rods, (c) colored ring, (d) colored plate, (e) colored pendant

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