Remote Plasma Source Chamber Anodization

SUPERIOR ANODIC COATINGS IN THE XSTREAM® RPS CHAMBER ENSURE RELIABLE, PARTICULATE-FREE CHAMBER CLEANING

Created by

Advanced Energy Industries, Inc.

Abstract

Most anodized aluminum plasma chambers are subject to aluminum fluoride formation and subsequent particulate generation when exposed to fluorine plasmas. Aluminum fluoride particles form when fluorine reaches the underlying aluminum surface and can be accelerated by the presence of substrate coating imperfections, thermal stress, and ion bombardment. The use of proprietary anodization processes and careful design techniques on Advanced Energy® (AE®)'s field-proven Xstream® Remote Plasma Source (RPS) platform virtually eliminate the formation of aluminum fluoride particles, providing reliable, particle-free, remote CVD chamber cleaning with minimal periodic maintenance requirements. The result is maximum tool uptime and drastically reduced maintenance costs.

Table of Contents

Introduction

Protective coatings on the plasma chamber walls of remote fluorine plasma sources attempt to ensure a clean, particle-free vacuum environment. The most common coating technique is anodization, which oxidizes the aluminum surface in order to provide a protective barrier between the plasma and the metallic aluminum chamber material. Without special design considerations, however, anodized coatings may corrode and fail in fluorine plasmas, resulting in particulate generation and costly periodic maintenance cycles. When compared to another common coating technique, Plasma Electrolytic Oxidation (PEO), anodization outperforms PEO due to its high breakdown voltage and lower leakage current. Over time, PEO can result in a lower etch rate. Engineered to eliminate anodization failures, the Xstream RPS platform generates no particulates and greatly reduces periodic maintenance requirements.

Anodization Overview

Anodization is a surface treatment process that produces an aluminum oxide coating on aluminum surfaces. Anodic coatings are characterized by a combination of high corrosion- and abrasion-resistance and superior adhesion. These properties make anodic coatings particularly suitable for a vast number of applications and environments, including plasma processing chambers.

In the anodization process, the object to be coated is immersed as the anode in an acid or molten salt electrolytic bath. When electric current is run through the bath, the surface of the aluminum object is oxidized, forming a porous aluminum oxide film (Figure 1).

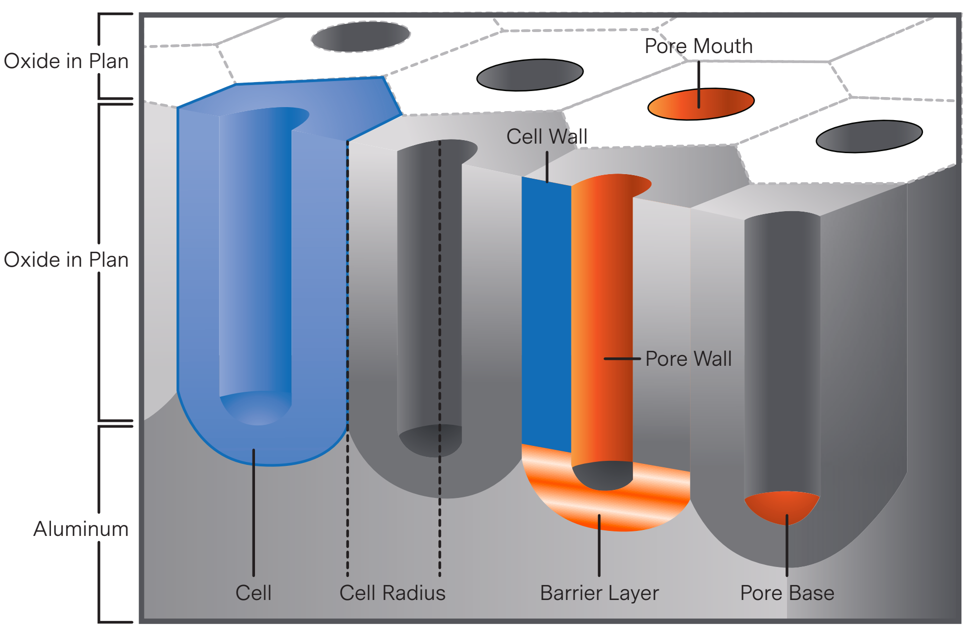

Figure 1. Typical cross section of a porous anodic film [adapted from P.G. Sheasby and R. Pinner, "The surface treatment and finishing of aluminum and its alloys," in Proc. ASM International, 2001.]

In the first stage of anodization, a compact aluminum oxide barrier layer with a thickness between 100 and 1000 Å forms on the aluminum surface. After barrier layer formation, the oxide layer continues to thicken and pores begin to develop. The diameter of these pores depends on the conditions of the anodization.

Figure 1 illustrates that the compact barrier layer separates underlying aluminum from the plasma and protects it from corrosion. Therefore, any conditions compromising the structural integrity of the barrier layer may become potential reasons for anodized coating failure. Figure 2 shows schematically how AlF_x forms in a small defect or void in the barrier layer. In plasma chambers, the barrier layer may be penetrated or compromised due to two main reasons: thermal stress (cracking) and substrate or coating imperfections (poor coating quality). Depending on the RPS plasma chamber design, ion bombardment from the plasma can also contribute to barrier layer failures.

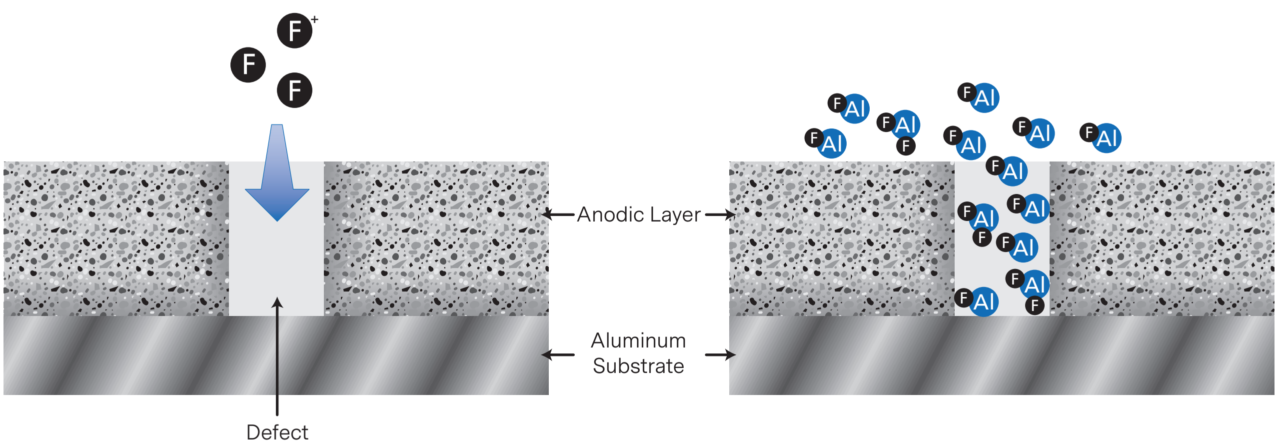

Figure 2. Cross section illustration of attack on the aluminum substrate by reactive species

Figure 3 shows the progress of the fluorine attack on a thermally stressed anodized surface exposed to fluorine produced by an NF_3 plasma. In the initial attack of the aluminum substrate, white aluminum fluoride crystals appear on the slightly cracked or crazed surface of the anodic coating. Once the AlF_x crystals occupy the voids, the crystals grow on top of the coating, eventually covering the surface with a relatively thick layer of aluminum fluoride powder.

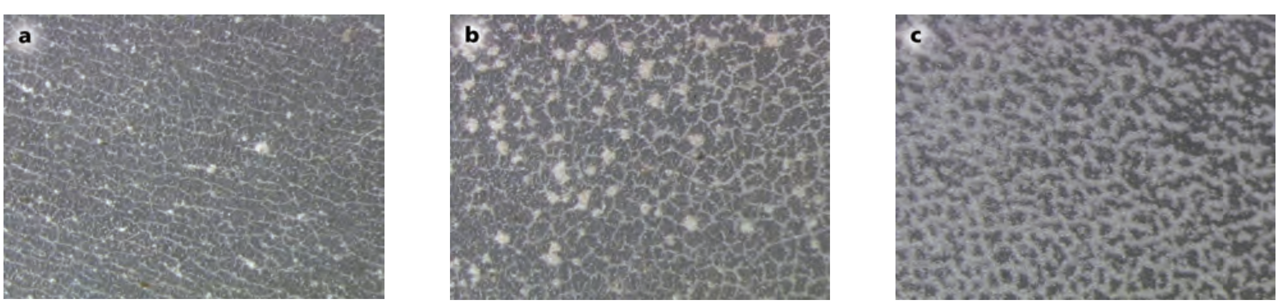

Figure 3. Progression of anodization failure: (a) initial cracking of the anodized layer, (b) AlF_x particulate formation, (c) heavy AlF_x powder formation. At this stage, you must clean the chamber in order to eliminate the risk of particulate generation.

Enhanced, Reliable Anodized Coating on Xstream® RPS Plasma Chambers

Minimization of Substrate Coating Imperfections

A large number of tests carried out at Advanced Energy, in addition to published data, show that precipitate particles in the aluminum chamber material that do not react to the anodization process are generally responsible for degraded performance of anodic coatings. Advanced Energy exhaustively researched the quality of anodic layers grown with different alloys. Certain alloys contain a relatively high percentage of non-aluminum metals such as iron, manganese, and silicon that nucleate and generate points of high concentration of inter-metallic compounds (IMCs). When anodized, the IMCs do not oxidize properly, creating pinholes in the coating that are associated with AlF_3 particle formation and catastrophic pitting. As an example, Figure 4 shows cross sections of anodic layers grown on 6061 aluminum alloys commonly used on anodized aluminum plasma chambers.

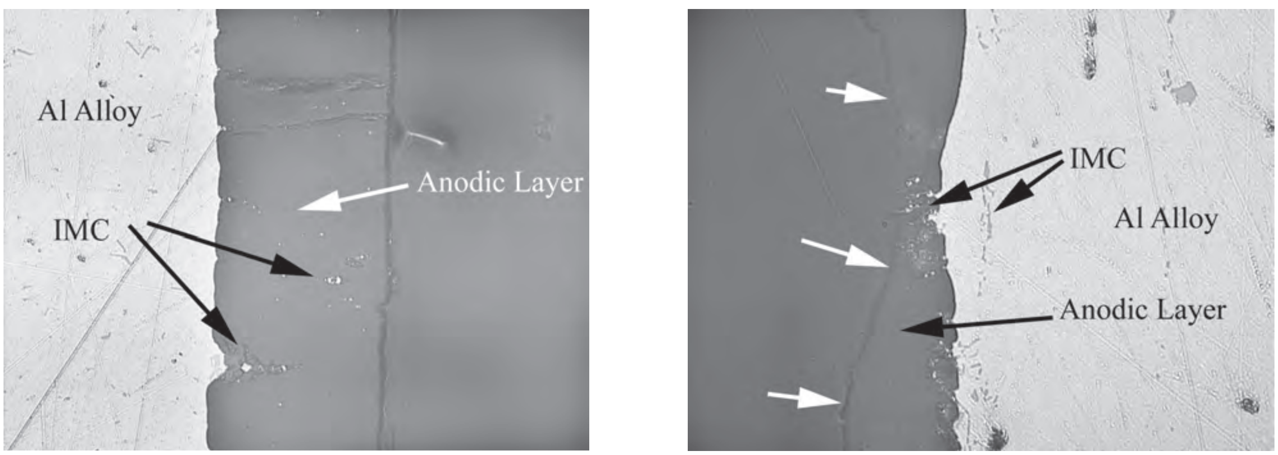

Figure 4. The incorporation of IMC particles is depicted at 500 x magnification. The presence of IMC particles may cause point failures and significant local anodic layer thinning.

The Xstream RPS utilizes a custom-made aluminum alloy with low IMC precipate levels in the construction of the plasma chamber. When coupled with a special, hard, Type III, Class 2 anodic coating, the result is superior protection of the aluminum substrate against chemical attack.

Thermal Stress Reduction

The drastic difference between the coefficient of thermal expansion (CTE) of aluminum ($25x10^{-6}$ C^{-1}) and aluminum oxide ($4x10^{-6}$ C^{-1}) causes thermal stress failures of anodized layers exposed to high heat loads. Any increase in the temperature of the aluminum chamber puts the anodic layer under tension and the metallic substrate under compression. At temperatures around 150°C (302°F) and above, the expansion mismatch is enough to crack the anodiclayer, as the cross sectional drawing in Figure 5 illustrates.

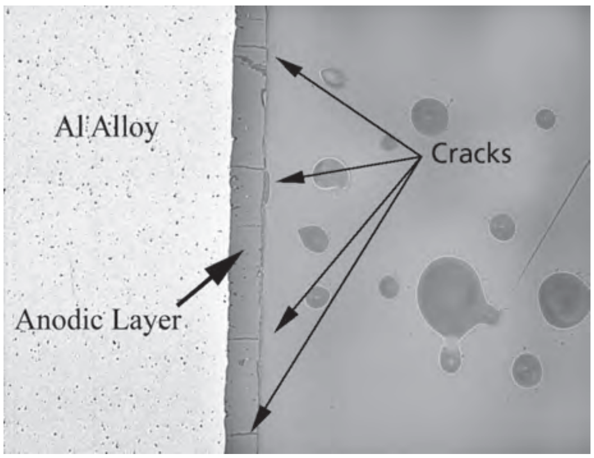

Figure 5. Cross section of an aluminum sample showing cracks on the anodic coating

The obvious solution to this problem is to maintain a low temperature for the aluminum. However, the thermal load that a high-power density plasma typically places on RPS chambers often makes this solution impractical. Advanced Energy's plasma chamber design includes a proprietary cooling method that allows the inner surface of the chamber to remain below 90°C (194°F) even at cooling water input temperature of 35°C (95°F). The result is the elimination of thermally induced cracks in the anodization layer, minimizing the likelihood of exposing bare aluminum to fluorine in the plasma.

Ion Bombardment Reduction

Ion bombardment is an additional variable that may perpetuate the corrosion of anodized components used in plasma chambers. Depending on the plasma source configuration and the way power is coupled to the plasma, high voltage between the plasma and the chamber wall accelerates ions into the anodized surface and may contribute to attack of the aluminum substrate. To avoid accelerated degradation of the chamber by ion impingement, the Xstream RPS plasma chamber has been designed with multiple dielectric gaps that minimize the energy with which the ions impact the wall.

Particulate Elimination in the Plasma Chamber

Advanced Energy's engineering team incorporated the results from their studies of the anodization process into the Xstream RPS plasma chamber design to produce enhanced, reliable anodic coatings. Figure 6 compares a corroded, anodized aluminum plasma chamber wall from a previous-generation RPS to the impenetrable anodized coating on the Xstream RPS. The barrier layer on the previous-generation RPS chamber wall has failed after only 300 hours of operation and requires maintenance to remove the fluorine powder residue. However, the higher-quality anodic layer on the Xstream RPS provides a maintenance-free protective coating that continues to endure, in this case even after 3000 hours of continuous operation.

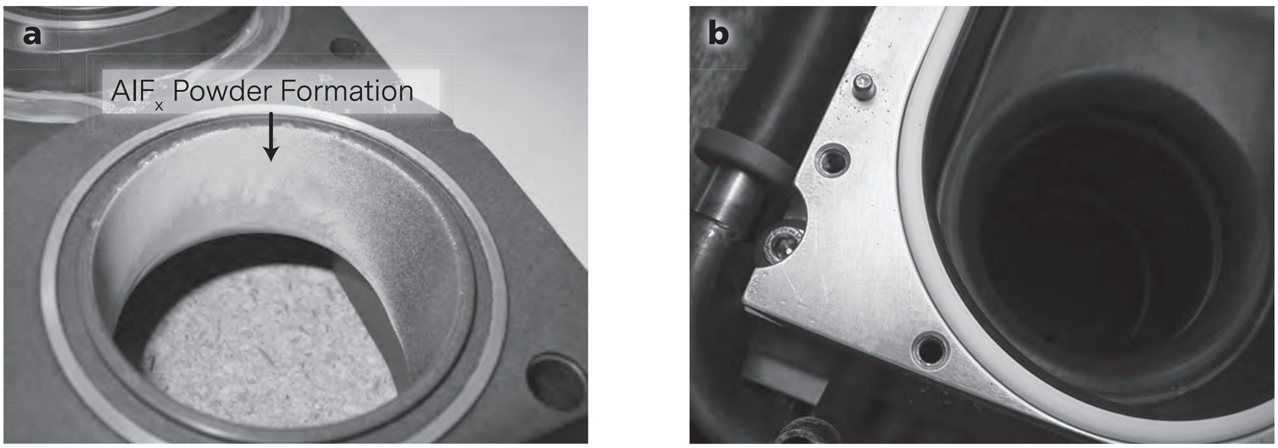

Figure 6. Field-proven results: a) corroded, anodized aluminum plasma chamber wall in a previous-generation RPS, b) superior barrier layer protection in the Xstream RPS

Plasma Electrolytic Oxide Coatings

Plasma Electrolytic Oxide, or PEO, has been used as an alternative to anodization because of its high hardness and protection against wear and corrosion. The PEO layer forming process is similar to anodization, with higher potentials applied resulting in plasma discharge at the oxidization layer, leading to enhanced hardness of the surface. PEO adhesion and quality is very dependent on the substrate material, just as anodization is, and is affected by IMC contamination in the same manner. Thus, the quality of the PEO coating is highly dependent on the quality of the substrate material. PEO also has a similar coefficient of thermal expansion to anodization and therefore suffers from similar cracking issues if the temperature is not regulated.

PEO, although very dense, does have a porous surface as shown in Figure 7. These pores can allow fluorine to reach the substrate, similar to the illustration in Figure 2 above. The coating is also prone to high leakage current after prolonged exposure to plasma, resulting in a reduction in the protection of the aluminum substrate. This lower breakdown voltage and higher leakage current result in more of the plasma power leaking into the chamber wall rather than creating radicals in the plasma and thus will start to show a lower etch rate. These effects are not seen with anodization when properly applied because the structure of the anodization is more tightly bound and does not present a path for leakage as easily as PEO.

AE has tested PEO coatings in plasma exposure and has determined that our proprietary aluminum substrate, enhanced cooling, and hard anodization process outperforms PEO in the Xstream plasma chamber, resulting in a longer chamber life and better, more consistent performance over the product lifetime.

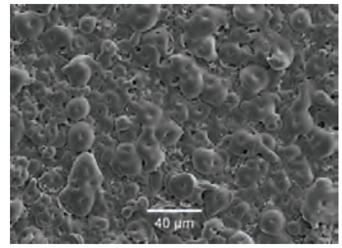

Figure 7. SEM micrograph of a typical PEO coating.

Conclusion

The anodic layer on the surface of RPS chamber walls may fail due to substrate coating imperfections, thermal stress, and ion bombardment. Anodic coatings that fail expose the aluminum substrate to fluorine attack, resulting in corrosion of the aluminum and the formation of AlF_x particulates, requiring frequent, periodic maintenance in order to keep the particulates from reaching the process chamber on the tool. Based on extensive independent research and review of published data, Advanced Energy has specially engineered the anodic coatings and configuration used in the Xstream RPS chamber to shield the aluminum substrate from chemical attack. This unique combination provides reliable, particle-free chamber cleaning and virtually eliminates the need for periodic maintenance.

ABOUT ADVANCED ENERGY

Advanced Energy (AE) has devoted more than three decades to perfecting power for its global customers. AE designs and manufactures highly engineered, precision power conversion, measurement and control solutions for mission-critical applications and processes.

AE's power solutions enable customer innovation in complex semiconductor and industrial thin film plasma manufacturing processes, demanding high and low voltage applications, and temperature-critical thermal processes.

With deep applications know-how and responsive service and support across the globe, AE builds collaborative partnerships to meet rapid technological developments, propel growth for its customers and power the future of technology.

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For international contact information, visit advanced-energy.com.

sales.support@aei.com
+1.970.221.0108