TECHtips

Electronics Manufacturing Insights from ACI Technologies, Inc.

ALD of Alumina Ceramic Films for Hermetic Protection

A primary issue in electronics reliability for military applications is the ability to ensure long term operability in harsh, extreme environments. This requires more rigid standards, such as the MIL-STD-883 (Department of Defense Test Method Standard for Microcircuits), which commercial grade electronics typically do not satisfy. A solution commonly employed is to package the critical electronic components in hermetically sealed metal or ceramic enclosures which are costly and labor intensive. Not only are the components more expensive, but the assembly process is more difficult to automate, resulting in a substantial cost premium for military grade electronics.

ACI Technologies has investigated a moisture impermeable coating as an alternative to hermetic enclosures. Polymer-based "glob-top" encapsulation and conformal coating techniques are commonly used to improve moisture resistance but they still allow diffusion and can be difficult to rework. Atomic layer deposition (ALD) is a potentially affordable method to coat electronic components with a moisture impermeable ceramic thin film coating.

ALD has been used at the laboratory scale for decades but has not achieved widespread commercial use. Improvements in manufacturing technologies have increased deposition rates, equipment reliability, and reduced cycle times.

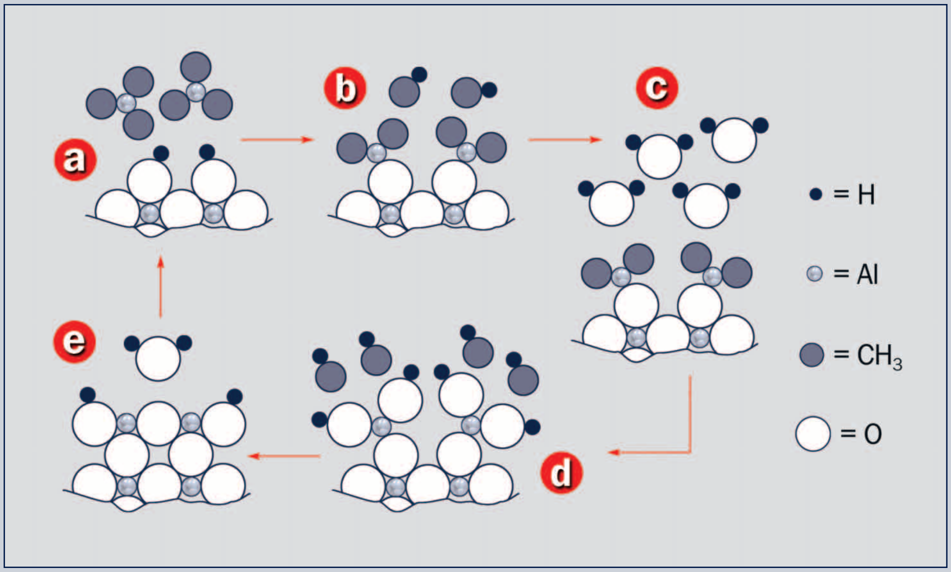

Figure 1: Five-step cycle (a through e) to produce one monolayer of alumina ceramic (Al_2O_3). Courtesy of Sundew Technologies, LLC.

One method to deposit alumina (Al_2O_3) ceramic thin films by ALD uses precursors of trimethyl aluminum ($Al(CH_3)_3$, TMA) and water. The binary self-limiting chemical reactions (A and B) occur between the gaseous precursor and the solid surface substrate result in a deposition of Al_2O_3. [1]

$$AlOH^* + Al(CH_3)_3 \rightarrow AlOAl(CH_3)^*_2 + CH_4, \quad (A)$$

$$AlCH^*_3 + H_2O \rightarrow AlOH^* + CH_4, \quad (B)$$

* represents the surface species

Each AB growth cycle consists of sequentially exposing a substrate to TMA and H_2O. The TMA reacts with all the hydroxyl (-OH) groups on the substrate surface until all the available hydroxyl sites are reacted. All the remaining reactants and by-products are purged from the chamber. Next, H_2O vapor enters the chamber and reacts with the surface methyl ($-CH_3$) groups until they have all reacted, leaving a fresh surface of available hydroxyl groups. This is followed by another purging step and the next AB cycle [1]. By repeating these AB cycles, the desired film thickness can be achieved one atomic layer at a time. This process, schematically illustrated in Figure 1, produces a conformal film that is uniform and free of pinhole defects. The cyclical nature of this process can create

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highly ordered lamellar nanostructures and incorporate materials with compositions tailored to achieve a variety of performance enhancements.

A monolayer of single crystal alumina is on the order of one nanometer thick (the c-axis lattice constant is 12.991 angstroms). With an atomic scale layer-by-layer approach to deposition, this method results in coherent crystalline thin films with thicknesses in the range of hundreds of nanometers. As a comparison, the average thickness of a human hair is around 100,000 nanometers. Because of its inability to deposit any more or less than one atomic layer of reaction product per cycle, ALD cannot deposit an excess or insufficient film at non-uniformities (corners, edges, or holes) of the object being coated. This is especially important in radio frequency (RF) applications where excess coating can degrade RF electrical performance. The more uniform ALD coating can provide a better electrical performance.

The atomic layer deposition based ALD-Cap process developed by Sundew Technologies delivers hermetic performance that passes MIL-STD-883E environmental endurance testing [2] with a thin conformal coating of high-quality, durable, and flexible ceramic films. It is currently employed as circuit protection on Navy ships. Commercially, ALD has many applications related to the emerging field of nano-technology and commercial success in the area of protective transparent coatings for jewelry [3].

For more information on hermetic ALD coatings, please contact the Helpline at 610.362.1320, via email to helpline@aciusa.org or visit the website at www.aciusa.org.

References

[1] Dillon, A. "Surface Chemistry of Al_2O_3 Deposition Using Al(CH3)3 and H_2O in a Binary Reaction Sequence." *Surface Science* 322.1-3 (1995): 230-42.

[2] Sundew Technologies, LLC. ALD-Cap: Thin Film Encapsulating Coating for Hermetic Environmental Protection. Topic no. N04-058. Navy Success Story. Web. <https://www.navysbirsearch.com/widgets/hyperlinking/successdetails.jsp?url=Doc URL&id=90078>.

[3] Jones, Anthony C., and Michael L. Hitchman. "Applications of ALD." *Chemical Vapour Deposition Precursors, Processes and Applications*. Cambridge: RSC, 2009. 197.

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