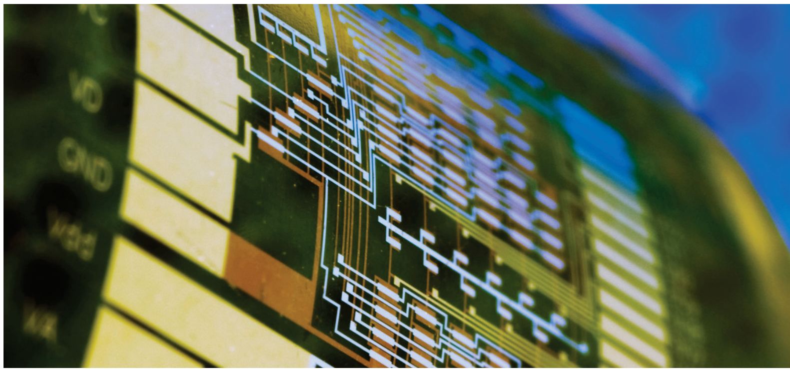
CambridgeNanoTech
Simply ALD

Flexible Electronics

Application Brief

Atomic Layer Deposition (ALD) is a low-cost, thin-film deposition technique capable of depositing flexible, multifunctional materials at low deposition temperatures. With excellent electrical, optical and encapsulation properties, these materials are perfectly suited for integration into flexible electronics, displays and sensors.



Applications

The drive towards low-cost electronics has spawned the use of organic materials as replacements for high-cost, metallic or rare-earth inorganic films traditionally used in the microelectronics and display industries. However, such inorganic materials are not as sensitive to damage or degradation that most organic components exhibit. Therefore, merging organic with inorganic components can serve to improve reliability and promote the early adoption of these novel processing steps. ALD is one such method to merge organics with inorganic materials. Several key applications, such as the use of ALD films for packaging, optical and electronic layers, have been demonstrated and will be briefly overviewed below.

Encapsulation/Moisture Barriers

ALD films are deposited without cracks or pinholes making them excellent encapsulation layers. Research has shown that as little as 30nm of ALD Al_2O_3 is effective for preventing the degradation of OLEDs and organic solar cells. Organic electronics packaged with ALD films exhibit operating lifetimes of years, instead of seconds in their uncoated forms. Research has shown that nanolaminates, of ZrO_2-Al_2O_3 [Advanced Materials 2009, 21, 1845] or HfO_2-Al_2O_3 [Organic Electronics 2009, 10, 1300] are exceedingly effective at precluding the transmission of water and oxygen into organic electronic devices. These nanolaminates exhibit water-vapor transmission (WVTR) rates of down to 10-6 g/cm^2/day, near the value repeatedly implicated as necessary for organic electronics packaging. Such films are superior to paralyene, resin or thin glass layer encapsulation as they are not prone to pinholes or voids, which can occur during the deposition or bonding process.

Surface Passivation/Optical Layers

Thin films of Al_2O_3 act as excellent charge-recombination barriers and passivate surface defects on dye-sensitized solar cells even after the first complete ALD cycle [J. Phys. Chem. C. 2008, 112, 19756]. Due to the ability of ALD to precisely grow nanolaminates or doped materials, finely tuned optical filters can be deposited to enable increased efficiency in multi-junction solar cells. As a hole injection layer, alumina ALD films greatly enhance the performance of OLEDS, by doubling luminous efficiency of devices. In addition, films as thin as 10 Å also have been shown to preventing the electroluminescent layer degradation during patterning/photolithiography [Organic Electronics 2008, 9, 667].

Dielectric/Capping Layers

When properly deposited, ALD films form superior interfaces (minimizing interfacial layers), possess few impurities and exhibit a low number of defects making them ideal dielectric films. The low deposition temperature possible with many ALD oxides has enabled them to be used for dielectric layers in flexible and organic transistors, Table 1. For instance, ALD hafnium oxide has been used extensively for device integration of printed and organic electronics. HfO_2 films retain high capacitance and enable the use of low voltages, which are required in order to preclude the premature breakdown of organic components from high voltages. Work continues by us and others to explore binary and ternary combinations of ALD films in order to optimize the electrical properties of such films: undoped TiO_2 and Ta_2O_5 can have high dielectric constants, but are inherently leaky and show little promise alone. Nevertheless, addition of these materials into other films, such as Al_2O_3, can greatly improve the dielectric constant and breakdown voltage.

ALD Film Dielectric Constants

ALD Film	Min. Practical Deposition Temperature °C	Dielectric Constant (k)
Al_2O_3	>25	6-9
SiO_2	>100	3.9
HfO_2	>80	>15
TiO_2*	>80	>20
Ta_2O_5	>100	>22
ZrO_2	>80	>14

Table 1. *Deposition using titanium tetrisopropoxide and water.

Transparent Conducting Oxides (TCOs)

Transparent conductors are required for almost all applications in flexible displays, plastic and organic based electronics. Inorganic options can be appealing due their stability and robustness compared to organic counterparts. While ALD can deposit the industry standard TCO, Indium-tin oxide (ITO) with low resistivity (down to 3 X 10-4 Ωcm), the process window is above 200°C, limiting its use for organic electronics. A more cost-effective and attractive choice is ZnO. Zinc oxide is a multi-functional material and can be readily deposited even at room temperature. The electronic and optical properties can be finely controlled via doping with common ALD materials (including Al, Hf, Zr, Sn, etc.) using water as the oxidant. This enables materials with resistivities spanning four orders of magnitudes (down to 10-3 Ωcm) depending on the film thickness and doping concentration. Optically, doped ZnO thin films have transmissions of >90% for the majority of the UV spectrum when under 50 nm thick. Choice and concentration of the dopants also allow for further tuning of the optical band-gap and transparency at different wavelengths.

ALD: From Research to Production

Uniformity over large-area substrates, reproducibility and low temperature deposition make ALD an ideal candidate for the next generation of large-scale manufacturing thin-film technology.

In 2006, Cambridge NanoTech collaborated with one of the world's largest manufacturers of consumer electronics to solve a thin film challenge; bringing ALD out of the research lab and onto the manufacturing floor. The staff of technologists with both organizations had recognized that the increasing capabilities of ALD, such as electric properties and uniformity had made this burgeoning technology ripe for translation into a high-volume production process. In response to this challenge, later that year Cambridge NanoTech released the Phoenix™, a GEN 2.5 batch production ALD system. After the successful release of the Phoenix, Cambridge NanoTech scaled up the ALD process even more and in 2009 released the Tahiti™, a GEN 4.5 large-area manufacturing system.

To date, the Phoenix and Tahiti have been successfully integrated with multiple automated production lines and manufacturing networks. The ultra-thin ALD films deposited on large-area substrates by the Phoenix and Tahiti have given manufacturers increased product quality and reliability as well as decreased operating costs and a greener footprint as compared to previous coating technologies that they had been using.

ALD as a manufacturing technology has been so successful that Cambridge NanoTech has scaled up the design of the Tahiti to produce even larger substrates for other applications. Other ALD production technologies that Cambridge NanoTech looks forward to releasing in the near future include Fast ALD and roll-to-roll systems.

Cambridge NanoTech ALD Systems for Flexible Electronics

Our ALD systems are engineered for a wide variety of applications from research to high-volume manufacturing. These systems deposit precise, conformal and ultra-thin films on multiple substrates. Their simplified system designs yield low startup and operating costs.

Savannah™: Compact, economical system for research applications.

Phoenix™: For production ALD needs; capable of batching large number of substrates at one time.

Fiji™: A high-vacuum ALD system capable of both thermal and plasma-enhanced deposition.

Tahiti™: A high volume production ALD system for large area depositions.

Deposition Services: Cambridge NanoTech provides coating services for a variety of materials; usual thickness of ALD coatings is below 0.5 um.

Glovebox Integration

Cambridge NanoTech systems are readily integrated with MBraun gloveboxes for handling thin film samples in an advanced inert atmosphere system that is free of oxygen and moisture.

ALD Films

At the forefront of ALD precursor and ALD thin film research, Cambridge NanoTech scientists continuously add to the list of standard ALD recipes:

- Oxides: Al_2O_3, HfO_2, La_2O_3, SiO_2, TiO_2, ZnO, ZrO_2, Ta_2O_5, In_2O_3, SnO_2, ITO, Fe_2O_3, MnO_x, Nb_2O_5, MgO, Er_2O_3
- Nitrides: WN, Hf_3N_4, Zr_3N_4, AlN, TiN, NbN_x
- Metals: Ru, Pt, W, Ni, Fe, Co

These films, their nanolaminates, and many more materials and their recipes are available from Cambridge NanoTech's own staff, its partnerships, and its 200+ customer base.

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