TransFlex-ALD™

Roll-to-Roll Atomic Layer Deposition, based on Substrate Translation, by Lotus Applied Technology

Summary

In recent years, Atomic Layer Deposition (ALD) has emerged as a unique process capable of depositing very high quality films at low temperatures, on polymer substrates. To date, it is the only thin film coating technology which has demonstrated the capability to produce single layer coatings with ultra-barrier properties, for films less than 20nm thick. However, conventional ALD requires processing in single-wafer or batch systems, and growth rates are exceedingly low due to the long times required for sequential introduction and purging of precursors. These limitations have lead to the widespread perception that ALD is not suitable for low cost, high rate coating on rolls of flexible material.

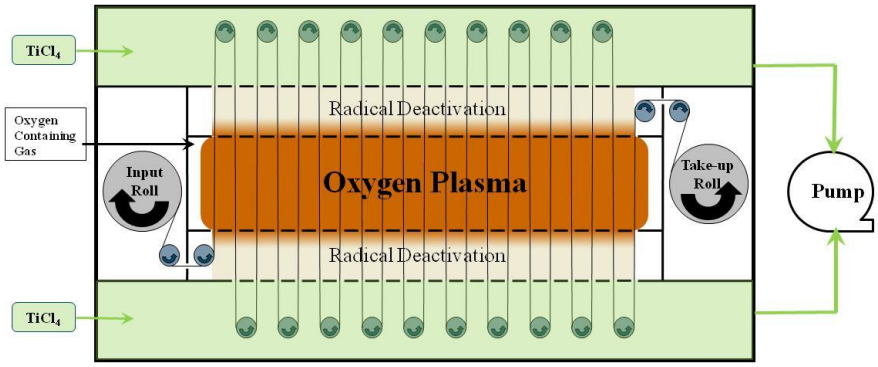
Recently, Lotus AT has developed a new patented technology which allows the continuous deposition of high quality ALD films on flexible substrates at low temperatures, in a Roll-to-Roll configuration, at high web speed. This is accomplished by transport of the substrate between precursor zones, rather than sequential introduction and purge of precursors. The result is a process which provides the exceptional physical and electrical properties of ALD films at low cost, with high system throughput and direct compatibility with other Roll-to-Roll processing systems. The keys to the high performance of this technology lie in the long exposure paths for each ALD cycle component, and to the use of plasma instead of water as the oxidation mechanism.

The Problem with Water

At temperatures below about 120°C, excess physisorbed water, in addition to the needed chemisorbed hydroxyl groups, remains on the substrate surface following water vapor exposure for a significant time. If this molecular water remains on the surface during the subsequent metal precursor exposure, a component of low quality CVD growth is incorporated, resulting in low film quality. Because the activation energy of this physisorbed water is quite high, long purge times are required following water exposure – up to minutes at temperatures below 100°C. This means that for low temperature ALD based on substrate translation, the web speed is limited by the dwell time following the water exposure, resulting in web speed limits of 1 meter per minute or less for high quality true ALD film deposition. Lotus has overcome this speed limit by incorporating an innovative patented plasma-based Radical Enabled ALD process in place of water, enabling the deposition of extremely high quality gas diffusion ultra-barriers at high web speed.

Technology

Lotus' patented TransFlex ALD technology is based on transport of the continuously moving substrate through individual precursor regions, rather than pulsing and purging the precursors to and from a shared volume. If this were attempted in a linear fashion, with individual precursor zones for each element of each cycle, such a system capable of coating films at high web speed with a reasonable thickness would be quite large and complex. But for flexible substrates, the web can be weaved back and forth into shared precursor zones operating under steady state conditions, greatly simplifying the equipment and the process. And unlike atmospheric pressure ALD processes, TransFlex ALD operates under moderate vacuum pressures, making separation of the precursor zones straightforward simply through differential pressure and pumping. A schematic representation of the system configured for deposition of TiO_2 is shown below:



In the system illustrated, the web is transported through a zone containing $TiCl_4$ vapor, then into the plasma zone for oxidation, then a zone containing $TiCl_4$ vapor, and back again through the plasma zone. This transported distance comprises two ALD cycles, and as the web propagates through the system, additional cycles are added on, with the total thickness determined simply by the number of turns, which corresponds to the number of ALD cycles. For thicker coatings, the web may be passed through the process multiple times.

To keep the precursors separated, the plasma and purge gas is introduced to the center chamber, while the precursor introduction and pumping are done in the outer zones. This results in a relatively higher total pressure in the purge zone, with the outward migration of the purge gas preventing the inward migration of the precursor vapors. To prevent the radicals generated from the plasma from interacting with the precursors, our patented Radical Deactivation technology is employed. With this technology, the reactive radicals are generated near the middle of the purge zone, and recombine into inert gas species prior to reaching the precursor zones, preventing CVD growth. With this approach, the web speed is limited only by the exposure time in the precursor and plasma zones. And because the path length through each zone is quite long, the web speed can be orders of magnitude faster than "coating head" approaches to spatial ALD.

Advantages

- Direct Compatibility with Continuous Roll-to-Roll Processing
- High Coating Rates – Lotus has demonstrated deposition of *single-sided, single-layer* ultra-barrier films (WVTR < 0.0005 10^{-4} g/m^2/day) as thin as 6 nm on PET, at web speeds up to 60 meters per minute.
- No Coating Occurs on the Chamber or Other Machine Surfaces – This is a truly unique feature, and results from the fact that only the web material itself is ever exposed to both precursors; thus only the web itself is coated with film. This eliminates the need for costly maintenance and downtime associated with cleaning and replacing interior shielding and components, and prevents defects and debris related to flaking of film build-up seen in conventional PVD, CVD and evaporation processes.
- Extremely High Precursor Utilization – Because the precursors do not share a common volume within the chamber or immediate pumping exhaust path, they may be trapped and recycled, providing the possibility of unprecedented precursor utilization efficiency. To the extent that efficient trapping is employed, the majority of the precursor may be utilized in coating only the web itself.
- Greatly Simplified Manufacturing Equipment and Processing – With ALD, film thickness and properties are determined only by the satisfaction of saturation characteristics and the number of cycles completed. As a result, neither precursor flux nor distribution needs to be well controlled – they simply must be sufficient to provide saturation. And sensitivity to web speed can be virtually eliminated since the coating thickness is defined strictly by the number of turns completed, rather than by web speed.