Vortex Rotary Batch ALD Technology

Radical Enabled ALD (RE-ALD), by Lotus Applied Technology

Summary

Lotus Applied Technology has developed plasma-based processes for ALD, using an innovative patented new way to simplify precursor separation in processes based on substrate translation. In addition to allowing greatly simplified reactor design, this technology has enabled higher deposition rates, at lower substrate temperatures, and allows processing using new precursor materials that do not react with water or ozone, but do react with atomic oxygen and other highly reactive radicals.

Background

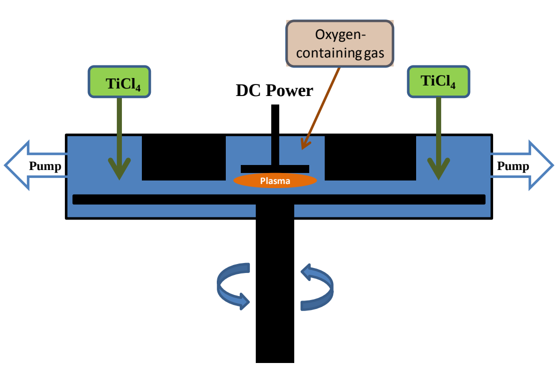
Atomic Layer Deposition (ALD) is a thin film deposition technology with well documented unique attributes, creating coatings with unmatched quality, even when extremely thin. Until recently however, cost-effective applications for conventional ALD processing, based on sequential precursor pulsing and purging, have been limited due to the low film growth rates and limited material set, particularly at low substrate temperatures. More recently, ALD researchers have begun to explore an alternative processing method, in which the precursors are separated into different regions in space, and the substrate is then physically transported between those regions to provide the alternating exposure to the two precursors. Using this method, the long times required for introducing and subsequently purging precursors from a common volume is eliminated, allowing dramatic increases in effective cycle time.

The use of plasma processing in conventional ALD is also a relatively recent development. In the case of deposition of oxide films, the use of oxygen-containing plasma as a substitute for the water vapor used in thermal-based ALD processing is of particular interest. Because of the relatively higher reactivity of oxygen radicals – particularly atomic oxygen – substrate temperatures may be reduced, improving compatibility with polymer substrates. In addition, this higher reactivity enables ALD processes for some precursors which are not reactive with water even at moderately high substrate temperatures, allowing deposition of SiO_2 films for example.

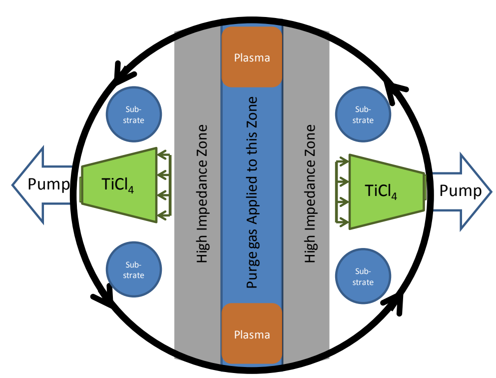
Precursor "Separation" by Radical Deactivation

The key to Lotus' unique patented Radical Enabled ALD (RE-ALD) technology lies in the use of short-lived radicals as the oxygen source for the ALD sequence, generated from an oxygen precursor gas that does not react directly with the metal precursor unless activated. This allows the dual use of the oxygen-containing precursor gas as the oxygen source and the purge gas. The advantages of this technique are best described by example. The following figure shows a schematic representation of the technology applied to a rotary reactor, operating in a batch mode with a rotating substrate platen providing the translation mechanism for alternate exposures to the oxygen-containing plasma and the metal precursor – in this case $TiCl_4$.

Side view



Overhead view



As with other ALD processes based on substrate translation, precursor and plasma sources are in continuous operation, and the movement of the substrate between the two precursor zones provides the alternating exposure to the metal and oxygen source. The key difference here is that the oxygen precursor actually does directly mix with the metal precursor, but is only reactive in the region “upstream” from the metal precursor. In the example illustrated, by the time the oxygen-containing gas reaches the metal precursor zone, the reactive radicals have recombined with other gas species, and are no longer reactive with the metal precursor, thus providing Precursor “Separation” by Radical Deactivation. With this approach, the more complicated differential pumping required to keep the precursors independently separated is not required, and two ALD cycles may be completed with each platen revolution. With this configuration, the process provides the beneficial characteristics of ALD coating, but with all the benefits of ALD based on substrate translation:

- Extremely high coating rates.
- Elimination of need for high speed / high reliability pulsing valves.
- Elimination of coating on all chamber surfaces except for the substrate platen itself. No film buildup on any surface above the plane of the substrates.
- Direct compatibility with any vacuum radical generation source, including DC plasma, operating in steady state, without accumulation of coating on the source electrode.

For the processes currently under development, atomic oxygen is used as the radical species for the ALD metal oxide deposition. This has the dual advantages of extremely high reactivity with metal precursors, and a short lifetime at conventional ALD process pressures of approximately one Torr. This means that the plasma can be confined to an area necessary for the ALD reaction, and the radicals may be de-activated in a short distance downstream from the plasma.

A key element in implementing this technology is the choice of oxygen-containing gas. Because many different radical species may be generated in a plasma, it is critical to choose a material that will not generate long-lived radicals that are reactive with the metal precursor. Most prominently, many ALD metal precursors react with ozone, which is generated in plasmas of pure O_2 gas, and has a much longer lifetime than atomic oxygen. Trimethylaluminum (TMA) for example is by far the most common precursor used for Al_2O_3 films, and is widely known to react with ozone. For that reason, a different oxygen-containing gas, which does not form significant amounts of ozone in a plasma, is used for these types of metal precursors. In development work to date, mixtures of CO_2 and Nitrogen have proven to be excellent low-cost gases for such processes. On the other hand, many precursors will react with atomic oxygen, but do not react with ozone, particularly at low substrate temperatures; for example $TiCl_4$ and several SiO_2 precursors. In these cases, many different oxygen-containing gasses may be used, including CO_2 and O_2. And in most cases, high purity gasses are not required. In fact, Lotus has demonstrated deposition of high quality oxide films using simple dry room air as the source/purge gas, providing the ultimate in low cost oxygen precursor.

Because of the high deposition rates, low coating costs and low substrate temperature compatibility, this technology opens the door to a great number of cost-sensitive applications in batch processing previously considered off limits to ALD, including:

- Semiconductor applications, including gate oxides, memory oxides, MEMS, etc.
- Hermetic encapsulation moisture and oxygen sensitive devices, including OLED displays and lighting, Thin Film Photovoltaics, and implantable medical devices.
- Optical coatings, including anti-reflection coatings, polarizers, dichroics, etc.
- TCO deposition for electronics applications.
- Oxide transistor and gate oxide materials for display applications.
- Sensors, thin film batteries, alternative energy storage devices.