Rational Design of a Full Plasma-Enhanced ALD Super-Cycle Process for Indium Gallium Zinc Oxide Based on in-Situ Characterization

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Transparent conducting oxides are a promising materials class for applications in the field of photovoltaics and thin film transistors. For the latter, indium gallium zinc oxide (IGZO) can be an enabler for the next generation of flexible electron devices and organic light-emitting diode displays due to its high optical transparency and electron mobility. In the past, IGZO was usually deposited by radio-frequency magnetron sputtering, solution processing, and pulsed laser deposition. More recently, atomic layer deposition (ALD) has shown the potential to overcome limitations of the other deposition methods allowing low-temperature processing and uniform depositions on 3D structures.

This work presents a bottom-up approach for the deposition of IGZO layers by a super-cycle ALD process using a SENTECH plasma-enhanced ALD (PEALD) reactor. Initially, a super cycle combining a thermal process (TALD) for zinc oxide (ZnO) and plasma-enhanced processes for gallium and indium oxide (Ga_2O_3, In_2O_3) was developed. The growth mechanisms of the individual processes within the super-cycle have been thoroughly investigated and monitored by in-situ ellipsometry (i-SE, SENTECH ALD Real-Time-Monitor). A nucleation delay for the thermal ZnO process was found, making it challenging to properly adjust the elemental composition by the sub-cycle ratio. Hence, the thermal ZnO cycle has been replaced by a plasma-enhanced ZnO process, which shows no nucleation delay, thus enabling a full PEALD super-cycle at low temperature (150°C).

X-ray photoelectron spectroscopy, grazing-incidence X-ray diffraction, and scanning electron microscopy in combination with energy-dispersive X-ray fluorescence analysis were used to investigate the elemental composition and morphology of the ALD films. Our results demonstrate that the elemental composition can indeed be precisely adjusted by varying the sub-cycle ratio within the super-cycle. Furthermore, metal/insulator/semiconductor (MIS) layer stacks were built to measure the electrical performance of the oxide films. This showed that the conductivity of films prepared using the full PEALD super-cycle is significantly higher than that of the layers deposited by the mixed TALD/PEALD process. Therefore, this approach allows the preparation of ultra-thin IGZO layers with controlled thickness, composition, and electrical properties, while thermally induced segregation is largely prevented.