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New Approaches for Overcoming Current Issues of Plasma Sputtering Process During Organic-electronics Device Fabrication: Plasma Damage Free and Room Temperature Process for High Quality Metal Oxide Thin Film

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The plasma damage free and room temperature processedthin film deposition technology is essential for realization of various next generation organic microelectronic devices such as flexible AMOLED display, flexible OLED lighting, and organic photovoltaic cells because characteristics of fragile organic materials in the plasma process and low glass transition temperatures (Tg) of polymer substrate. In case of directly deposition of metal oxide thin films (including transparent conductive oxide (TCO) and amorphous oxide semiconductor (AOS)) on the organic layers, plasma damages against to the organic materials is fatal. This damage is believed to be originated mainly from high energy energetic particles during the sputtering process such as negative oxygen ions, reflected neutrals by reflection of plasma background gas at the target surface, sputtered atoms, bulk plasma ions, and secondary electrons. To solve this problem, we developed the NBAS (Neutral Beam Assisted Sputtering) process as a plasma damage free and room temperature processed sputtering technology. As a result, electro-optical properties of NBAS processed ITO thin film showed resistivity of 4.0×10^{-4} Ω•m and high transmittance (>90% at 550 nm) with nano- crystalline structure at room temperature process. Furthermore, in the experiment result of directly deposition of TCO top anode on the inverted structure OLED cell, it is verified that NBAS TCO deposition process does not damages to the underlying organic layers. In case of deposition of transparent conductive oxide (TCO) thin film on the plastic polymer substrate, the room temperature processed sputtering coating of high quality TCO thin film is required. During the sputtering process with higher density plasma, the energetic particles contribute self supplying of activation & crystallization energy without any additional heating and post-annealing and forminga high quality TCO thin film. However, negative oxygen ions which generated from sputteringtarget surface by electron attachment are accelerated to high energy

by induced cathode self-bias. Thus the high energy negative oxygen ions can lead to critical physical bombardment damages to forming oxide thin film and this effect does not recover in room temperature process without post thermal annealing. To salve the inherent limitation of plasma sputtering, we have been developed the Magnetic Field Shielded Sputtering (MFSS) process as the high quality oxide thin film deposition process at room temperature. The MFSS process is effectively eliminate or suppress the negative oxygen ions bombardment damage by the plasma limiter which composed permanent magnet array. As a result, electro-optical properties of MFSS processed ITO thin film (resistivity 3.9×10^{-4} Ω•cm, transmittance 95% at 550 nm) have approachedthose of a high temperature DC magnetron sputtering (DMS) ITO thin film were. Also, AOS (a-IGZO) TFTs fabricated by MFSS process without higher temperature post annealing showed very comparable electrical performance with those by DMS process with 400°C post annealing. They are important to note that the bombardment of a negative oxygen ion which is accelerated by dc self-bias during rf sputtering could degrade the electrical performance of ITO electrodes and a-IGZO TFTs. Finally, we found that reduction of damage from the high energy negative oxygen ions bombardment drives improvement of crystalline structure in the ITO thin film and suppression of the sub-gab states in a-IGZO semiconductor thin film. For realization of organic flexible electronic devices based on plastic substrates, gas barrier coatings are required to prevent the permeation of water and oxygen because organic materials are highly susceptible to water and oxygen. In particular, high efficiency flexible AMOLEDs needs an extremely low water vapor transition rate (WVTR) of 1×10^{-6} $gm^{-2}day^{-1}$. The key factor in high quality inorganic gas barrier formation for achieving the very low WVTR required (under ~10^{-6} $gm^{-2}day^{-1}$) is the suppression of nano-sized defect sites and gas diffusion pathways among the grain boundaries. For formation of high quality single inorganic gas barrier layer, we developed high density nano-structured Al2O3 single gas barrier layer usinga NBAS process. The NBAS process can continuously change crystalline structures from an amorphous phase to a nano- crystalline phase with various grain sizes in a single inorganic thin film. As a result, the water vapor transmission rates (WVTR) of the NBAS processed Al_2O_3 gas barrier film have improved order of magnitude compared with that of conventional Al_2O_3 layers made by the RF magnetron sputteringprocess under the same sputtering conditions; the WVTR of the NBAS processed Al_2O_3 gas barrier film was about 5×10^{-6} $g/m^2/day$ by just single layer.

Keywords: Plasma Damage Free Sputter, Low TemperatureProcess, TCO, AOS, Gas Barrier