Formation of a bilayer of low-temperature CVD-SiO$_2$ and sputtered Al$_2$O$_3$ films on polyethylene terephthalate substrates for an OLED encapsulation layer

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Organic light-emitting diode (OLED) devices have promising potential for flat-panel display to replace liquid crystal displays (LCDs). The limited lifetime of OLED is a major drawback for its commercial applications such as TV and monitor. Since the organic materials and low work-function metals used in OLEDs are sensitive to moisture, OLED displays are easily degraded in humid environment. Encapsulation with organic or inorganic thin films has been actively investigated to fulfill a requirement of low water permeability ($< 10^{-6}$ g/m$^2$·day). Recently, multilayers of inorganic thin films have been proposed for the encapsulation of OLEDs using various deposition methods such as sputtering, atomic layer deposition (ALD), and chemical vapor deposition (CVD).[1-5].

In this study, we prepared a single-layer barrier of sputtered Al$_2$O$_3$ and a bilayer barrier consisting of CVD SiO$_2$ and sputtered Al$_2$O$_3$ as a potential moisture barrier for an OLED encapsulation. Sputtered Al$_2$O$_3$ films were prepared at room temperature using an RF magnetron sputtering system (CS5000, SNTek Co.). The process pressure and Ar flow rate were 5 mTorr and 10 sccm, respectively. The RF power of Al$_2$O$_3$ target was 150 W. For the bilayer barrier, the CVD SiO$_2$ thin films were formed at 100°C using tris(ethyl-methyl-amino)silane (TEMS, HSi[ (CH$_3$)$_2$CH](CH$_3$)$_3$)] and O$_2$ as a Si precursor and oxidant gas, respectively.

Figure 1 shows the Fourier transform infrared spectroscopy (FTIR) spectra of CVD SiO$_2$ layer. Absorbance bands at 1070 cm$^{-1}$ and 800 cm$^{-1}$ are ascribed to the stretching and bending vibrations of Si-O-Si, respectively. The peak at 950 cm$^{-1}$ has been reported to be associated with the stretching mode of Si-OH. The absorbance band at 880 cm$^{-1}$ is assigned to the bending modes of H-SiO$_2$, indicating that CVD SiO$_2$ contains small amount of –OH radicals. Since CVD SiO$_2$ with –OH radicals exhibits a flowable behavior, the CVD-SiO$_2$ film exhibits a conformal gap-filling at the acute angle region between the silica particle and the substrate, as shown in Fig. 2. Because the conformal gap-filling behavior of CVD SiO$_2$ enhanced the blocking of the pin holes or cracks of sputtered Al$_2$O$_3$ layer, the bilayer barrier with CVD-SiO$_2$ layer and sputtered Al$_2$O$_3$ layer reduced the water permeation compared to the Al$_2$O$_3$ single-layer barrier, as shown in Fig. 3. The bilayer with the 100 nm thick Al$_2$O$_3$ and the 100 nm thick CVD-SiO$_2$ exhibits lower water vapor transmission rate (WVTR) (0.214 g/m$^2$·day) than the 200 nm thick sputtered Al$_2$O$_3$ single-layer (0.325 g/m$^2$·day), although both barriers have the same thickness.

In summary, the encapsulation bilayer with CVD SiO$_2$ and sputtered Al$_2$O$_3$ layers was studied to reduce the moisture permeation through PET film. Even though the WVTR (0.214 g/m$^2$·day) of the bilayer barrier is much lower than the target value ($10^{-6}$ g/m$^2$·day) of the OLEDs, the inorganic bilayer barrier of OLEDs with different materials and different deposition methods makes it possible to reduce the water permeation to OLEDs. Especially the gap-filling property of flowable CVD-SiO$_2$ plays the key role in a surface planarization and blocking of surface defects.

References

Fig. 1. The FTIR spectra of CVD-SiO$_2$ film.

Fig. 2. Cross-sectional SEM image showing the coverage of CVD-SiO$_2$ film at the acute angle underneath a silica particle.

Fig. 3. The comparison of the WVTR of the single-layer and bilayer barriers.