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Architectural float glass as a substrate for organic light-emitting diodes

J. Thompson[a,*] V. Maiorano[a], S. Carallo[a], E. Perrone[a], A. Biasco[a], R. Cingolani[a], A. Croce[b], A. Daneu[b] and R.I.R. Blyth[a],

[a] National Nanotechnology Laboratory of INFM, Distretto Tecnologico ISUFI, Universita' di Lecce, via Arnesano, 73100 Lecce, Italy

[b] Vitrum-Lux, Boulevard de Contournement, 4823 Rodange, Luxembourg

Abstract

While ITO has proven a succesful transparent anode material for laboratory-based investigations of OLEDs, it is perhaps less suited to large-scale production. Here we show that float glass with an evaporated gold coating functions extremely well as the transparent anode for OLEDs. We discuss the production of an ultrathin conductive gold layer in terms of the roughness and surface energy of the float glass. We demonstrate large area OLEDs based on these substrates, in particular a green-emitting device using spin-coated films of Poly[(9,9-dioctylfluorenylene-2,7-diyl)-co-(1,4-diphenylene-vinylene-2-methoxy-5-{2-ethylhexyloxy}-benzene)] as the active layer, and a white-emitting device using, as the active layer, spin-coated films of Poly(9-vinylcarbazole) doped with the phosphorescent materials Iridium bis(2-(4,6-difluorophenyl)pyridinato-N,$C^{2'}$)picolinate and Iridium bis(2-(2'-benzothienyl)pyridinato-N, $C^{3'}$)(acetylacetonate). Atomic force microscopy was used to investigate the morphology during each stage of OLED fabrication. We show that large area OLEDs can be fabricated on such substrates, with the area limited by the deposition techniques used.

Keywords: Glass surfaces, metal/insulator interfaces, organic/inorganic interfaces, light sources

1. Introduction

The availability of a cheap, large-area, transparent, conducting substrate continues to be a limiting factor for the exploitation of organic LED technology. Though ITO is the transparent anode of choice for laboratory based OLED research, its high cost and high roughness [1] make it unattractive for large area commercial devices. Depositing conducting films on glass substrates is a route relatively less explored, but this may well be related to the type of glass routinely found in laboratories - depositing metals on laboratory glass generally leads to island formation at coverages low enough to retain transparency. 95% of the world's glass is produced by the float glass method - the molten constituents of the glass are floated on a bath of molten tin and cooled. The resulting sheet of glass, by a combination of the high surface temperature, surface tension and mass, is *extremely* smooth, with a correspondingly high surface energy. The glass formed in this way has two distinct sides, one which incorporates a small amount of tin inclusions. The smoothness of both sides, apart from these inclusions, are, however, comparable. There is a practical limit to the thickness of the glass, of the order of a few mm. Thus, glass found in laboratories, e.g. microscope slides, is not float glass. Even if optically smooth, the surface of non-float glass is inevitably rough, with a corresponding lower surface energy than float glass. Metals typically have high surface energies, which would tend towards island growth, rather than wetting, when deposited on a (low surface energy) glass surface. Moreover, metal cluster growth on oxides is known to be defect moderated [2], thus a rough (on the atomic scale) glass surface is a poor substrate for the growth of thin, conducting films.

Float glass, by virtue of its very low roughness and high surface energy is a far better candidate than laboratory glass as a substrate for transparent, conducting, metal films. Further, although specialist glass can be prohibitively expensive, float glass is cheap. Thus, a suitable substrate may already exist – a substrate, moreover, which is already available not just in large sizes relative to the common research OLED, but large on the architectural scale: the typical raw product is a piece of float glass 12m x 3m.

In this work we show that a conducting film of a high surface energy metal – gold – can be deposited onto industrial float glass while retaining transparency, and that

*Corresponding Author. E-mail: julie.thompson@unile.it

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the resulting substrate can be used as the anode for organic LEDs.

2. Experimental

The float glass substrates, from Vitrum-Lux, were first cleaned with solvents, with a final rinse with de-ionized water, before being placed in an oven to dry. Thin gold films were thermally evaporated in a vacuum chamber with a base pressure of $<10^{-6}$mbar, at a rate of 0.5Å/s. Organic LEDs were fabricated on these substrates, consisting of a spin coated layer of PEDOT:PSS, followed by a spin coated layer of the emissive materials, 30nm of AlQ_3 (evaporated in high vacuum) and finally 150nm of aluminium as the cathode. Two different types of OLED were fabricated, by changing the emissive layer. In the first, the active layer was a spin-coated film of the fluorescent polymer poly[(9,9-dioctylfluorenylene-2,7-diyl)-co-(1,4-diphenylene-vinylene-2-methoxy-5-{2-ethylhexyloxy}-benzene)], the commercial material ADS125GE. In the second, the active layer was a spin-coated blend of the two phosphorescent materials Iridium bis(2-(4,6-difluorophenyl)pyridinato-N,$C^{2'}$)pic-olinate, Ir(Fpy)2pi, and Iridium bis(2-(2'-benzothienyl)-pyridinato-N, $C^{3'}$)(acetylacetonate), $(btpy)_2Ir(acac)$, in a Poly(9-vinylcarbazole) PVK matrix. The structures of the active materials are shown in fig. 1.

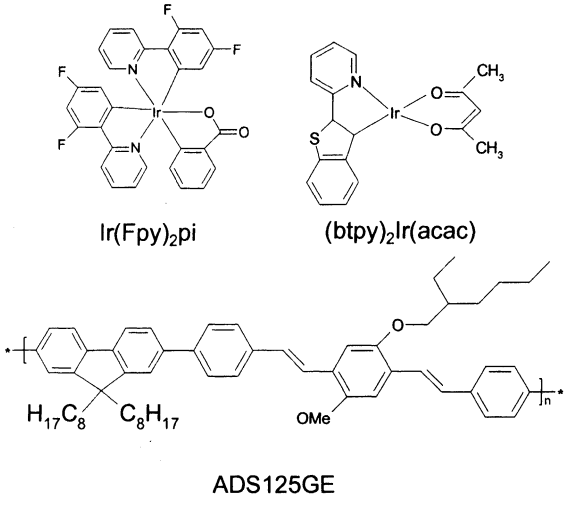

Fig. 1. Structres of the active organic materials used.

Electroluminescence spectra were recorded using an Ocean Optics spectrometer, while transmittance measurements were performed using a Varian Cary 100 spectrophotometer. The active materials were obtained from American Dye Source, while PVK and AlQ_3 were obtained from Sigma-Aldrich, and PEDOT:PSS from Bayer. All organics were used as-received. Atomic force microscopy was performed using an Autoprobe CP Research Thermomicroscopes AFM.

3. Results and Discussion

AFM images of the float-glass showed a local roughness < 1nm on both sides, with Sn-oxide inclusions on the float side. After deposition of a thin gold film, roughness remained < 1nm, which compares to the gold atomic step height of 0.4nm. No evidence of crystallite formation or clustering was seen, in contrast to, for example, AFM images of thin films of gold on mica [3]. The transmittance, across the visible region of the spectrum, of the film on float glass is shown in fig. 2. It can be seen that the transmittance is above 60% over the whole visible range, and up to 80% in the green.

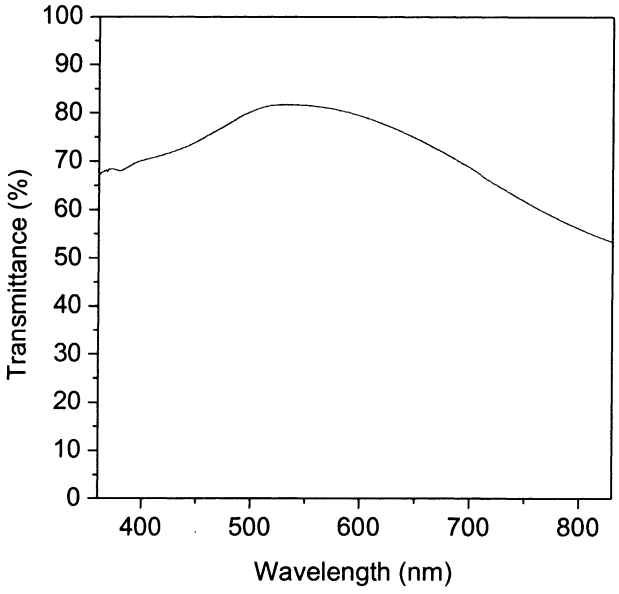

Fig. 2. Transmittance spectrum of a 5nm Au film on float glass

A signature of cluster formation on gold films is a peak in the region 600-750 nm in Uv-visible absorption spectroscopy, with the wavelength dependent on the cluster size [3]. This peak, which is due to the formation of plasmons, would correspond to a dip in the transmittance.

The data of fig. 2 show no such dip, with only a smooth variation in the transmittance in the region of interest. This provides spectroscopic evidence for the absence of cluster formation, to complement the topographical AFM data.

These data suggest that the high surface energy of float glass and its intrinsic smoothness, i.e. low defect density, allows the layer-by-layer growth of flat, transparent, gold thin films. The absence of clustering, which would, at low nominal coverages, give a non-continuous film, results in the deposited film retaining conductivity.

We have used such substrates to fabricate large area OLEDs. Fig. 3 shows a 5cm x 5cm green-emitting device, with the fluorescent polymer ADS125GE as the active layer. The corresponding electroluminescence spectrum of this device is shown in fig. 4. The turn on voltage for this