Abstract

Organic light emitting diodes have been able to achieve up to 100% in their internal quantum efficiencies. The realization of 100% in their external quantum efficiencies, however, are limited by the low light outcoupling efficiency (η_{out}) of ~20%. The η_{out} describes the fraction of photons that escape into the forward viewing direction relative to the total amount generated and is heavily influenced by the device structure and materials used. Low η_{out} results from light lost to substrate guided modes (due to light rays being totally internally reflected, TIR, at the air/glass interface) and evanescent modes (due to coupling between the EM radiation and surface plasmons, SPs at the organic/cathode interface). The aim of this research is to enhance η_{out} by targeting these light loss channels via device and materials engineering strategies, respectively.

Hole patterns were first micromachined via a femtosecond laser (IMRA America Inc.) onto the air/glass side of the OLED substrate. Simulated results revealed that the maximum η_{out} maybe realized by using hole patterns with conical shape, 5 μm diameter, 10 μm depth, arranged in a rectangular lattice and separated by 1 μm. Experimental results agreed well with simulation and showed that up to 60% η_{out} enhancement ($\Delta\eta_{out}$) can be achieved in patterned devices. The mechanism of $\Delta\eta_{out}$ is ascribed to the extraction of substrate guided modes where a smaller contact angle is made between the incident light rays and slanted conical surface, therefore TIR events at the air/glass interface can be avoided. Additionally, strong scattering events at the air/glass interface disarray interference effects that would normally cause viewing angle dependence (VAD) of the emission (EL) spectra. VAD was reduced from 11 nm to 4 nm thanks to the substrate patterning. Past strategies for $\Delta\eta_{out}$ have unfortunately resulted in the VAD of the EL spectra while textures used to reduce VAD have no effect on η_{out}. Our strategy represents an improvement milestone in this regard for general lighting OLEDs since our air/glass patterns demonstrate simultaneous $\Delta\eta_{out}$ and reduction of VAD.

A materials engineering approach was used to develop potential strategies that can prevent losses to evanescent modes. π-conjugated polymers used as the emissive layer in OLEDs naturally adopt a horizontal orientation relative to the z-axis and thus emit TE-polarized radiation. Since SPs only couple to TM-polarized radiation, losses to evanescent modes are reduced and η_{out} is enhanced. For the realization of highly efficient OLED displays, these devices must naturally emit linearly polarized luminescence (LPL). This will be achieved by the uniaxial orientation of the polymer's molecular chain and transition dipole moment (TDM) in the x-y plane. For this purpose, we have devised a novel strategy, "solution withdrawal coating (SWC)" for the simultaneous deposition of the polymer film and control over uniaxial orientation. P3HT was used as the proof-of-concept material and demonstrated that up to 0.43 in optical anisotropy is possible. P3HT readily forms solution-state aggregates (nanofibrils) after UV-irradiation and fibrils readily align parallel to the direction of the moving solution during SWC. Although UV-irradiation does not induce molecular aggregation in solution for all OLED polymers (ex. F8BT), other strategies maybe explored, ex. electric field induced alignment. Once solution-state alignment is achieved, uniaxial orientation of polymer chains is expected, and LPL can be realized.

Keywords: Organic light-emitting diodes, outcoupling efficiency, substrate patterning, substrate guided modes, evanescent modes, molecular orientation.