From Deposition to Encapsulation: Roll-to-roll manufacturing of organic light emitting devices for lighting

Program: DOE EERE SETP CSP subprogram award number DE-EE0008723

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Objectives

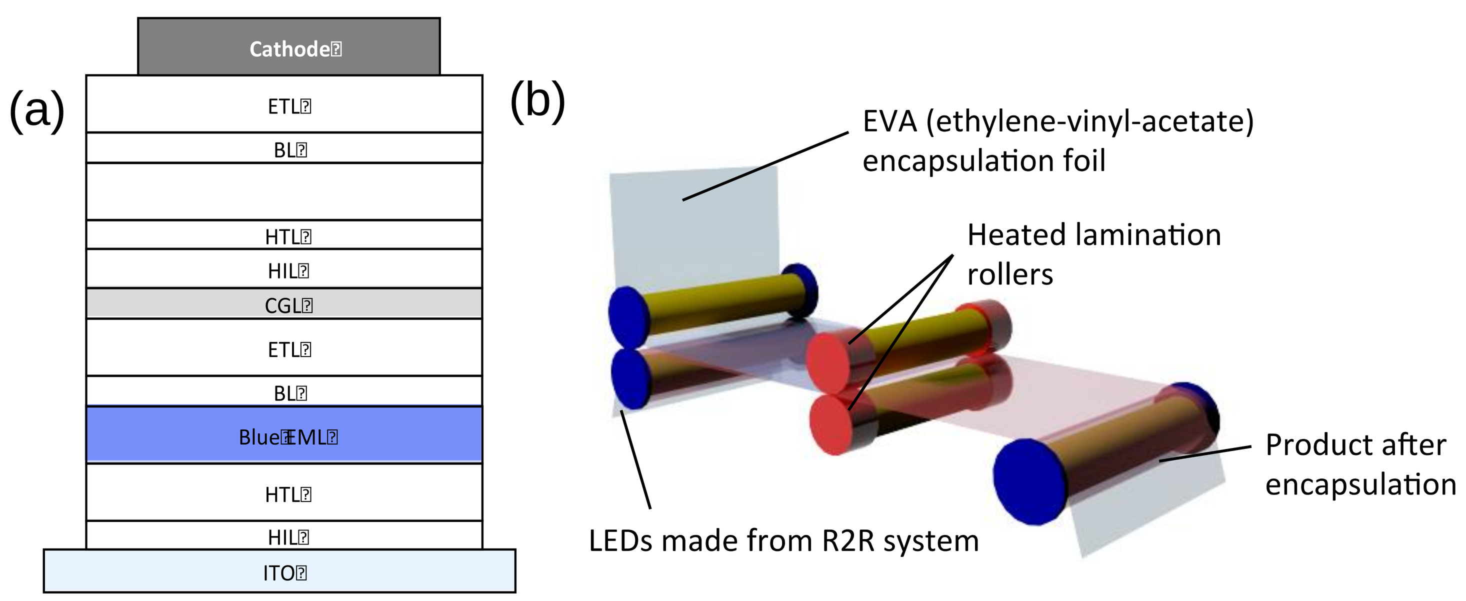

Figure 1: (a) Archetype stacked OLED for lighting applications. ETL=electron transport layer, BL=blocking layer, HTL=hole transport layer, CGL=charge generation layer, HIL=hole injection layer. B=blue, G=Green and R=red emitting layers (EML). (b) Conceptual diagram of the R2R encapsulation system to be constructed in this program.

- ❑ Goal: Demonstrate all aspects of white emitting OLEDs (WOLEDs) roll-to-roll (R2R) manufacturing on a continuous web: from organic active layer and electrode deposition, all the way to encapsulation into a flexible and lightweight package.
- ❑ Product: reliable, encapsulated, 25 cm^2 flexible phosphorescent WOLED panels with 50 lm/W efficacy and CRI>85 on barrier coated plastic films produced entirely in a single, integrated system.
- ❑ Impact: OLED lighting creates uniform lighted environment with tunable color coordinates and temperature. R2R manufacturing can lead to drastic cost reductions needed for the widespread application and deployment of OLED lighting.

Milestones

Milestone	Description	Completion Dates	Percent Complete
Task 1.1	Develop R2R process integrating VTE and OVPD growth with film thickness variation <10% on translating substrates	9/30/19	100%
Task 1.2	Fabricate a WOLED with 50 lm/W, CRI>85 by R2R	3/31/20	50%
Go/NoGo	Demonstrates 100nm bilayer growth by VTE and OVPD with film thickness variation <10%	3/31/20	100%
Go/NoGo	Fabricate 1 cm^2 WOLED in R2R system with 3000 nits, 15% EQE, and CRI > 80.	3/31/20	50%
Task 1.3	Encapsulate the WOLED with 50 lm/W, CRI>85, L_0=1000 nits, and T_{80}=500 hr, in the R2R tool	3/31/21	15%
Task 2	Develop market forecast and cost models for the volume manufacture of OLED lighting	6/30/20	0%
Task 3	Develop roadmap for rapid insertion of R2R manufacturing of WOLED lighting fixtures into the commercial sector	3/31/21	0%

R&D Approaches

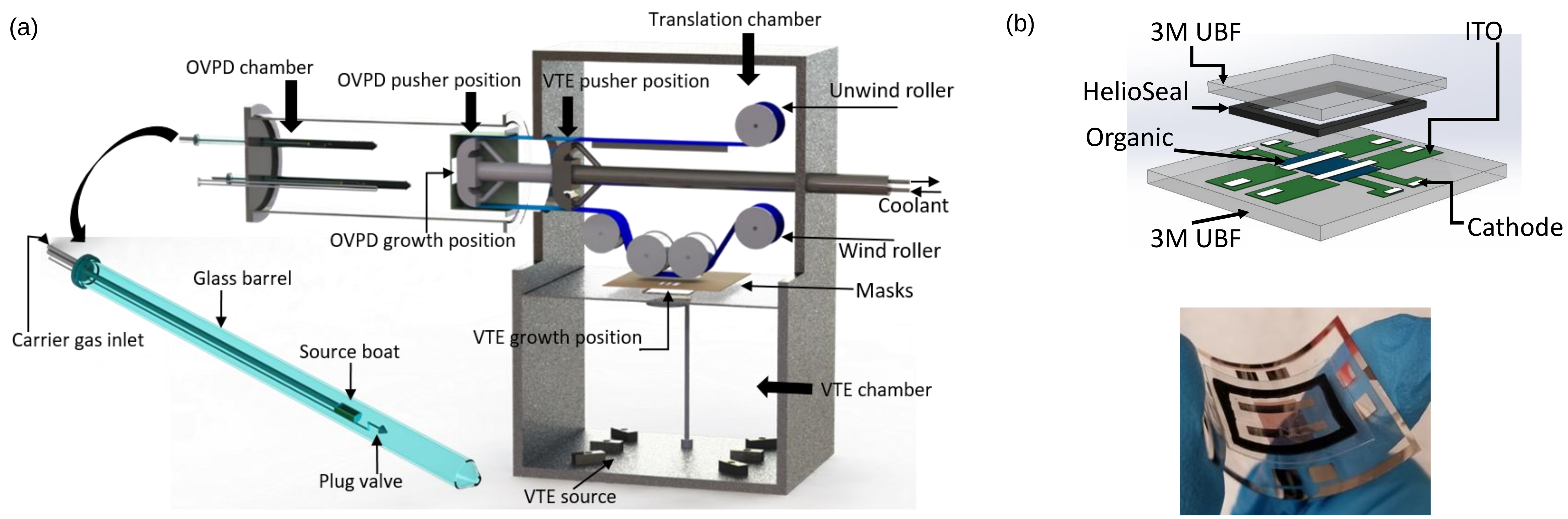

Figure 2: (a) Cross-section schematic of the roll-to-roll (R2R) system integrating vacuum thermal evaporation (VTE) and organic vapor phase deposition (OVPD), and a magnified view of OVPD source barrel containing the organic source boat and plug valve. (b) Flexible Organic device package and device architecture demonstrated at the University of Michigan.

- ❑ R2R film growth on translating substrates integrates multiple deposition techniques of different processing parameters.
- ❑ Interconnected deposition chamber with different pressures; 6-source OVPD: exciton blocking and active emitting layers deposition with accurate doping control; 6-source VTE: metal contacts, charge transport and charge generation layers; in-situ masked patterning; adjustable web translation speed.
- ❑ Flexible encapsulation of WOLED without air exposure using 3M Ultra Barrier® or equivalent non-permeable package material.

Technology: OVPD

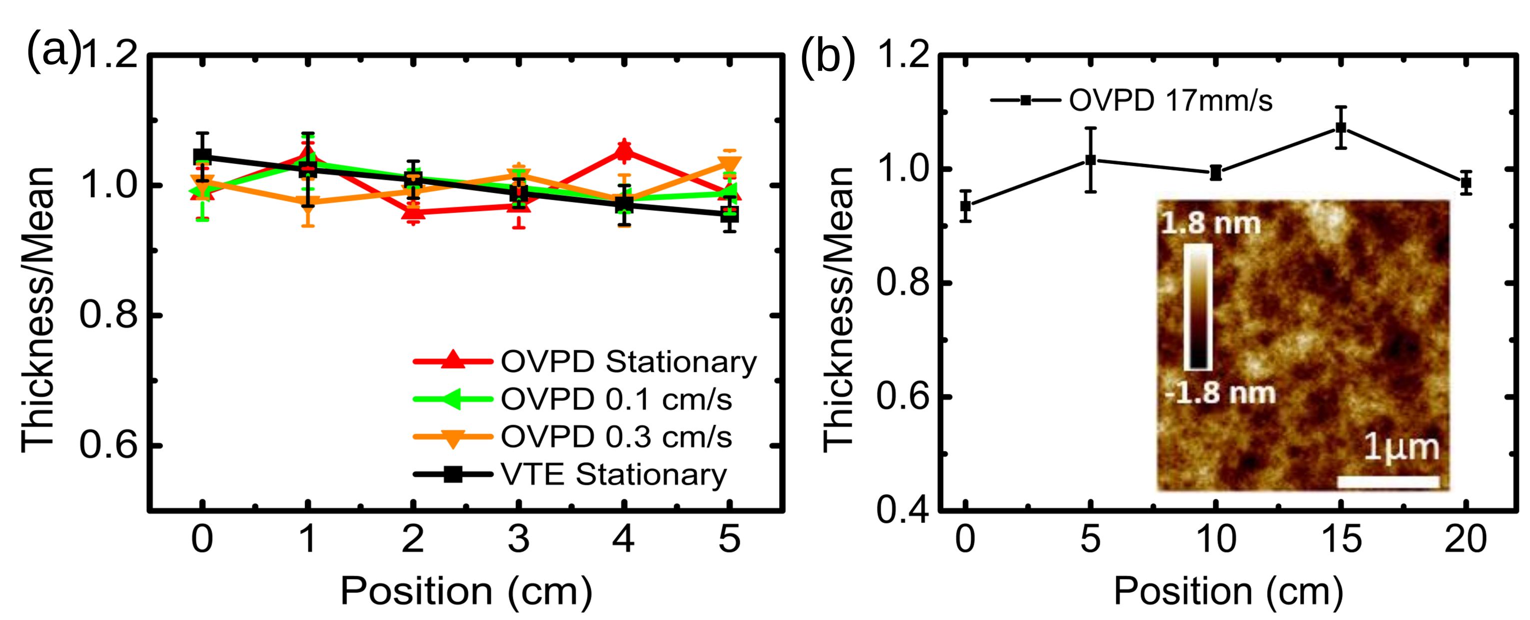

Figure 3: (a) Normalized 6-position thickness profiles of BPhen films grown by OVPD and VTE at different substrate translation speeds. The film thickness of stationary, 0.1 cm/s, and 0.3 cm/s translation OVPD as well as stationary VTE growth are 57.3 nm, 19.8 nm, 6.4 nm and 20.8 nm, respectively. (b) Normalized thickness profile of 6.2 nm BPhen film grown using OVPD at 15.8 Å/s with 1.7 cm/s substrates translating speed. Inset: Atomic force microscope image of the BPhen film with root mean square roughness of 0.40 nm.

- ❑ In OVPD, the molecular species are thermally evaporated into a stream of inert carrier gas in a hot walled reactor held at low pressure and transported in equilibrium towards a cooled substrate.
- ❑ OVPD is particularly suited to low cost volume manufacturing due to its very high deposition rate without sacrificing film quality.
- ❑ Growth during translation within the OVPD system shows high film thickness uniformity, smooth surface morphology, and no systematic dependence on the translation speed.

Preliminary Results

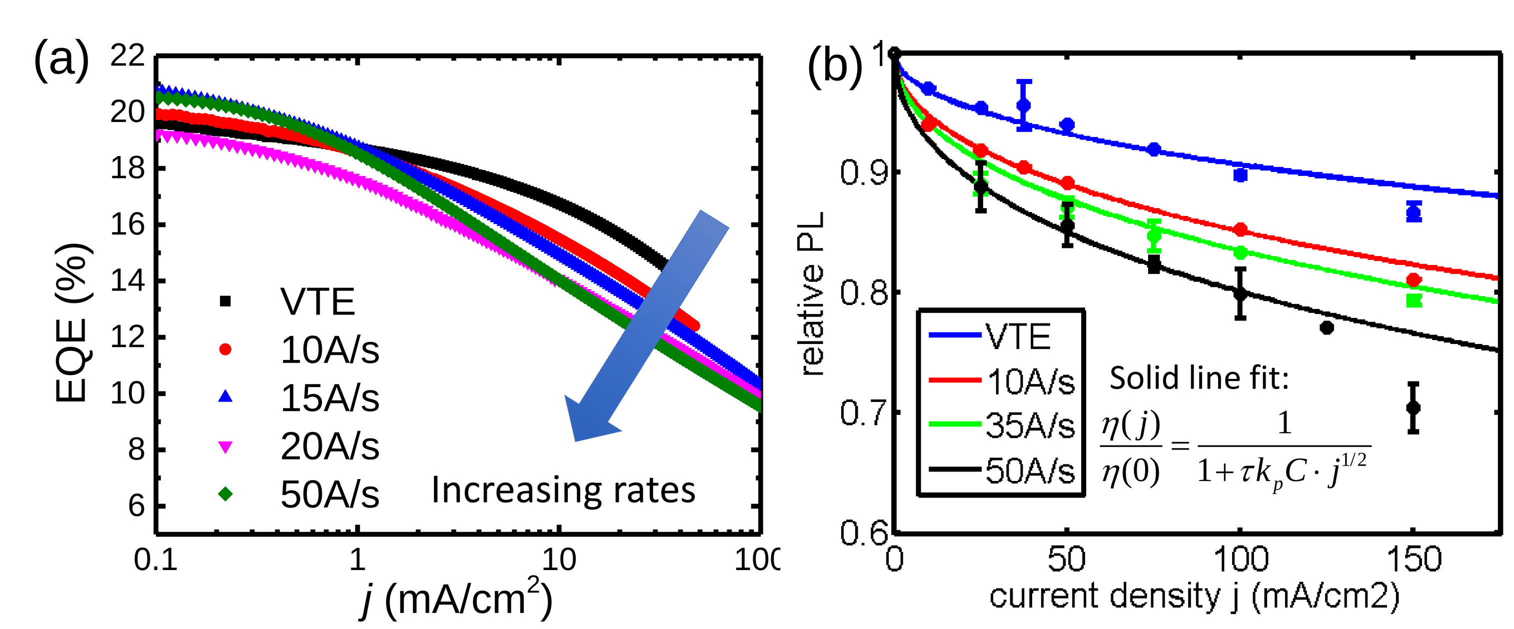

Figure 4: (a) External quantum efficiency (*EQE*) vs. current density *j* of OLEDs fabricated at different deposition rates by OVPD and VTE. OLED structure: ITO/40nm TAPC/ 25nm 8% $Irppy_2(acac)$ doped CBP/65nm TPBi/100nm Alcathode. (b) Dot: Measured relative photoluminescence intensity of hole only devices fabricated at different deposition rates as a function of current densities; Solid line: fit using inset equation generated from triplet-polaron quenching model.

- ❑ OLEDs with the emission layers fabricated at different deposition rates from 2 to 50 Å/s by OVPD show similar max *EQE* = 20±1 %.
- ❑ As the emission layer deposition rate increases, OLEDs show increased efficiency roll-off at high current densities.
- ❑ From the PL fitting based on the space charge limited current model and the triplet-polaron quenching rate equation, higher emission layer deposition rate yields higher quenching rate, potentially due to the inhomogeneity in host matrix.

Reference: B. Qu and S.R. Forrest, Appl. Phys. Lett. 113, 053302 (2018).