[Scdt] PhD Open Seminar: Mr. Chandra Kant (16106263) MSE Dept. on 13th June @ 3:30 PM in FB421

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Date 2022-06-07 12:42

Department of Materials Science and Engineering

PhD Open Seminar Announcement

Mr. Chandra Kant (16106263) will present his PhD Open Seminar on

Title: **LARGE-AREA FLEXIBLE ORGANIC LIGHT-EMITTING DIODES USING INKJET PRINTING**

Date: 13th June 2022 (Monday)

Time: 3:30 pm

Venue: FB 421

All interested are welcome to attend.

Monica Katiyar

(Thesis Supervisor)

Abstract:

There is a rapidly increasing demand for flexible, lightweight, high-quality displays and lighting devices. The solution-processed organic light-emitting diodes (OLEDs) could meet these aforementioned requirements easily. Researchers have focused on printing as a major technique as it can be used to deposit liquid functional inks with high accuracy and reproducibility. Hence, inkjet printing (IJP) is a promising emerging technology in this field. Using the drop-on-demand advantage and manufacturing costs, it can significantly reduce material wastage by minimizing waste products and their disposal. IJP has many challenges, inherent limitations, and advantages. This work’s aim is to understand the challenges and exploit the advantages to develop low-cost displays using IJP.

The focus of this work is on (i) formulation of functional inks of light-emitting materials, electrodes, and dielectric material to print OLEDs and (ii) printing parameters, such as substrate temperature, nozzle temperature, waveform optimization, jetting frequency, and print height (distance between the nozzle and the substrate) to control the droplet formation, drying mechanism, and quality of the printed layer. Inkjet printing requires a specific range of ink parameters such as homogeneous solubility, solvent density (~1g mL^{-1}), surface tension (28-32 mN m^{-1}), and viscosity (1-10 cP). The solubility of organic solid varies widely with the solvent, and the choice of proper solvent plays a vital role. Hence, the Hansen solubility parameter (HSP) has been used to pick the appropriate solvent. The Hansen model estimates solubility using three molecular interactions: dispersion forces, polarity, and hydrogen bonding. In this study, HSP is used to formulate the suitable ink for different materials, which were inkjet printed, and developed layers are tested in an OLED. Device stability, I-V-L characteristics, luminescence, and current efficiency are found comparable to solution-processed methods like spin-coated devices.

Three case studies are presented for light-emissive layers: small molecules such as thiopyridinyl-based iridium molecule (PO-01), a thermally activated delayed fluorescent (TADF) materials -ACRXTN, and light-emitting polymers. After extensive optimization of various parameters, we conclude that jetting parameters such as pulse width (3-5 μs) and applied pulse voltage (16-32 Volts) are crucial for the stable drop ejection from the nozzle. To avoid clogging at the nozzle, optimized ink formulation by mixing a low boiling point solvent (Toluene) with a higher boiling point solvent (methyl benzoate) is required. The use of such a solvent mixture decreases the drying rate of the film after deposition. The effect of pulse width on drop volume and drop speed was investigated in detail. The ink composition and printing resolution were optimized until good quality large-area films suitable for OLEDs were obtained. The goal was to print a large area of text, images, or logos without using complex lithography steps, proving IJP's versatility. A photolithography-less OLED processing was developed, taking advantage of inkjet printing.

Finally, we have successfully printed the PO-01/CBP, and TADF ink formulations of light-emitting materials on a standard small area (4*4 mm^2) OLEDs; different sizes, patterns, and up to 80*80 mm^2 large area OLED tiles have been demonstrated on the glass as well as flexible substrates. IJP PO-01 devices exhibited the maximum current efficiency of 9 cd A^{-1} and maximum luminance of 5985 cd m^{-2} with a low turn-on voltage of 3.5 V. In contrast, TADF devices achieved a maximum current efficiency of 16 cd A^{-1} with the maximum luminescence of 3000 cd m^{-2} for the optimized device. The results obtained were comparable to the spin-coated devices.

To fabricate inkjet-printed polymer-emissive layer based OLEDs, various printing inks containing one or two components were prepared. As an emissive layer, two polymer materials, red and blue, were inkjet-printed using three different solvent systems: Toluene (INK 1), Toluene/Methyl benzoate (INK 2), and Toluene/mesitylene (INK 3). After a few jetting cycles, INK 1 clogged the nozzles, and INK 2 formed a non-uniform film on the PEDOT:PSS layer due to dewetting, whereas INK 3 formed a homogeneous film on the PEDOT:PSS layer, therefore INK3 was used to fabricate OLEDs with ITO/PEDOT:PSS/Poly-Red-or-Poly-Blue/Ca/Al configurations.

A dielectric polymer layer is also inkjet printed with SU-8 material. SU-8 cannot be printed in its pristine form by commercially available inkjet printheads owing to its higher surface tension and viscosity. Hence the material was diluted with N-methyl-1-pyrrolidone (NMP) to decrease the viscosity. The jetting of SU-8-NMP was found to be stable, whereas that of SU-8-in low boiling point solvents was not because they evaporated, leaving partially solidified SU-8 at the nozzle's meniscus. This can cause a misdirected jet. The effects of the ink viscosity and solvents on the optical quality of the microstructures studied. The ink properties and the printing parameters are varied to improve the uniformity and crystalline structure of the printed layer. In photolithography, a photoresist material can be applied using spin coating, leading to photoresist material wastage. The inkjet printing technique is used to deposit the SU-8 in the desired pattern, eliminating the photolithography step for pixelization.

An inkjet-printed silver electrode on flexible substrates is also developed as a replacement for indium tin oxide (ITO) which is the standard anode for OLED fabrication for the past three decades. Inherent sheet resistance and intrinsic brittleness of ITO make it unsuitable for large-area flexible devices. Hence IJP silver as an electrode could be a low-cost alternative to ITO's high conductivity. Here, the effects of the substrate temperature, the number of the printed droplets, and the solvents' properties are analyzed to get the desired thickness. After inkjet printing, photonic sintering reduces the silver NPs ink to metallic silver. Therefore, this process does not require high temperatures and is suitable for temperature-sensitive substrates such as PET and PEN. Photonic sintered printed silver layers show good electrical conductivity in the order of 10^7 S m^{-1}. We could achieve the minimum feature value of 200 μm thin lines. Moreover, the electrical characteristics were analyzed to understand how the control of the molecular organization can affect the device's performance. The printed OLEDs offer high bending stability when fabricated with flexible substrates, enabling flexible applications. Such a strategy could be a very effective way of reducing indium usage and opening new printed low resistance electrodes to technological viability. An ITO-free OLEDs were produced to demonstrate the capabilities of an inkjet-printed silver layer via solution processing in a simple top-emitting structure.

In summary, our results show the potential for fabricating large-area OLEDs using inkjet printing technology, potentially paving the way for a new generation of flexible, low cost, and low power displays.