High-density organic light emitting diodes by nanoimprint technology

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Advances in nanophotonics could revolutionize established as well as emerging fields such as quantum computing, ultrahigh density data readout, nanoscale optical imaging, photolithography, fiber communications, bio-MEMS, etc. Many of these applications would require nanoscale light sources. Despite the considerable development of inorganic semiconductor based light emitting diodes, they are not suitable as nanoscale light sources due to the effects of quantum confinement and fabrication constrains of miniaturization to nanoscale. Organic light emitting diode (OLED) technology is immune to quantum confinement since its transport characteristics are dominated by carrier hopping. Therefore OLED is the ideal candidate for miniaturization to nanoscale. However, current approaches to fabricate nanoscale OLEDs suffer from complicated or impractical fabrication as well as charge spreading which causes the emissive area to become much larger than the pixel dimensions. We aim to eliminate the problem of charge spreading while maintaining uncomplicated fabrication.

Our processes are centered on functional polymer separation between features or pixels, using nanoimprint lithography, to completely eliminate charge spreading. We have developed a low-temperature UV nanoimprint process to pattern Su-8 structures to achieve functional polymer separation. As depicted in Fig. 1, a layer of Su-8 is first spun coated onto ITO coated glass and imprinted with a mold containing large arrays of multi-shape patterns; the imprint is performed at 85 °C and 5 MPa, and the Su-8 is cured with UV for 5 seconds during the imprint. The patterns in Su-8 sit on top of a residue layer, which must be removed to expose ITO between pixels. Therefore, the patterned Su-8 undergoes a dry etch process with a mixture of O_2 and CF_4 gases (Fig. 2 shows the Su-8 structures after the etch step). The substrate is then coated with the functional polymer OPA 2311 (purchased from HW Sands). An optional imprint step using a flat mold can be used to help polymer flow in between the Su-8 structures. The, now freestanding, Su-8 structures give us separation of the functional polymer. The substrate is then coated with aluminum or other cathode material. We characterized the polymer and observed that imprinting of the polymer, at 120 °C, results in significant improvement in the intensity of the light output, as shown in Fig. 3. The first device fabricated using this approach is shown in Fig. 4a; light is being emitted from 20 μm squares separated by Su-8 lines (dark areas). Since thermal imprinting of OPA 2311 indicated better light emitting performance, we are also developing another imprint process to directly imprint OPA 2311 to form discrete polymer pixels. The OPA 2311 has a glass transition temperature of about 90 °C. Direct imprint at 120 °C reveals good pattern transfer, as shown in Fig. 4b. Both imprint processes can be utilized to fabricate high density large arrays of nanoscale OLEDs containing different structures of any shape; the shape and dimensions can be precisely controlled by nanoimprint lithography. Demonstration of micron scale OLEDs in this paper is our first step for initial characterization of device performance. With the fabrication of nanoscale molds, we expect to demonstrate OLEDs with dimensions smaller than 50 nm. Fig. 4c demonstrates a Si mold with sub-20 nm structures made by electron beam lithography and inductive coupled plasma etching.

We believe that the development of nanoscale OLEDs as nanoscale light sources will have a significant impact to various applications. The nanoimprint approaches developed here offer much needed control and flexibility as well as ease of fabrication.

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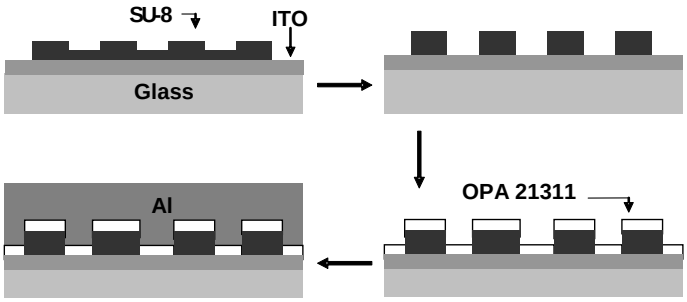

Fig. 1 – Schematic of a low-temperature UV nanoimprint process to fabricate Su-8 structures for pixel separation. Details are described in the abstract.

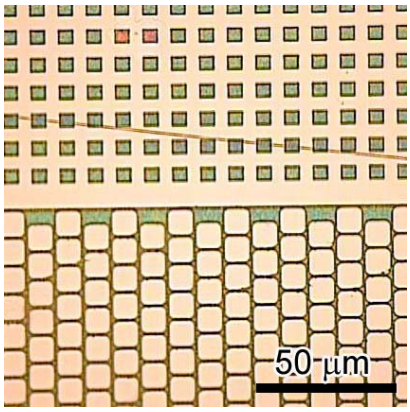

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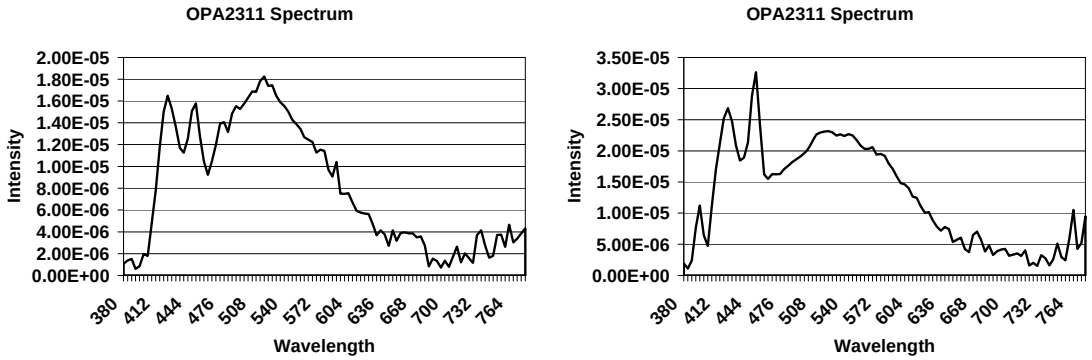
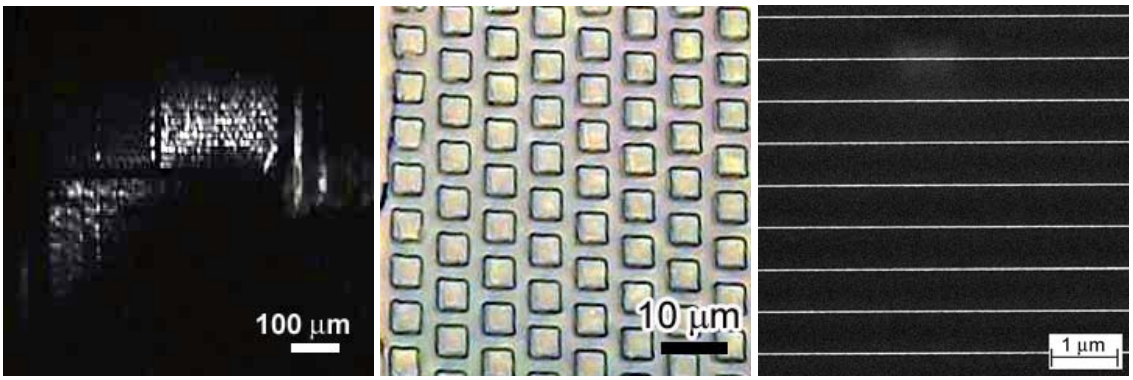
Fig. 2 – Su-8 squares after nanoimprint and plasma etch step.



(a) (b)

Fig. 3 – Emission spectrum of the functional polymer (OPA 231) utilized in the OLED. (a) Before imprint and (b) After imprint.



(a) (b) (c)

Fig. 4 – (a) Optical microscope image (dark field) of the light output from our first device fabricated with the Su-8 pixel separation process; (b) Direct imprint in OPA2311 polymer to form discrete microstructures; (c) SEM image of sub-20 nm lines in a Si mold.