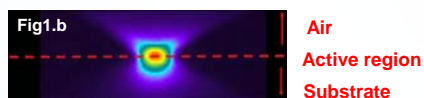
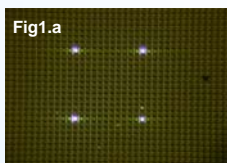


# Patterning and integration of polyfluorene polymers on micropixelated UV AlInGaN Light Emitting Diodes

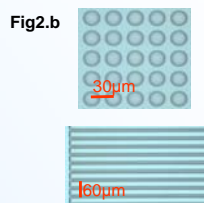
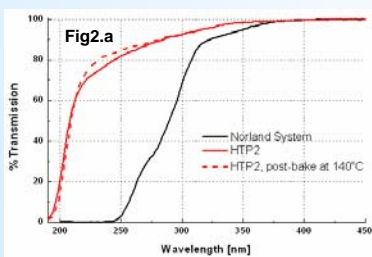
## ABSTRACT

We report the integration of micro-patterned polyfluorene conjugated polymers onto GaN-based ultraviolet (UV) micro-pixelated light-emitting diode arrays (micro-LEDs). The 64x64 element matrix-addressable AlInGaN devices have a pixel size of 20  $\mu\text{m}$  in diameter on a 50  $\mu\text{m}$  pitch, emitting at 368nm. Each array is covered with a 2.5 $\mu\text{m}$ -thick photo-curable deep-UV-transparent polymer and a 30nm thick polyfluorene film. This polymer bi-layer is subsequently patterned into an array of 28 $\mu\text{m}$ -diameter disks aligned to the pixels of the micro-LED array. Polymer down-converted visible emission from these pattern-programmable organic/inorganic electroluminescent micro-arrays is achieved.

The aim of the polyfluorene integration is to provide a hybrid GaN/polymer optoelectronic device technology combining the advantageous characteristics of the inorganic and organic materials. The AlInGaN LEDs used are micro-pixelated UV devices in a matrix-addressable format (fig1.a)[1]. Each pixel delivers a typical CW output power of 2.5 $\mu\text{W}$  at a driving current of 3.5mA. The beam divergence, measured by confocal microscopy (fig1.b) is 32° half-angle [2]. The representative polyfluorene material used is a commercial PFO (poly(9,9-dioctylfluorene)) polymer from Sumitomo.



The PFO polymer is spin-coated onto a 2.5 $\mu\text{m}$  thick proprietary UV-transparent photo-curable polymer used as a planarization layer (interlayer) on top of the inorganic device, thus producing a polymer bi-layer (inset fig4). The polymer interlayer (designated HTP2) was developed by the Chemistry Department at Strathclyde University. The transmission characteristics of this interlayer are shown in Fig2.a. for a film of thickness 20 $\mu\text{m}$ , alongside the characteristics of a commercially available epoxy (NOA63 from Norland Products Inc). It can be seen that this film is fully transparent at the UV LED operating wavelength of 370nm. The surface RMS roughness of the polymer interlayer was measured by AFM to be 2.5nm over a representative 5x5 $\mu\text{m}^2$  area. This polymer has also been used to fabricate micro-optical elements, as illustrated in fig2.b.



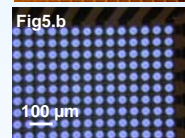
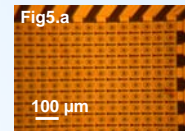
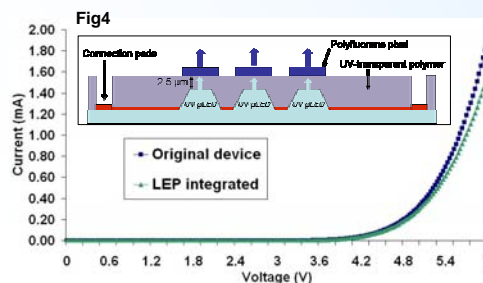
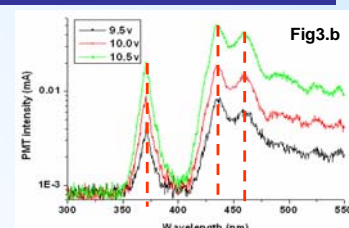
The integration of generic PFO was performed in two steps. First, a bare film of PFO, 30nm thick, was spin-coated on top of the polymer interlayer/GaN micro-LED structure. Colour conversion in this unpatterned polymer layer is shown in fig3.a. and spectrally in fig3.b. as a function of the drive voltage. Residual (unconverted) pump light at 370nm is evident, in addition to the vibronic structured spectrum characteristics of PFO. Secondly, a photolithography step followed by O<sub>2</sub>/CF<sub>4</sub> RIE dry etching with a photoresist sacrificial mask was used to pixelate the polymer film in alignment with the GaN pixels underneath. The IV curves of the device before and after polymer integration are shown in fig4. Microscope images of the device under white light and 370nm lamp illumination (showing all the polymer pixels luminescing) are shown in figs5.a and 5.b, respectively.

## References:

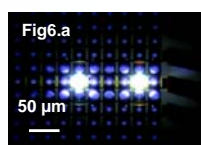
- [1] C.W. Jeon *et al*, "High-density Matrix-Addressable AlInGaN-based 368nm Micro Array Light Emitting Diodes", *IEEE Photon. Technol. Lett.*, vol.16, (2004)  
 [2] C. Griffin *et al*, "Beam measurements of InGaN/GaN Micro Array Light Emitting Diodes using confocal microscopy", *App. Phys. Lett.*, vol. 86, (2005)  
 [3] C.W. Jeon *et al*, "Mask-free lithography exposure using a matrix-addressable micropixelated AlInGaN UV LED", *App. Phys. Lett.*, vol. 86, (2005)



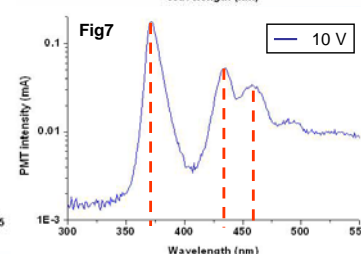
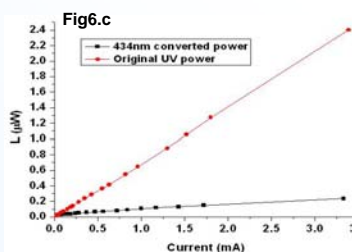
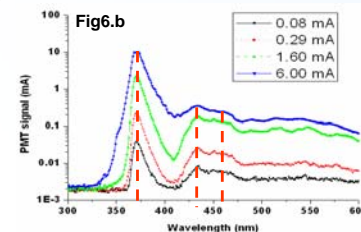
@ 10 V driving voltage



The electroluminescence performance of the final hybrid device is shown in fig6. Fig6.a shows 2 representative pixels operating. Fig6.b shows the spectral characteristics of the output. The measured optical-to-optical conversion efficiency (UV electroluminescent light in to blue photoluminescence light out) of this first generation integrated device is ~10% (fig6.c). The spectrum in fig6.b shows some evidence of oxidation of the PFO. To address the problem a 6 $\mu\text{m}$  thick NOA63 cap layer has been coated on top of the PFO film prior to the etching step and the resulting spectra in shown in fig7.



@ 1.6 mA driving current



## CONCLUSIONS:

- We have demonstrated micro-pixelated GaN/polymer light-emitting diodes. Colour conversion from UV to blue is achieved by optical pumping of the PFO polymer pixels from the respective GaN pixels underneath.
- This approach combines advantageous properties of organic and inorganic media into a very promising and versatile hybrid device technology.