**Electrospun Light-Emitting Nanofibers**

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Principal Investigators: Harold G. Craighead¹, George G. Malliaras², Héctor Abrúña³

Users: Jose M. Moran-Mirabal¹, Jason D. Slinker¹,², John A. DeFranco¹,²


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Contact: hgc1@cornell.edu, ggm1@cornell.edu, jmm248@cornell.edu, js395@cornell.edu, jad93@cornell.edu

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**Abstract**

We have fabricated sub-wavelength light sources based on electrospun nanofibers deposited on microfabricated interdigitated electrodes. The nanofibers contained transition metal complexes embedded in a polymer carrier which emitted light when a bias was applied across the electrodes. The fibers showed light emission at low operating voltages, with turn-on voltages approaching the band gap limit of the organic semiconductor. Because of the fiber diameter and the operation mechanism of the transition metal complex, emission from light-emitting nanofibers was confined to sub-wavelength dimensions, an attractive feature for sensing applications and lab-on-a-chip integration, where highly localized excitation of molecules is required.

**Summary of Research**

Micropatterned interdigitated gold electrodes were fabricated on silicon oxide surfaces by patterning a photosensitive layer, followed by gold evaporation and lift-off. Nanofibers were then deposited on the micropatterned interdigitated electrodes by electrospinning a solution containing a mixture of ruthenium(II)tris(bipyridine)/polyethylene oxide ([Ru(bpy)]²⁺(PF₆⁻)/PEO) in acetonitrile. Electro-spinning is a well developed electrohydrodynamic method used to produce micro- and nanofibers from a variety of dissolved materials without the need of expensive fabrication methods [1-3]. In our electrospinning setup, high voltage was applied between a droplet of the solution that rested on a sharp conducting tip and a grounded substrate (Figure 1). As a result of molecular ionization and charge redistribution, a jet of the solution was extracted, accelerated by the electric field, and collected on the substrate [4]. The volatile solvent used for the electrospinning solution evaporated in flight, yielding solid fibers on the substrate containing the micropatterned electrodes.

The nanofibers were lit up by applying a dc bias across an array of interdigitated electrodes in a nitrogen environment. Because each fiber could span more than one inter-electrode gap, a single fiber could produce more than one emission zone (although in practice not all of them did, Figure 2). The size of the emission zone for a particular fiber segment spanning an interelectrode gap is determined in the axial dimension by the operation mechanism of the transition metal complex, and in the transverse dimensions by the fiber cross-section. We imaged the lit up fibers through an inverted microscope and captured the images with a CCD camera. Figure 3 shows the highly-confined electroluminescence from an 800 nm diameter fiber lit at 4 V. Image analysis of the intensity of the emitted light revealed an emission area with dimensions of 240 nm along the axis and 325 nm in the transverse dimension. In reality,
this emission could be even smaller, as the resolution of the measurement is restricted by the diffraction limit of optical microscopy.

In all experiments performed, the current passing through the device and the luminance from the fibers was monitored as the voltage was ramped up/down. While the current monitored was the total current flowing through all the fibers in each device, only a few lit junctions could be imaged in each experiment. Thus, the luminance measured in each experiment was that of a section of an array of emitters from a single fiber. Multiple measurements from different fibers were performed and averaged to obtain the characteristic behavior for the device as a whole. In this way, luminance versus voltage and current versus voltage plots were generated (Figure 4). The turn-on voltage for the nanofibers on ramp-up was 3.2 V, with a subsequent exponential increase of the luminance at higher voltages. Interestingly, the current showed a two-step ramping behavior, which corresponds to monopolar and bipolar injection regimes [5]. Upon application of the voltage, PF₆⁻ ions redistribute, leading to the onset of monopolar injection at 1.7 V. As the bias is increased, the monopolar current continues to increase in an exponential fashion until sufficient PF₆⁻ motion has occurred to establish the second carrier injection at 3.2 V, initiating light emission.

In summary, this research shows that light-emitting nanofibers made of [Ru(bpy)$_3$]PF$_6$/PEO mixtures can be easily produced via the electrospinning method. The fibers were successfully lit on devices containing interdigitated electrodes with 500 nm gaps. Light emission was readily detectable with a CCD camera at voltages as low as 3.2 V and visible to the naked eye at 4 V, approaching the band gap limit for the organic semiconductor [6]. Emission from the fibers was found to be highly confined, with imaged emission areas small enough to be diffraction limited.

References