Benjamin Isenhart Honors College Thesis Proposal

Title: Lasing in Electrically Pumped Stacked OLED Device

Abstract:

Electrically pumped organic lasers could replace their inorganic counterparts in many practical applications due to the higher tunability, lower fabrication cost, and higher stability across a range of operational temperatures. To date, only optically pumped organic lasers have been demonstrated, which rely on inorganic lasers or flashlamps to provide the optical pumping. A new design based on a stack of organic light emitting diode (OLED) devices with metal electrodes, doubling as boundaries to optical resonant cavities, will be implemented and tested. The resulting device will be tested for the prevalence of stimulated emission in the radiative output.

Description of Project:

The goal of this project is to design, fabricate, and characterize the optical and electrical performance of stacked OLED devices. These devices may be capable of electrically pumped lasing in thin films of organic materials. To date, the fabrication of such a device has not been published. Electrically pumped organic lasers would have many practical applications due to their low-cost fabrication and high tunability compared to similar devices made from inorganic compounds (Baldo *et al*, 2002). Optically pumped organic lasers have been demonstrated since the late 1960's by various scientists, but such devices maintain the same limitations of inorganic lasers due to the need of an inorganic diode to provide the optical excitation to the organic materials (Kozlov *et al*, 2000). The distinction between feasibility of optically pumped and electrically pumped arises from the low charge carrier mobility in organic films. This leads to a limitation of organic film thickness to around 100 nm in electrically pumped devices, while the thickness of optically pumped devices is not mobility limited (Kozlov *et al*, 2000). We propose an organic diode laser based on an alternating OLED structure, keeping each film within the limitations imposed by the charge carrier mobility and using the metal electrodes as microcavity boundaries to create optical resonance cavities around each OLED device. Stacking the OLEDs on each other will provide multiple reflective surfaces for the mirror (distributed feedback) and reduce the maximum current in each individual OLED while keeping the same total current in the device (distributed gain). This distributed feedback distributed gain method has never been tried before, and potentially addresses all of the hurdles to realizing an electrically pumped organic diode laser.

Previous Work:

Since the 1960's, lasing in organic material has been demonstrated by a variety of scientists, but only in optically pumped devices (Kozlov *et al*, 2000, Baldo *et al*, 2002). These devices use an optical excitation source in the form of an inorganic laser to photoexcite the organic molecules which generate stimulated emission. The major limiting factor of organic materials in electrically pumped lasers is the low charge carrier mobility (Baldo *et al*, 2002). The use of waveguides to aid in the development of electrically pumped organic lasers was suggested by Kozlov *et al* in 2000 in a paper in which they laid out the argument that waveguides were necessary due to the significant changes in the optical properties of organic films while under the electrical excitation required for stimulated emission. Similarly, Bulović *et al* proposed the use of metal electrodes that doubled as mirrors on the edge of an optical cavity in 1998. Finally, Baldo *et al* noted in a detailed examination of the requirements of an electrically pumped organic laser that a device with significantly decreased nonradiative losses at high current densities compared to current organic diodes is required.

In order for the stacked OLED device to work as intended, OLEDs must be designed that have high power conversion efficiency and low turn-on voltages. One device that meets these criteria was introduced by Cai *et al* in 2011. This device uses a relatively simple three-layer organics design along with a LiF:Al electrode. Additionally, the ultra-thin molybdenum oxide layer suggested by Matsushima *et al* in 2008 can be used to develop a bright diode with a fairly low tun-on voltage.

Significance:

As mentioned above, an efficient organic laser would have many practical applications due to the low fabrication costs and high tunability achievable with organic materials. Some of the most important of these applications are optical communication technology, sensor applications, and optical memory (Bulović *et al*, 1998). Organic devices also show promise of being more temperature stable than their inorganic counterparts. Although optically pumped organic lasers have been demonstrated, their reliance on an inorganic excitation source negates the benefits of their organic composition. Only an electrically pumped organic laser would be capable achieving the benefits of the organic material without the use of an inorganic excitation source.

Proposed Methodology:

In order to complete this project, an alternating stack OLED device will be fabricated and tested for significant stimulated emission with respect to spontaneous emission. If stimulated emission were found to be stronger than spontaneous emission, this would be evidence of lasing. Prior to fabricating the entire device, a sequence of steps will be taken, with appropriate testing being done to each step before moving on.

To begin, a recipe for a suitable OLED must be found and tested. In this stage of the project, we will decide the materials that will eventually make up the device. To do so, OLEDs of different recipes are fabricated and tested. The materials suitable for this project would create an OLED with low turn-on voltage and high power conversion efficiency, as well as keeping the organics layers close to a total of 100 nm. The total thickness of our OLED device, including half of the metal electrode on each end, must be close to half of the wavelength of the peak emission. This stage of the project is occurring at the time of this writing and will continue for the majority of the spring of 2018. To date, the most success has been found using the recipe laid out by Cai *et al* with a substitution of indium tin oxide instead of PEDOT:PSS as the transparent electrode.

Upon finding a feasible OLED recipe, we will replace the transparent electrode with a metal electrode, most likely silver, which will have a much higher conductivity and very low transmission. The metal electrodes will then function as an optical resonance cavity for the light generated by the electrical excitation of the organic materials. Such devices would be fabricated on glass substrates initially, but the devices can also be fabricated on silicon substrates if the glass proves to be too rough. This stage of the project is expected to take approximately the first half of the fall semester of 2018.

After successfully making metal electrode diodes, stacks of devices will be fabricated. To do this, each diode will be oriented in the opposite direction as the devices on either side of it such that each diode shares its cathode with one of the neighboring diodes and shares its anode with the other neighboring diode. In this way, multiple devices can be formed on top of one another such that two electrical contacts can power all of the diodes in the stack. The electrodes will also act as reflective boundaries to the optical microcavities made by each diode. Initially, only a few diodes will be stacked in order to test the process of alternating the OLED direction. During these stages, we can use the current-voltage characteristics of the device to ensure that the device is acting as we intended. The stacked device should act the same as the same number of component diodes wired in parallel, giving a simple comparison to an easily testable model. This is expected to take the remainder of the fall semester of 2018 to complete.

Beginning in the spring semester of 2019, devices with more component diodes will be fabricated. At this point, we hope to be capable of constructing devices of up to fifty diodes stacked in the alternating pattern. This will likely be a time-consuming section of the project due to both the time required to fabricate these complicated devices as well as the probability of defects in the devices, which would cause them to be inoperable. Previous experience has shown that it is not uncommon for some diode devices to simply not work due to defects such as pinholes through the organics layers. If any such defects occurred in even one of the diodes in the stack, the entire device would be inoperable. Thus, about half of the spring semester of 2019 is dedicated to making reliable devices of significant size.

For the conclusion of this project, the devices will be stimulated using electrical currents in an attempt to excite stimulated emission from the device. To do so, an electric potential will be put across the two sets of electrodes, and a spectrometer used to measure the spectra of light coming out of the device. In the case of stimulated emission, very sharp peaks of intensity at certain wavelengths in a direct beam perpendicular to the sample will be seen rather than the broader peaks with wide-angle emission seen in spontaneous emission. If sharp peaks were found, this would be evidence of lasing in the stacked OLED device.

References:

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