Precise Control of Organic LED Emission Through Optical Resonance Microcavities

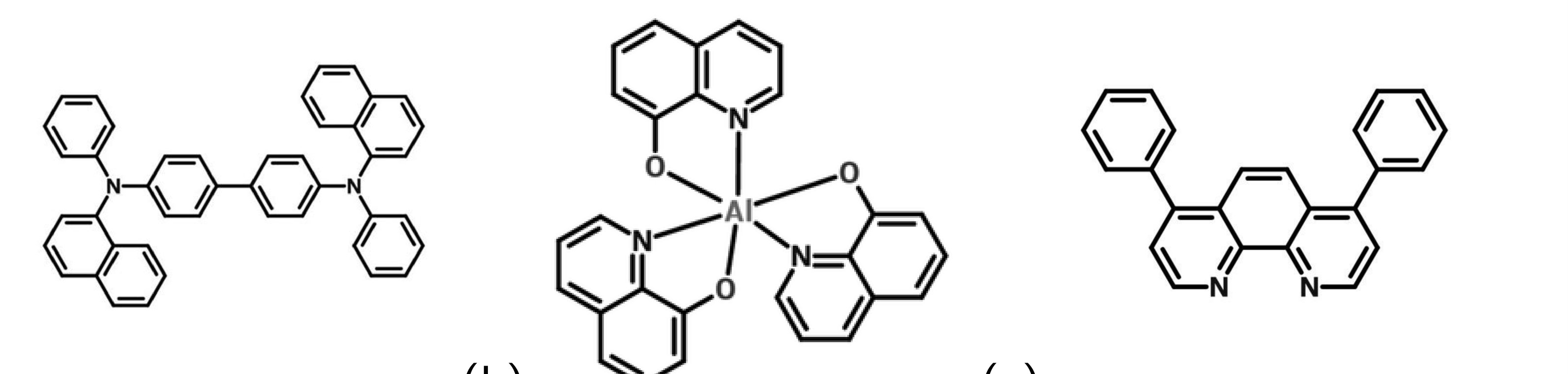
Benjamin Isenhart[1], Matthew White[1,2], Ekraj Dahal[2], Karen Cianciulli[3]

[1]Department of Physics, the University of Vermont, Burlington VT,
[2]Materials Science Program, the University of Vermont, Burlington VT,
[3]Asheville School, Asheville NC

The University of Vermont

Introduction

Light emitting diodes (LEDs) have become an integral part of daily life, from televisions to headlights on cars. While LEDs have substantial benefits over incandescent bulbs, they have significant environmental impacts, often using hazardous materials [2]. This has been mitigated in part by the advent of organic LEDS (OLEDs), which are generally less harmful and expensive, but the emission spectrum of organic molecules is strongly dependent on structure, and thus more difficult to control [1]. Conventionally, the emission spectrum is modified using dopants, which need to be added in very precisely controlled concentrations, making precision control difficult. In this project, we demonstrate a technique for taking a single organic emitter, and modifying its emission spectrum through device design alone. Additionally, we explore the ability to generate multi-peaked emission profiles with only a single organic emitter material, giving rise to the potential of designing a device to generate any desired emission profile.

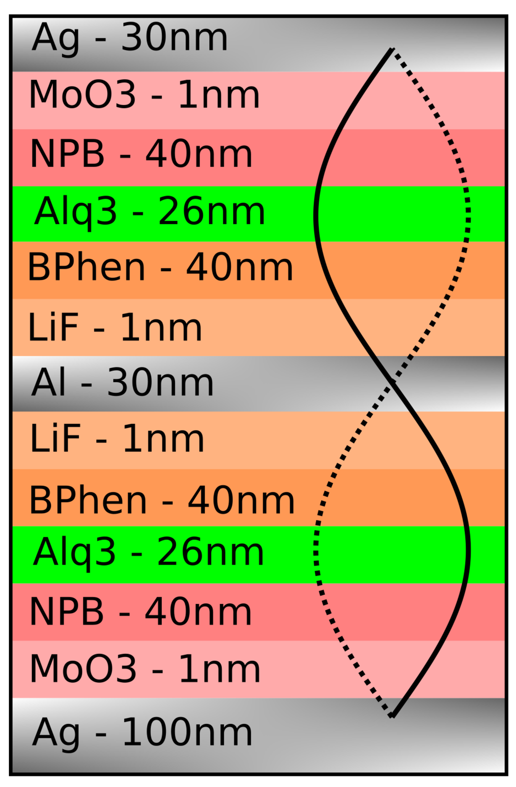


(a) (b) (c)

Chemical structures of (a) NPB hole transport material, (b) Alq_3 emissive material, and (c) BPhen electron transport material

Device Fabrication and Characterization

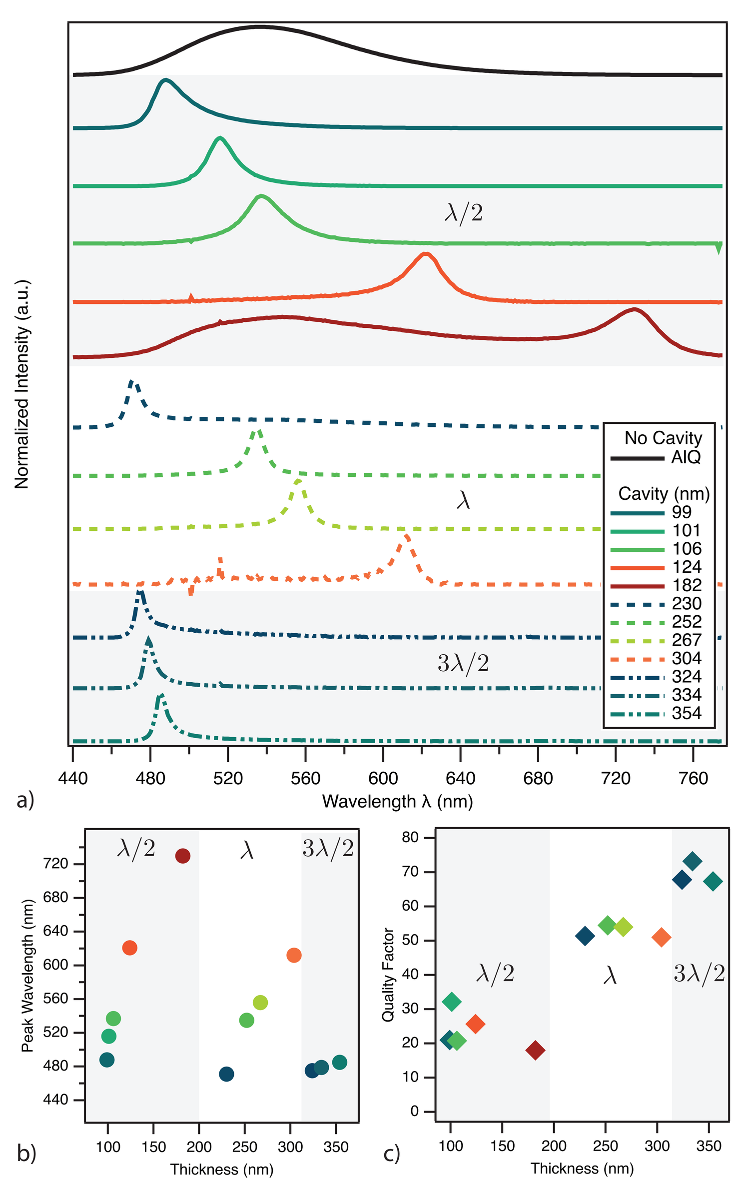
- 30nm metal electrodes act as partially reflective barriers between cavities
- Resonant modes characterized by nodes at metal electrodes, and strongly selected by the cavity
- Emission spectra collected for varying angles with respect to the cavity



Device schematic for a 2 cavity device

Results of Forward Emission Spectroscopy

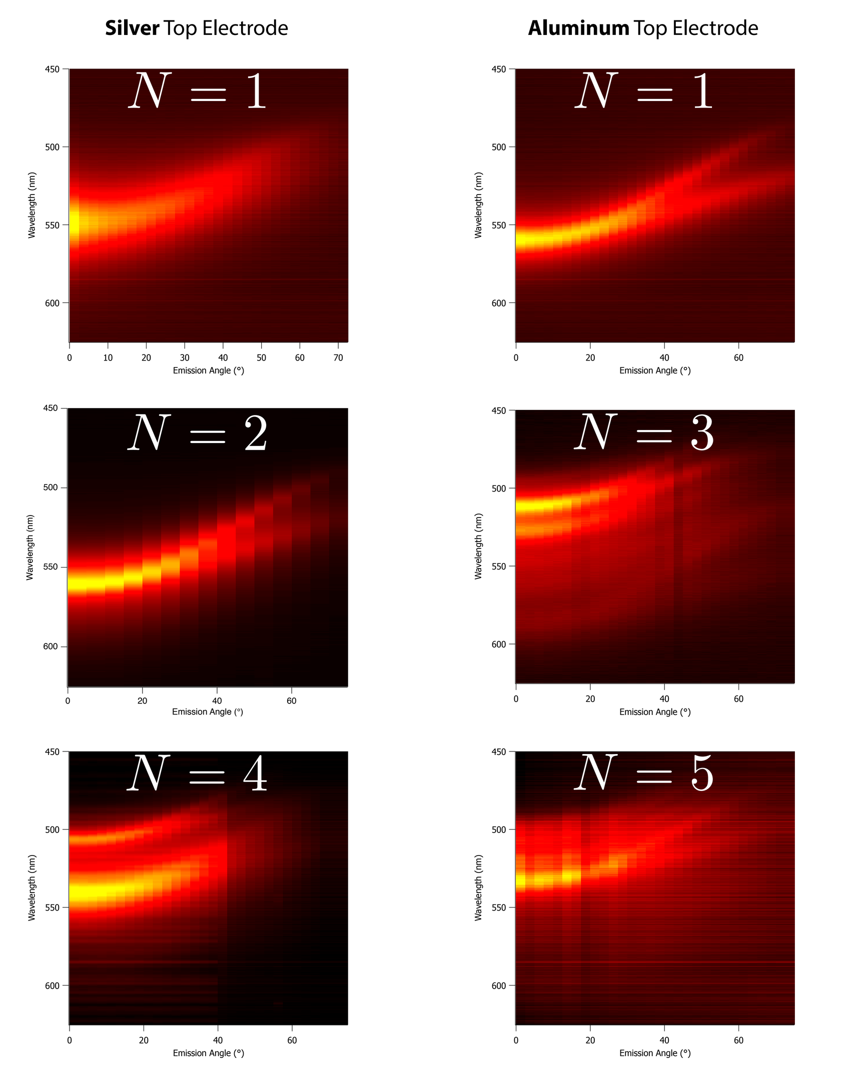
- Linear relationship of peak emission wavelength to cavity thickness
- Linear relationship of quality factor to bandwidth



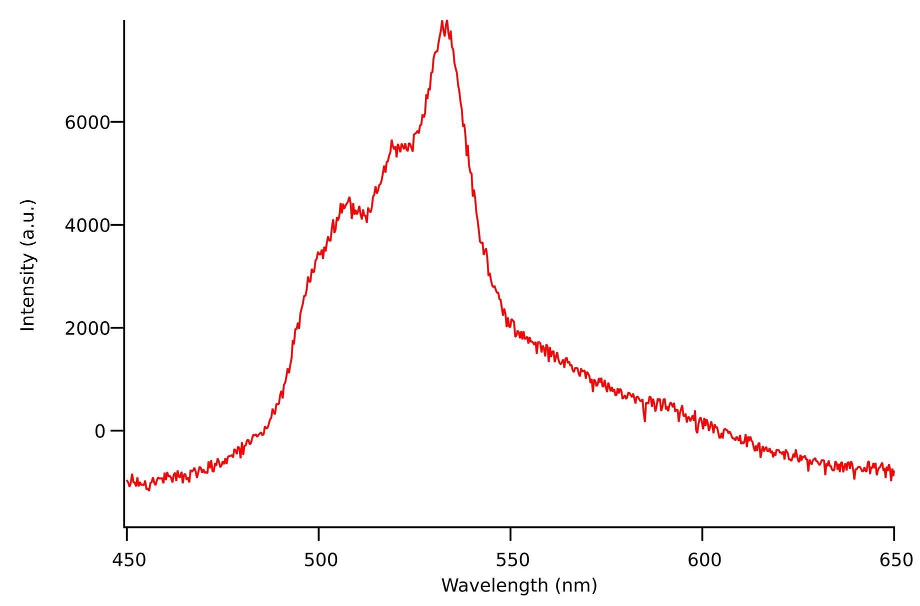
Emission characteristics of single cavity devices: (a): Emission spectrum as a function of cavity thickness, (b): Peak wavelength as a function of cavity thickness, (c): Quality factor as a function of cavity thickness

Results of Angular Resolved Emission Spectroscopy

- Emission peak blueshifts as the angle of emission is increased
- The emission peak splits into two modes at large angles. This is the transverse electric (TE) and transverse magnetic (TM) modes of propogation in a waveguide [4]
- The emission profiles of the N=1 devices with aluminum and silver as top electrodes is different due to the higher absorption in aluminum [3]
- Devices with $N > 2$ produce a more complex modal structure
  - For $N = 3$ and $N = 4$, we see two distinct forward emission modes
  - For $N = 5$, we see three distinct forward emission modes
  - All modes experience blueshifting at large angles, indicating they are resonant modes [4]
- Emission bands can be seen to narrow with each additional cavity



Angular resolved emission profiles for resonant microcavity devices where N is the number of resonance cavities in the device



Forward emission spectrum for $N = 5$ device

Conclusions and Future Works

In this project, we have demonstrated a technique to precisely control the peak emission wavelength and bandwidth of an organic LED as well as a method for generating more complex emission profiles. The linearity between cavity thickness and peak emission allows for very exact prediction of emission wavelength for a device, to within the resolution of our ability to deposit films. The modal structure of the multi-cavity devices provide several avenues of potential future exploration, including dependence of modal separation on cavity thickness, behavior at higher numbers of cavities, and structure under higher current densities. A strong understanding of these modal structures could lead to fabrication of devices to match any desired emission spectrum, which could be used to make high quality OLED screens and potentially organic diode lasers.

Acknowledgements

This project was supported by the University f Vermont Office of Undergraduate Research and Clean Energy Fund during the summer of 2018. Funding was also provided by the UVM Department of Physics through the Crowell award during the summer of 2017. This research is also presented in a UVM Honors College thesis.

References

[1] Bernard Geffroy, Philippe le Roy, and Christophe Prat. "Organic light-emitting diode (OLED) technology: materials, devices and display technologies". In: *Polymer International* 55.6 (2006), pp. 572–582. DOI: 10.1002/pi.1974. URL: https://doi.org/10.1002/pi.1974.

[2] Seong-Rin Lim et al. "Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification". In: *Environmental Science & Technology* 45.1 (Jan. 2011), pp. 320–327. DOI: 10.1021/es101052q. URL: https://doi.org/10.1021/es101052q.

[3] L. G. Schulz and F. R. Tangherlini. "Optical Constants of Silver, Gold, Copper, and Aluminum II The Index of Refraction n". In: *Journal of the Optical Society of America* 44.5 (May 1954), p. 362. DOI: 10.1364/josa.44.000362. URL: https://doi.org/10.1364/josa.44.000362.

[4] P. N. Stavrinou et al. "Angular spectrum of visible resonant cavity light-emitting diodes". In: *Journal of Applied Physics* 86.6 (Sept. 1999), pp. 3475–3477. DOI: 10.1063/1.371233. URL: https://doi.org/10.1063/1.371233.