Fabrication of CuPc/C60 Heterojunction Mediated Broadband Photodetector Using Physical Vapor Deposition

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Introduction

A photodetector is an optoelectronic device that “senses” light by converting incident photons into electrical signal. They are generally constructed using layers of semiconductor material that forms a PN junction. They are used in remote controls, biomedical imaging, gas sensing, motion detection. From industry, entertainment, and research, photodetectors are a ubiquitous technology in the modern world.

Commercial photodetector technologies are dominated by inorganic semiconductors. However, organic semiconductors offer several advantages over inorganic semiconductors, including greater flexibility, transparency, spectral response tunability, and low-cost manufacturing. However, organic semiconductors have low stability and can degrade due to air exposure, leading to shorter lifespans

The P-type material copper phthalocyanine (CuPc) and N-type material fullerene (C60) are common organic materials that were chosen for investigation. Two versions of the devices were fabricated and tested. Device 1[CuPc/C60 ~ 80/100] had CuPc and C60 thicknesses of 80 nm and 100 nm, respectively. Device 2[CuPc/C60 ~ 120/120] had CuPc and C60 of equal thicknesses of 120 nm. Both devices had Al electrode thicknesses of 100 nm.

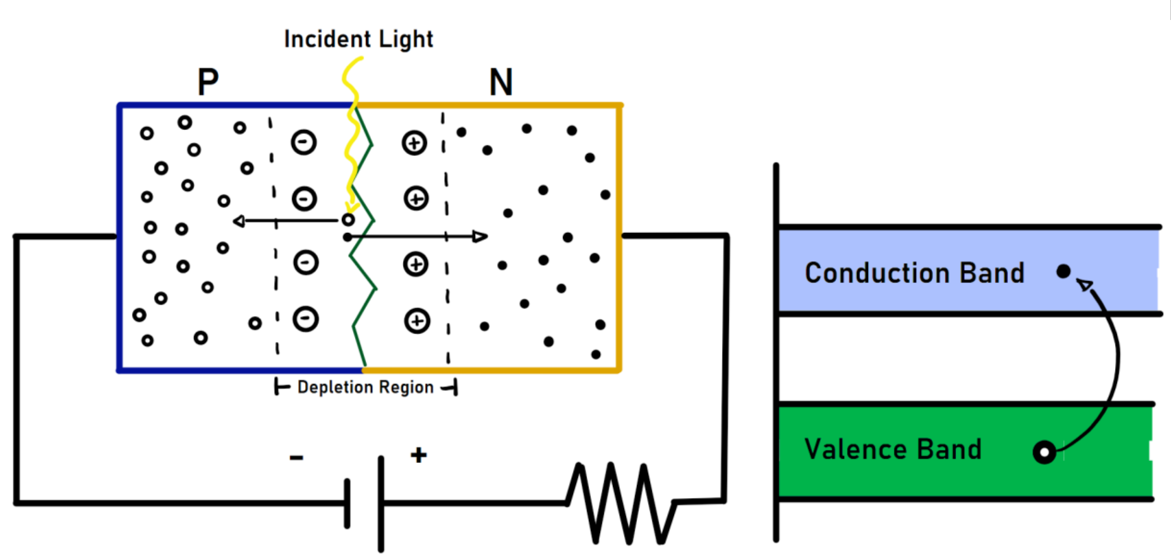
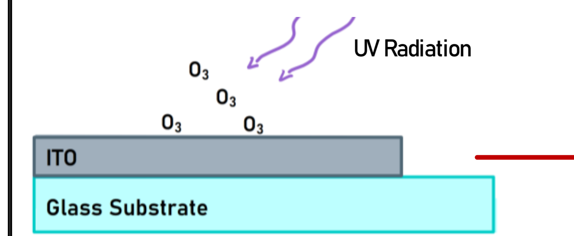


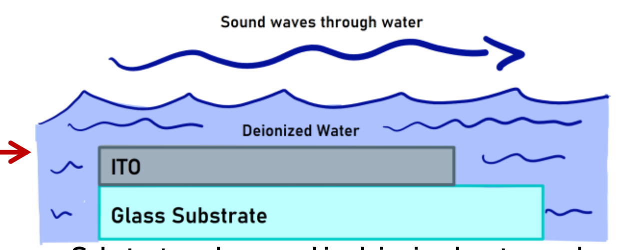
Figure 1: Demonstrates PN junction between 2 semiconductors. P-type material contains many positvely- charged “holes”, while N-type contains many free electrons. When light shines on the “depletion region” of the junction, it can excite electrons into conduction band of material to create an electron-hole pair, which move to opposite sides of the diode, creating a current.

Experimental

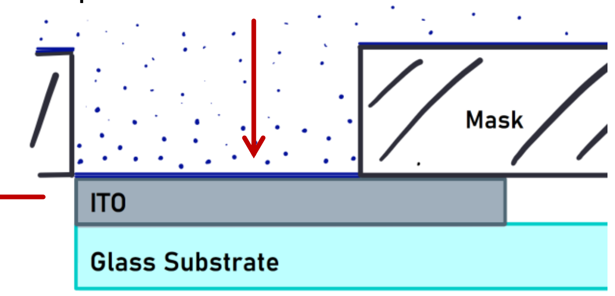
Device Fabrication Workflow



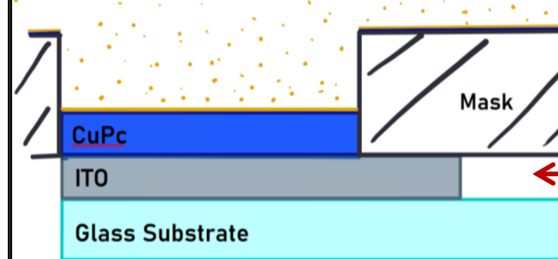
Substrate cleaned in UVO cleaner for 15 minutes



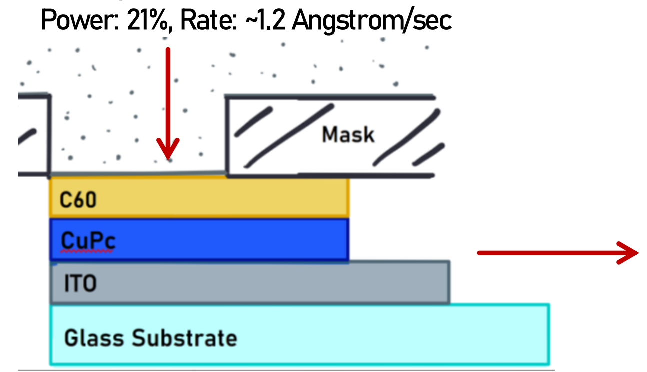
Substrate submerged in deionized water and placed in ultrasonic cleaner for 10 minutes



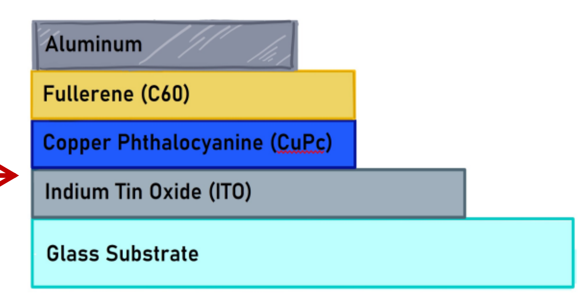
CuPc deposited on Glass/ITO substrate. Power: 20%, Rate: ~1.2 Angstrom/sec



C60 deposited on Glass/ITO/CuPc substrate. Power: 21%, Rate: ~1.2 Angstrom/sec

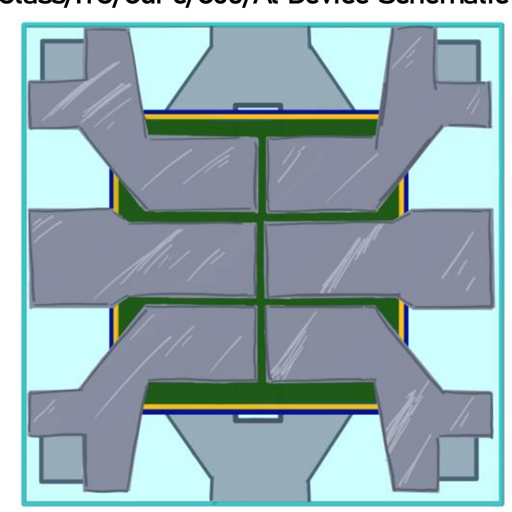


Aluminum deposited on Glass/ITO/CuPc/C60 substrate. Power: 45%, Rate: ~1.2 Angstrom/sec



Glass/ITO/CuPc/C60/Al Device Schematic

Figure 2: (right) Top-view of fully fabricated device. Includes 6 individual devices. Note that each device shares common ITO cathode but has individual aluminum anodes.



Circuit Diagram & Device Testing

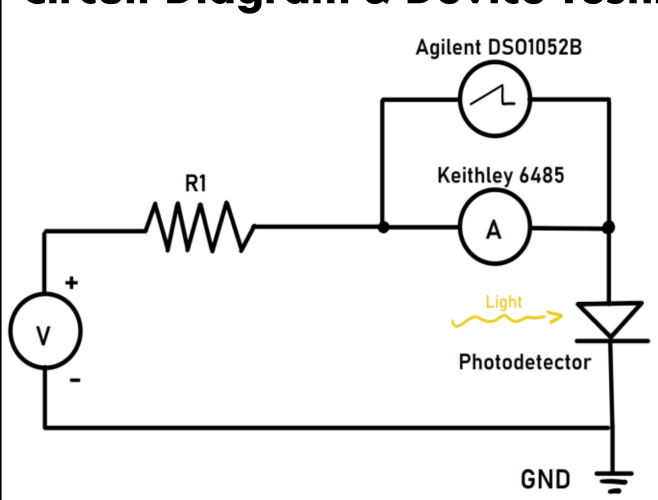


Figure 3: Experimental circuit setup

The devices were tested using an Agilent E3631A voltmeter and a Keithley 6485 picoammeter. The devices were biased in increments of 0.5 V in the range of -5 and 5 V. Current of the devices were measured at each bias under full spectrum white light, broadband red fiber optic, and 360 nm monochromatic light. The current over the spectrum between 200 - 1100 nm was measured using a Stanford Research Systems SR830 Lock-In Amplifier.

Results

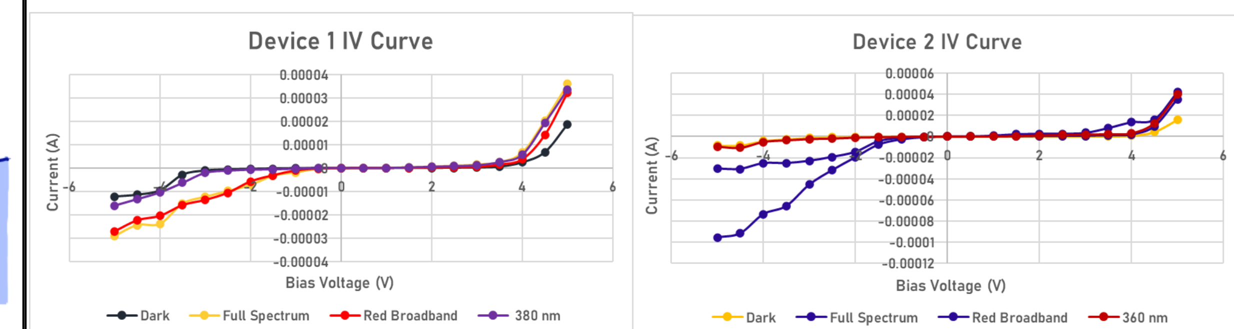


Figure 4: IV curves for device 1 and 2 including full spectrum, red broadband, and 380/360 nm monochromatic light

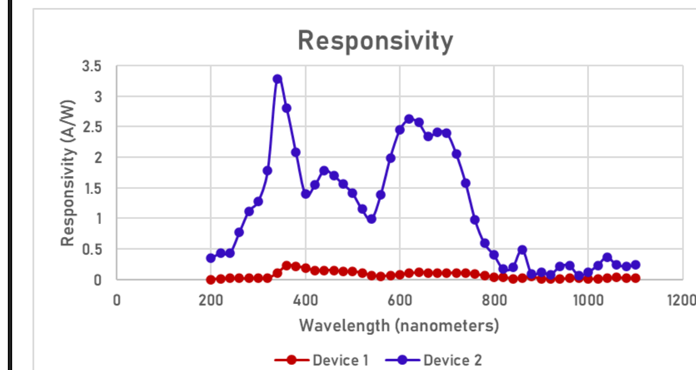


Figure 5: Peak responsivity for device 1 was 0.22 at 340 nm. The peak responsivity for device 2 was much higher at 3.28 A/W at 340 nm

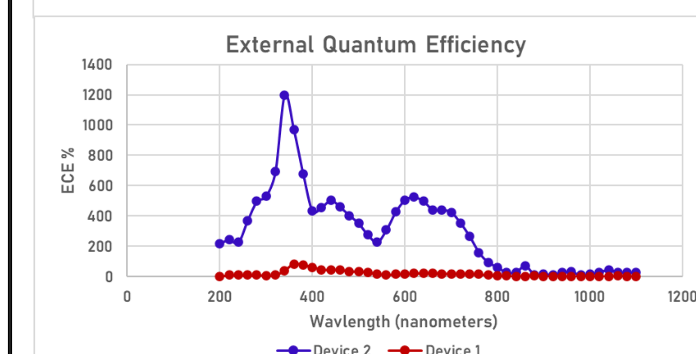


Figure 6: Highest EQE for device 1 was 81.8% at 340 nm. Highest EQE for device 2 was 1199% at 340 nm.

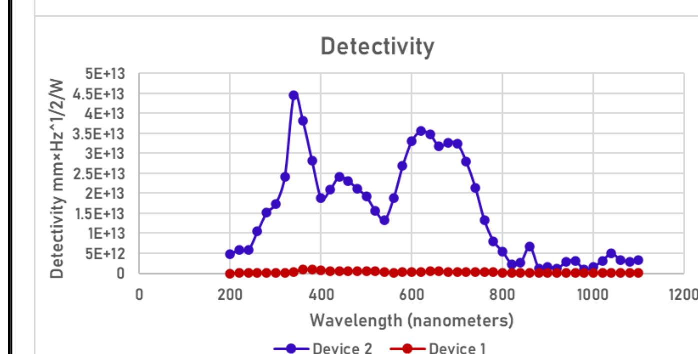


Figure 7: Highest detectivity for device 1 was 2.87E13 mm×Hz$^{1/2}$/W at 340 nm. Device 2 had a peak detectivity at 4.45E13 mm×Hz$^{1/2}$/W at 340 nm.

Conclusions

Both devices were most responsive at 340 nm within the high ultraviolet range. Device 2 exceedingly outperformed device 1, which could have been due to device 2’s greater thickness, which allowed for a larger depletion region for electron excitations. However, the photoresponse in both devices were feeble than those of high-end commercial silicon photodetectors. Performance of these devices could be improved by exploring more variations in thickness and further optimizing the fabrication process.

References

Wei, G., Lu, Z., Cai, Y., & Sui, C. (2017). CuPc/C60 heterojunction photodetector with near-infrared spectral response. *Materials Letters, 201*, 137-139.Nath, D., Dey, P., Joseph, A. M., Rakshit, J. K., & Roy, J. N. (2020).

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