Resonant-Infrared Matrix-Assisted Pulsed Laser Evaporation: Enabling Room-Temperature Mid-Infrared Detection Through Intraband Transitions

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Abstract

Resonant-Infrared, Matrix-Assisted Pulsed Laser Evaporation (RIR-MAPLE), is a technique developed in the Stiff-Roberts Group that has been used to deposit blended organic-inorganic thin-films on a variety of substrates. In previous work towards room temperature photodetection in the mid-infrared range, RIR-MAPLE enabled the use of intraband transitions in the detection process. RIR-MAPLE-dispersed CdSe colloidal quantum dots inside a conducting polymer matrix provided energy properties necessary for intraband states to occur. Results of that work are presented with special consideration for the mechanisms of action, and the research direction taken since is outlined.

Motivation

The Mid-Infrared spectrum is usually defined within the field of photodetection as containing spectra with wavelengths ranging from 3 to 5 μm. Generation and detection in this range have been topics of interest for the communications, spectroscopy, and military industries, where the search for room-temperature photodetectors has proven difficult.

Traditional attempts include Quantum Well Infrared Photodetectors (QWIPs), Indium-Based Superlattices, and Mercury Cadmium Telluride based devices. These devices share operation being limited to below ambient temperatures, requiring active cooling systems to be used in order for them to be utilized. We seek to pursue the options provided by organic electronic devices as a possible solution, and to explore their competence in operation compared to today’s state of the art.

RIR-MAPLE

RIR-MAPLE is a deposition system with unique applications in the field of organic-inorganic hybrid devices. Through precise targeting of the enveloping matrix through bond resonance, we can safely transfer our components to the substrate of our choice in a purely physical manner.

What does RIR-MAPLE offer us?

- Control over deposited material as a function of time
- Versatility in our material and substrate choices
- Low Energy Process conserves organic material integrity
- Peace of Mind over no solvent interactions occurring

Intraband Photodetection

![Fig. 1. RIR-MAPLE system & target composition overview. Fig. from [1]](image)

![Fig. 2. (a) General intraband infrared Polymer/CQD photodetection system. (b) Intraband states & allowed transitions in Polymer/CQD nanocomposite photodetection of Mid-IR light. Fig. from [2]](image)

Traditionally, we think of photodetection occurring when impinged radiation has high enough energy to provide the amount necessary for an electron to travel from the valence band to the conduction band. These interband transitions are what enable conventional photodetectors, whereas the system explored by the Stiff-Roberts’ Group operates completely independently of this type of transitions.

Intraband transitions are a unique result of band alignment where an offset of about 1 eV is present across the two material’s conduction bands. As shown, confinement states are sustainable in such a system, where our targeted Mid-IR spectrum will provide electrons with enough energy to travel to excited states in an intraband manner. Ultimately, electron tunneling across organic ligands will yield the measured photocurrent.

Current Work

Knowing that intraband transitions are a feasible alternative, the work continued towards finding the extent of their applicability and competitiveness. The presence of the toxic heavy metal Cadmium in the previously tested devices creates an area of concern. Having to conform to standards like the Restriction of Hazardous Substances Directive (RoHS) where Cadmium appears as a restricted substance offsets the potential impact of these novel devices.

Standing by the knowledge that the mechanisms of action will apply to material systems with similar band structures, work began to reproduce the findings with safer alternative inorganic materials. Copper Indium Telluride (CulnTe, or CIT) nanocrystals have exhibited interesting optical properties in their nanocrystal form [4], and provide an avenue for further research with our devices. A heavy metal-free alternative, CIT provides us the same opportunity as CdSe to be deposited through our RIR-MAPLE to form the hybrid nanocomposite.

![Fig. 3. (a) Peak absorption coefficient as a function of organic ligand length. (b) Ligands previously modelled (clockwise from top left): Pyridine, Butyamine, Oleic Acid, TOPO. (a) from [2] An important consideration in our system design is our choice of these organic ligands. Their lengths have been demonstrated to affect the absorption of the impinged radiation, relating ligand choice to a direct impact on the device’s properties. Previously, a ligand commonly used in CdSe CQDs, trietylphosphine oxide (TOPO) was used in our system, only later was the relationship between ligand length and absorption explored, showing TOPO’s inadequacy.

Resulting devices of this work proved that intraband transitions are a feasible mechanism to achieve room temperature photodetection of the Mid-Infrared spectrum.

![Fig. 4. Clockwise from top left: planar device structure, spectral responsivity results tested around 2.5 – 4 μm, MEH-CN-PPV/CdSe in-situ photopolymerized target utilized in RIR-MAPLE deposition. Bottom left from [3]](image)

![Fig. 5. Band structure diagram of Polyaniline/CulnTe nanocomposite](image)

Cited Works

[1] Emulsion-Based RIR-MAPLE Deposition of Conjugated Polymers: Primary Solvent Effect and its Implications on Organic Solar Cell Performance


[4] Cu-In-Te and Ag-In-Te colloidal nanocrystals with tunable composition and size

Acknowledgements

I would like to extend my thanks to Wangyao Ge for his previous work shown here, and for the training that was required to obtain these results.