

# Hybridized Luminescent Lanthanide Super Crystals Used as Spectral Convertors to Increase Photoconductivity in Opto-Electronic Devices

Alexis Bullock<sup>1,\*</sup>

<sup>1</sup>Center for Materials Research, Norfolk State University, Norfolk, VA 23455, USA

\*Correspondence should be addressed to Alexis Bullock, a.d.bullock18904@spartans.nsu.edu

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## Abstract

Discovering new forms of energy has been essential for the innovation of more efficient technologies in the future and is a phenomenon in optical and scientific industries worldwide. A solar cell converts electromagnetic radiation or artificial light into energy due to the photovoltaic effect. Solar cell efficiency has increased over the years due to different device material and design. Lanthanide elements are the interest for solar cell research due to their absorption of lost photons by utilizing the photoelectric effect. Lanthanide super crystals can increase photonic interactions and have the possibility of enhancing photoconductivity to create more efficient solar cells. In this research  $\text{Ln}^{3+}$  complexes will be used as spectral converters to increase photonic activity within inorganic solar cell devices. The research objective of this project is to enhance photonic absorption within existing inorganic solar cells from the ULTRAVIOLET(UV)-VISIBLE(VIS)-INFRARED(IR) electromagnetic spectrum. Overall, we were able to develop efficient light absorbing UC lanthanide metamaterials for opto-electric device applications.

**Keywords:** Opto-Electronic, Absorption, Photons, Crystals, Energy, Radiation, Nanoparticles

## Introduction

The nonlinear optical effect can be stimulated by upconverted lanthanide nanoparticles on the surface of meta-materials to enhance unusual optical effects that are stimulated by electromagnetic radiation which will increase photonic activity within solar cells. Lanthanides are a family of 15 chemical elements whose atomic numbers range from 57 to 71 and they consist of the elements in the f-block of period six in the periodic table. The 15 elements include: lanthanum (La), cerium (Ce), praseodymium, (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu) [3]. Two rare earth ions from the lanthanide series were used in this experiment with the addition of a ligand to fabricate nano super crystals. The purpose of the experiment was to create light absorbing materials from lanthanide elements that can increase light energy absorption within silicon solar cells devices [1]. Recent developments in solar

cell and metamaterials studies have demonstrated various possibilities to control light in extreme ways, and affect various quantum processes (spontaneous emission, energy, or charge transfer etc.) for silicon solar cell technologies. To probe these effects and facilitate them for applications for solar cell devices, materials need to absorb light from the VISIBLE(VIS)-INFRARED(IR) spectrum that will increase energy within current functioning solar cells. Organic systems with lanthanide ions are promising materials for research studies, since they can be efficiently excited via organic ligands, subsequent energy transfer to rare earth ions has been shown in spectroscopic studies, and they demonstrate optical transitions at both electric and magnetic dipole transitions [2,3]. Super crystals  $\text{X}_{0.5}(\text{NO})_3\text{X}_{0.5}(\text{NO})_3(\text{By})_2$  were fabricated and spectroscopic characterization of the materials shows that many crystals can be efficiently excited with UV light (330nm) and materials can efficiency absorb visible and infrared light waves from the sun depending on rare earth ions energy transitions in visible or infra-red spectrum [5-7]. Lanthanide's elements are extremely important in many scientific applications including

biotechnologies, chemistry, and solar cell studies [8,9]. In our research, we are interested in the fabrication, characterization, energy transfer mechanism, absorption spectra, transmission spectra, and data analysis of super crystals to ensure materials are quality for future application on solar cell devices. Our goal is to fabricate quality rare earth materials from two rare earth materials that exhibit the ability to utilize the upconversion mechanism and to utilize the nanoparticles in the future to increase energy within solar cell devices without altering the existing design.

## Materials and Methods

### Lanthanide elements and materials used in the experiment.

The following materials Europium (Eu), Neodymium (Nd), and a molecular concentrator 2,2, and Bipyridine were used in our experiment to fabricate Super Crystals (Nd-Eu).

### The following materials were used to conduct the experiment

Europium (Eu), Neodymium (Nd), and the molecular concentrator 2,2, Bipyridine.

Table 1. Lanthanide materials molecular weight.	
Molecular Compound	Molecular Weight [g/mol]
Eu (NO <sub>3</sub> ) <sub>3</sub> *5(H <sub>2</sub> O)	427.640
Nd (NO <sub>3</sub> ) <sub>3</sub> *1(H <sub>2</sub> O)	348.240
2,2'-Bypridine	156.19

### Fabrication of crystals

Lanthanides Crystals with two rare earth ions  $X_{0.5}(\text{NO}_3)_3X_{0.5}(\text{NO}_3)_3 \cdot (\text{Byp})_2$  were fabricated and amount of Ln  $*2(\text{NO}_3)_3$  proportional to their molecular weight was placed in a vial and solved in ethanol to obtain 0.1 M solution (Table 1). 0.2 M solution of 2,2'-Dipyridyl was prepared in a separate vial [4]. After this, the solutions from the vials were poured into one beaker, mixed and left for several hours or days at different regimes. Each,  $X_{0.5}X_{0.5}(\text{NO}_3)_3$  and 2,2'-Dipyridyl amount proportional to the elements molecular weight was placed in separate vials and solvated in ethanol. Each vial was placed into sonication for 30 minutes then the vials were poured into one beaker, mixed and placed for the crystal growth under various conditions. They are made using the methods slow room temperature evaporation, double concentration, seed crystal, and increased temperature method [4]. Each Lanthanide was used 28 with three nitrate ions, and a hydrate ion(s) (1, 2, 3, 4, 5, or 6). 2,2 Bipyridine was then weighed on the electronic scale and placed separately in a separate vial. Then the solvent ethanol was placed in each of the vials in the amount of 1 ml each and then both vials were placed

into the equipment for sonication device for 1 to 2 hours. If the compound looks cloudy when sonication is complete just place back in equipment for additional 10 minutes until it was clear. Various crystals were produced from crystal growth methods and were observed under the Axio Cam-3 optical microscope for characterization and precise measurements of crystals.

### Crystals growth methods

**Growth at 4°C:** Beaker placed under the hood in an ice bath chilled at 4°C.

**Growth at increased temperature:** The same recipe was followed to prepare a solution in a beaker, which was then placed in a larger beaker of sand with a uniform temperature of 55°C that was on a hot plate and left for about 7 hours for the ethanol to evaporate. Crystals of a larger size were obtained from the experiment.

**Increased temperature growth:** Same recipe was followed to prepare a solution in a beaker, which was then placed in a larger beaker of sand with a uniform temperature of 55°C that was on a hot plate and left for about 7 hours for the ethanol to evaporate. Crystals of a larger size were obtained.



Figure 1. Image of Eu-Nd Super crystal without the measurements. This image was observed under 40X objectives lenses.



Figure 2. Image of Eu-Nd super crystals that that measured at 123.67 um using the seed crystal method.

### Lanthanide super crystal complex solution

Lanthanides crystals with two rare earth ions  $X_{0.5}(\text{NO}_3)_3X_{0.5}(\text{NO}_3)_3 \cdot (\text{Byp})_2$  were fabricated and an amount of Ln  $*2(\text{NO}_3)_3$  proportional to their molecular weight was placed in a vial and solved in ethanol to obtain 0.1 M solution. 0.2 M solution of 2,2'-Dipyridyl was prepared in a separate vial [10]. In order to fabricate the lanthanide solution complex, first, two mother solutions were prepared separately. Then, 6 mg of  $X_{0.5}(\text{NO}_3)_3X_{0.5}(\text{NO}_3)_3 \cdot (\text{Byp})_2$ , dissolved in a mix solution of 0.2 ml

ethanol and 0.1 ml of deionized water-solution. In a separate valve place 6 mg of PVP (8k), dissolved in 1 ml of ethanol [10]. Then, the solutions were mixed and placed in the ultrasonic bath for 1 hour [10]. The obtained solution was used to ensure the quality of materials in a solution matrix. Then the materials were deposited using the drop coating method on transparent glass to observe emission spectra properties.

### Characterization

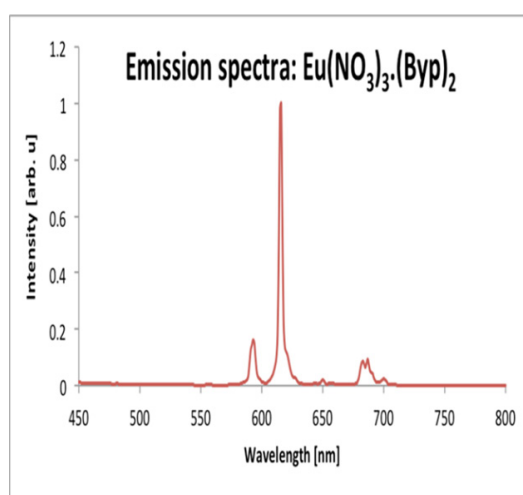
#### Spectrofluorometer and UV/Visible Spectrophotometer:

Materials were characterized by using UV/Visible transmission spectroscopy instrumentation and Fluorescence Spectroscopy Instrumentation. The UV/Visible transmission spectroscopy instrumentation was used to determine the transmission and absorption of the super crystals (Snell's Law) while

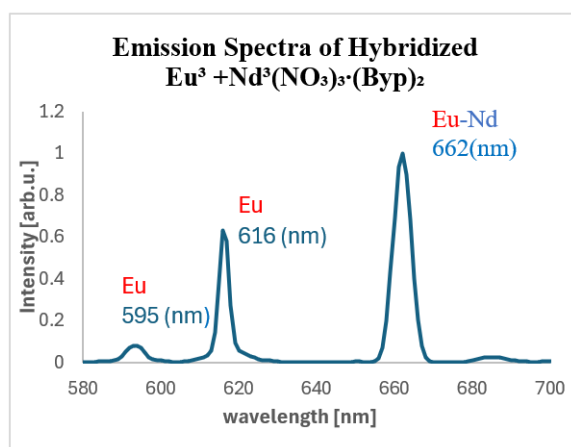
the Visible Spectrophotometer was used to determine the emission properties of the super crystals (Planks Law). Using these instruments, the spontaneous emission properties and absorption/transmission properties of the super crystal's materials were determined.

### Results and Discussion

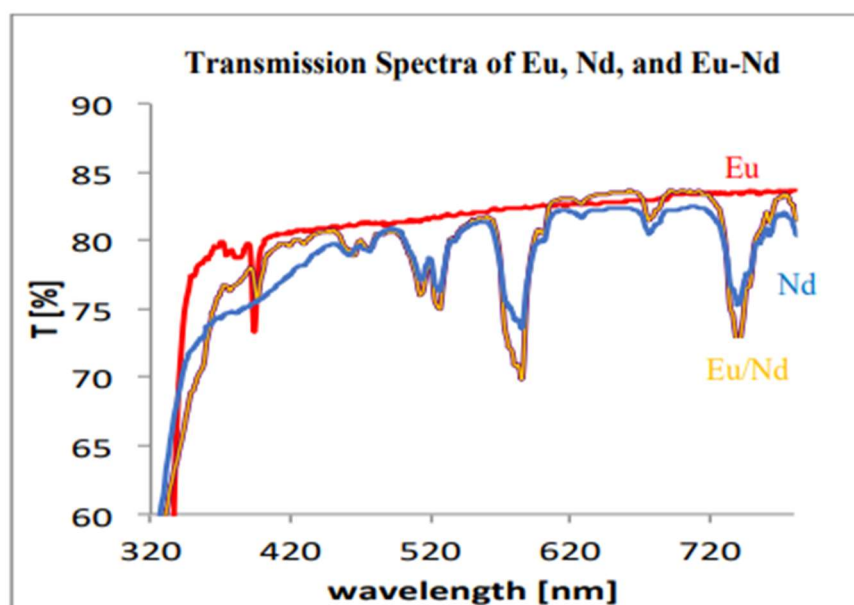
Rare earth super crystals  $\text{Eu}^{3+}\text{-Nd}^{3+}$  solution was drop coated on a transparent glass substrate and excited at 330 nm. From previous research studies on this material emission, spectra are different for  $\text{Eu}^{3+}$  vs  $\text{Eu}^{3+}\text{-Nd}^{3+}$  super crystals on this material, which indicates the UC energy transfer process. The spectra line at 662 nm in **Figure 4** is more intense when compared to Europium alone in **Figure 3**. Upconversion luminescence processes were observed in the  $\text{Eu}^{3+}\text{-Nd}^{3+}$  super crystals



**Figure 3.** Shows  $\text{Eu}^{3+}$  materials magnetic emission peak at 590 nm, electric emission peak at 614 nm, and no peak at 662 nm.



**Figure 4.** Displays  $\text{Eu}^{3+}\text{-Nd}^{3+}$  upconverted (UC) energy transfer peak at 662 nm on a transparent glass substrate. These materials can be excited in UV light and emitted in visible light.



**Figure 5.** Light waves excited nanoparticles with UV light at 330 nm, and  $\text{Nd}^{3+}$ -  $\text{Eu}^{3+}$  crystals were upconverted (UC) by the two-photon mechanism at peaks 479 nm, 514 nm, 527 nm, 585 nm in the visible spectrum, and peak was excited at wavelength 741 nm in IR spectrum. Spectra proves that these materials are great candidates to use as spectral converters for solar cell devices.

respectively at 662 nm. Rare earth  $\text{Eu}^{3+}$ - $\text{Nd}^{3+}$  super crystals UC energy transfer occurred at 662 nm but  $\text{Eu}^{3+}$  did not UC at 595 nm and 616 nm [12]. More studies are in progress to observe  $\text{Eu}^{3+}$ - $\text{Nd}^{3+}$  crystals in the IR spectrum to compare to pure  $\text{Nd}^{3+}$  crystals.

Light waves excited  $\text{Nd}^{3+}$ -  $\text{Eu}^{3+}$  nanoparticles crystals with UV light (330 nm) utilizing the UV/VIS spectrofluorometer instrumentation. Super crystals ( $\text{Nd}^{3+}$ -  $\text{Eu}^{3+}$ ) were upconverted (UC) by the two-photon energy transfer mechanism at peaks (479 nm) 49.43%, (514 nm), (527 nm), (585 nm) in the visible spectrum, and at wavelength (741 nm) in IR spectrum as shown in **Figure 5**. Transmission spectra data reflects that the amount of light transmitted in at peaks (514 nm) 45.98%, (585 nm) 45.11%, and for the peak transmitted in the IR spectrum was (714 nm) measured at 42.53%. Transmission data reflects that less light was transmitted in the  $\text{Eu}^{3+}$ -  $\text{Nd}^{3+}$  crystals at the referenced peaks (514 nm, 527 nm, and 585 nm) which proves that more light is absorbed in super crystals ( $\text{Nd}^{3+}$ -  $\text{Eu}^{3+}$ ) materials due to the UC energy transfer mechanism. These materials can be explored to be used to enhance absorption of energy in silicon solar cell devices [12].

## Conclusion

Lanthanides are metals and when Eu-Nd nanoparticles were deposited on transparent dielectric materials surface plasmons were induced at the interface and super crystals

were stimulated by UV electromagnetic radiation at 330 nm [11,12]. An intense emission spectra line at 662 nm was shown in **Figure 4**. It shows upconverted energetic lanthanide nanoparticles enhanced unusual optical effects that are stimulated by electromagnetic radiation which will increase photonic activity with solar cells due to absorption emission in visible light spectrum [11,12]. Transmission data in **Figure 5** reflects that less light was transmitted in the  $\text{Eu}^{3+}$ -  $\text{Nd}^{3+}$  crystals at the referenced peaks (479 nm, 514 nm, 527 nm, and 585 nm) which proves that more light is absorbed in super crystals ( $\text{Nd}^{3+}$ -  $\text{Eu}^{3+}$ ) materials due to the UC energy transfer mechanism. In conclusion, hybridized luminescent lanthanide super crystals can be used as spectral converters to increase photoconductivity in opto-electronic devices. More studies are in progress.

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## Disclosures

The authors declare that there are no conflicts of interest related to this article.

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