



## Master in Photonics – “PHOTONICS BCN” Master ERASMUS Mundus “EuroPhotonics”

### MASTER THESIS PROPOSAL

**Laboratory:** Department of Electronics and Biomedical Engineering

**Institution:** University de Barcelona (UB)

**City, Country:** Barcelona, Spain

**Title of the master thesis:** Investigation of optical properties with different composition of  $\text{Cs}_4\text{PbBr}_6$  in the composite raisin bread  $\text{Cs}_4\text{PbBr}_6\text{-CsPbBr}_3$  hybrid perovskite.

**Name of the master thesis supervisor and co-supervisor:**

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**Scholarship:** Eligible for a scholarship

**Keywords:** Perovskites, inkjet printing, raisin-bread architecture, photodetectors, LED's

**Objective:**

To investigate how varying the composition of  $\text{Cs}_4\text{PbBr}_6$  in the composite "raisin-bread"  $\text{Cs}_4\text{PbBr}_6\text{-CsPbBr}_3$  hybrid perovskite influences its optical properties, including absorption, photoluminescence, and bandgap characteristics, in order to understand the role of  $\text{Cs}_4\text{PbBr}_6$  in tuning the material's optoelectronic behaviour.

#### 1. Summary of the subject (maximum 1 page):

Halide perovskites are the rising star in optoelectronic materials due to their exotic properties including strong light absorption, tuneable band gap, long charge carriers' length, excellent charge transport properties and solution processability. Halide perovskites are typically represented by the formula  $\text{ABX}_3$ , where 'A' denotes a large monovalent cation such as methylammonium (MA), formamidinium (FA), cesium or rubidium; 'B' represents a divalent metal cation like lead or tin; and 'X' corresponds to a monovalent halide anion, such as chlorine, bromine, or iodine. Among different halide perovskites, all-inorganic cesium lead bromide perovskites ( $\text{CsPbBr}_3$ ) have attracted particular attention owing to their superior thermal and environmental stability compared to organic-inorganic counterparts [1].

$\text{CsPbBr}_3$  exhibits a three-dimensional crystal structure composed of corner-sharing  $[\text{PbBr}_6]^{4-}$  octahedra, which form a continuous framework responsible for its excellent optoelectronic properties.  $\text{CsPbBr}_3$  has attracted significant attention for its potential in various photonic and electronic applications, including light-emitting diodes (LEDs), lasers, and photodetectors, due to its direct bandgap, strong photoluminescence, and high carrier mobility. Despite various advantages,  $\text{CsPbBr}_3$  suffers from several limitations including phase degradation under continuous exposure and environmental instability. Our previous work has demonstrated that the annealing conditions of perovskite films play a crucial role in inducing significant structural transformations. These transformations lead to the formation of a distinctive “raisin-bread” hybrid structure, in which

CsPbBr<sub>3</sub> nanocrystals are embedded within a Cs<sub>4</sub>PbBr<sub>6</sub> matrix. As illustrated in Figure 1, this structure not only provides enhanced environmental protection but also improves the overall structural stability of the material. Moreover, the unique “raisin-bread” architecture contributes to notable improvements in the optical properties of the composite. During high-temperature annealing, the less crystalline and unstable CsPbBr<sub>3</sub> phases tend to convert into Cs<sub>4</sub>PbBr<sub>6</sub>, while only the highly crystalline CsPbBr<sub>3</sub> domains remain. This process can be viewed as a “survival of the fittest” phenomenon, where the thermally stable and well-crystallized CsPbBr<sub>3</sub> phase dominates. As a result, the material exhibits stronger light absorption, reduced non-radiative recombination losses, and enhanced photoluminescence intensity. [2].

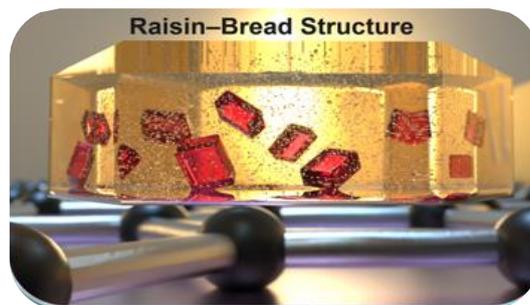


Figure 1. Raisin bread structure of composite perovskite

The solution processability of halide perovskite along with its capability to get converted into raisin bread structure make it a very interesting candidate to use it with inkjet printing process. Printed electronics are rapidly gaining prominence as a superior alternative to conventional lithography for the fabrication of flexible, stretchable, and sustainable electronics, offering high precision, scalability, cost efficiency, and environmental friendliness [3], [4], [5]. The main components which include conductive ink active materials, solvents, substrate and deposition process are illustrated in Figure 2.

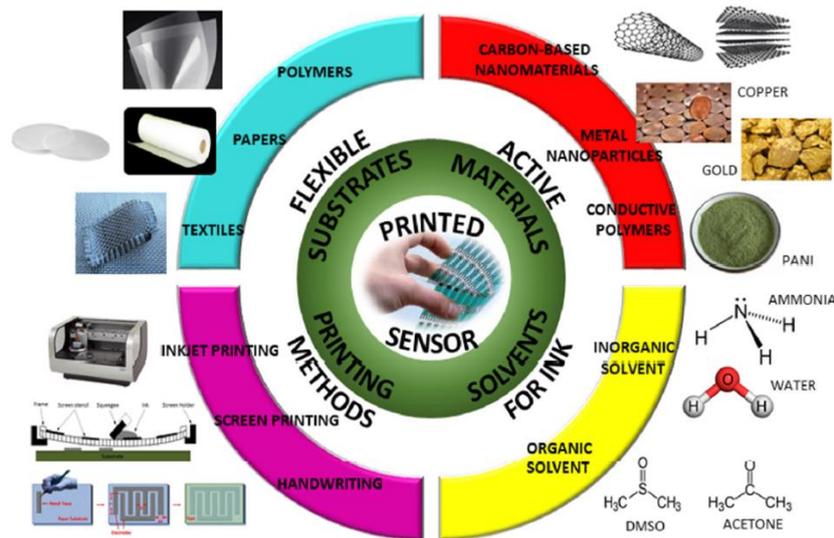


Figure 2. Components of printed electronics

The master student will be integrated in the ongoing European Union project “PIXIE SENS” to continue the project related to CsPbBr<sub>3</sub> perovskite inks. In principle the student will be involved in ink formulations and modification, inkjet printing and studying the effect of different Cs<sub>4</sub>PbBr<sub>6</sub> phases on the optoelectronic properties of the mixed phase composite inks. The optimization of the

annealing conditions will be made and application including broadband photodetection or printed LED's will be targeted.

## 2. Workplan and timeline:

Sr. No	Timeline (months)	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	6 <sup>th</sup>
1	Literature Review						
2	Starting hypothesis and objectives						
3	Inkjet printing process optimization						
4	Annealing modification of composite ink						
5	Measurement of optical properties and optimization						
6	Applications in photodetection and LED's						
7	Final report, thesis writing and presentation						

## 3. Key learning outcomes

- Mastering of inkjet printing techniques, ink modifications and substrate preparation
- Integration of physics, materials science, optoelectronics and photonics
- Analytical and characterization expertise including material properties, lasers, detectors and optoelectronic measurements
- Project management and research skills
- Innovation and problem solving in cutting-edge technologies
- Working in an international group with possibilities of continuing research activities

## 4. References:

- [1] W. Zhang *et al.*, "Cesium lead bromide perovskite nanocrystals for the visual detection of chloride ions: A review," *J. Solid State Chem.*, vol. 329, p. 124418, Jan. 2024, doi: 10.1016/J.JSSC.2023.124418.
- [2] Y. Su *et al.*, "Highly efficient CsPbBr<sub>3</sub> perovskite nanocrystals induced by structure transformation between CsPbBr<sub>3</sub> and Cs<sub>4</sub>PbBr<sub>6</sub> phases," *J. Mater. Chem. C*, vol. 7, no. 25, pp. 7548–7553, Jun. 2019, doi: 10.1039/C9TC01763A.
- [3] J. Khan *et al.*, "Flexible and highly selective NO<sub>2</sub> gas sensor based on direct-ink-writing of eco-friendly graphene oxide for smart wearable application," *Chemosphere*, vol. 367, p. 143618, Nov. 2024, doi: 10.1016/j.chemosphere.2024.143618.
- [4] J. Khan, M. Weis, and M. Mariatti, "Inkjet-Printed Temperature Sensor From Eco-Friendly Edge-Oxidized Graphene Oxide Ink on Biodegradable Polyvinyl Alcohol Substrate," *IEEE Sensors Lett.*, vol. 8, no. 7, pp. 1–4, Jul. 2024, doi: 10.1109/LSENS.2024.3414427.
- [5] J. Khan, M. Mariatti, S. A. Zubir, A. Rusli, A. A. Manaf, and R. K. Khiretdin, "Eco-friendly alkali lignin-assisted water-based graphene oxide ink and its application as a resistive temperature sensor," *Nanotechnology*, vol. 35, no. 5, p. 055301, Jan. 2024, doi: 10.1088/1361-6528/ad06d4.



I joined the University of Barcelona (UB) as a professor in 1995 (full professor 2011). My research between 1995 and 1999 focused on materials for microelectronics. In a second phase, between 1999 and 2009, I established myself as a group leader and initiated several research projects (as a Principal Investigator) in optoelectronic devices and materials. In my first European project as a Principal Investigator (SINERGIA, 2000), I delved into integrated photonics. Subsequent European projects in FP6 and FP7 as a Principal Investigator and as a Work Package leader in the fields of photonics and integrated optoelectronics included PHOLOGIC and LANCER. My first national project as a Principal Investigator was NANOMEM(2001), focusing on Si nanocrystals and nanomemories, which I continued with other projects as a Principal Investigator and coordinator (NANOSIGE, OASIS, SILUZ). During this phase, I supervised 6 doctoral theses and 10 research projects.

The third phase encompasses the period from 2010 to the present day. My consolidated group, GEF (Electro-Photonics Group), increasingly focuses on photonic and photovoltaic devices and applications, as well as LED lighting systems. I enhanced international visibility through my role as a Principal Investigator and Work Package leader in numerous European projects (HELIOS, NASCENT, MULTISCALE SOLAR, FET Open Phenomen, and currently FET Open Drop it) and national projects (LASSI, LEOMIS, SENA, METALONIC, and currently PRITES). During this phase, I supervised 11 doctoral theses and numerous third-cycle research projects, master's theses, and undergraduate theses. With the material and human resources obtained from various competitive projects, I established and equipped several research laboratories with analysis and fabrication techniques: i) Optoelectronics, ii) Photonics, iii) Photovoltaic devices, iv) Design and simulation for electro-photonics, and v) Deposition methods (evaporation, inkjet, spin coating, electrospray).

Scientific Production Achievements: >320 indexed publications, >40 invited conferences, >350 contributions to congresses, 2 patent applications, 1 PCT patent, and 1 patent in exploitation. I founded the start-up company Enlighting Technologies in 2017 (now Kumux) to commercialize advanced spectral control systems for luminaires, in which UB participates. I have been awarded 5 six-year research periods. Throughout my professional career, I have led a total of 7 National Plan projects as a Principal Investigator, 4 special actions, 7 integrated actions, and 2 infrastructure projects. I have also served as a partner Principal Investigator in 7 European projects.

Management and Evaluation Achievements: I directed the master's and doctoral programs in Devices, Sensors, and Actuators at UB for 7 years (1998-2006). Throughout my career, I coordinated doctoral programs and participated in the committees for doctoral programs in the Faculty of Physics, including Physics, Nanoscience, and Photonics. Between 2011 and 2016, I served as an evaluator for ANECA for national accreditations. I have acted as an evaluator for numerous projects for ANECA, and in particular, I was a member of the evaluation panels for projects in the TEC area from 2004 to 2010. Between 2012 and 2018, I participated as a remote evaluator, panel member, rapporteur, and vice-chair in IST, Nano, MAT, and FET open projects. I also conducted evaluations for the Catalan accreditation agency. I contributed to the development of study plans for degree programs in Physics, Electronic Engineering, Systems Computing, and master's programs in Photonics, Nanoscience and Nanotechnology, Renewable Energies, and Sustainability. I am the director of the Technology Transfer Center (CEMIC) at the Department of Electronic and Biomedical Engineering at UB and a member of the management committees of the UB Institute of Nanoscience and Nanotechnology (IN2UB) and the Catalan Society of Physics (SCF). Additionally, I represent my institution in various national and international associations such as SECPHO, IEEE, ECS, EPIC, and others.