PEROVSKITE NANOCRYSTALS: AN ACTIVE MATERIAL FOR INTEGRATED OPTICS

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PEROVSKITE NANOCRYSTALS

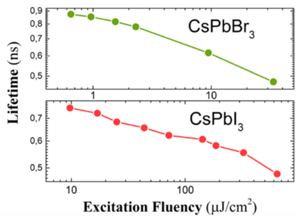
All-inorganic $CsPbX3$ (X_3 = Cl_3, Br_3, I_3) perovskite nanocrystals (PNCs) have recently emerged as an outstanding material for integrated optics. PNCs are synthetized under low cost chemical methods in cubic nanoparticles with sizes closed to the Bohr radius of the bulk material (10 nm) [1].

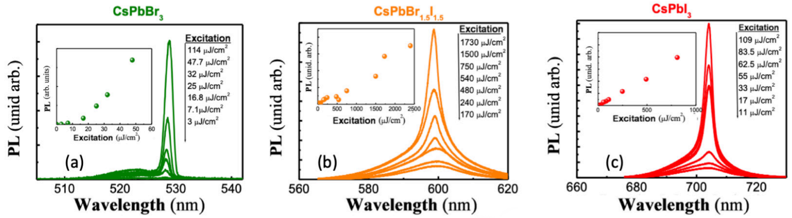
Their interesting optical properties include a high efficiency of absorption, a quantum yield of emission exceeding 90 % at room temperature, or a tunable band gap depending on chemical composition [2].

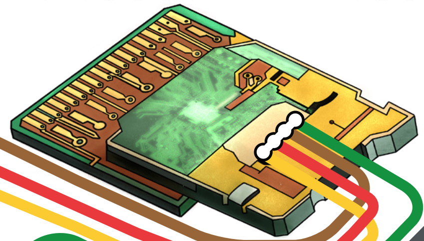
Consequently, during the last 3-4 years PNCs have been extensively studied as an active material, with demonstrated applications in light emitting diodes, lasers or optical amplifiers [3].

AMPLIFIED SPONTANEOUS EMISSION IN PNC BASED THIN FILMS

PNCs with three different bandgaps reveals that the optical gain in these materials is formed by the formation of single excitons [4]. Inverted population can be reached under small thresholds (as low as 5 μJ/cm²).



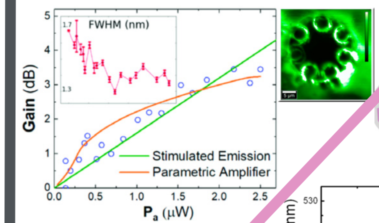




OPTICAL AMPLIFICATION IN PNC-DOPED HOLLOW-CORE NEGATIVE-CURVATURE FIBERS (HC - NCF)

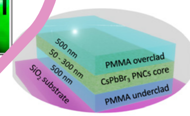
We demonstrated that a HC-NCFs filled with PNCs shows an amplification under CW pumping and at room temperature. The gian mechanism is given by the nonlinear properties of the nanocrystals [5].

This kind of device combines the light confinement properties of HC-NCFs and the optical properties of the perovskite nanocrystals, which is of great importance for both fundamental physics investigation and practical integrated applications.

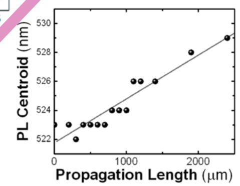


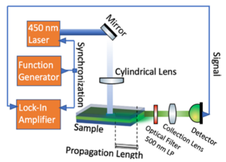
REABSORPTION IN PNC-THIN FILM WAVEGUIDES

Once the optical gain is demonstrated, PNC films are integrated in a rectangular waveguide which efficiently enhances the propagation of a fundamental TE_0 (TM_0) mode highly confined in the active layer. This strong overlap between the propagating mode and the active film enhances the reabsorption and reemission processes responsible for stimulated emission.

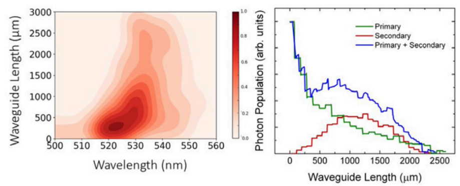


Here, we evaluate the generation of photons emitted by the reabsorption of the light as the basis of optical amplification mechanism.



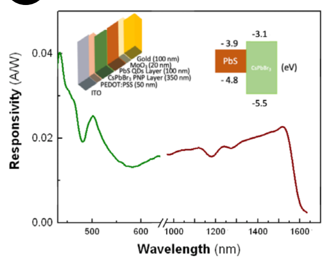


We evaluated by the Monte Carlo simulations that the generation of these secondary photons enhances the light emitted by the structure, indicating that this is a promising configuration for optical amplification.



TANDEM PbS QUANTUM DOT-PNC PHOTODIODES

A tandem structure was integrated in the same photovoltaic architecture: a film of PbS QDs on top of a first film made of $CsPbBr_3$ PNCs. The resulting device has a wide spectral response, ranging from the UV to the NIR, offering responsivity levels of 40 mA/W at visible wavelengths and 20 mA/W around the telecom C-band (1525-1565 nm). These results can be basis of future photodiode array or CMOS-like cameras operating simultaneously at visible and NIR wavelengths or low-cost applications in the fields of IOT and optical sensing.



CONCLUSIONS

In this work the optical gain of perovskite nanocrystal films is thoroughly analyzed. Since these nanoparticles present a low threshold (5 μJ/cm² for the best film) of stimulated emission together with a straightforward integration in optical architectures, we believe that they are promising candidates for future integrated sources or amplifiers. In particular, we propose a waveguide configuration that enhances the absorption and generation of light by a high confinement of the propagating mode within the active layer. As a result, we demonstrate that the photons reemitted in the layer enhance the signal by a factor of 3 indicating that this is a promising approach for future active devices. Light confinement can also be exploited in hollow-core fibers filled with PNCs; in this way, the nonlinear optical properties of the PNCs can provide signal regeneration with low pump powers, much below the threshold of stimulated emission. Finally, we have developed a tandem UV-VIS photodetector architecture implementing PbS QDs and PNCs. This device offers interesting perspectives in the development of integrated applications.

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