Nano- and single-crystals of lead halide perovskites: from bright light emission to hard radiation detection

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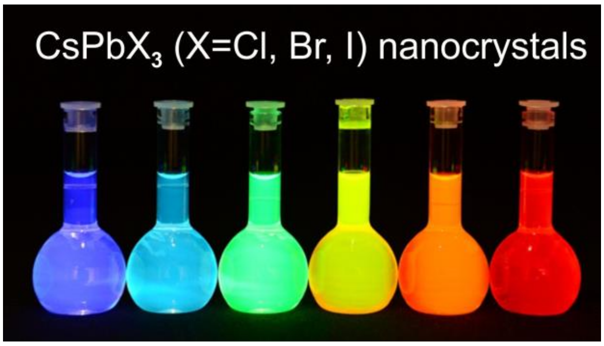
Chemically synthesized inorganic nanocrystals (NCs) are considered to be promising building blocks for a broad spectrum of applications including electronic, thermoelectric, and photovoltaic devices. We have synthesized monodisperse colloidal nanocubes (4-15 nm edge lengths) of fully inorganic cesium lead halide perovskites ($CsPbX_3$, X=Cl, Br, and I or mixed halide systems Cl/Br and Br/I) using inexpensive commercial precursors [1]. Their bandgap energies and emission spectra are readily tunable over the entire visible spectral region of 410-700 nm. The photoluminescence of $CsPbX_3$ NCs is characterized by narrow emission line-widths of 12-42 nm, wide color gamut covering up to 140% of the NTSC color standard, high quantum yields of up to 90% and radiative lifetimes in the range of 4-29 ns. Post-synthetic chemical transformations of colloidal NCs, such as ion-exchange reactions, provide an avenue to compositional fine tuning or to otherwise inaccessible materials and morphologies [2]. Identical synthesis methodology is perfectly suited also for hybrid perovskite nanocrystals of $CH_3NH_3PbX_3$ [3] and $CH(NH_2)_2PbX_3$ [4].

We also present low-threshold amplified spontaneous emission and lasing from $CsPbX_3$ NCs [5]. We find that room-temperature optical amplification can be obtained in the entire visible spectral range (440-700 nm) with low pump thresholds down to 5±1 $\mu J\ cm^{-2}$ and high values of modal net gain of at least 450±30 cm^{-1}.

Here we also demonstrate that 0.5-1 centimeter large, solution-grown single crystals of $APbI_3$ (where A is methylammonium or formamidinium mixed with Cs^+) can serve as inexpensive, operating at ambient temperatures solid-state gamma detectors (*e.g.* for direct sensing of photons with energies as high as mega-electron-volts, MeV) [6]. Such possibility arises from extremely high room-temperature mobility(μ)-lifetime(τ) product of $1.8 \times 10^{-2}\ cm^2\ V^{-1}$, low dark carrier density 10^9 - $10^{11}\ cm^{-3}$ and low density of charge traps ($\sim 10^{10}\ cm^{-3}$), and high absorptivity of hard radiation by lead and iodine atoms.



1. L. Protesescu *et al*. Nano Letters **2015**, *15*, 3692–3696
2. G. Nedelcu *et al.* Nano Letters **2015**, 15, 5635–5640
3. O. Vybornyi et al. Nanoscale **2016**, *8*, 6278-6283
4. L. Protesescu *et al*. J. Am. Chem. Soc. **2016**, **DOI:** 10.1021/jacs.6b08900
5. S. Yakunin *et al.* Nature Communications **2015**, *9*, 8056.
6. S. Yakunin *et al.* Nature Photonics **2016**, *10*, 585–589