Tunable Optical Gain for Negative Index Materials by Integration of Near-Infrared Emitting Nanocrystals

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We recently have designed and fabricated negative index materials (NIMs) with a metal/dielectric/metal stack "fishnet" structure which operates at near-IR region by nanoimprint lithography [1, 2]. However, one problem with metallic NIMs is that the response is strongly dispersive and lossy. Herein we use chemically synthesized PbSe nanocrystals (NCs) as gain media to mitigate the losses.

Fig. 1 shows a transmission electron microscope (TEM) image of the synthesized PbSe NCs. The diameter is about 7 nm with excellent size uniformity. The photoluminescence of PbSe NCs has been tuned to the operating wavelength of our NIMs by controlling the size of the NCs. Fig. 2 shows that the photoluminescence peak shifts to longer wavelength with the growth time during synthesis. Photoluminescence of PbSe NCs drop cast onto a quartz substrate is shown in Fig. 3. The photoluminescence peak position remains the same as that in hexane solution.

Incorporation of nanocrystals to the NIMs will affect their electromagnetic properties. We have performed Finite Difference Time Domain (FDTD) calculations and made corresponding adjustments to the geometry of our "fishnet" structures to compensate the operational wavelength shift of NIMs in the presence of nanocrystals. Fig. 4 schematically illustrates the incorporation of NCs to fishnet NIMs. Previous work [3] has already demonstrated tunable near-IR optical gain and amplified spontaneous emission from PbSe NCs, suggesting high feasibility of our current approach.

Instead of using traditional quantum well structures obtained by high-temperature epitaxy, our current approach using NCs as the gain media has the following advantages: (1) they are highly efficient photon emitters; (2) emission is tunable due to quantum confinement; (3) their solution processability enables easy integration with NIMs. Achieving optical gain from NCs for NIMs will present a great step in broadening the applications of NIMs in near-field optics and nano-photonics.

References:
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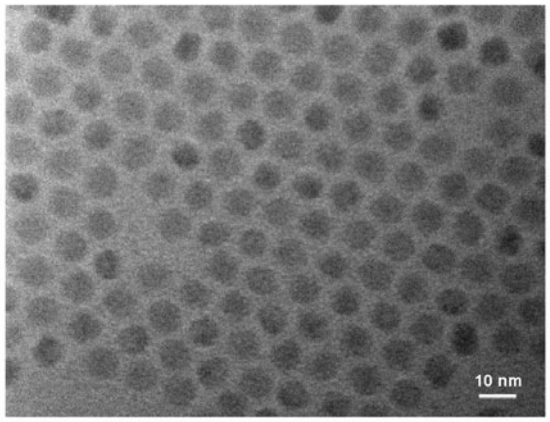

Fig. 1 Representative TEM image of the synthesized PbSe NCs with an average diameter of about 7 nm.

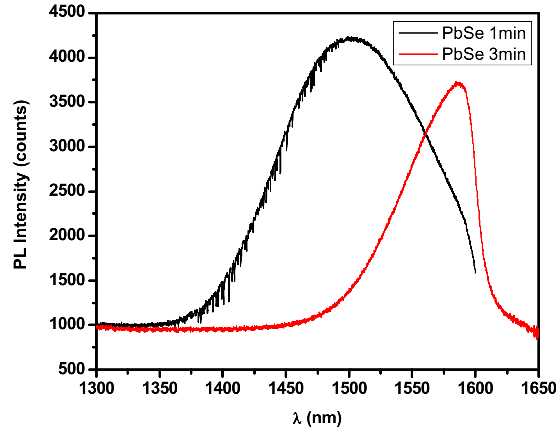

Fig. 2 Photoluminescence of PbSe NCs in solution (hexane) as a function of NC growth time.

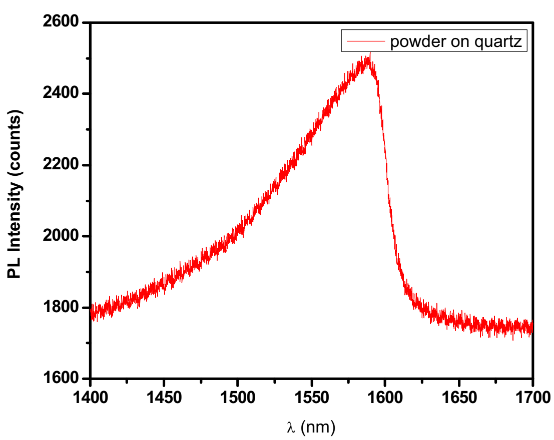

Fig. 3: Photoluminescence of PbSe NCs (3 min synthesis) drop cast on quartz.

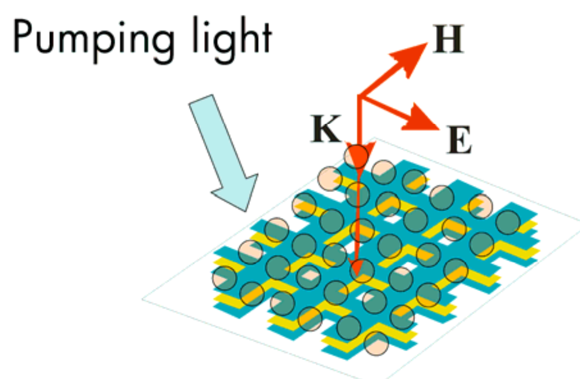

Fig. 4 Schematic illustration of integration of NCs with the metallic fishnet NIMs to achieve optical gain. The NCs emit at the operating wavelength of the NIMs.