Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supporting Information

Modulated Spontaneous and Stimulated Emission in Luminescent Films Using One-Dimensional Photonic Crystal Filters

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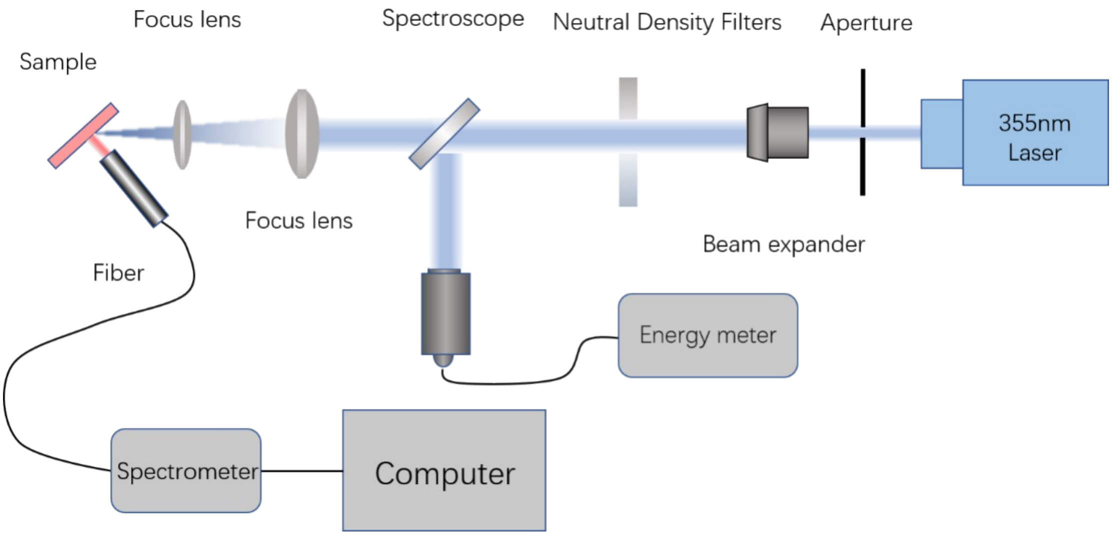

Figure S1. PL spectra test optical path in the front side normal direction.

This image is a light path structure diagram for spectral testing of 1DPC and reference samples. The purpose is to test the fluorescence spectrum in the normal direction of the sample surface. The pump light source is a 355 nm Nd^{3+}: YAG pulse laser, and a neutral density filter adjusts the pump light intensity. A spectroscope is placed in the light path to separate a beam of light to monitor the pulse energy. The pulse pump light source is finally focused on the sample surface through a convex lens at a certain inclination angle to the normal direction, and the spectrometer probe is in the normal direction.

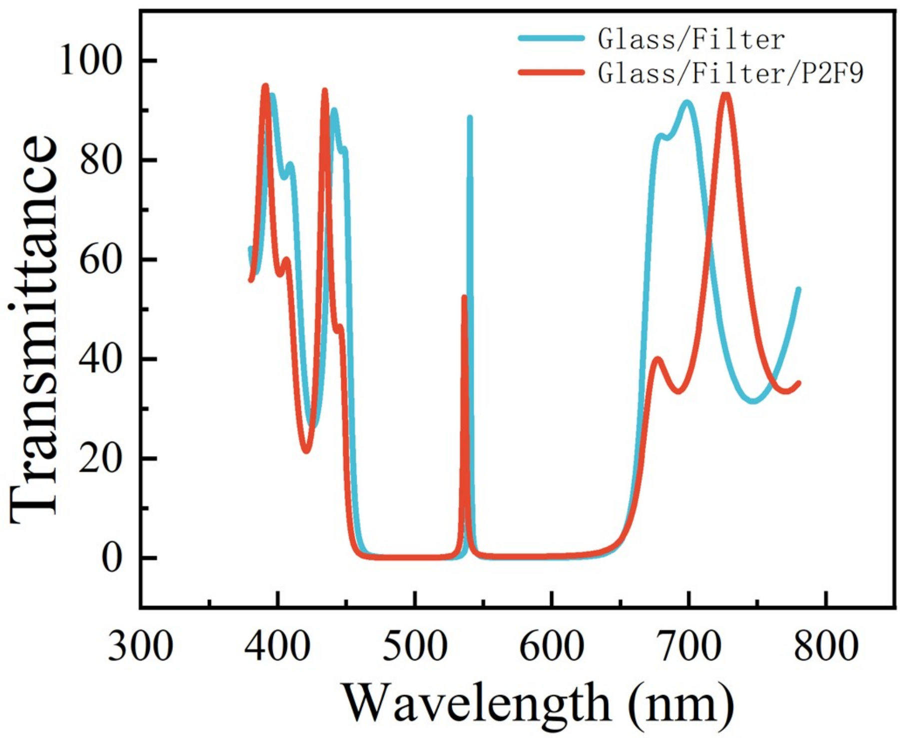

Figure S2. Transmission spectra of Glass/Filter 2/P2F9 (1DPC sample 2) and Glass/Filter 2 simulated by the transmission matrix method.

The simulated transmission spectra in Figure S2 shows that the Filter 2 has a defect mode at 540 nm. After add a P2F9 layer on top of the Filter 2, the resulting defect mode in 1DPC sample 2 is shifted to 536 nm.

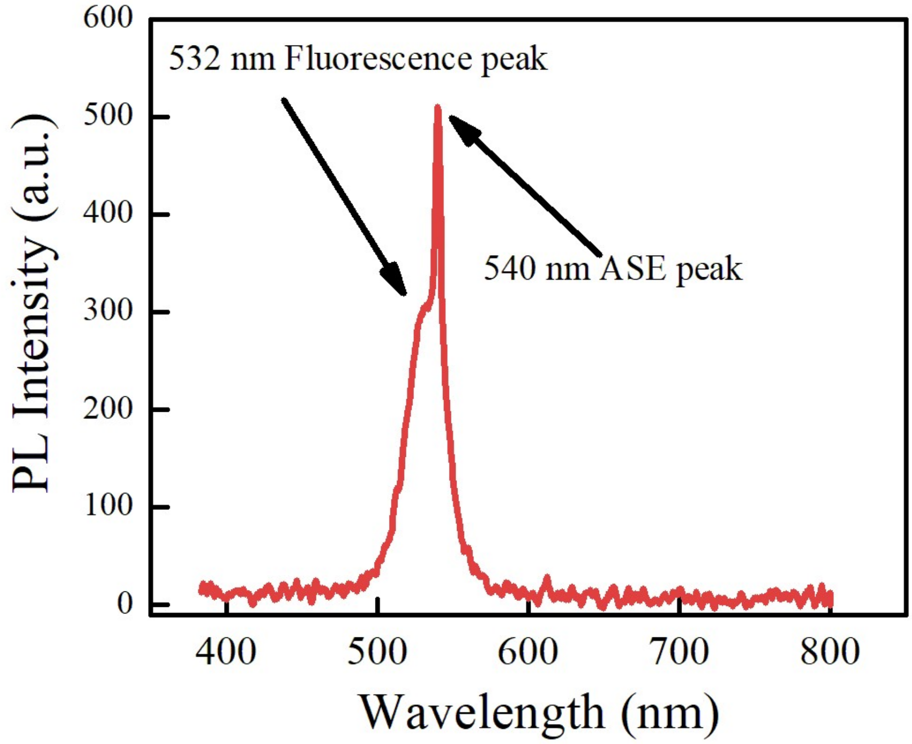

Figure S3. Surface-emitted spectrum of reference sample 2 (Glass/P2F9) with fluorescence peak at 532 nm and an ASE peak at 540 nm under optical pumping near threshold by a 355nm UV pulse laser.

The emission spectrum was measured in the surface normal direction of the quasi-two-dimensional perovskite material P2F9 film. The P2F9 material has a fluorescence peak at about 532 nm under a low pump energy. As the pump energy increases, a narrow band emission at 540 nm gradually increases, indicating the appearance of the amplified spontaneous emission (ASE).

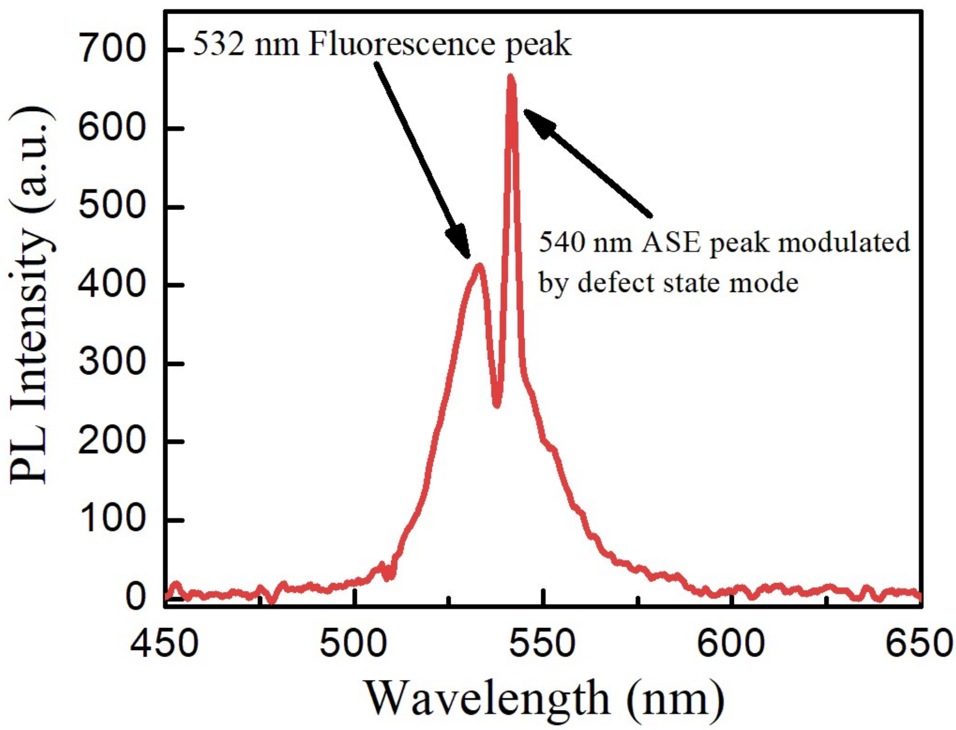

Figure S4. Surface-emitted spectrum of 1DPC sample 2 under optical pumping near threshold by a 355nm UV pulse laser, with a fluorescence peak at 532 nm, and an ASE emission peak at 540 nm that modulated by the defect state mode.

The structure of 1DPC sample 2 is Glass/filter 2/P2F9. The emission spectrum is measured in the normal direction of the sample surface. Because the ASE emission is coupled with the defect state mode of filter 2, the ASE threshold can be effectively reduced.

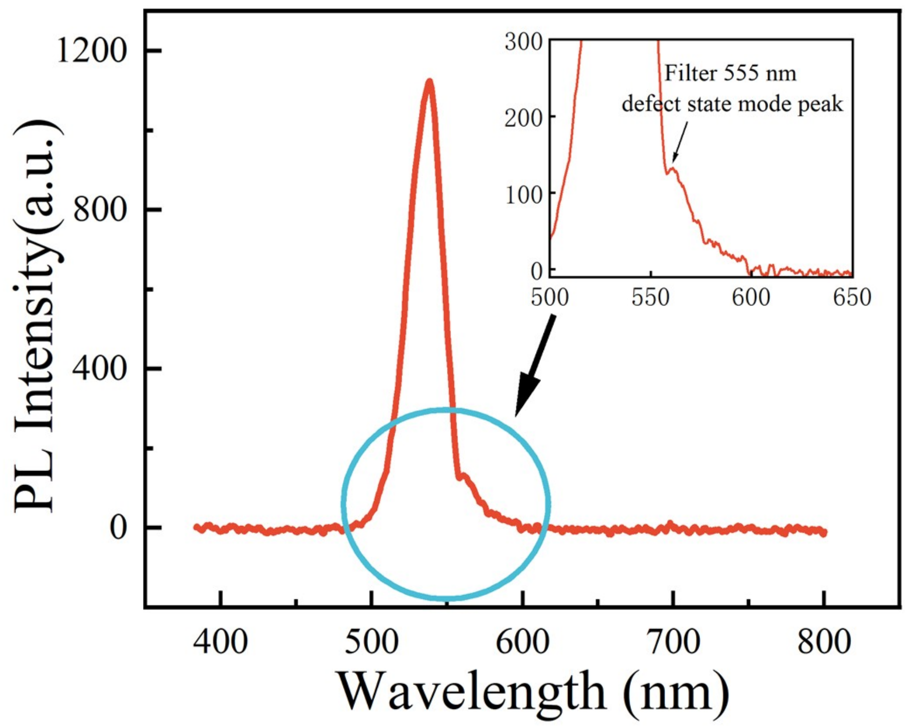

Figure S5. Emission spectrum of 1DPC sample 3 with filter defect state mode at 555 nm.

The PL emission spectrum of 1DPC sample 3 (Glass/Filter/P2F9) is measured in the normal direction of the sample surface. The filter used has a defect state mode peak at 555 nm. The emission spectrum indicates that the main emission results from the regular fluorescence of the thick P2F9 film (~100 nm). By contrast, the emission at 555 nm, which is not obvious, is modulated by the defect state mode.

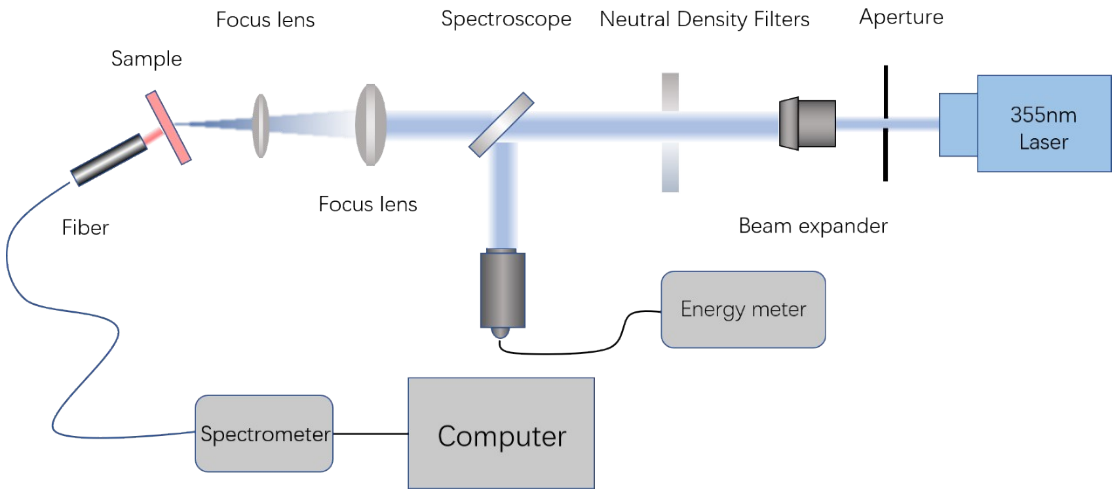

Figure S6. PL spectra test optical path in the backside (glass side) normal direction.

This figure shows the optical path to test the emission spectrum in the normal direction on the back of the sample. The optical components are the same as in Figure S1.

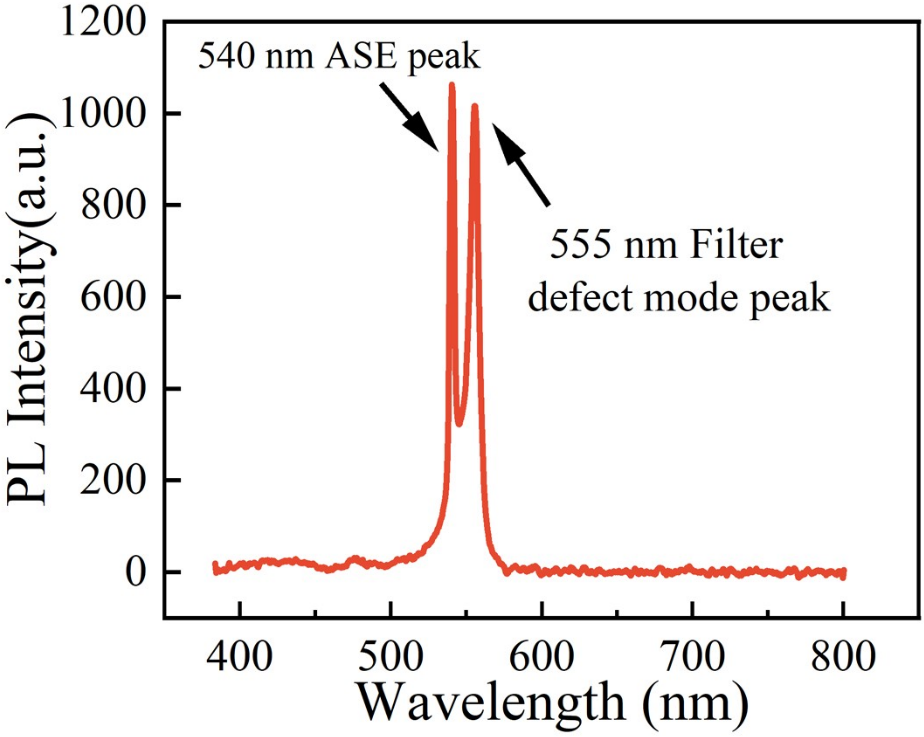

Figure S7. Emission spectrum in the normal direction of the back (glass) side, showing an ASE peak at 540 nm and a filter defect state mode peak at 555 nm.

The emission spectrum of 1DPC sample 3 is measured by using the light path shown in Figure S6. The test probe is in the normal direction of the back of the sample, and the filter defect state mode of the sample is at 555 nm. Under a certain pump fluence, both narrowed ASE emission peak at 540 nm and defect state mode-modulated emission peak at 555 nm can be observed.

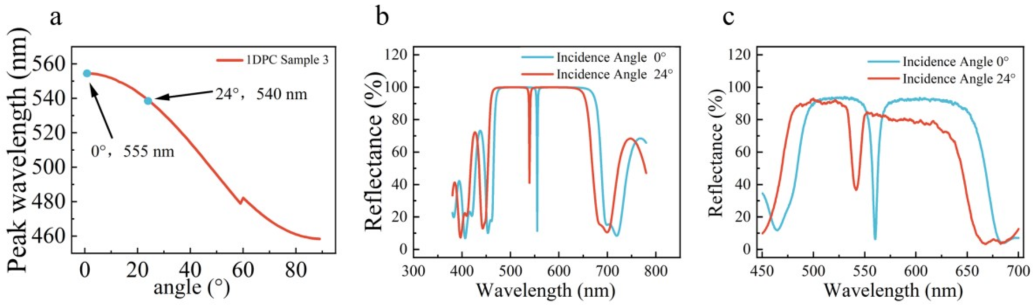

Figure S8. (a) The simulated defect state mode of the filter changes with the viewing angle; (b) The simulated reflectance spectra of 1DPC sample 3 in the normal direction and at 24° viewing angle by the transmission matrix method; (c) The measured reflectance spectra of 1DPC sample 3 in the normal direction and at 24° viewing angle.

Based on transfer matrix method,[S1] the change of defect state mode of the filter with the observation (or incident) angle can be simulated. Figure S8 shows that the peak wavelength of defect state mode is blue shift with the observation angle. At the incident angle of 0°, the defect state mode of the filter is at 555 nm. As the incident angle increases to 24°, the defect state mode is changed to 540 nm. The measured defect state modes in reflectance spectra of 1DPC sample 3 at 0° and 24° is consistent with the simulation ones.

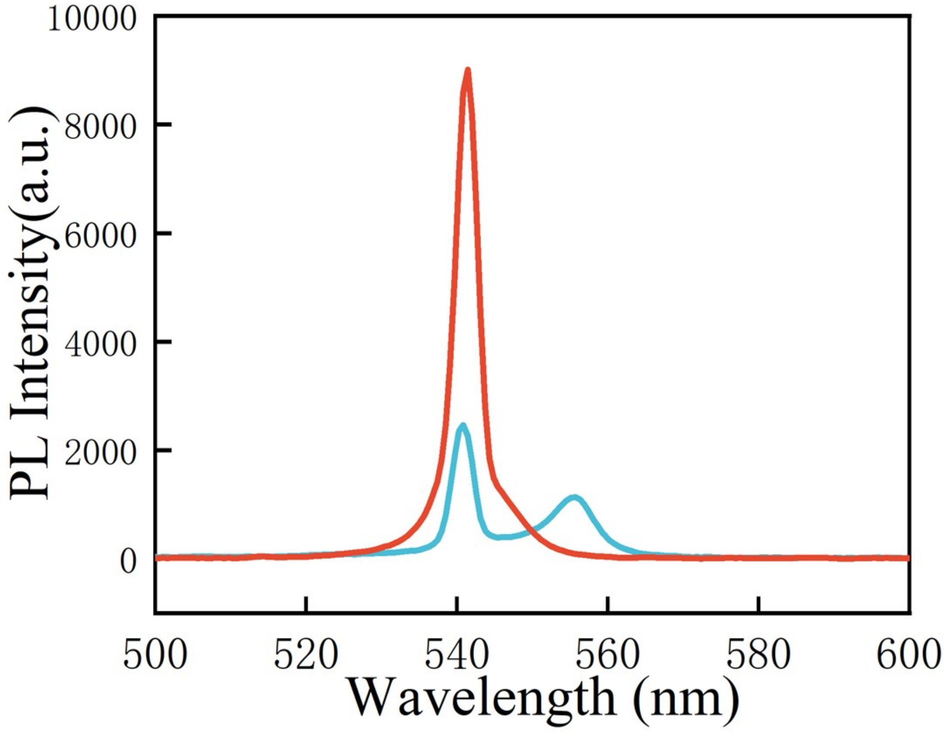

Figure S9. Comparison of ASE emission spectra of 1DPC sample 3 at the viewing angle of 0° (blue) and 24° (red). At the same pump fluence, the emission intensity of 1DPC sample 3 modulated by the defect state mode of the filter to the ASE position (red line) is about 3 times higher than that of the unmodulated case (blue line).

Under the same pump energy, when the probe position is in the normal direction, the measured spectrum (blue) shows a ASE peak is at 540 nm, and a defect state mode peak at 555 nm. The emission intensity of both is not strong. However, when the tilt angle of the probe is adjusted, the defect mode peak is blue-shifted. At the viewing angle of 24°, the defect mode peak (red) locates at 540 nm, which enhances the emission intensity of the 1DPC sample 3 by about three times in comparison to the case of 0°.

Figure S10. Schematic diagram of 1DPC sample structure. (a) 1DPC sample 1, (b) 1DPC sample 2, and (c) 1DPC sample 3.

The Filter of 1DPC sample 1 is composed of two materials, ZnSe and YF_3, alternately. That of samples 2 and 3 are alternately composed of TiO_2 and SiO_2 materials. Because the defect state mode positions are different, the thickness of the same material of in sample 2 and 3 is different. All three filters have a defect layer composed of the corresponding low-refractive index material in the middle of 1DPC to generate defect state.

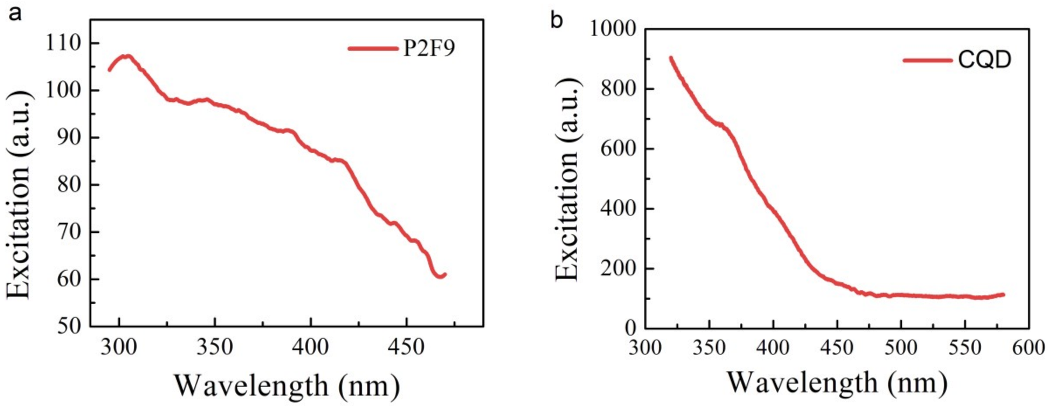

Figure S11. (a) Excitation spectra of the P2F9 film; (b) Excitation spectra of the CQD film.

References

S1. R. S. Dubey, Gautam D. K., *Optoelectron. Adv. Mater. Commun.,* 2007, **1**, 436-441.