Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information

Linearly polarized lasing based on coupled perovskite microspheres

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Content

Table S1. Polarized emissions in micro/nano structures.

$CH_3NH_3PbBr_3$Nanoplatelets [1]	spontaneous emission	0.11
PTCDI Nanobelt [2]	spontaneous emission	0.7
CdSe/CdS nanorods [3]	spontaneous emission	0.61
CdSe nanoplatelets [3]	spontaneous emission	0.43
$CsPbX_3$ quantum dots [4]	spontaneous emission	~0.4
$CsPbBr_3$ nanowires [5]	spontaneous emission	0.17-0.3
ZnO nanowhiskers [6]	lasing	0.47
Coupled $CsPbBr_3$ microspheres*	lasing	0.78

* presents this work

Corresponding FSR calculation of microspheres before and after coupling.

Suppose the FSR of these two microspheres are FSR_1 and FSR_2, respectively, then the condition for observing the Vernier effect is $N_1FSR_1 = N_2FSR_2$, where N_1 and N_2 are co-prime integers. Given that WGMs are generated inside circular cross-sections of microspheres, FSR of microspheres with diameters DA and DB can be approximately calculated as follows:

$$FSR_{A(B)} = \frac{\lambda^2}{\pi n_g D_{A(B)}}$$

Where n_g is the group refractive index of 3.7 [5]. The FSR for the coupled microsphere cavity is estimated by the following equation:

$$FSR_{AB} = \frac{\lambda^2}{\pi n_g |D_B - D_A|}$$

The calculated FSR_{AB} is 40.2 nm. As a result, $FSR_{AB} = 2FSR_B = 3FSR_A$.

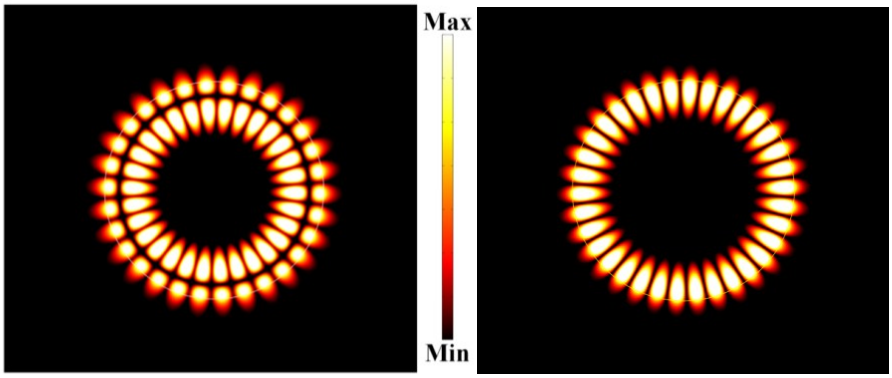

Fig. S1 Numerical simulations on the standing wave field distributions of microsphere A. Left: high-order lasing mode; Right: low-order lasing mode.

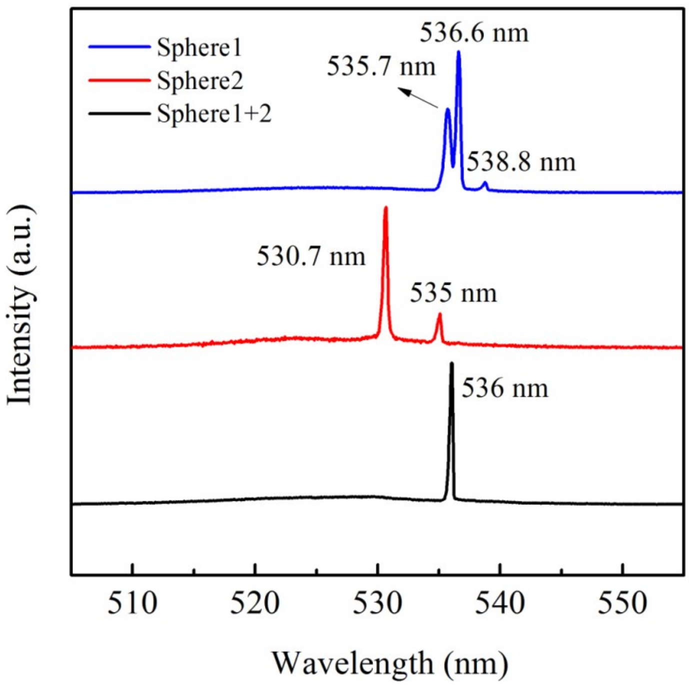

Fig. S2 Single-mode lasing obtained from coupled microspheres with diameters of 1.9 μm and 1.5 μm.

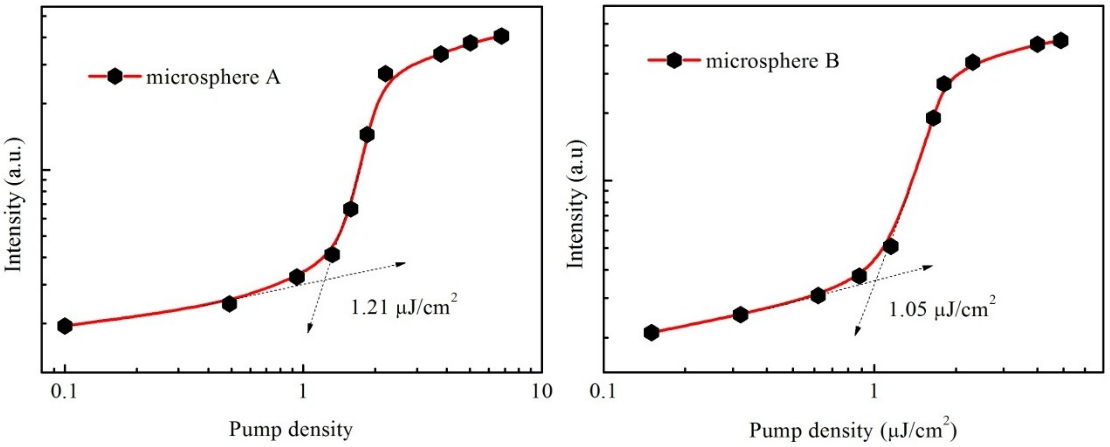

Fig. S3 The integrated lasing intensity as a function of pumping density from the microsphere A and B show the lasing threshold are 1.21 μJ/cm^2 and 1.05μJ/cm^2, respectively.

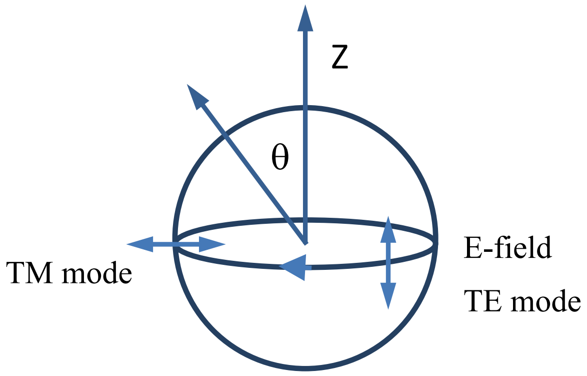

Fig. S4 Schematic diagram of spherical coordinate system.

In the coordinate calculation, the homogeneous linear isotropic medium can be described by Debye potential as follow:

$$\nabla^2\psi(r,\theta,\emptyset:t) - \frac{1}{v^2}\frac{\partial^2\psi(r,\theta,\emptyset:t)}{\partial t^2} = 0$$

Suppose the relationship of Debye potential with time is

$$\psi(r,\theta,\emptyset:t) = \psi(r,\theta,\emptyset)^{e^{-i\omega t}}$$

Thus the equation resolves to

$$\nabla^2\psi(r,\theta,\emptyset) + n^2k^2\frac{\partial^2\psi(r,\theta,\emptyset)}{\partial t^2} = 0$$

Where $k = \frac{\omega}{c} = \frac{2\pi v}{c}$ is the wave vector of vacuum, n is the index of refraction of the medium. By solving the equation, the optical field propagating in the direction of r can be decomposed into two polarization modes, TM mode and TE mode. The radius and emission wavelength of the perovskite microspheres we used are satisfied $R \gg \lambda$. Thus outside the boundary of the microsphere ($r > R$), the field distribution can be simplified as follows:

$$\begin{cases} E_\theta(r,\theta,\emptyset) \propto -\frac{knm}{\sin\theta}\left[\frac{j_l(nkr)}{h_l^{(2)}(kR)h_l^{(2)}(kr)}\right]Y_l^m(\theta,\emptyset) & TE\ modes \\ E_r(r,\theta,\emptyset) \propto -\frac{l(l+1)}{r}h_l^{(2)}(kr)j_lY_l^m(\theta,\emptyset) & TM\ modes \end{cases}$$

This is the analytical solution of the microsphere whispering gallery mode.

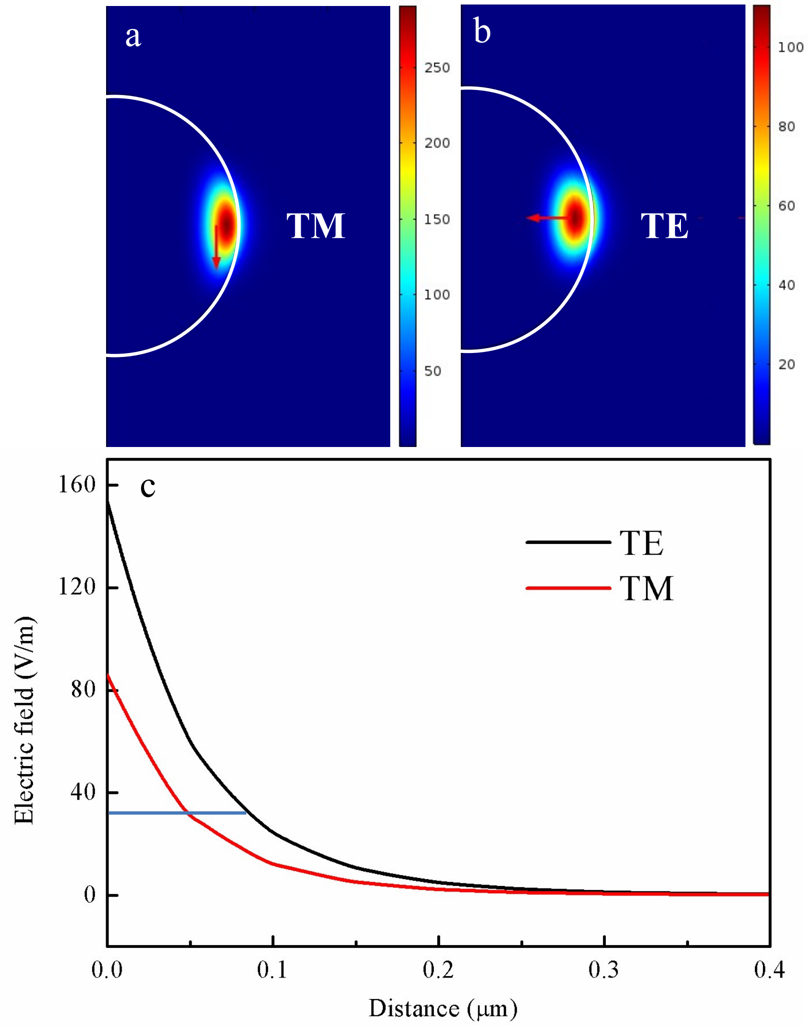

Fig. S5 The mode distribution of microsphere cavity. Evanescent field distributions of (a) TM mode and (b) TE mode in $CsPbBr_3$ microsphere with diameter of 1.8 μm. (c) The decay curves of TE and TM modes intensity with the distance from the microsphere surface.

Fig. S5 shows the TE (a) and TM (b) modes distributions of microsphere cavity with diameter of 1.8 μm, which are simulated by the COMSOL Multiphysics. By taking values along the radial direction，the decay curves of TE (black) and TM (red) modes intensity with the distance from the microsphere surface are obtained. The Fig. S5(c) shows that the intensity of TE mode on the microsphere surface is much higher than that of the TM mode. In addition, the decay rate of the TE mode with the distance from the microsphere surface is slower than that of the TM mode. These entire results illustrate that the TE mode has higher coupling efficiency.

References

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