Supporting Information

The hot-e lasers based on effectively electron transfer enhanced by electric polarization in perovskite and metal

S1. The details for $CsPbX_3$ QDs preparation

Chemicals and reagents: Cs_2CO_3 (anergic), Oleicacid (anergic), oleylamine (TCL), octadecene (90%, innochem), $PbBr_2$ (Aladdin), PbI_2 (Aladdin), $PbCl_2$ (RON).

All these reagents are used directly without further purification.

Synthesis process: The first step is to synthesize the precursor solution cesium oleate by using the thermal injection method. The 82.3 mg cesium carbonate, 0.3 ml oleic acid and 3.5 ml octadecene was weighed. Then, the mixed solution was put into a dried 50 ml three neck flask, and filled with argon, heated to 120 ℃ and stirred at the same time. After heating for 60 minutes, the temperature was raised to 150 ℃ and continue heating for 30 minutes. The solution became clear and bright to obtain the precursor solution. It should be noted that the precursor solution is white and solidified at room temperature. Therefore, it should be heated to 100 ℃ before injection.

The second step is to synthesize $CsPbX_3$ quantum dots. The PbBr 269 mg (52.3 mg for $PbCl_2$ and 86.7 mg for PbI_2) and 5 ml for eighteen dilutions was weighed. The mixed was put into a dried 50 ml three neck flask, filled with argon, heated to 130 ℃ and stirred at the same time. After heating for about 60 mins, 0.5 ml of oleamine and oleic acid was added, continue heating for 30 mins. Here, the solution became clear again, and then the temperature was raised to 140~200 ℃. At this time, 0.4 ml of precursor solution with a pipette gun was quickly injected. After 5 s, the flask was put into an ice water and quickly cooled to room temperature. The obtained crude solution was centrifuged and purified, centrifuged at 5000 rpm for 15 minutes. The supernatant was discarded after centrifugation, the precipitation was dispersed in n-hexane, the obtained n-hexane dispersed colloidal solution was centrifuged again (5000 rpm, 15 minutes). The impurities in the precipitation were discarded, the supernatant was taken, and finally a clear long-term stable dispersed colloidal solution can be obtained, as shown in Figure 1. Since $CsPbX_3$ QDs were easily degraded under polar conditions (water, oxygen, temperature and ultraviolet light in the environment), the resulting colloidal solution needs to be stored in a sealed low-temperature environment. Anion exchange reaction after synthesis: the synthesized $CsPbX_3$ QDs solutions of different halogen components were mixed in a certain proportion at room temperature to obtain $CsPb(Br_xCl_{1-x})_3$ or $CsPb(Br_xI_{1-x})_3$ QDs colloidal solution.

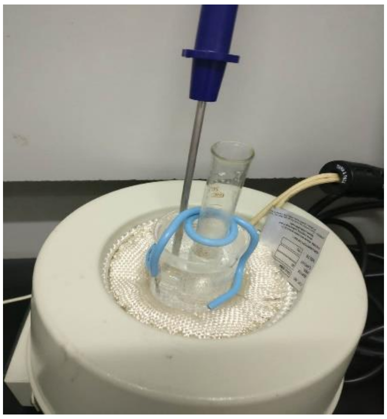

Figure S1. The photo of experimental package heating.

S2. The details of TA spectrum test

The photoluminescence (PL) was obtained by fluorescence spectroscopy (NIR512). The 405 nm picosecond pulsed laser was selected as excitation light for PL test, which came from LDH, Picoquant. The laser was focused on the sample, and the fluorescence was measured by the optical fiber probe of the spectrometer (Ocean optics). The PL test picture can be seen in the figure S4.

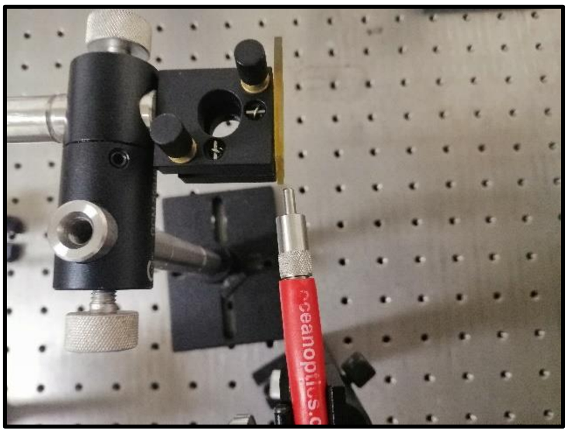

Figure S2. The picture of testing in the sample.

S3. The size distribution of QDs

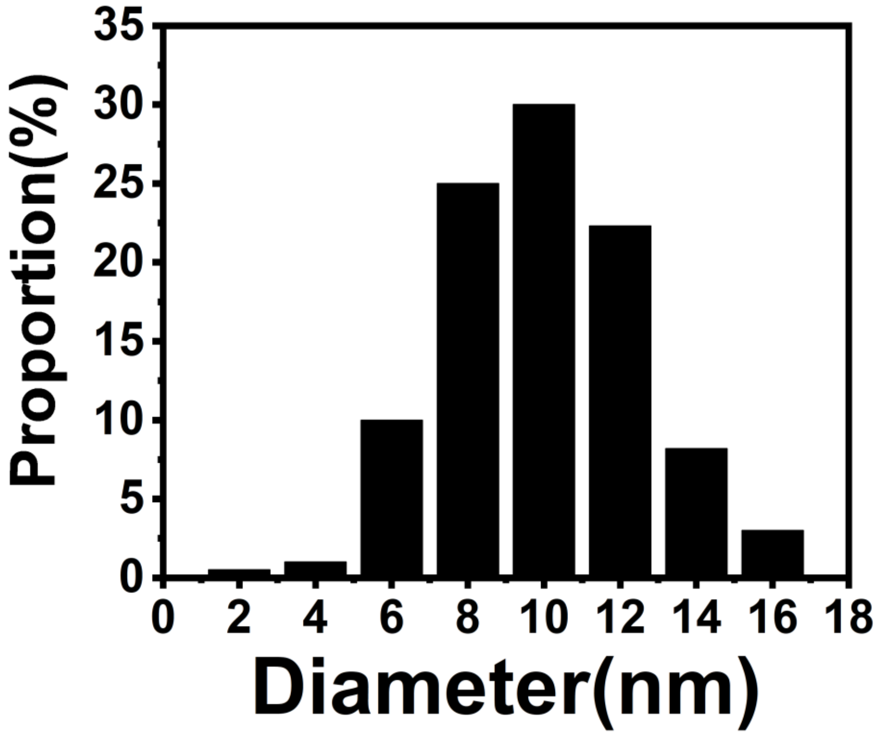

Figure S3. The size distribution of QDs at the specific area.

S4. The method of high-quality surface

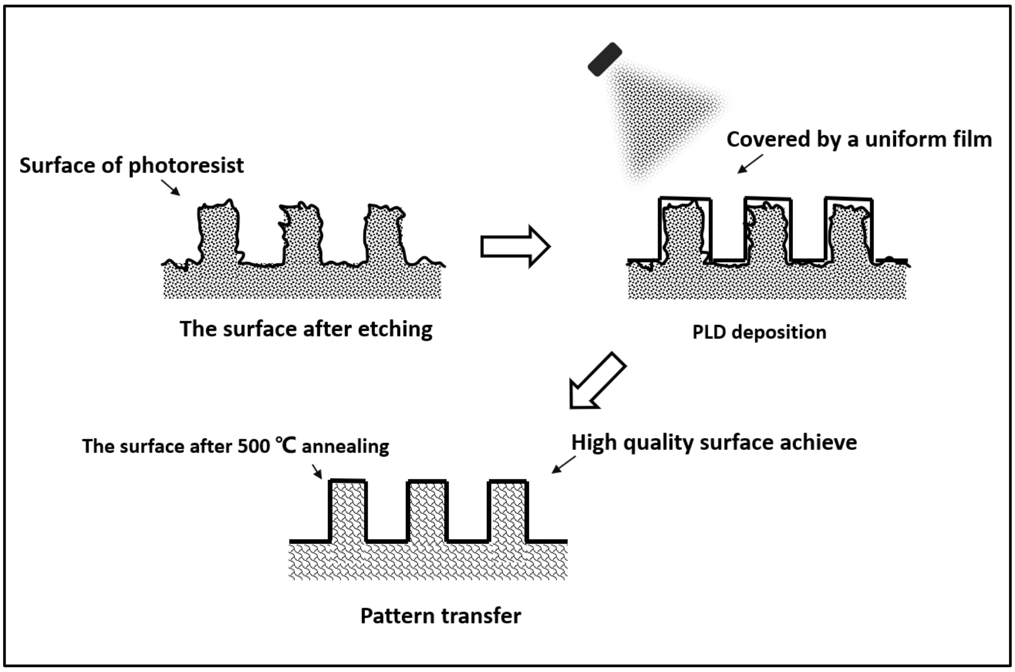

Figure S4. The method of high-quality surface.

S5. The structure model of perovskite

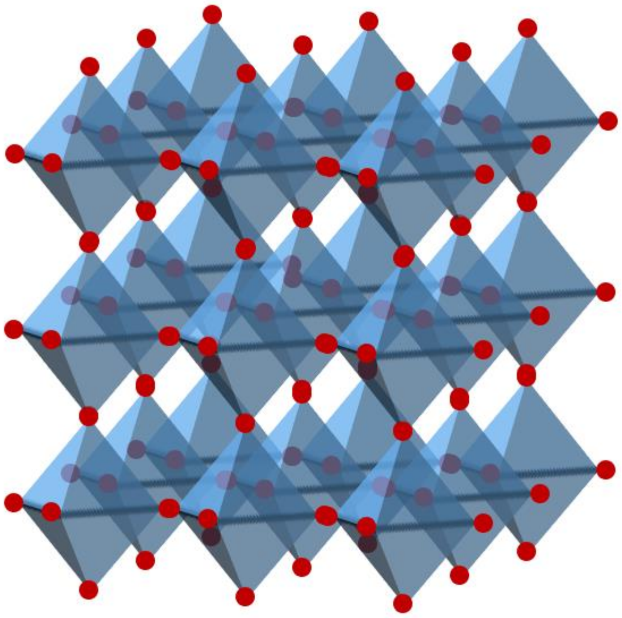

Figure S5. The structure model of perovskite.

S6. The details of preparation $CsPbBr_3$ nanorod arrays

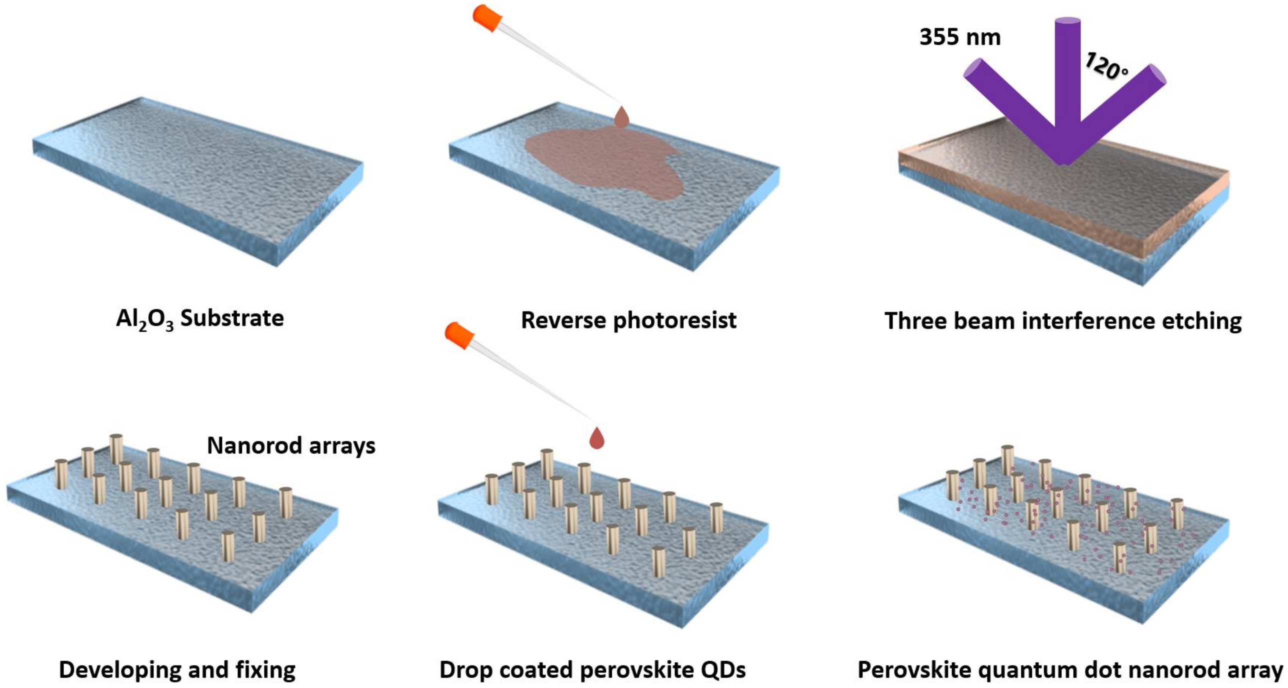

Figure S6. The details of preparation $CsPbBr_3$ nanorod arrays. The purpose of this part is to prove the induction of metal plasmons. In the absence of metal, only perovskite nanorod arrays were prepared for comparative study.

S7. The details of preparation $CsPbBr_3$ nanorod arrays

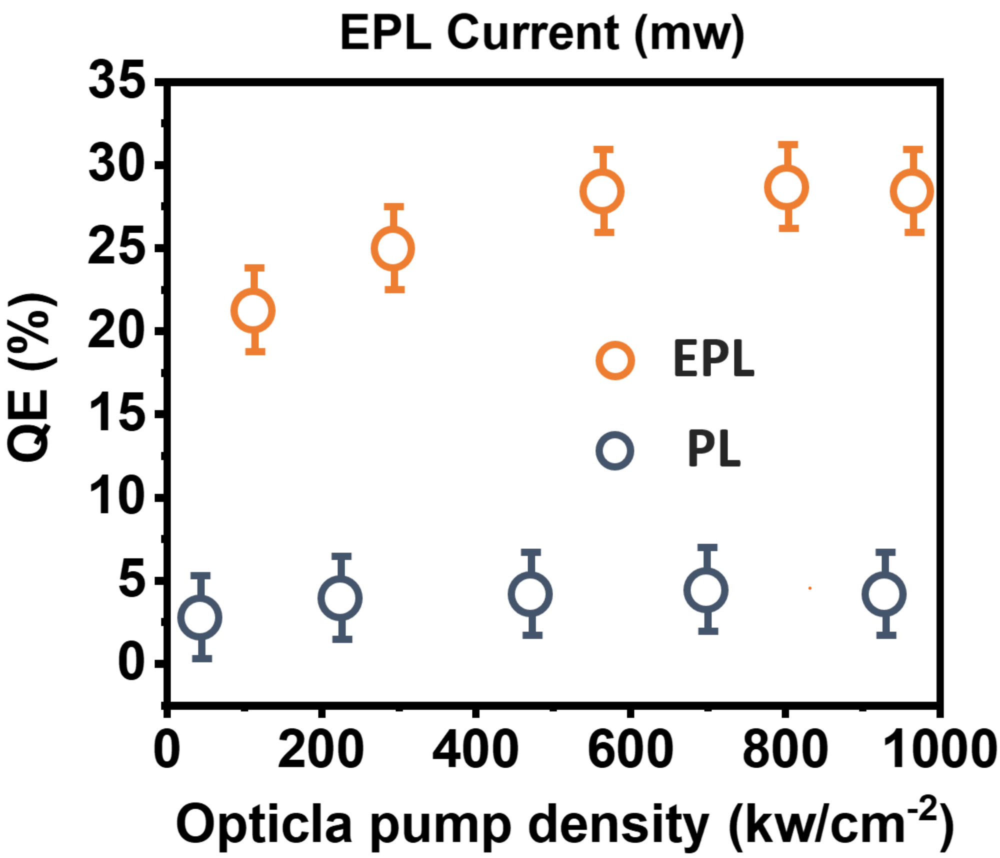

Figure S7. Comparison of plasmon induced hot electron generation efficiency of PL and EPL. The total plasmon induced hot electron generation efficiency is proportional to the product of hot electron generation efficiency and hot electron transfer efficiency. This relationship can be express by $QE_{PI-HEG}(R) \propto QE_{HEG} QE_{HET}$.

S8. Comparison of performance parameters in different plasmonic nanolasers

Table S1 The comparison of parameters in different plasmonic nanolasers

Year	Wavelength	Pump	Threshold	PI-QE	Ref.
2009	489 nm	optical	40 MW cm^{-2} (<10 K)	10%	16
2012	1520 nm	optical	100 kW cm^{-2}	0.1%	17
2018	700 nm	optical	3.5 mW	11.9%	18
2019	396 nm	electrical	70.2 A cm^{-2}	0.02%	19
2020	1200 nm	optical	140 kW cm^{-2}	18%	20
2021	530 nm	optical	138 MW cm^{-2}	/	21
2022	770 nm	optical	18 kW cm^{-2}	21%	22
This work	532 nm	optical+electrical	5 kw cm^{-2} & 1 μA	30.1%	