Supplemental information for:

High-density and Uniform Lead Halide Perovskite Nanolaser Array on Silicon

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In the main text, we have discussed the formation of high density nanolaser array with lead halide perovskite microwire or microplate. In this supporting information, we will show some experimental details about the solution processed synthesis (1), optical characterization setup (2), axial Fabry-Perot (FP) modes in microwire on AZ grating (3), the process of E-beam lithography (4), and the simulation results of the WG modes (5).

(1) Synthesis of the lead halide perovskite microwire and microplate

The $CH_3NH_3PbBr_3$ perovskite microstructures were synthesized on hydrophobic ITO coated glass with a modified one-step solution processed method. In principle, 0.05M $CH_3NH_3Br•PbBr_2$ solution, which was prepared by mixing equal volumes of solutions of CH_3NH_3Br (0.1 M) and $PbBr_2$ (0.1 M) in DMF (N,Ndimethylformamide), was casted onto a ITO glass side and sealed in a 250 ml beaker (with 75 ml containing CH_2Cl_2). After 24 hours, $CH_3NH_3PbBr_3$ perovskite microstructures can be obtained. Figure S1 shows the top-view scanning electron microscope (SEM) image of the synthesized perovskites. We can see that $CH_3NH_3PbBr_3$ microwires are the dominate structures and some microplates can also be formed.

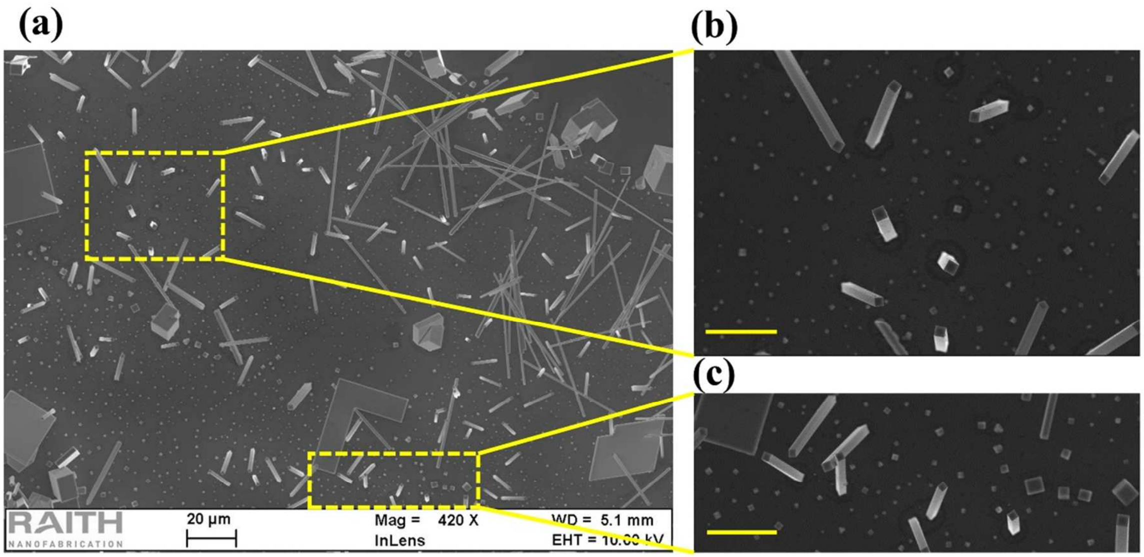

Figure S1. *(a) Top-view scanning electron microscope image of the synthesized lead halide perovskite microstructures. (b) and (c) are enlarged image of the area in (a) marked by yellow dashed box and the scale bar is 10 μm.*

(2) Setup for optical measurement

In our lasing experiment, the optical properties of lead halide perovskites are studied by optical excitation. The schematic picture is shown in Figure S2. The lead halide perovskite microwires or microplates on gratings are placed onto a three-dimensional translation stage, which is fixed under a homemade optical microscope. Basically, an ultrafast pulsed laser beam from a regenerative amplifier (800 nm, repetition rate 1 kHz, pulse width 100 fs, seeded by MaiTai, Spectra Physics) is frequency doubled by a BBO (Beta barium borate) crystal and focused by an objective lens onto the top surface of microstructure. The emitted lights are collected by the same objective lens and coupled to a CCD (Princeton instrument, PIXIS BUV) coupled spectrometer (Acton SpectroPro2700i) via a multimode fiber.

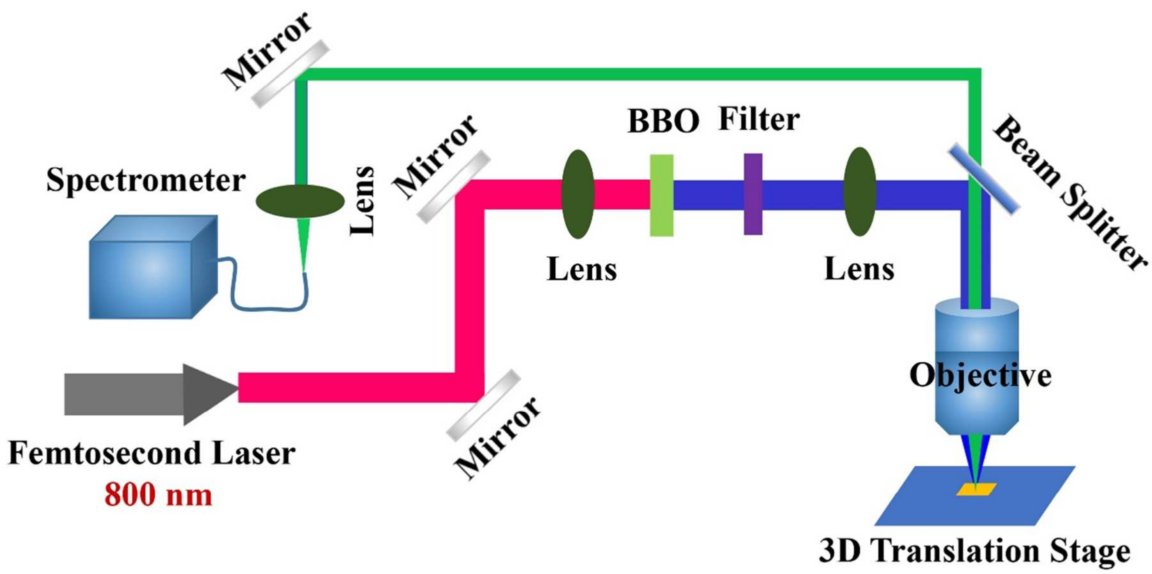

Figure S2. *Schematic picture of the setup for optical characterization.*

(3) Transverse lasers and axial FP laser in lead halide microwire

In the main text, we have mentioned that the microwire on an AZ grating can generate axial FP lasers when the entire microwire is pumped. All the results are summarized in Figure S3. Figures S3(a)-(c) show the lasing spectra of different subunits on AZ grating, respectively. The grating parameters are exactly the same as the ones in Figure 2 in the main text. When the microwire is selectively pumped, we can see that bright spots appear at the side facets of each subunit. Meanwhile, the recorded laser spectrum shows a single lasing mode (see Figure S3(a)). Such kind of phenomena can also be repeated by selectively pumping another subunit (see Figure S3(b)). And we can see that the laser spectra from different subunit are almost the same. All these results are consistent with the reports in the main text. Figure S3(c) shows the lasing spectra of two subunits, which maintain the uniform lasing wavelength. However, As shown in Figure S3(d), the lasing spectrum contains a number of periodic peaks, which are different from the emissions from one or two subunits. And the corresponding fluorescent microscope image (inset in Figure S3(d)) shows that the bright spots, which closely relate to the lasing actions, appear at two end facets of the microwire instead of the side facets. This clearly shows the onset of axial FP lasing actions. Because now the entire microwire contributes to the FP laser, the microwire on grating cannot function as a microlaser array anymore.

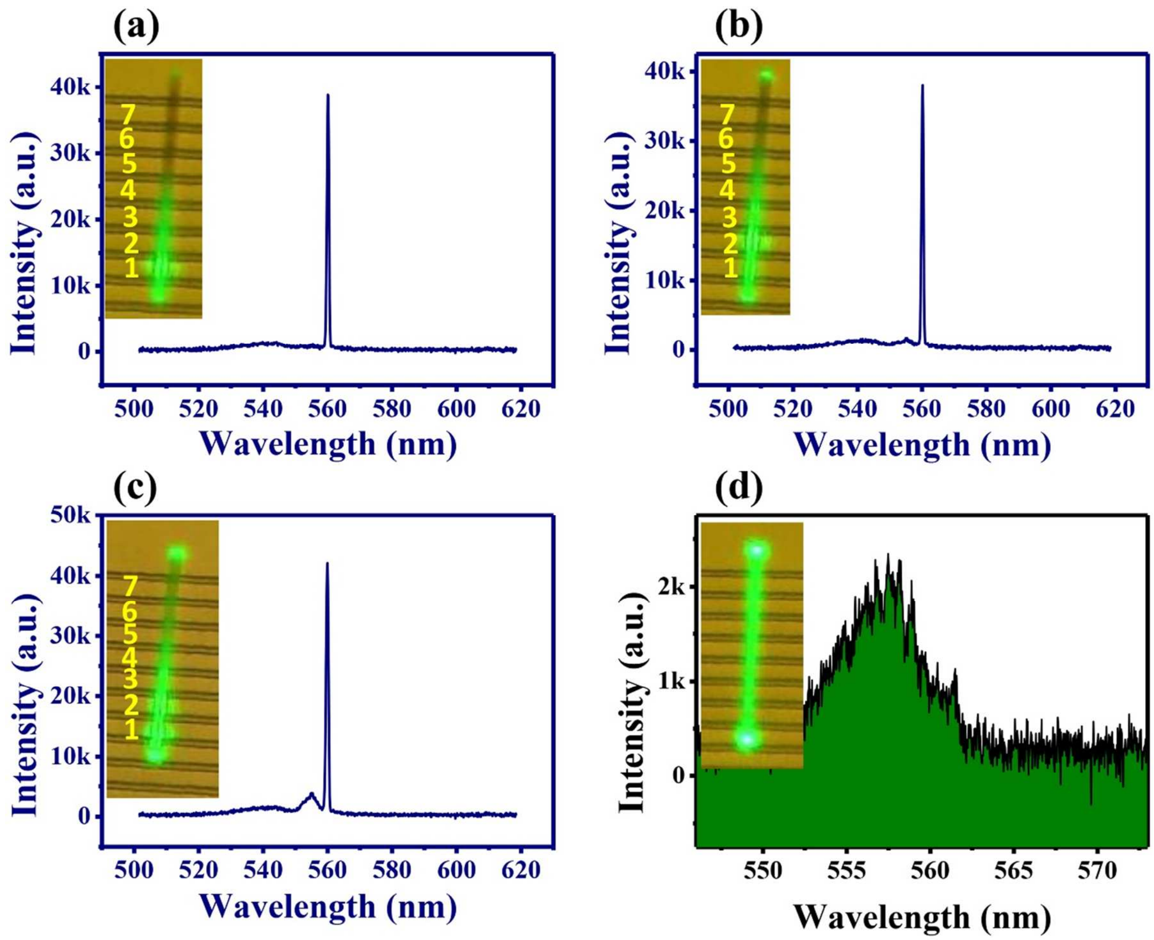

Figure S3. *(a), (b) and (c) are the laser spectra recorded from different subunits. (d) The laser spectrum from the entirely pumped microwire with increased pump density. The insets in (a)-(d) are their corresponding fluorescent microscope images.*

(4) E-beam lithography

In the main text, we have fabricated silicon grating with each subunit around 400 nm via E-beam lithography and ICP etching. Here we use a schematic picture to illustrate the fabrication process. Basically, a 300 nm PMMA film is spin-coated onto a silicon wafer and baked at 160^{o}C for one hour. Then the sample is written by an electron beam in E-beam writer (Raith E-line, 30 kV) and developed in MIBK/IPA (1:3) solution 50 seconds. After rinsing in IPA for 30 seconds, the sample is dried by a nitrogen gun and etched with CHF_3/SF_6 in ICP (Oxford plasmalab 100, ICP 180) for 30 seconds. Here the CHF_3 and SF_6 are 30 sccm and 15 sccm. And the powers of ICP and RF are 1200 W and 30 W, respectively. After immersing the PMMA in RemoverPG for 8 hours at room temperature and 0.5 hour at 80^{o}C, the silicon grating in Figure 6(a) can be achieved.

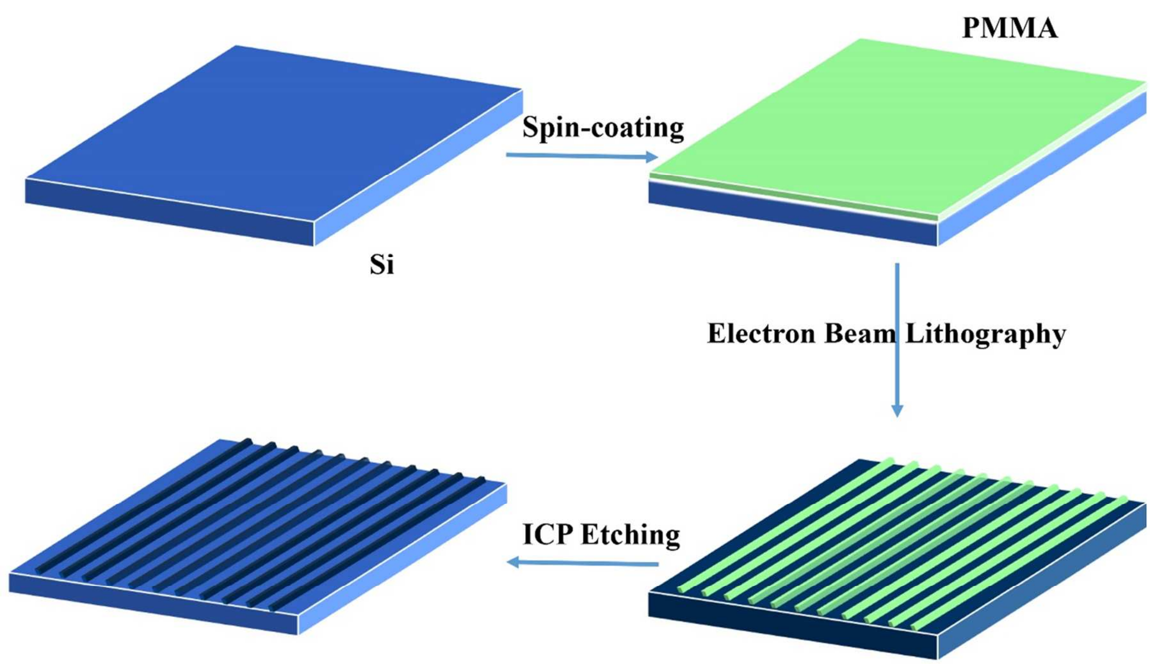

Figure S4. *The schematic picture of the E-beam lithography and ICP etching.*

(5) Simulation results for the microwires/microplates

To intuitively demonstrate the lasing modes in the transverse plane of perovskite microwires and microplates, finite element method (FEM) based simulation has been carried out with Comsol

Multiphysics 3.5a. The refractive index of perovskite is 2.45 and the surrounding environment is air (n=1). The simulation results are summarized in Figure S5.

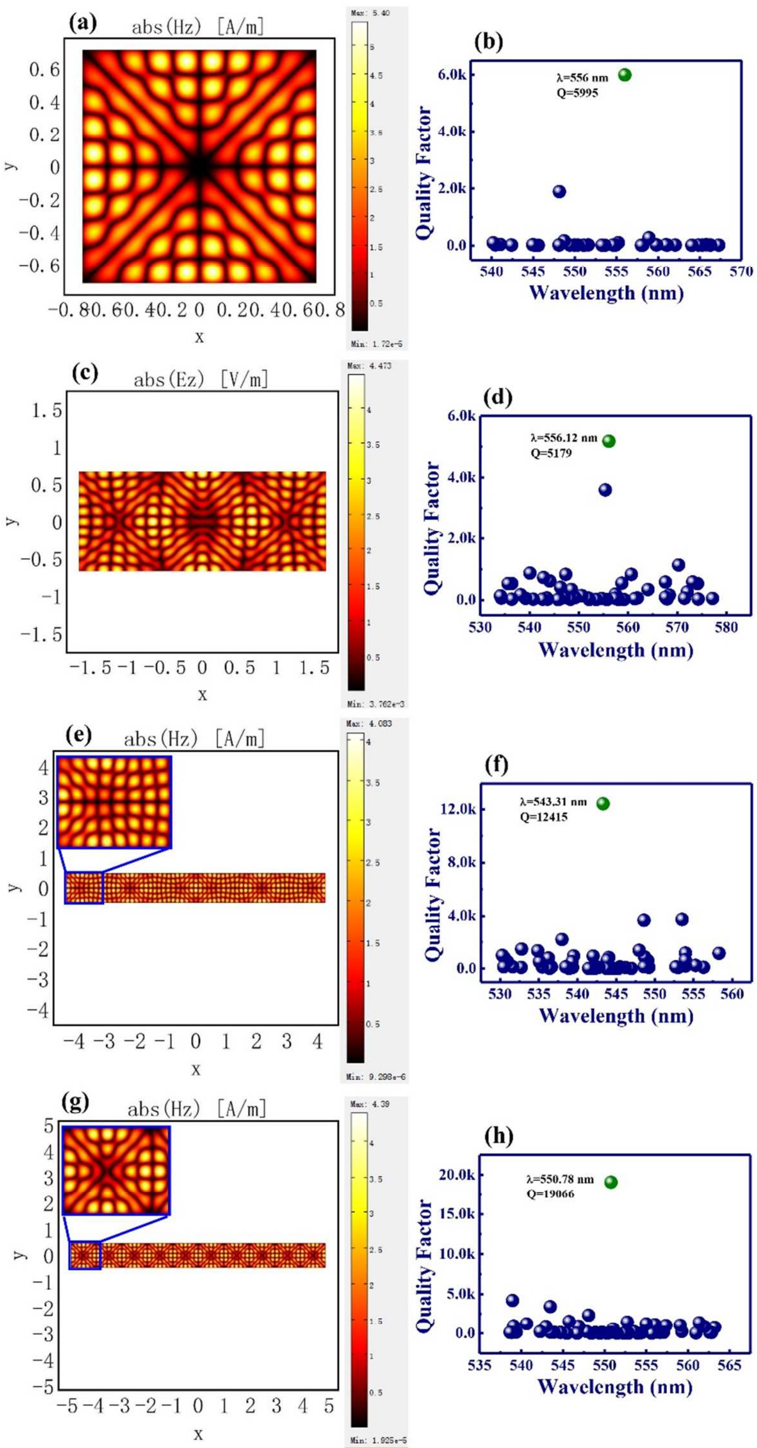

Figure S5. *Simulation results for the microwires/microplates in Figure 2, 4, 5 and 6, respectively. Left-column images show the field distribution in the transverse plane. Right-column images present the calculated Q factors at different wavelengths.*