Quasi-2D perovskites for high-power passively Q-switch in 1.9 μm solid-state laser

Bingxuan Li [a,c], Ge Zhang [a] and Shan Xu [b,*]

a. Key Laboratory of Optoelectronic Materials Chemistry and Physics, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, Fujian 350002, China.
b. School of Physics and Optoelectronic Engineering, Hubei University of Arts and Science, Xiangyang, Hubei, 441053, China.
c. University of Chinese Academy of Sciences, Beijing 100049, China.
* E-mail: xushan@yangtzeu.edu.cn

Laser damage threshold (LDT) measurements were performed on these five sample using a 1.9 μm laser (pulse width $\tau_p = 10$ ns, repetition rate f = 1 Hz) as the damage-inducing source. An optical concave lens was applied to modulate the diameter of laser beam for different power densities. The investigation was operated by gradually increasing the laser power until the sample became transparent and got damaged. The damage threshold was calculated from the equation $I(\text{threshold}) = E/(\pi r^2 t_p)$, where E is the energy, r is the radius of laser spot, and t_p is the pulse width. The results, shown in **Table S1**, are higher than the actual value (2.7 MW/cm^2) in intracavity Q-switching application. This is because the damage-inducing source are nanosecond laser pulses, and the heat accumulation is much smaller than that in Q-switching resonator. The fundamental frequency laser and pump laser in the cavity are both irradiated on the SAs simultaneously. It also can be seen that the $(OA)_2(MA)_{n-1}Pb_nBr_{3n+1}$ expressed the best performance due to its better crystallization and thermal stability caused by the longest chain of OA cation among these five cations.

Table S1: Laser damage thresholds of SAs based on quasi-2D perovskite

SA	LDT(MW/cm^2)
$(BA)_2(MA)_{n-1}Pb_nBr_{3n+1}$	20.29
$(OA)_2(MA)_{n-1}Pb_nBr_{3n+1}$	21.06
$(PA)_2(MA)_{n-1}Pb_nBr_{3n+1}$	18.86

$(PEA)_2(MA)_{n-1}Pb_nBr_{3n+1}$	17.01
$(TMA)_2(MA)_{n-1}Pb_nBr_{3n+1}$	18.35

In Q-switching operation under incident pump power at 9 W, we monitored the pulse laser parameters continuously for 100 minutes. As shown in the **Figure S1**, the FWHM was around at 220 nm and 230 nm, the average power was stable around 1.25 W, and the pulse repletion rate was stable at 125 kHz. The experimental results show the Q-switching operation is relatively stable under long term illumination using quasi-2D $(OA)_2(MA)_{n-1}Pb_nBr_{3n+1}$ as SA.

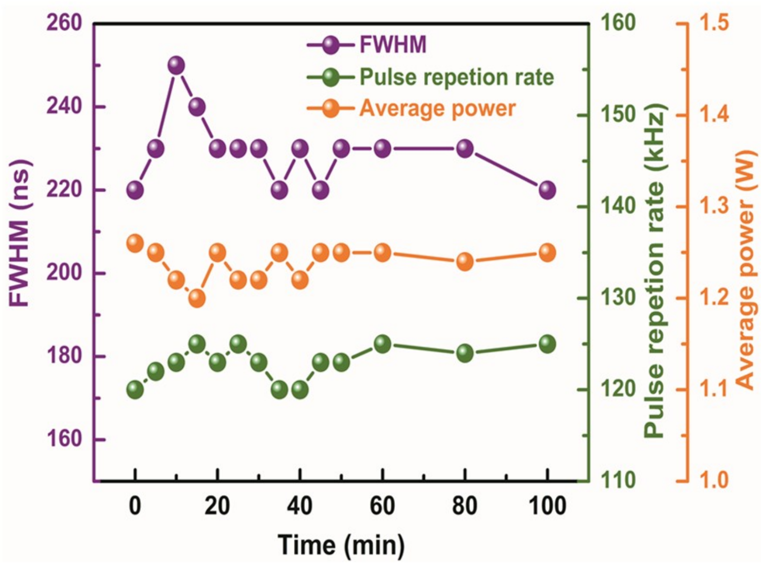

Figure S1. Pulse parameters in Q-switching operation monitored for 100 minutes

We repeated the experiment in July using the initial $(OA)_2(MA)_{n-1}Pb_nBr_{3n+1}$ SA kept in a drying cabinet at a constant humidity of 25% and a temperature of 27°. The experimental results are shown in the **Figure S2**, which are not much different from the initial experimental data.

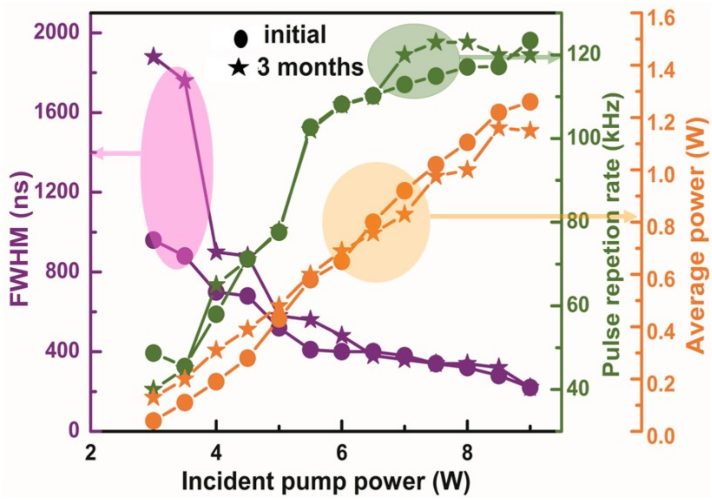

Figure S2. Pulse parameters in Q-switching operation at 3-month interval

In order to investigate more performance on saturated absorption, the nonlinear optical transmission measurement and Q-switching operation in other wavelength were carried on by corresponding pump laser. The nonlinear optical response in 1.3 μm was measured by an acousto-optic Q-switched Nd:YVO_4 solid-state laser at 1319 nm with 3.1 W output power, 40 ns pulse duration, and 10 kHz repetition rate, shown in **Figure S3(a)**.The modulation depth (α_s) is 10.37%, the saturation intensity (I_{sat}) is 1.59 MW/cm^2, and the non-saturable loss (T_{ns}) is 6.3%. The nonlinear optical response in 1.0 μm was measured by an acousto-optic Q-switched Nd:YVO_4 solid-state laser at 1064 nm with 2.3 W output power, 21 ns pulse duration, and 10 kHz repetition rate,, shown in **Figure S3(b)**.The modulation depth (α_s) is 8.65%, the saturation intensity (I_{sat}) is 1.71 MW/cm^2, and the non-saturable loss (T_{ns}) is 13.9%.

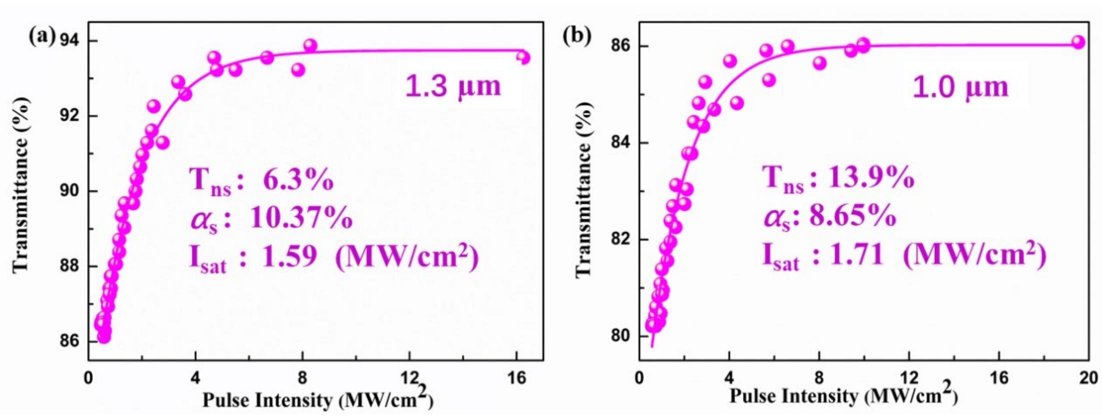

Figure S3. the nonlinear optical responses in (a)1.0 μm and (b)1.3 μm.

The Q-switching performances, shown in **Figure S4,** were also measured in 1.0 μm and 1.3 μm when the Tm:YAP in experimental setup was replaced by $Nd{:}YVO_4$.

Table S2 The Q-switch performance in different wavelength

Wavelength/μm	The maximum repetition rate/kHz	The narrowest pulse duration/ns	The maximum pulse energy/μJ
1.9	125	220	9.3
1.3	121	560	4.5
1.0	210	280	5.6

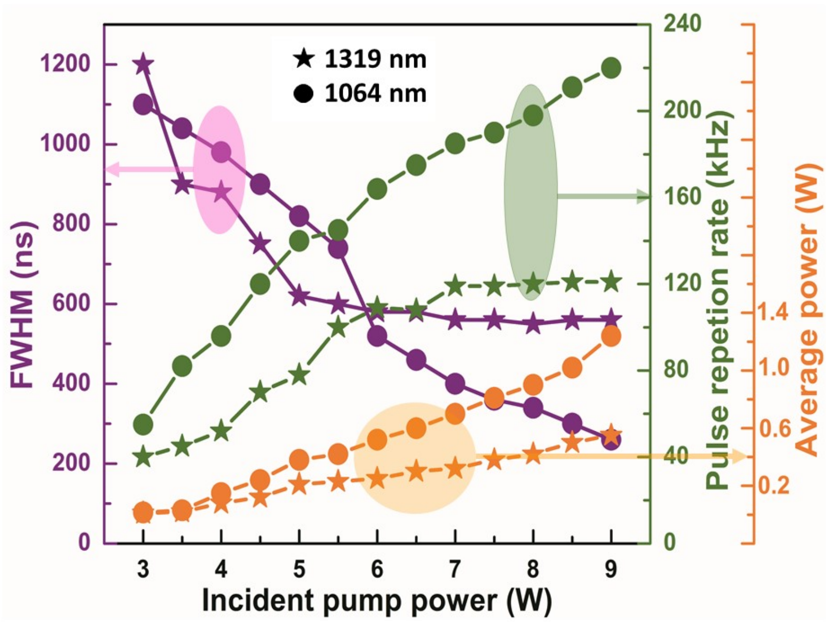

Figure S4. Quasi-2D perovskites based SA saturable absorber can operate at other wavelength in 1.0 μm and 1.3 μm.