Diode-Pumped Solid-State Q-Switched Laser with Rhenium Diselenide as Saturable Absorber

Chun Li 1,2,3, Yuxin Leng 2,* and Jinjin Huo 4

1 School of Physics Science and Engineering, Tongji University, Shanghai 200092, China; lichunqingchen@126.com
2 State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
3 University of Chinese Academy of Sciences, Beijing 100049, China
4 Jingjiang Photoelectric Technology Co. Ltd., Jinan 250000, China; jingjiang_opt@163.com

* Correspondence: lengyuxin@mail.siom.ac.cn

Received: 7 August 2018; Accepted: 20 September 2018; Published: 28 September 2018

Abstract: We report a solid-state passively Q-switched Nd:YVO 4 laser adopting rhenium diselenide (ReSe 2 ) as saturable absorber (SA) materials. ReSe 2 belongs to a type of transition metal dichalcogenides (TMDs) materials and it has the weak-layered dependent feature beneficial for the preparation of few-layer materials. The few-layer ReSe 2 was prepared by ultrasonic exfoliation method. Using a power-dependent transmission experiment, its modulation depth and saturation intensity were measured to be 1.89% and 6.37 MW/cm 2 . Pumped by diode laser and based on few-layer ReSe 2 SA, the Q-switched Nd:YVO 4 laser obtained the shortest Q-switched pulse width of 682 ns with the highest repetition rate of 84.16 kHz. The maximum average output power was 125 mW with the slope efficiency of 17.27%. Our experiment, to the best of our knowledge, is the first demonstration that used ReSe 2 as SA materials in an all-solid-state laser. The results show that the few-layer ReSe 2 owns the nonlinear saturable absorption properties and it has the capacity to act as SA in an all-solid-state laser.

Keywords: all-solid-state laser; ReSe 2 SA; Q-switched laser

1. Introduction

Few-layer materials are of great importance to researches and applications due to their unique optical and electronic characteristics. Current researches on few-layer materials are principally focused on graphene, insulating hexagonal boron nitride (hBN), topological insulators (TIs), black phosphorus (BP), and transition metal dichalcogenides (TMDs) [1–6]. Among these materials, TMDs are a large family, which exhibits a variety of photo-electric properties and offers a wide range of applications in broad research fields [5,6].

TMDs include some metals, various semiconductors, as well as superconductors. Over years of development, studies of TMDs have mainly concentrated on MoS 2 , MoSe 2 , WS 2 , and WSe 2 [7–9]. They have a changed characteristic (such as electronic structure, band gap) with their different layer thickness, owing to interlayer interactions and the variations of screening. While some TMDs have different transformation characteristics when the structure is changed from bulk to single or few-layer. Reports show that both SnS 2 and SnSe 2 (one type of TMDs) are layer-independent on in-plane lattice parameters, interlayer distances, and binding energies [10,11]. In addition, the ReSe 2 class also has different transformation characteristics with the change of the number of layers.

ReSe 2 , a new member of semiconductor TMDs, owns the distorted 1T structure, compared with the typical 2H-shaped MoS 2 class of TMDs [12]. In their in-plane, Re atoms arrange in linked Re 4 “diamond” shapes along the b [010] direction. These Re 4 ’diamonds’ are coplanar and are
coupled with one another to form a one-dimensional clustering pattern of ‘diamond chains’ [13]. Its distorted 1T structure results in the weaker interlayer coupling action [12–17]. Further, ReSe₂ behaves as electronically and vibrationally decoupled monolayers [15,16]. The weaker interlayer coupling action makes ReSe₂ weak-layered dependence. Due to the distorted 1T structure, ReSe₂ has a low-symmetry lattice characteristic that is similar to ReS₂ and BP [18]. In different directions of the in-plane structure of ReSe₂, there are significant differences in properties, including phonon behavior, magnetic characteristics, transport properties, and so on [19]. Therefore, this material has a larger variation in physical, chemical, optical, and electrical properties, and it has great potential in applications [20–26].

With the rapid development of the material applications, one of the significant applications of the few-layer TMDs are to be used as SA. Such as MoS₂ have been widely studied in the field of fiber laser and all-solid-state laser [27,28]. Recently, SnS₂ and SnSe₂ are successfully applied to pulse lasers acting as saturable absorber (SA) in fiber laser and in waveguide laser, respectively [29,30]. ReSe₂, as a specific TMDs, is able to work as a SA. Because of the weak-layered dependent feature, it is not necessary to strictly control the thickness of ReSe₂ for many applications, which greatly simplifies the preparation requirements [17]. There is a report about a Q-switched fiber laser with ReSe₂ SA, whose shortest pulse width was 4.98 µs and highest repetition rate was 16.64 kHz [31]. However, based on ReSe₂ SA, the all-solid-state laser performances have not been reported.

In this paper, we firstly demonstrated a passively Q-switched Nd:YVO₄ laser incorporating ReSe₂ as SA in an all-solid-state laser. The ReSe₂ with a few-layer structure was prepared by the ultrasonic exfoliation technique. A series of measurements were used to characterize the properties of ReSe₂ sample. The saturation intensity was about 6.37 MW/cm², the non-saturable absorbance equaled to 16.84%, and the modulation depth was fitted to be 1.89%. For the Q-switched pulse laser, the threshold absorbed pump power was 227 mW. The maximum average output power was 125 mW. When the absorbed pump power was 837 mW, the shortest pulse width of 682 ns and the highest repetition rate of 84.16 kHz were obtained. Our experiment shows that the few-layer ReSe₂ could be used as 1 µm SA in all-solid-state lasers.

2. Preparation and Properties of Rhenium Diselenide

In the experiment, based on the feature of weak-layered dependence, there was no need to strictly control the uniformity of the ReSe₂ SA. So, the ultrasonic exfoliation method was chosen to prepare ReSe₂ SA. This method was simple and efficient. The ReSe₂ dispersion solution was prepared by adding 0.5 mg ReSe₂ powder to 200 mL of 15% alcohol. The mixture was placed in the ultrasonic cleaner for 48 h, and then stored at room temperature for 24 h. For the SA fabrication, the supernatant was made to spin on sapphire base and put in a drying cabinet for 24 h. Additionally, the properties of the ReSe₂ were characterized by using a Raman spectrometer (HORIBA LabRAM HR Evolution, Paris, France), a scanning electron microscope (SEM, Zeiss Sigma 500, Oberkochen, Germany), a transmission electron microscope (TEM, JEM-2100, Tokyo, Japan), and a home-built Yb-doped mode-locked laser.

Raman scattering experiments reported that ReSe₂ had the abundant spectra [16]. As shown in Figure 1a, the powdered ReSe₂ Raman spectrum is displayed. There were marked three main Raman shifts, corresponding to the E₉ (124 cm⁻¹) and A₉ (159 cm⁻¹ and 173 cm⁻¹) modes. The E₉ and A₉ were equivalent to in-plane and out-of-plane vibrational modes, respectively. At the same time, because of the low-symmetry of ReSe₂, many small peaks were noticed in the experimental scope [32]. The morphology of ReSe₂ powder was elucidated by the SEM image, which is reproduced in Figure 1b. SEM image shows that the pre-dispersed ReSe₂ powder is a multi-layer structure with micro level in size.
To test the shape of ReSe$_2$ through ultrasonic exfoliation, the TEM image of the dispersion solution is shown in Figure 2. Compared with the SEM image, ReSe$_2$ was effectively stripped into nano-scale sheets. The optical resolution of the TEM microscope was 50 nm.

A power-dependent transmission technique was employed for investigating the saturable absorption properties of ReSe$_2$ SA. For this experiment, the pump source was a home-built nonlinear polarization rotation mode-locked Yb-doped fiber laser with 68 ps pulse width at 1064 nm and repetition rate of 38.6 MHz. Based on the formula:

\[ T(I) = 1 - T_{ns} - \Delta T \times \exp\left(-I/I_{sat}\right) \]  

where \( T(I) \) is the transmittance, \( T_{ns} \) represents the non-saturable absorbance, \( \Delta T \) is the modulation depth, \( I \) signifies the input intensity of laser, and \( I_{sat} \) is the saturation intensity [30]. The experimental results are shown in Figure 3. Fitting the experimental results, the saturation intensity, non-saturable absorbance, and modulation depth were 6.37 MW/cm$^2$, 16.84%, and 1.89%, respectively. In subsequent experiments, attempts were made to change raw material parameters and optimize the preparation process. ReSe$_2$ SA materials with different parameters are expected to be obtained, thus making them more suitable for a variety of applications.
Figure 3. Nonlinear saturable absorption curve of the few-layer ReSe$_2$ SA.

3. The Passively Q-Switched Experiment

The passively Q-switched Nd:YVO$_4$ experiment was pumped by a fiber coupled diode laser. Its central wavelength, core diameter and numerical aperture were 808 nm, 200 µm and 0.22, respectively. An 1:1 optics coupling system focused the pump laser into a commercialized Nd:YVO$_4$ bulk crystal stabilized by a water-cooling system to remove heat. The linear type resonator had two mirrors, M1 and M2, of which M1 was the input mirror with radius of 100 mm and M2 was the output mirror with transmission of 5%. The cavity length was about 30 mm. After acquiring the continuous wave (CW) laser, the ReSe$_2$ SA was inserted in the resonator. Owing to the effect of ReSe$_2$ SA, the passively Q-switched laser was then obtained.

Figure 4a shows the average output power properties for CW and Q-switched laser. The CW laser obtained the maximum average output power of 284 mW and it had a slope efficiency of 36.72%. For the Q-switched laser, the threshold of absorbed pump power was 227 mW, and the pulse laser had an average output power of 17 mW. When the absorbed pump power was increased to 837 mW, the maximum average output power was 125 mW. The average output power was linear with the absorbed pump power, and the slope efficiency was 17.27%. As illustrated in the Figure 4b, the measured beam profile was close to the TEM$_{00}$ mode, and the spot size is as shown. The laser spectrum, as shown in Figure 4c, is centered at 1064.4 nm, with a full width at half maximum of 0.68 nm (The spectrometer had a sampling resolution of 0.24 nm).

At the absorbed pump power of 227 mW, the passively Q-switched laser was established with a pulse width of 1.16 µs and repetition rate of 42.08 kHz. As the absorbed pump power increased, Figure 5a presents the behaviors of the pulse width and the pulse repetition rate. The experiment acquired the shortest pulse width of 682 ns and the highest repetition rate of 84.16 kHz. The corresponding pulse energy and peak power are shown in Figure 5b. Under the absorbed pump power of 837 mW, the Q-switched laser was calculated to be a pulse energy of 1.49 µJ and a pulse peak power of 2.18 W. Figure 6 shows the corresponding pulse form. For these measurements, we used a power meter (Ophir 30(150)A-BB-18, Jerusalem, Israel), optical spectrum analyzer (Ocean Optics HR4000, Largo, FL, USA), fast photodiode (EOT ET-3000A, Traverse, MI, USA), and digital oscilloscope (Tektronix MD03104, Beaverton, OR, USA).
Figure 4. (a) Average output power properties for CW and Q-switched laser, (b) two-dimensional (2D) image of Q-switched output beam spatial profile, and (c) the laser spectrum at the maximum output power for Q-switching.

Figure 5. (a) The variation of the pulse width and repetition rate, and (b) the variation of the pulse energy and peak power.

Figure 6. The pulse profile of the Q-switched laser.
Table 1 summarized the various Q-switched lasers that were used to the diverse TMDs as SA in all-solid-state devices, with Nd-ion-doped gain medium and emitting wavelength at near 1064 nm. When compared with results, based on ReSe$_2$ SA, our works obtained the comparable laser performances. Table 1 concludes that ReSe$_2$ has the capacity to act as SA for all-solid-state pulse laser experiments. More importantly, the weaker interlayer coupling properties greatly reduced the preparation requirements of few-layer materials. Further optimizing the material, better results are expected to be achieved.

Table 1. Comparison of the passively Q-switched results in all-solid-state lasers based on transition metal dichalcogenides saturable absorber (TMDs SA).

| Sa    | Gain Medium | Pulse Width (ns) | Repetition Rate (kHz) | Output Power (mW) | Slope (%) | Ref. |
|-------|-------------|------------------|-----------------------|-------------------|-----------|------|
| MoS$_2$ | Nd:LuAG     | 280              | 210                   | 290               | 5.2       | [33] |
|       | Nd:YVO$_4$  | 327              | 5                     | 199               | 9         | [34] |
|       | Nd:GdVO$_4$ | 970              | 732                   | 227               | -         | [35] |
|       | Nd:YAG      | 2800             | 20.8                  | 23.5              | -         | [36] |
| WS$_2$ | Nd:YVO$_4$  | 153              | 1578                  | 1190              | 30        | [37] |
|       | Nd:GdTaO$_4$ | 560             | 70                    | 309               | 6.87      | [38] |
|       |              | 668              | 61.2                  | 356               | 7.91      | [38] |
|       | Nd:YAG      | 922              | 52.48                 | 42.6              | -         | [39] |
|       | 1030         |                  | 47.05                 | 46                | -         | [39] |
|       | 1280         |                  | 45.25                 | 54                | -         | [39] |
| ReSe$_2$ | Nd:YVO$_4$ | 682              | 84.16                 | 125               | 17.27     | Our  |

4. Conclusions

In summary, a few-layer ReSe$_2$ was prepared by ultrasonic exfoliation and demonstrated as SA in an all-solid-state pulsed Nd:YVO$_4$ laser. The passively Q-switched Nd:YVO$_4$ experiment acquired the maximum average output power of 125 mW with a slope efficiency of 17.27%. The spectrum was centered at 1064.4 nm. The shortest pulse width was 682 ns and the highest repetition rate was 84.16 kHz, corresponding to a pulse energy of 1.49 µJ and pulse peak power of 2.18 W. Further, the ReSe$_2$ SA was characterized with its saturation intensity of 6.37 MW/cm$^2$ and modulation depth of 1.89%. The experiment results show that ReSe$_2$ is an effective SA for 1 µm all-solid-state pulse lasers and they promote the potential applications of weak-layered dependent TMDs.

Author Contributions: Y.L. supervised and supported the experiment. C.L. executed the experiments, handled the experimental data and wrote the manuscript. J.H. provided the ReSe$_2$ SA and corresponding parameters.

Funding: This research was funded by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDB1603); International S&T Cooperation Program of China (Grant No. 2016YFE0119300); National Natural Science Foundation of China (NSFC) (Grant Nos. 61521093, 61505224).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bonaccorso, F.; Sun, Z.; Hasan, T.; Ferrari, A.C. Graphene photonics and optoelectronics. Nat. Photonics 2010, 4, 611–622. [CrossRef]
2. Wang, W.; Li, L.J.; Zhang, H.T.; Qin, J.P.; Lu, Y.; Xu, C.; Li, S.S.; Shen, Y.J.; Yang, W.L.; Yang, Y.Q.; Yu, X.Y. Passively Q-switched operation of a Tm, Ho:LuVO$_4$ laser with a graphene saturable absorber. Appl. Sci. 2018, 8, 954. [CrossRef]
3. Sobon, G. Mode-locking of fiber lasers using novel two-dimensional nanomaterials: Graphene and topological insulators. Photonics Res. 2015, 3, A56–A63. [CrossRef]
4. Wang, X.; Wang, Z.F.; Wang, Y.G.; Li, L.; Yang, G.W.; Li, J.P. Watt-level high-power passively Q-switched laser based on a black phosphorus solution saturable absorber. Chin. Opt. Lett. 2017, 15, 011402. [CrossRef]
5. Chen, H.; Yin, J.D.; Yang, J.W.; Zhang, X.J.; Liu, M.L.; Jiang, Z.K.; Wang, J.Z.; Sun, Z.P.; Guo, T.; Liu, W.J.; Yan, P.G. Transition-metal dichalcogenides heterostructure saturable absorbers for ultrafast photonics. Opt. Lett. 2017, 42, 4279–4282. [CrossRef] [PubMed]
6. Woodward, R.I.; Kelleher, E.J.R. 2D saturable absorbers for fibre lasers. *Appl. Sci.* 2015, 5, 1440–1456. [CrossRef]

7. Zhang, H.; Lu, S.B.; Zheng, J.; Du, J.; Wen, S.C.; Tang, D.Y.; Loh, K.P. Molybdenum disulfide (MoS$_2$) as a broadband saturable absorber for ultra-fast photonics. *Opt. Express* 2014, 22, 7249–7260. [CrossRef] [PubMed]

8. Woodward, R.I.; Howe, R.C.T.; Hu, G.; Torrisi, F.; Zhang, M.; Hasan, T.; Kelleher, E.J.R. Few-layer MoS$_2$ saturable absorbers for short-pulse laser technology: Current status and future perspectives. *Photonics Res.* 2015, 3, A30–A42. [CrossRef]

9. Janisch, C.; Mehta, N.; Ma, D.; Elias, A.L.; Perea-López, N.; Terrones, M.; Liu, Z.W. Ultrashort optical pulse characterization using WS$_2$ monolayers. *Opt. Lett.* 2014, 39, 383–385. [CrossRef] [PubMed]

10. Gonzalez, J.M.; Oleynik, I.I. Layer-dependent properties of SnS$_2$ and SnSe$_2$ two-dimensional materials. *Phys. Rev. B* 2016, 94, 125443. [CrossRef]

11. Huang, Y.; Sutter, E.; Sadowski, J.T.; Cotlet, M.; Monti, O.L.A.; Racke, D.A.; Neupane, M.R.; Wickramaratne, D.; Lake, R.K.; Parkinson, B.A.; Sutter, P. Tin disulfide; an emerging layered metal dichalcogenide semiconductor: Materials properties and device characteristics. *ACS Nano* 2014, 8, 10743–10755. [CrossRef] [PubMed]

12. Zhong, H.X.; Gao, S.Y.; Shi, J.J.; Yang, L. Quasiparticle band gaps, excitonic effects, and anisotropic optical properties of the monolayer distorted 1T diamond-chain structures ReS$_2$ and ReSe$_2$. *Phys. Rev. B* 2015, 92, 115438. [CrossRef]

13. Hafeez, M.; Gan, L.; Li, H.Q.; Ma, Y.; Zhai, T.Y. Chemical vapor deposition synthesis of ultrathin hexagonal ReSe$_2$ flakes for anisotropic Raman property and optoelectronic application. *Adv. Mater.* 2016, 28, 8296–8301. [CrossRef] [PubMed]

14. Su, X.C.; Nie, H.K.; Wang, Y.R.; Li, G.R.; Yan, B.Z.; Zhang, B.T.; Yang, K.J.; He, J.L. Few-layered ReSe$_2$ as saturable absorber for 2.8 µm solid state laser. *Opt. Lett.* 2017, 42, 3502–3505. [CrossRef] [PubMed]

15. Zhang, E.Z.; Wang, P.; Li, Z.; Wang, H.F.; Song, C.Y.; Huang, C.; Chen, Z.G.; Yang, L.; Zhang, K.T.; Lu, S.H.; et al. Tunable ambipolar polarization-sensitive photodetectors based on high-anisotropy ReSe$_2$ nanosheets. *ACS Nano* 2016, 10, 8067–8077. [CrossRef] [PubMed]

16. Wolverson, D.; Crampin, S.; Kazemi, A.S.; Ibie, A.; Bending, S.J. Raman spectra of monolayer, few-layer, and bulk ReSe$_2$: An anisotropic layered semiconductor. *ACS Nano* 2014, 8, 11154–11164. [CrossRef] [PubMed]

17. Tian, H.; Zhao, H.A.; Wang, H. Novel electronic and photonic properties of low-symmetry two-dimensional materials. In Proceedings of the 2016 IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC), Hong Kong, China, 3–5 August 2016; pp. 234–238.

18. Lorchat, E.; Froehlicher, G.; Berciaud, S. Splitting of interlayer shear modes and photon energy dependent anisotropic Raman response in N-layer ReSe$_2$ and ReS$_2$. *ACS Nano* 2016, 10, 2752–2760. [CrossRef] [PubMed]

19. Yang, S.X.; Wang, C.; Sahin, H.; Chen, H.; Li, Y.; Li, S.S.; Suslu, A.; Peeters, F.M.; Liu, Q.; Li, J.B.; Tongay, S. Tuning the optical, magnetic, and electrical properties of ReSe$_2$ by nanoscale strain engineering. *Nano Lett.* 2015, 15, 1600–1606. [CrossRef] [PubMed]

20. Cui, F.F.; Li, X.B.; Feng, Q.L.; Yin, J.B.; Zhou, L.; Liu, D.Y.; Liu, K.Q.; He, X.X.; Liang, X.; Liu, S.Z.; et al. Epitaxial growth of large-area and highly crystalline anisotropic ReSe$_2$ atomic layer. *Nano Res.* 2017, 10, 2732–2742. [CrossRef]

21. Qj, F.; Wang, X.Q.; Zheng, B.J.; Chen, Y.F.; Yu, B.; Zhou, J.H.; He, J.R.; Li, P.J.; Zhang, W.L.; Li, Y.R. Self-assembled chrysanthemum-like microspheres constructed by few-layer ReSe$_2$ nanosheets as a highly efficient and stable electrocatalyst for hydrogen evolution reaction. *Electrochim. Acta* 2017, 224, 593–599. [CrossRef]

22. Ho, C.H.; Huang, C.E. Optical property of the near band-edge transitions in rhenium disulfide and diselenide. *J. Alloy. Compd.* 2004, 383, 74–79. [CrossRef]

23. Ho, C.H.; Liao, P.C.; Huang, Y.S.; Yang, T.R.; Tong, K.K. Optical Absorption of ReS$_2$ and ReSe$_2$ Single Crystals. *J. Appl. Phys.* 1997, 81, 6380–6383. [CrossRef]

24. Jian, Y.C.; Lin, D.Y.; Wu, J.S.; Huang, Y.S. Optical and electrical properties of Au- and Ag-doped ReSe$_2$. *Jpn. J. Appl. Phys.* 2013, 52, 04CH06. [CrossRef]

25. Ho, C.H.; Huang, Y.S.; Tong, K.K.; Liao, P.C. Absorption-edge anisotropy in ReS$_2$ and ReSe$_2$ layered semiconductors. *Phys. Rev. B* 1998, 58, 16130–16135. [CrossRef]
27. Liu, H.; Luo, A.P.; Wang, F.Z.; Tang, R.; Liu, M.; Luo, Z.C.; Xu, W.C.; Zhao, C.J.; Zhang, H. Femtosecond pulse erbium-doped fiber laser by a few-layer MoS\textsubscript{2} saturable absorber. \textit{Opt. Lett.} \textbf{2014}, \textit{39}, 4591–4594. [CrossRef] [PubMed]
28. Lu, J.; Zou, X.; Li, C.; Li, W.K.; Liu, Z.Z.; Liu, Y.Q.; Leng, Y.X. Picosecond pulse generation in a mono-layer MoS\textsubscript{2} mode-locked Ytterbium-doped thin disk laser. \textit{Chin. Opt. Lett.} \textbf{2017}, \textit{15}, 041401.
29. Cheng, C.; Li, Z.Q.; Dong, N.N.; Wang, J.; Chen, F. Tin diselenide as a new saturable absorber for generation of laser pulses at 1 \textmu m. \textit{Opt. Express} \textbf{2017}, \textit{25}, 6132–6140. [CrossRef] [PubMed]
30. Niu, K.D.; Chen, Q.Y.; Sun, R.Y.; Man, B.Y.; Zhang, H.N. Passively Q-switched erbium-doped fiber laser based on SnS\textsubscript{2} saturable absorber. \textit{Opt. Mater. Express} \textbf{2017}, \textit{7}, 3934–3943. [CrossRef]
31. Du, L.; Jiang, G.B.; Miao, L.L.; Huang, B.; Yi, J.; Zhao, C.J.; Wen, S.C. Few-layer rhenium diselenide: An ambient-stable nonlinear optical modulator. \textit{Opt. Mater. Express} \textbf{2018}, \textit{8}, 926–935. [CrossRef]
32. Jiang, S.L.; Zhang, Z.P.; Zhang, N.; Huan, Y.H.; Gong, Y.; Sun, M.X.; Shi, J.P.; Xie, C.Y.; Yang, P.F.; Fang, Q.Y.; et al. Application of chemical vapor–deposited monolayer ReSe\textsubscript{2} in the electrocatalytic hydrogen evolution reaction. \textit{Nano Res.} \textbf{2018}, \textit{11}, 1787–1797. [CrossRef]
33. Wang, C.; Zhao, S.Z.; Li, T.; Yang, K.J.; Luan, C.; Xu, X.D.; Xu, J. Passively Q-switched Nd:LuAG laser using few-layered MoS\textsubscript{2} as saturable absorber. \textit{Opt. Commun.} \textbf{2018}, \textit{406}, 249–253. [CrossRef]
34. Wang, G.J.; Song, Q.; Zhang, B.Y.; Gao, Y.J.; Wang, W.J.; Wang, M.H. Passively Q-switched Nd:YVO\textsubscript{4} laser using molybdenum disulfide (MoS\textsubscript{2}) as a saturable absorber. \textit{Optik-Int. J. Light Electron. Opt.} \textbf{2016}, \textit{127}, 3021–3023. [CrossRef]
35. Wang, S.X.; Yu, H.H.; Zhang, H.J.; Wang, A.Z.; Zhao, M.W.; Chen, Y.X.; Mei, L.M.; Wang, J.Y. Broadband few-layer MoS\textsubscript{2} saturable absorbers. \textit{Adv. Mater.} \textbf{2014}, \textit{26}, 3538–3544. [CrossRef] [PubMed]
36. Lin, T.; Sun, H.; Wang, X.; Mao, D.; Wang, Y.G.; Li, L.; Duan, L.N. Passively Q-switched Nd:YAG laser with a MoS\textsubscript{2} solution saturable absorber. \textit{Laser Phys.} \textbf{2015}, \textit{25}, 125805. [CrossRef]
37. Wang, X.; Li, L.; Li, J.P.; Wang, Y.G. 1.5-MHz repetition rate passively Q-switched Nd:YVO\textsubscript{4} laser based on WS\textsubscript{2} saturable absorber. \textit{Opt. Commun.} \textbf{2016}, \textit{367}, 234–238. [CrossRef]
38. Li, M.X.; Jin, G.Y.; Li, Y. Diode-pumped passively Q-switched Nd:GdTaO\textsubscript{4} laser based on tungsten disulfide nanosheets saturable absorber at 1066 nm. \textit{Infrared Phys. Techn.} \textbf{2018}, \textit{90}, 195–198. [CrossRef]
39. Wang, X.; Wang, Y.G.; Duan, L.N.; Li, L.; Sun, H. Passively Q-switched nd:YAG laser via a WS\textsubscript{2} saturable absorber. \textit{Opt. Commun.} \textbf{2016}, \textit{367}, 234–238. [CrossRef]