Dear editor and reviewer,

Thank you very much for giving us an opportunity to revise our manuscript. We greatly appreciate the reviewer's comments on our early manuscript titled "**Narrow linewidth passively *Q*-switched fiber laser based on microsphere resonator" (ID TMOP-2020-0130)**. The comments are all valuable and helpful for revising and improving our manuscript. We have carefully addressed all the comments. The major revisions are highlighted by using bold and colored text in the revised manuscript. The corresponding changes and refinements made in the revised paper are summarized in our response below.

If you find any problems or have any advice to us, please feel free to let us know and we will write to you as soon as possible.

Thank you and best regards.

Yours sincerely,

Hong Zhang, Yajie Wu

Response to the comments of reviewer

Comment 1:

Significance 1: The author places a weakly coupled microsphere resonating filter in a q-switching cavity and measured linewidth narrowing as well as changes to pulse shape. While it seems true that there is no published graphene passively q-switched laser stabilized with a microsphere, the author provides no justification as to why one would choose to over more conventional filtering techniques (such as FBGs) that provide comparable performance, with greater ease.

I do not believe this will be of interest to be cited, but I would change my mind with motivation.

Response:

For the comment described above, we may not describe the advantages of our works clearly in the previous manuscript, so there are some doubts as to the significance of our works. We have added description of the advantages of microsphere compared with other filters and some previous works from page 3 line 9 to page 4 line 3.

As we all know, microsphere is an excellent optical microcavity, we will describe the advantages in detail and compare microsphere with conventional filters.

- **The advantages of microsphere cavity:**

1. The microsphere cavity has a broad free spectral range(FSR) and high Q factor which can reach 10^9, by using simple fabrication method[1,2]. And microsphere cavity also has the characteristics of compact structure and high fineness[3].
2. When the microsphere cavity is used as a filter, its coupling methods are mainly free light field coupling, optical waveguide coupling, prism coupling, and tapered fiber coupling. Because the microsphere cavity is introduced into the fiber laser in this work, we adopt a relatively simple and compact fiber taper-microsphere coupling to maintain the all-fiber structure. This method has great convenience, low cost and high stability.

- **The advantages and disadvantages of conventional filters for fiber lasers:**

1. Fiber Fabry–Perot filter (FFP): It has flexible structure and is easy to tune the wavelength, but the Q factor is relatively low compared with microsphere. And FFP filter insertion loss is also relatively high[4].
2. Fiber Mach-Zehnder filter: It is made by connecting two or more couplers. Such filter is cheap and has simple structure. However, it is necessary to control the phase difference of the two arms to achieve a good filtering effect, and its anti-interference ability is poor[5].
3. FBG: It has the advantages of fiber compatibility, ease of use, and low cost. But the fabrication method is relatively complicate and inflexible. And it is difficult to further compression the bandwidth[6,7].

In conclusion, the microsphere cavity has small size which makes it easy to integrate. It also possesses the advantages of broad FSR, high Q factor, low cost and high stability, but conventional filters cannot have these advantages at same time. It has been demonstrated by theory and experiment that bandwidth of microsphere filter is much narrower than other filters [8]. The key parameters of the above filters are listed in table 1.

Table. 1 Comparison of narrow linewidth Q-switched based on different filters

filters	**Q-switching method**	**repetition rate (kHz)**	**pulse duration (μs)**	**output power (mW)**	**3dB(nm)**	**OSNR (dB)**	**Ref**
FBG	Bi_2Te_3	49.40	3.71	/	<0.04	/	[8]
FFP	Electricoptical (E-O) switch	Irregular oscillation			0.06	28	[4]
multimode interference filter	AOM	/	~0.185	~10	0.1	/	[9]
ultranarrow tunable bandpass filter	single wall carbon nanotubes	13.3	2.94	0.00251	0.017	/	[10]
Microsphere	**graphene**	**28**	**5.2**	**0.26**	**0.016**	**57**	**our work**

Comment 2:

Scientific Validity: Page 10 line 17 of the proof numbering states a FWHM of 0.016 nm. I think this is approximately the response of the OSA the author is using. This should be confirmed and specified as the author may be overstating the resulting linewidth.

Narrowing is much more dramatic than the same filter would generate external to the cavity (as expected).

Lasing efficiency is not heavily impacted (as desired).

I am not convinced by the paper that the author has maintained comparable pulse energy. If average power has remained the same, but pulse energy has decreased significantly, then this is a very bad result (bad in terms of utility and significance not bad in terms of science accomplished). The manuscript requires an evaluation of pulse energies.

Response:

Thanks for the comment. I will explain from the following points:

About linewidth of the microsphere

We have added a description at the end of page 6 and page 9 to explain the fileting effect of our microsphere. The more detailed explanations are as follows:

1. When we measured the transmission characteristic of the microsphere, the laser source we used was the CL-Band ASE (1528 nm-1602 nm), and the optical spectrum analyzer (OSA) was YOKOGAWA AQ6375B which spectral resolution is 0.5 nm. The precision accuracy of measure method is relatively low, which limits us to obtain the real Q factor of the prepared microsphere. Regarding the author's question, we consulted the reference again. In the reference[11], the 3 dB bandwidth of the microring measured is 0.066nm which is also larger than the laser output linewidth of 0.016nm by this measure method(OSA; Yokogawa AQ6370C).
2. In the laser experiment, due to the failure of the YOKOGAWA AQ6375B, we used YOKOGAWA AQ6370D to measure the laser output wavelength. Its spectral resolution is 0.02

nm. The linewidth of output laser is 0.016nm, which is close to the resolution limit of the OSA. Therefore, the 3dB bandwidth may be smaller than 0.016 nm.

3. In reference [12], WGM is excited by a tunable laser , the tuning step is 0.5 pm, and then detected by a photodetector, which can avoid missing some resonance wavelengths and accurately measure 3dB bandwidth of resonant peak. Therefore, our next step is to purchase new instruments and improve measurement methods to obtain more accurate transmission spectra of microsphere.

About lasing efficiency

Thanks to the reviewer's question about the laser efficiency, we have added the data of max pulse energy and peak power in page 9 line 3 and 10 line 16, and we also explain the reason of the increased laser threshold and reduced the efficiency in the cavity with microsphere in page 9 line 13.

In the previous manuscript, we provided data curves of the average output power versus pump power in two cases. It can be clearly seen from the figure that the introduction of microsphere brings additional losses to the laser, which increases the laser threshold and reduces the efficiency of the laser. Because the purpose of this article is to make the pulse laser with a narrow linewidth spectrum, so the results of pulse energy were not provided in our early manuscript. This type of laser has the advantages of narrow linewidth and high peak power, and has important requirements in lidar and optical communications etc.

We show the curves in Fig. 1(a) and Fig.1(b) which provide pulse energy and peak power of our *Q*-switched fiber laser with and without microsphere. It can be seen that the pulse energy increased irregularly, which may be related to the different growth rate between the repetition frequency and the average power. The repetition frequency increases faster than that of the average power, which causes the pulse energy to decrease at the high pump power. This phenomenon also appears in Ref [8] and Ref [13].

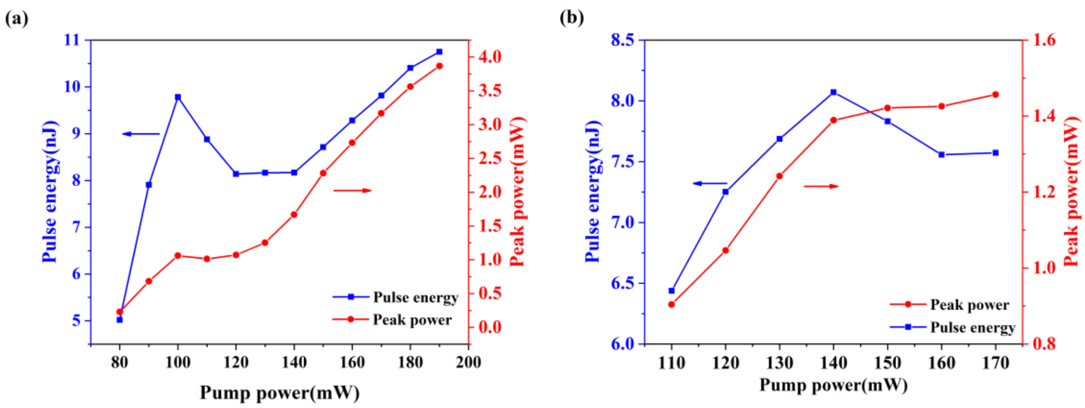

Fig. 1 (a) The peak power and the pulse energy versus pump power of laser without microsphere. (b) The peak power and the pulse energy versus pump power of laser with microsphere.

As we all know, inserting some optical components into laser cavity will bring some losses. In our works, the maximum pulse energy and peak power obtained are of 10.8 nJ and 3.9 mW under the pump power of 190 mW in cavity without microsphere. In cavity with microsphere，the maximum pulse energy and peak power obtained are of 8.1 nJ and 1.5 mW. After inserting the microspheres, the output energy of the pulsed laser is lower and the threshold is increased than before. The reasons may be:

1. There will be loss when the fiber taper is coupled with the microsphere.

2. The loss will be introduced, due to the simple fabrication method and the unsmooth surface of the microsphere. If the fabrication method is improved, such as using CO_2 laser, the loss will be reduced.

At the same time, we believe that keeping a narrow linewidth with less impact on output energy can become the focus of our future research.

In addition, there is another reason why the output power is low. The saturable absorber in the experiment limits the pump power to increase. This problem can be solved by preparing a more excellent saturable absorber, then the average laser power will be improved.

Comment 3:

Scientific Contribution: This is relatively insignificant as the microsphere resonator does not seem to provide filtering that cannot be accomplished through simpler means.

I do believe a revised version of this paper belongs somewhere in the literature to either dissuade duplication of effort or encourage the creativity of someone who can determine a more useful feature of a microsphere resonator in this type of laser.

Response:

Thanks to the review's comments, the more detailed description of our works' significance have been added in page 3 line 21 and page 4 line 20. The application of microspheres as filters has been proven. The narrow linewidth fiber lasers based on microspheres have been studied a lot in continuous-wave lasers, but the power of continuous wave output is relatively lower. The main purpose of our research is to improve the output power of narrow linewidth lasers based on microspheres. So, we adopted passively *Q*-switching technology to increase the peak power of the laser output. In our works, the linewidth of pulsed laser is significantly compressed, which is much narrower than previous works used conventional filters. This paper mainly provides a new way to achieve narrow linewidth pulsed fiber laser which can be used in Doppler lidar, differential lidar, optical coherent detection, remote sensing and optical communication.

Comment 4:

Overall Presentation: The abbreviation WGM is not described before use.

All figures in the proof are numbered Figure 1. I don't know if this is an artifact of the submission process, but it needs fixing.

While nearly completely understandable, the manuscript requires grammatical review by someone more skilled in English.

Response:

Thanks for the suggestion. We have already added description of the abbreviation WGM highlighted in red text in page 3 line 8 and modified the figure number. The revisions of English grammar are marked in bold.

Comment 5:

Any Other Comments to the Author

I do not believe seven people made scientific contributions to this work. I expect the number to be 5 or fewer based on the number of custom components in the experiments and measurements. Please review the authors list and limit it to only those who made scientific impact on the work so that the scientists can be appropriately valued.

Response:

Thanks for the suggestion. This is my first scientific research experience, so many people have helped me and I list their contributions to this work.

1. Hong Zhang: he and I put forward the experiment idea together, and he guided me to do the whole experiments.
2. Hao Zhou: at the beginning of my microsphere coupling experiment, I tried various parameters but the coupling experiment always failed. He answered my questions and gave me suggestions.
3. Fangjie Wang: he worked with me on coupling experiments, taught me how to use instruments, make microspheres.
4. Fengqiong Long: teaching me to do the experiment of passively *Q*-switched pulse fiber laser.
5. Shutong Wang, Jiulin Yang: fabricating and providing *Q*-switched materials.
6. Shouhuan Zhou: guiding my experiment and explaining various confusions in the fiber laser experiments.

We appreciate for editors and reviewer's warm work earnestly, and hope that the correction will meet with approval.

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Narrow linewidth passively *Q*-switched fiber laser based on microsphere resonator

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Abstract: We experimentally demonstrate a stable narrow linewidth passively *Q*-switched fiber laser based on a microsphere resonator (MSR) and graphene saturable absorber (SA). The MSR made by the arc discharge method has the characteristics of easy fabrication, broad free spectral range (FSR) and flexibility. And it acts as a narrow band-pass filter to ensure narrow linewidth operation. A stable passively *Q*-switched pulse with 0.016 nm narrow spectral linewidth is successfully achieved. The output pulse has the pulse width of 5.2 μs, repetition frequency of 28 kHz and high signal to noise ratio (SNR) of ~60 dB. The results demonstrate that our works may provide an effective way to achieve narrow-linewidth pulsed fiber lasers.

1. Introduction

In recent decades, narrow linewidth fiber lasers have been comprehensively and thoroughly investigated owing to their extensive applications in high-resolution spectroscopy, dense wavelength division multiplexing (WDM), high-sensitivity sensing and optical communications[1-4]. Most of narrow linewidth lasers operate in continuous wave (CW) mode. However, their output power is relatively low compared with pulsed fiber lasers, which limits the applications of them. **As we all know, *Q*-switching is an effective technique to generate giant laser pulses.** By introducing *Q*-switching operation into narrow linewidth laser, **the output power will increase observably and coherence of laser will not be distorted.** Such lasers are in great demand in Doppler lidar, differential laser radar, optical coherent detection and remote sensing[5-8]. Therefore, it is significant to exploit narrow linewidth *Q*-switching fiber laser.

To date, various narrow band-pass filter components have been developed and inserted into laser cavity to achieve narrow linewidth operation, such as fiber Mach-Zehnder filter, fiber Fabry-Perot cavity comb filter, fiber Bragg gratings (FBGs) [9-11], etc. As development of whispering gallery mode (WGM) microcavities, they have been used as wavelength selectors and stabilizers in narrow linewidth lasers. The WGM optical microcavity possesses the advantages of broad FSR, high Q factors, easy integration, low cost and high stability, while conventional filters cannot own these advantages at same time and could not guarantee the stable narrow linewidth to work in tandem with the *Q*-switched operation [12-15]. The WGM resonators include microsphere, mirroring, microdisk, etc. In these WGM resonators, the microsphere has the highest Q factor, the relatively simple fabrication method, compact structure and high fineness [16-18]. Furthermore, some works have shown the great advantages of microspheres as filters. In 2007, a narrow linewidth fiber laser based on a high-Q glass microsphere have been demonstrated. The microsphere is used as a wavelength-selective mirror in laser cavity [19]. And in Ref.[20], a double-ring cavity single longitudinal-mode narrow linewidth fiber laser is proposed and demonstrated. The MSR with ultra-narrow transmission band of 1 pm is used as the single longitudinal-mode selector. It is noticed that the previously demonstrated narrow linewidth fiber lasers based on microspheres are mainly CW lasers.

However, such a configuration could not provide high output power. It is worth considering how to increase the output power of the narrow linewidth fiber laser based on microspheres.

In order to obtain narrow linewidth giant pulse, narrow linewidth operation can be combined with passively *Q*-switching technique. Passively *Q*-switching is an effective technique to generate giant pulses. **It benefits from the saturable absorption properties of the materials, and possesses the advantage of compact structure, simple design and low cost.** Many kinds of saturable absorbers (SA) have been used in fiber lasers to achieve passively *Q*-switching [21-25]. Compared to other materials, graphene is an excellent saturable absorber with the characteristics of low saturation strength, deep modulation depth, high damage threshold, easy fabrication, ultra-fast recovery time and broadband saturation absorption range[23]. Thus, the graphene was used in our experiments to trigger passively *Q*-switching operation.

Up to now, a few methods have been employed to obtain stable narrow linewidth *Q*-switching pulse. Distributed feedback (DFB) fiber laser with narrow linewidth has been successfully achieved by introducing FBG and new *Q*-switching devices into the cavity [26]. A 212-kHz-linewidth single frequency *Q*-switched fiber laser has been successfully demonstrated by the combination of a Bi_2Se_3 saturable absorber and an ultra-narrow pass filter. **A 1-m unpumped EDF together and a 0.06-nm-bandwidth fiber Bragg grating form the ultra-narrow bandpass filter** [27]. However, there still need to make efforts to further compress spectral linewidth with improved stability and compactness, as well as a reduced cost for narrow linewidth *Q*-switched laser operation. In several CW lasers, it has been proved that WGM microcavities have good performance of acting as wavelength selectors to obtain ultra-narrow linewidth. However, WGM microcavities have not been used in pulsed fiber lasers to achieve narrow linewidth.

In this paper, to the best of our knowledge, we present the first design and demonstration of a stable narrow linewidth passively *Q*-switched fiber laser based on MSR. **In our design, the graphene SA initiated *Q*-switching operation.** The 192 μm diameter MSR was used to compress linewidth of the fiber laser, which had the characteristics of easy fabrication, a broad FSR and flexibility. In the laser cavity configuration with MSR, the spectral linewidth of the output signal kept as narrow as 0.016 nm at different pump power. The output pulse with the minimum pulse duration of 5.2 μs, the maximum repetition frequency of 28 kHz and the SNR of ~60 dB was also obtained. **It shows that our design exhibits a huge potential in achieving pulsed laser with narrow linewidth.**

2. Experimental preparation and setup

2.1. Preparation and characterization of graphene SA film

In our experiment, the thin-film graphene was in the form of graphene/PVA composite which was fabricated as follows: Firstly, the graphene dispersion was diluted. Then, the dispersion was mixed with polyvinyl alcohol (PVA) and stirred by an ultrasonic cleaner. Finally, the mixture was spread on the slide to form the thin film.

The nonlinear absorption of the SA was characterized by a standard two-arm transmission setup, as shown in Fig.1. The film was placed between two fiber connectors to form a fiber-integrated device. Then we measured the dependence of the transmission ratio of the device on the pump power density, by using a 1550 nm mode-locked laser with the repetition rate of 25.7 MHz and the pulse width of 52.5 ps. Variable optical attenuator (VOA) was used to vary the incident average power. A 90/10 optical coupler split the output from VOA into two parts. One output was directed into the first power meter, while another portion entered the graphene SA then exited into the second power meter. The result is depicted in Fig.2, the experimental data of the transmission is fitted according to the following formula:

$$T = 1 - \alpha_{ns} - \frac{\alpha_s}{1 + \frac{I}{I_s}}$$

where T is the transmission ratio, α_s and α_{ns} are the saturable and non-saturable absorption components, I and I_s are input and saturable intensities, respectively. The modulation depth, non-saturable loss and saturation intensity were found to be 45%, 11.2%, 3.3 MW/cm^2, respectively.

2.2. Microsphere resonator fabrication and characterization

In our works, microspheres were fabricated by heating fiber tips with a fiber fusion splicer, and the tapered fibers employed to couple with the microspheres were produced by a tapering machine. Additionally, the diameter of the prepared microsphere and the tapered fiber was 192 μm and 1.7 μm, respectively. The microsphere and the tapered fiber were placed on an adjustable three-dimensional system to precisely control the gap and coupling position. The WGM of the microsphere was excited by a C+L ASE laser source, and the output signal was monitored by an optical spectrum analyzer (YOKOGAWA, AQ6375B). It is worth mentioning that the transmission spectrum measured by this method is not very accurate due to the low precision accuracy of coupled system.

Fig.3(a) is the transmission spectrum of the entire broadband when microsphere coupled with tapered fiber on the equatorial plane. The inset in Fig.3(a) shows the coupling position observed in vertical direction. Fig.3(b) depicts several resonance peaks ranging from 1590 nm to 1600 nm. WGM transmission spectrum with extinction ratio of ~8 dB, full width at half maximum (FWHM) bandwidth of 0.81 nm and the measured FSR of 3.3 nm can be observed. We used this microsphere for following experiments.

2.3.Experimental Setup

Fig.4 shows the schematic configuration of the passively Q-switched fiber laser combined with the MSR. Pump source was a 976 nm laser diode which was launched into the ring cavity through a 980/1550 nm wavelength-division multiplexer (WDM). A 1 m long erbium doped fiber was used as the gain medium. A polarization-independent isolator (PI-ISO) and a polarization controller (PC) were utilized to force the unidirectional operation and adjust the polarization states of the laser in the cavity, respectively. The as-prepared graphene/PVA thin film as a SA played the key role to initiate passively Q-switched operation. The MSR was designed to ensure the narrow-linewidth operation. The Q-switched laser was output from one port (5%) of the 95/5 WDM coupler, analyzed by an optical spectrum analyzer (YOKOGAWA, AQ6370D) and a digital oscilloscope (ROHDE&SCHWARZ, RTO 1022).

3. Experimental results and discussions

3.1. Without MSR

In order to explore the different characteristics between conventional Q-switching operation and narrow linewidth *Q*-switching operation, the experiments were performed in laser cavities with and without the MSR. **Firstly, we investigated the characteristics of output laser without the MSR in cavity, with the tapered fiber for coupling retained. In the absence of the graphene/PVA thin film,** only CW operation was observed. Nevertheless, when the SA was inserted into the laser cavity, the standard passively *Q*-switched laser operation was established at the pump power of 80 mW. **It also confirmed that the generation of *Q*-switched pulses originated from the graphene/PVA thin film in the cavity instead of the tapered fiber.**

In our experiments, the passively *Q*-switched operation became unstable when the pump power exceeded 190 mW. As the pump power decreased back to a value below 190 mW, the *Q*-switched pulses were observed again, which means that the SA had not been destroyed. This phenomenon is due to over-saturation of the SA at high incident power [28]. **Fig.5 illustrates the measured output power of the *Q*-switched fiber laser as a function of the pump power.** There are two different states at different pump power, which are the CW operation (pump power <80 mW) and the *Q*-switching operation (pump power >80 mW). The maximum output power obtained is 330 μW. Fig.6(a) plots the broad output laser spectrum at the pump power of 160 mW, ranging from 1560 nm to 1570 nm. The 3dB bandwidth of right peak is 0.7 nm, and the SNR of the spectrum is ~49 dB. Fig.6(b) shows the pulse train under different pump powers. **It can be seen that repetition frequency of the pulse train is significantly increased, by rising the pump power.** The typical pulse shape recorded under the pump power of 170 mW is depicted in Fig.6(c), with the pulse width of 3.1 μs. With the pump power rising from 80 to 190 mW, the pulse width of output pulse varies from 21.9 μs to 2.7 μs, at the same time, the repetition frequency gradually increases from 7.3 kHz to 30.7 kHz as shown in Fig.6(d), exhibiting the typical feature of passively *Q*-switching. In addition, the pulse energy and the single pulse peak power are also calculated, the maximum pulse energy and peak power obtained are of 10.8 nJ and 3.9 mW under the pump power of 190mW.

3.2.With MSR

To achieve the narrow linewidth passively *Q*-switched operation, the MSR was then placed between the output coupler and the SA as a wavelength selector. Only certain wavelengths which are consistent with the resonant wavelength can couple into the WGM microcavity to achieve filtering effect. Therefore, narrow linewidth laser can be established in our experiments by MSR[20].

During the experiments, coupling system is in over-coupling state, in order to assure a robust structure and achieve a stable narrow linewidth operation which can eliminate environmental vibration influence[20]. In this case, the building-up of passively *Q*-switched operation required higher pump power than before owing to the extra losses introduced by microsphere. In Fig.7, we can see the maximum output power is 212.8 μW when the input pump power is 170 mW. In addition, the *Q*-switched pulse became unstable mode-locking pulse when the pump power was larger than 170 mW. The narrow linewidth passively *Q*-switched laser spectrum is shown in Fig.8(a). With the introduction of the MSR in the cavity, the FWHM bandwidth of the output spectrum is reduced from 0.7 nm to 0.016 nm, and the peak wavelength at 1564.5 nm. The real linewidth should be even narrower, limited by the resolution (0.02 nm) of our optical spectrum analyzer. It demonstrates that the MSR is an effective wavelength selector. The SNR of the spectrum is ~57 dB which exhibits a low-noise laser output. Besides, Fig.8(b) shows the stable laser output spectra. As the pump power increases, the FWHM and the center wavelength remain stable.

In this construction, the other characteristics of narrow linewidth *Q*-switched were also monitored and recorded. The typical *Q*-switched pulse trains at the pump power of 110 mW to 170 mW and single pulse profile at the pump power of 170 mW are shown in Fig.9(a) and Fig.9(b), respectively. It can be observed that the repetition frequency is increased with increasing pump power. However, the amplitude of the pulse train is irregular. One possible reason for this phenomenon is modulation induced by MSR. Interestingly, there are lots of sub-pulses in the *Q*-switching single pulse which may be mode-locking pulse, due to the nonlinear effect in the microsphere cavity with high-Q factor. According to Fig.10(a), by tuning pump power from 100 mW to 170 mW, the repetition frequency is gradually risen from 12.8 kHz to 28 kHz. At the same time, the pulse width is decreased to 5.2 μs, which presents a normal passively *Q*-switched feature. In this case, the maximum pulse energy and peak power obtained are of 8.1 nJ and 1.5 mW. For proving the stability of the narrow linewidth passively *Q*-switched laser, we measured the radio frequency (RF) spectrum of the output laser under the pump power of 170 mW. In Fig.10(b), a strong signal peak with SNR of ~60 dB is obtained at a fundamental frequency centered at 28 kHz. The excellent RF SNR demonstrates that our narrow linewidth pulsed fiber laser has the characteristics of low-noise and high-stability.

4. Conclusion

In conclusion, a narrow linewidth Q-switched EDFL based on a graphene SA and MSR were proposed and experimentally demonstrated. The graphene was used to generate the Q-switching, and the 192 μm diameter MSR was employed to achieve stable narrow linewidth operation. In our experiment, the narrow linewidth Q-switched pulses with the minimum pulse width of 5.2 μs and the maximum repetition frequency of 28 kHz were obtained. **Compared with the passively *Q*-switched fiber laser without MSR,** the output spectrum linewidth of passively Q-switched fiber laser with MSR (0.016 nm) was effectively decreased. The results demonstrate that our work may provide an effective way to achieve narrow-linewidth pulsed fiber lasers and could have some applications in coherent detection, coherent optical communications, and high-sensitivity optical sensing.

Disclosures

No potential conflict of interest was reported by the author(s).

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