Optical Fiber Technology 68 (2022) 102764

Contents lists available at ScienceDirect

Optical Fiber Technology

journal homepage: www.elsevier.com/locate/yofte

Artificial saturable absorbers for ultrafast fibre lasers

Sergey M. Kobtsev

Division of Laser Physics and Innovative Technologies, Novosibirsk State University, Pirogova 1, Novosibirsk 630090, Russia

ARTICLE INFO

Keywords:
Mode-lock
Ultrashort pulse
Saturable absorption

ABSTRACT

A paper is presented of artificial saturable absorbers as applied in fibre lasers. Shown are the advantages and drawbacks of this saturable absorber type in comparison with material-based natural counterparts. The prospects of further development of components for passive (or self) mode locking in fibre-optical technology are discussed. Analysis demonstrates that artificial absorbers relying on comparatively short optical fibres hold higher potential and may become a real alternative to natural absorbers.

1. Introduction

The saturated absorption effect is traditionally one of the generation mechanisms of pulsed laser radiation [1-5]. Numerous reviews and books are available that discuss this effect and its application in passive mode locking [6-26]. Typically, this effect relies on materials with nonlinear dependence of their transmittance, which in these materials sharply increases as the incident optical power is raised, thus making the mode-locked operation more efficient energetically and therefore preferable. New homogeneous as well as composite materials keep emerging till the present day [27-29] in efforts to make them cheaper, more accessible, and long-lasting. They are introduced as a more attractive alternative to complex semiconductor multi-layer structures such as semiconductor saturable absorption mirror (SESAM) [30-32] and others. However, the progress in fibre-optical technologies also led to the notion of so-called artificial saturable absorbers (Fig. 1). This progress spread to lasers in general and to laser components, which began to incorporate the possibilities of these technologies. Inaccessibility (or lack of availability) of materials and technologies required for fabrication of natural saturable absorbers became one of the motivations for the development of artificial saturable absorbers, which are based on various optical effects capable of bringing about saturation of absorption or reflection of radiation. Presently, various components exhibiting the effect of saturable absorption are being advanced both in their material-based form (lately, even with growing diversity) and as artificial versions. Schematic examples of the position of such components in fibre laser configurations are presented in Fig. 2. Artificial saturable absorbers are based not on their actual material (the majority of such absorbers are fabricated from optical fibre), but on fibre-optical solutions and nonlinear effects taking place in the optical fibre. Earlier on, this category could only be said to include the Kerr lens, an effect widely used for passive mode locking in Ti:Sapphire lasers [33], even though the Kerr effect is dominant in many cases of the saturable absorption effect in fibre lasers and governs the character of optical phenomena as a function of the light intensity.

Many parameters (speed, wavelength independence, modulation depth, saturation intensity, non-saturable loss, damage threshold, longevity) of artificial saturable absorbers are on a par with those of natural absorbers and in certain aspects, such as wavelength independence, longevity, and availability of electronic control over the absorber/radiation, artificial absorbers substantially surpass their natural analogues.

It is important to point out that the following is meant by advantages of artificial saturable absorbers such as wavelength independence and life time. The properties of artificial saturable absorbers certainly do depend somehow upon the radiation wavelength. However, since many of such absorbers are based on optical fibre whose properties depend comparatively weakly on the radiation wavelength, the key parameters of artificial saturable absorbers also depend weakly upon the wavelength, so that it is possible to speak of wavelength independence of artificial absorber parameters as an approximation. The life time of artificial saturable absorbers may also be limited due to aging of optical fibre, but quartz fibres last significantly longer, for example, as compared to SESAM whose life time according to the users does not exceed ~ 5 ths hours.

The present work is focused predominantly on artificial saturable absorbers, the category so far less thoroughly explored than that of natural absorbers. We will consider these absorbers from the viewpoint of their application prospects for generation of short pulses in fibre lasers rapidly progressing in recent years. First of all, we are interested in

---

E-mail address: s.kobtsev@nsu.ru.

https://doi.org/10.1016/j.yofte.2021.102764
Received 30 August 2021; Received in revised form 10 November 2021; Accepted 20 November 2021

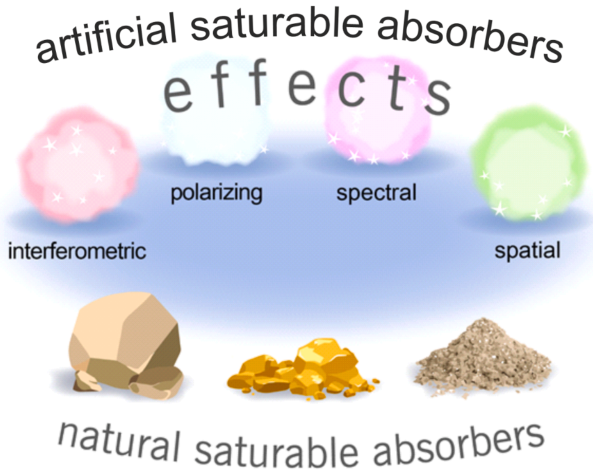

Fig. 1. Artificial and natural saturable absorbers.

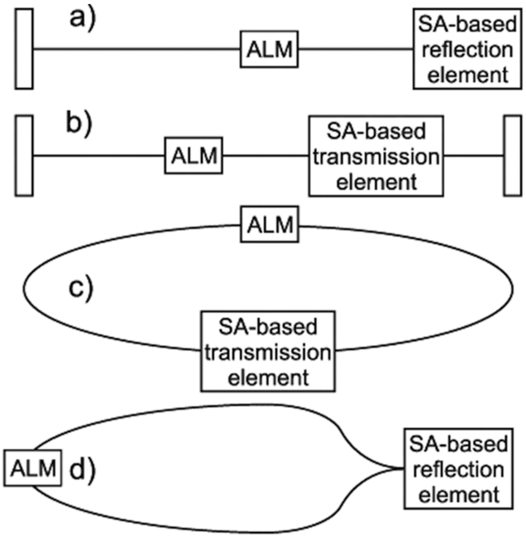

Fig. 2. Common schemes of a lasers with saturable absorbers: ALM – active laser medium, SA – saturable absorber: a) and b) linear laser resonator configurations, c) and d) ring laser resonator configurations.

the question whether or not artificial saturable absorbers could supplant natural absorbers in fibre laser applications. We will also analyse such artificial absorbers as nonlinear optical loop mirror (NOLM) [34], nonlinear amplifying loop mirror (NALM) [35], their modifications [36,37] and combinations [38] including various forms of non-spatial interference effects [39], NPE-based (nonlinear polarisation evolution) absorbers [40], and absorbers relying upon the Kerr nonlinearity in other implementations [41-46] including so-called Mamyshev oscillator concept [47-55], nonlinear spatial-mode interference [56-67] and others spanning also hybrid methods (combining artificial and natural saturable absorbers [68-71]), those based on nonlinear dynamics, such as Fourier-domain mode-locking [72] and self-beam cleaning [73,74].

It is necessary to note that the progress in development of more controllable, convenient, and inexpensive artificial absorbers in general facilitates significantly advances in ultrafast fibre lasers [75,76]. We will try to keep our focus on the ability of the mentioned effects and devices to trigger mode-locked operation in lasers based on fiber platform, even though some of them may be used in unrelated applications [77].

Further, we would like to draw the reader's attention not solely to the mere fact of mode locking, but also to specific types of mode locking, that is generation of certain pulses or pulse clusters, as well as to electronic control over parameters of such pulses. Mere initiation of mode locking operation in a laser progressively becomes less and less interesting. Conversely, more and more attention is paid to achievement of regimes generating pulses with desirable pre-determined parameters (duration, radiation wavelength, etc.).

We would also like to point out that in this overview we will not summarise the quoted publications. We will attempt focusing on conceptual problems related to short-pulsed fibre lasers and artificial saturable absorbers they use. We hope that the suggested references will be a solid addition to the present paper.

We will be first of all interested in answering the question whether or not synthetic saturable absorbers may be a complete replacement of their natural analogues. This work is focused on artificial saturable absorbers, which have so far enjoyed relatively little attention as compared to their material-based counterparts, even though some of the artificial saturable absorbers are more than 25 years old.

We will be most interested in solutions providing the highest parameter flexibility of short-pulsed fibre lasers, while retaining cost-effective manufacture and simple operation allowing normal use by unqualified personnel.

2. Distinctive features of fibre lasers

Fibre lasers possess a number of peculiarities, which provide, in particular, the possibility of efficient inclusion into them of artificial saturable absorbers. These features present at the minimum two levels, the engineering one (from the viewpoint of researchers and developers) and the user level. At the engineering level, fibre lasers allow easy implementation of various cavity configurations due to their comparatively high gain [78] (high generation efficiency, possibility of using elements and methods that have intrinsically high optical loss), easy implementation of interferometric configurations due to permanently aligned cavity, as well as relative simplicity of assembly and operation of different configurations. At the user level, fibre lasers provide high reliability of output parameters and high output radiation quality. Other advantages of fibre lasers also play a substantial role [79]. It is due to the explosive development in fibre laser that artificial saturable absorbers have also rapidly advanced and many of such new components were used specifically in fibre lasers and complied with the requirements of all-in-fibre integration.

3. Artificial saturable absorbers on the basis of reflectors (NOLM/NALM)

In principle, at the minimum, the same generated pulse parameters are expected from the artificial mode locking components as from their natural counterparts. The difference is that the artificial components are expected to also have at least some better properties: longer or potentially unlimited lifetime, electronic control, etc. Artificial absorbers mentioned in the section title meet these expectations and can provide competitively short output pulses [80-111]. Of course, developers continually improve technologies making them more reliable and accessible and their results more reproducible (for instance, by using polarisation-maintaining optical fibre or additional controllable elements [108,112]), but so far, an ideal artificial absorber for all applications was not found, and efforts continue to improve existing ones instead. The conventional Kerr-lens artificial absorber used in Ti:Sapphire [33] and other solid-state lasers [113] turned out not very applicable to fibre lasers because of its shallow modulation depth, which is insufficient for mode locking of fibre lasers with their high single-pass gain. Fibre lasers can "tolerante" relatively higher losses, thus enlarging the number of possible fibre reflectors able to perform the function of an artificial saturable absorber [114].

Transmittance of absorbers based on reflecting fibre elements depends on the phase incursion of two pulse copies propagating in opposite directions [115]. Saturable absorbers for fibre lasers should meet more stringent modulation depth requirements: where in the other laser types having relatively low gain (Ti:Sapphire, Dye, etc.), a few percent or even less of absorption modulation is sufficient [32,43,116], in fibre lasers the modulation depth should be considerably higher than dozens percent [117]. Furthermore, high gain of fibre lasers affords broad opportunities of artificial saturable absorber design even in cases where such an absorber introduces relatively high optical losses into the cavity (not exceeding the gain, of course). It is due to greater tolerance of fibre lasers to introduced losses that artificial saturable absorbers found such broad application in such lasers.

The dependence of saturable absorber parameters upon the radiation wavelength deserves special mention. Such dependence exists in any absorber and although one may think that in artificial saturable absorbers such dependence should be weaker or completely absent, this is not generally so. The parameters of artificial saturable absorbers depend not only upon the properties of the optical fibre itself, but also upon sensitivity of these properties to the external factors and upon spectral dependence of other cavity elements. The latter statement is also valid for any other type of absorber. It should be noted that this (spectral) dependence is important both for measurement of the absorber's working spectral range and for spectral tuning of the laser output. The gain profile in fibre lasers is not very wide (~100 nm), and in such a relatively narrow spectral band, even the properties of natural absorbers may vary only insignificantly [118].

The advantage of this type of artificial absorbers is substantially longer (or unlimited) lifetime and the possibility of higher pulse radiation powers (at the level where natural absorber material suffers optical damage). Their drawback is their dependence on external factors: everything that affects the parameters of the optical fibre in a noticeable degree also affects the parameters of artificial absorbers containing such fibre. First of all, this is ambient temperature, but also other external factors (ambient humidity, fibre bending, vibrations, etc.). During development of fibre-optical artificial saturable absorbers, it became obvious that at this moment they could only replace or provide an alternative to material-based natural absorbers in laboratory conditions when saving the time needed for preparation of an absorber and adjustment of the output radiation parameters are more important.

It is necessary to point out that fibre laser generating ultra-short pulses are still more of an exotic case [119]. Typical pulse duration provided by the majority of ultra-short-pulsed commercial lasers lies within the 100–200 fs range [120] and longer. This is caused both by comparatively narrow gain bandwidth of the fibre-optical active media and by excessive amount of efforts required to reach pulse durations shorter than 100 fs [81,121] necessary because of non-linear and dispersion effects in fibre [122]. This is why in most cases, the objective of an artificial saturable absorber in a fibre laser is to initiate and sustain mode-locked generation, even though the problem of achieving the shortest possible pulses in this type of laser is always present as well.

It is necessary to note that artificial saturable absorbers on the basis of reflectors (NOLM/NALM) have the advantage of being easily implemented in the conditions of a fibre-optical laboratory or a manufacturing facility. Additionally, the optical damage threshold of these absorbers is relatively high. Their disadvantage is that their parameters depend on the condition of the optical fibre (its temperature, bending, etc.). In the laboratory environment, variability of generation parameters does not, as a rule, constitute a problem. Therefore absorbers, such as NOLM/NALM, their modifications, and combinations are widely used in scientific laser installations. In order to stabilise the properties of these absorbers, some fairly complicated measures have to be taken, this is why such absorbers are not often used in commercial lasers. Of course, developers are trying to reduce the influence of ambient factors by using polarisation maintaining fibres and so forth. This alleviates the problem but does not solve it completely.

A weak point of artificial absorbers of this type is the possibility of incomplete interference of the pulse components. Of course, the relevant configurations use 50/50 splitters, but in reality, this ratio may deviate, for instance, to 51/49 or some other, therefore preventing complete interference. Incomplete interference affects detrimentally mode locking and may become a cause of regime instability or mediocre parameters. The problem is that the splitter ratio cannot be adjusted on the spot since this element is usually purchased as an off-the-shelf component fabricated with special technological equipment. Nevertheless, artificial absorbers of this type are relatively inexpensive, reliable and accessible. They are, therefore, in practical use even today [36,123].

4. Artificial saturable absorbers on the basis of polarisation effects

The most common example of lasers using these effects is fibre laser with nonlinear evolution of radiation polarisation [124]. The advantage of such lasers consists in their sheer simplicity (nonlinear evolution of polarisation takes place in the very fibre of which the laser cavity is made). The same circumstance, however, is also their drawback: radiation polarisation in these lasers depends on many external and internal factors [125]. Various attempts to involve artificial intelligence technologies in the process of tuning such lasers [126,127] so far have been limited to the laser becoming on a regular basis (for example, every morning) an object of research with all concomitant details. Additionally, these lasers normally need adjustment of the radiation polarisation state, whereas polarisation controllers available for this are still not implemented at a proper technical level. Therefore, lasers with nonlinear polarisation evolution remain to this day more of an experimental platform for study of physical effects [128-132], despite ongoing efforts aimed at lowering the sensitivity of their output parameters to external perturbations [133-136].

It should be mentioned that polarisation effects are often coupled with non-polarisation ones, since polarisation effects are intrinsic to the cavity fibre and to many elements comprising the cavity. Polarisation of radiation is difficult to control even if polarisation-maintaining fibre is used [108,137,138], as well as corresponding fibre-optical elements that maintain radiation polarisation.

Artificial saturable absorbers relying on polarisation effects [139-144] are also very popular in research environments since they can be fabricated in any lab and cost very little. Their disadvantage shared by any fibre-based absorbers is that their properties depend on the condition of the fibre (its temperature, bending, and so on). Furthermore, polarisation controllers used in many implementations of such absorbers become an additional source of issues. Nevertheless, because of their simplicity and low cost, this type of artificial saturable absorber is the most widely used, even though its employment can result not only in generation of different pulses, but also different regimes. The attempts to make parameters of this type of saturable absorbers more predictable continue, although there is still no final solution in sight. Some lasers with this type of absorbers have been commercialised, but such examples are few.

5. Artificial saturable absorbers based on spatial effects

Spatial effects internal to optical fibre (coupling single-mode fibre with multi-mode one, etc.) are of interest since they are not easily affected by external perturbations. Using such effects for fibre laser mode locking may give this technology a new life. Nevertheless, as is shown by analysis, it is scarcely possible to create a better artificial saturable absorber just on the basis of a single physical effect (intra-fibre spatial phenomena, in this case). Users not only expect an alternative to conventional material-based saturable absorbers, but also certain new possibilities (expanded working spectral range, electronic control, higher damage threshold, etc.). Such expectations may be met by some combination of multiple effects, such as nonlinear spatial-mode interference and controlling the absorber/radiation parameters through evanescent field [145-147] or through pump power adjustment [36,37]. Artificial saturable absorbers without any kind of polarisation controllers appear more promising in development of mode-locked fibre lasers because the available polarisation controllers used in fibre laser cavities need their own development to improve stability and reproducibility of the state of the laser radiation polarisation. Frequently, the most important element in tuning of short-pulsed fibre lasers happens to be the setting of a polarisation controller rather than the saturable absorber (natural or artificial). It is not guaranteed that a different person (or even the same one) will be able to reproduce the necessary tuning, neither is it guaranteed that such tuning will remain stable over a long period of time (weeks or months, for instance). Polarisation controllers for short-pulsed fibre lasers need significant improvement, for many promising technologies of mode locking that rely on artificial saturable absorbers depend on polarisation controllers, and very often it is these components that become the bottleneck in advancement of these technologies.

Artificial saturable absorbers relying on spatial effects [148-151] may become an alternative to their material counterparts. Their strong points are fairly small dimensions, weak dependence of the optical fibre diameter upon the ambient conditions and certainly their high optical material damage threshold (of the fibre itself). These artificial absorbers were introduced relatively recently, this is why solutions on their basis are now undergoing a development stage. It is possible for them to become considerably more popular in the future.

6. Artificial saturable absorbers on the basis of spectral effects

The idea of this type of artificial saturable absorbers rests on nonlinear spectral broadening of pulses as they travel along the fibre with subsequent filtration around two radiation wavelengths, longer and shorter than the central pulse wavelength [48,49,152]. The laser cavity contains two spectral filters with transmittance maxima located on either side of the central wavelength of the gain profile (or of the CW radiation generated in the absence of filters). In the presence of these filters, CW radiation is either not generated or is generated very weakly because of high optical losses introduced by the filters. However, it now becomes more efficient energetically to generate radiation pulses with broad spectrum that passes through both filters. In this way, two different spectral filters may play the role of an artificial saturable absorber [153-161], because the fraction of pulse spectrum passing through the filter gates depends on the pulse peak power that drives nonlinear spectral broadening. In this case, power-dependent transmission is implemented due to nonlinear radiation spectrum broadening (self-phase modulation) and subsequent offset spectral filtering.

Some researchers consider this type of artificial mode locker as the main element of short-pulsed lasers of the next generation [75], even though its operative mechanisms have not yet been thoroughly studied and its presence may lead to emergence of a high-energy pulse pedestal or to multi-pulse generation. It should be noted that this configuration's advantage consists in relatively high peak power in short pulses [157,162,163], whereas its drawbacks are complicated triggering of mode-locked operation and two radiation outputs instead of one.

7. General analysis

Fibre-optical technology has been deeply integrated into laser manufacturing and continuous-wave fibre lasers already became a key break-through that changed many aspects of human life [164]. It turned out, however, that pulsed fibre lasers are far more complicated [165-167] and, in general, the existing technologies have not been advanced enough to meet their challenge. This is the cause of significant efforts presently made by scientists, engineers, and technologists in order to advance the technology of short-pulsed fibre lasers to the level of a reliable and broadly used product. The sealed-off self-contained design of fibre lasers, which essentially made them so valuable (no alignment or maintenance required), also did a significant disservice to the technology of short-pulsed fibre lasers. Wherever it is necessary to adjust anything (to trigger a desired regime, tune the generation spectrum, etc.), the sealed-off configuration of fibre lasers leads to mostly hard problems, which cannot be solved quickly. In attempts to address them there may appear various random improvised materials, even such coffee [168] or alcohol [169].

It is necessary to mention emergence of hybrid solutions, in which both artificial and natural absorbers are used at the same time. Such approaches may lead to better generation parameters (shorter pulses, higher mode-locked signal/noise ratio, etc.) owing to a second absorber.

The Table given below summarises the parameters of lasers with artificial absorbers discussed earlier. Since various absorbers were studied under different conditions, some parameters have a spread of measured values and therefore were given as ranges.

One of the interesting conclusions arising from the table data analysis is that about the absence of a definite pulse duration boundary between what may be obtained directly within the laser cavity and with the help of extra-cavity compression. More uncertainty in this respect is further added by configurations with pronounced intra-cavity pulse compression (performed with the help of a similar pair of diffraction gratings). It should be brought to the reader's attention that many configurations of pulse compression involving two diffraction gratings, either placed outside or inside the cavity, derogate from the all-fibre laser concept. Those solutions are more attractive that provide ultrashort radiation pulses within the all-fibre laser format relying (if possible) on in-fibre compression without need of discrete optical elements.

Some comparison of pulse parameters obtained with the best (in the opinion of author) samples of different artificial absorbers is shown in the Table 1. The comparison cannot be considered correct, as the parameters are obtained in lasers with different schemes at different pumps and under different conditions. However, the table can be used to get an overview of the level of pulse parameters that can be achieved using these absorbers.

8. Conclusion

Artificial saturable absorbers present certain advantages over their natural material-based counterparts, but are not able to replace them completely because artificial saturable absorbers are mostly made of optical fibre and, correspondingly, are sensitive to the properties of the ambient air. So far, the alternative to material saturable absorbers may be seen in their artificial counterparts using short fibre lengths and therefore having reduced sensitivity to ambient conditions. These are artificial saturable absorbers based on nonlinear multimode interference. Their undoubted advantages are relatively inexpensive fabrication, high temporal discrimination and optical damage threshold, as well as the possibility of integration into fibre lasers, also including all-fibre configurations. Perhaps, absorbers of this type are the most realistic replacement of natural absorbers.

Among the approaches to improvement of the properties of artificial saturable absorbers is application of machine learning technologies. Until present, however, these technologies in the context of saturable absorbers are rather a discussion topic than a solution to the problem. Attempts to fully hand over the problem of triggering the desired short-pulsed regime in a fibre laser to computer algorithms [127,176] can be neither optimal nor universal. This problem turned out more complicated than it was supposed initially. Artificial saturable absorbers offer specific advantages (long or even unlimited lifetime under rather high energy/power of radiation pulses, relatively easy fabrication in modest laboratory conditions, etc.), but at the same time they cannot be classed as a unconditional alternative to natural absorbers, owing to a number of limitations they suffer from. First of all, the output pulse duration they provide is, in general, quite far from the shortest possible. Secondly, not all geometries of fibre laser cavities are compatible with artificial saturable absorber designs. Third, not every artificial saturable absorber provides automatic triggering of mode-locked operation. Furthermore,

Table 1

Artificial absorber	pulse duration, ps	repetition rate, MHz	Output power (average or pulse energy)	wavelength, um	ref
Interferometric effect	0.05[c]/0.51		70 mW	~1.5	[81]
NOLM	~0.1[c]	10–250	3–10 mW	~1, 1.5, 2	[84,88]
	~0.2[c]/19.5	15	3.4 nJ	1.03	[87]
	~0.3/13.5	9.6–30	5.9 nJ	1.06, 1.535	[97]
	~0.4[c]/	2.85	720 mW/252 nJ	1.99	[94]
	~0.5[c]/14	13.4	10 mW/0.78 nJ	1.035	[82]
	~0.7	11.8	0.84 mW/71 pJ	1.997	[90]
	1–2	1.3–3.8	560 pJ	~1.5	[83,96]
	63	1.23	1.23 nJ	1.115	[91]
	920	1.45	70 mW	2.04	[92]
	2.1–4 ns	3.44	25 mW/7.3 nJ	1.05	[95]
	21.5 ns	0.205	600 mW	1.56	[99]
	71–120 ns	0.095	250 mW/10 nJ	~1.5	[89]
Interferometric effect	~0.1[c]	34.4–54	21–51 mW/0.61 nJ	1.03	[100,101]
NALM	0.065–0.26	78	~100 mW	1.03	[108]
	~0.2[c]/34	8–34	21–60 mW	1.03, 1.57	[102,103]
	~0.5	121–201	~0.6–2 mW	~1.5	[104,111]
	0.63	3.57	84 pJ	1.7	[105]
	~3	1.84	17.4 pJ	1.55	[106]
	4.3 ns	9.5	~2.5 mW	~1.5	[110]
	2–104 ns	0.5–2.5	~ 1 mW	~1.5	[107]
	48 ns	0.362	11 mW/30 nJ	1.338	[109]
Polarizing effects	0.052[c]	56	~0.1 mW	1.55	[139]
Nonlinear polarization evolution	0.25[c]	124	0.92 nJ		[140]
	0.26[c]	24.5	4.5 mW	1.03	[141]
	~1.3	111	0.47 nJ	1.03	[142]
	0.66–1.44	60	~20 mW	1.03	[143]
	11,7	43.8	2.1 nJ	1.03	[144]
Spatial effects	0.52	33.7	256 pJ	1.566	[148]
Coupling SMF with MMF etc.	0.625	8.726	~1.7 mW	~1.6	[59]
	0.98[c]/11	27.32	3.11 mW	1.04	[149]
	1.89	15.56	212.4 mW/13.6 nJ	~1.5	[138]
	7.3	20.5	3.2 mW	1.03	[150]
	180	9	56.3 mW	1.045	[151]
Spectral effects	0.017[c]	17.5	3.5 nJ	1.045	[157]
Nonlinear frequency broadening	0.065[c]	16.1	21 nJ	1.05	[161]
	0.108[c]	8.935	190 mW/21.3 nJ	1.55	[158]
	0.23	3.18	18 nJ	1.04	[159]
	15	16	8.2 mW/0.5 nJ	1.55	[160]
Hybrid solution	0.072[c]	38.5	38.5 mW / 1 nJ	1.04	[171]
Artificial + material-based absorbers	0.25[c]/0,63	18.72	2.8 mW/120 pJ	1.56	[172]
	0.33	23.8	6 mW/0.25 nJ	1.9	[173]
	0.69	14.7	0.4 nJ	1.53	[174]
	0.9	3.8–4.9	< 0.1 mW	1.56	[175]
	1.4	14.9	4.7 mW/0.3 nJ	2.08	[176]
	39–147	15.6	14.5 mW	1.55	[177]

[c] compressed/before compression.

as the fundamental capabilities of artificial saturable absorbers (pulse duration, energy, repetition rate) are studied, the laser customers are also interested in complex questions: in what range and how, if at all, it will be possible to maintain wavelength tuneability, adjust pulse duration, etc. Most likely, it is these complex matters that will become the subject of artificial saturable absorber studies in the near future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by the Ministry of Science and Higher Education of the Russian Federation (grant # FSUS-2020-0036) and by the Russian Foundation for Basic Research (project #18-29-20025).

References

[1] E. Garmire, A. Yariv, Laser mode-locking with saturable absorbers, IEEE J. Quantum Electron. 3 (6) (1967) 222–226, https://doi.org/10.1109/JQE.1967.1074489.

[2] B.K. Garside, T.K. Lim, Laser mode locking using saturable absorbers, J. Appl. Phys. 44 (5) (1973) 2335–2342, https://doi.org/10.1063/1.1662561.

[3] T.K. Lim, M.M. Denariez-Roberge, Ultrashort-pulse generation by lasers with saturable absorbers, Appl. Phys. 15 (4) (1978) 439–450, https://doi.org/10.1007/BF00886165.

[4] E.P. Ippen, Principles of passive mode locking, Appi. Phys. B 58 (3) (1994) 159–170, https://doi.org/10.1007/BF01081309.

[5] F. Kurtner, J. Au, U. Keller, Mode-locking with slow and fast saturable absorbers-what's the difference? IEEE J. Sel. Top. Quantum Electron. 4 (2) (1998) 159–168, https://doi.org/10.1109/2944.686719.

[6] P. French. The generation of ultrashort laser pulses. Rep. Prog. Phys., v. 58 (2), 169-(1995). https://doi.org/10.1088/0034-4885/58/2/001.

[7] L.E. Nelson, D.J. Jones, K. Tamura, H.A. Haus, E.P. Ippen, Ultrashort-pulse fiber ring lasers, Appl. Phys. B 65 (2) (1997) 277–294, https://doi.org/10.1007/s003400050273.

[8] G. Steinmeyer, D. Sutter, L. Gallmann, N. Matuschek, U. Keller, Frontiers in ultrashort pulse generation: pushing the limits in linear and nonlinear optics, Science 286 (5444) (1999) 1507–1512, https://doi.org/10.1126/science.286.5444.1507.

[9] J. Diels, W. Rudolph. Ultrashort laser pulse phenomena fundamentals, techniques, and applications on a femtosecond time scale. Academic Press, 680p. Second Ed. (2006). ISBN 978-0-12-215493-5.

[10] M. Fermann, I. Hartl, Ultrafast fiber laser technology, IEEE J. Sel. Top. Quantum Electron. 15 (1) (2009) 191–206, https://doi.org/10.1109/JSTQE.2008.2010246.

[11] A.S. Kurkov, Q-switched all-fiber lasers with saturable absorbers, Laser Phys. Lett. 8 (5) (2011) 335–342, https://doi.org/10.1002/lapl.v8.510.1002/lapl.201010142.

[12] Z. Sun, T. Hasan, A. Ferrari, Ultrafast lasers mode-locked by nanotubes and graphene, Physica E Low Dimens. Syst. Nanostruct. 44 (6) (2012) 1082–1091, https://doi.org/10.1016/j.physe.2012.01.012.

[13] C. Zhao, H. Zhang, X. Qi, Y.u. Chen, Z. Wang, S. Wen, D. Tang, Ultra-short pulse generation by a topological insulator based saturable absorber, Appl. Phys. Lett. 101 (21) (2012) 211106, https://doi.org/10.1063/1.4767919.

[14] S. Kozlov, V. Samartsev. Fundamentals of femtosecond optics. Woodhead Publishing, 272p. (2013). ISBN 978-1-78242-128-3.

[15] I. Sorokina, V. Dvoyrin, N. Tolstik, E. Sorokin, Mid-IR ultrashort pulsed fiber-based lasers, IEEE J. Sel. Top. Quantum Electron. 20 (5) (2014) 1–12, https://doi.org/10.1109/JSTQE.2014.2310655.

[16] N. Nishizawa, Ultrashort pulse fiber lasers and their applications, Jpn. J. Appl. Phys. 53 (9) (2014) 090101, https://doi.org/10.7567/JJAP.53.090101.

[17] J. Kim, Y. Song, Ultralow-noise mode-locked fiber lasers and frequency combs: principles, status, and applications, Adv. Opt. Photon. 8 (2016) 465–540, https://doi.org/10.1364/AOP.8.000465.

[18] Z. Luo, D. Wu, B. Xu, H. Xu, Z. Cai, J. Peng, J. Weng, S. Xu, C. Zhu, F. Wang, Z. Sun, H. Zhang, Two-dimensional material-based saturable absorbers: towards compact visible-wavelength all-fiber pulsed lasers, Nanoscale 8 (2) (2016) 1066–1072, https://doi.org/10.1039/C5NR06981E.

[19] G. Sobon. Application of 2D materials to ultrashort laser pulse generation. Chapter 7 in book: "Two-dimensional materials - synthesis, characterization and potential applications" (ed. P. K. Nayak). IntechOpen, 280p., 2016. ISBN 978-953-51-2555-6. https://doi.org/10.5772/63336.

[20] M. Chernysheva, A. Rozhin, Y. Fedotov, C. Mou, R. Arif, S. Kobtsev, E. Dianov, S. Turitsyn, Carbon nanotubes for ultrafast fibre lasers, Nanophotonics 6 (1) (2017) 1–30, https://doi.org/10.1515/nanoph-2015-0156.

[21] C. Ma, C. Wang, B.o. Gao, J. Adams, G.e. Wu, H. Zhang, Recent progress in ultrafast lasers based on 2D materials as a saturable absorber, Appl. Phys. Rev. 6 (4) (2019) 041304, https://doi.org/10.1063/1.5099188.

[22] J. Ma, Z. Qin, G. Xie, L. Qian, D. Tang, Review of mid-infrared mode-locked laser sources in the 2.0 μm–3.5 μm spectral region, Appl. Phys. Rev. 6 (2) (2019) 021317, https://doi.org/10.1063/1.5037274.

[23] G. Chang, Z. Wei. Ultrafast fiber lasers: an expanding versatile toolbox. iScience, v. 23 (5), 101101 (2020). https://doi.org/10.1016/j.isci.2020.101101.

[24] C.e. Shang, Y. Zhang, H. Qin, B. He, C. Zhang, J. Sun, J. Li, J. Ma, X. Ji, L. Xu, B. o. Fu, Review on wavelength-tunable pulsed fiber lasers based on 2D materials, Opt. Laser Technol. 131 (2020) 106375, https://doi.org/10.1016/j.optlastec.2020.106375.

[25] Y. Han, Y. Guo, B.o. Gao, C. Ma, R. Zhang, H. Zhang, Generation, optimization, and application of ultrashort femtosecond pulse in mode-locked fiber lasers, Prog. Quantum. Electron. 71 (2020) 100264, https://doi.org/10.1016/j.pquantelec.2020.100264.

[26] T. Jiang, K. Yin, C. Wang, J. You, H. Ouyang, R. Miao, C. Zhang, K. Wei, H. Li, H. Chen, R. Zhang, X. Zheng, Z. Xu, X. Cheng, H. Zhang, Ultrafast fiber lasers mode-locked by two-dimensional materials: review and prospect, Photon. Res. 8 (2020) 78–90, https://doi.org/10.1364/PRJ.8.000078.

[27] W. Liu, M. Liu, X. Liu, M. Lei, Z. Wei, SnSSe as a saturable absorber for an ultrafast laser with superior stability, Opt. Lett. 45 (2020) 419–422, https://doi.org/10.1364/OL.380183.

[28] L. Li, L. Pang, Q. Zhao, Y. Wang, W. Liu, Niobium disulfide as a new saturable absorber for an ultrafast fiber laser, Nanoscale 12 (7) (2020) 4537–4543, https://doi.org/10.1039/C9NR10873D.

[29] H. Zhang, P. Ma, M. Zhu, W. Zhang, G. Wang, S. Fu, Palladium selenide as a broadband saturable absorber for ultra-fast photonics, Nanophotonics 9 (8) (2020) 2557–2567, https://doi.org/10.1515/nanoph-2020-0116.

[30] G. Jacobovitz-Veselka, U. Keller, M. Asom, Broadband fast semiconductor saturable absorber, Opt. Lett. 17 (24) (1992) 1791–1793, https://doi.org/10.1364/OL.17.001791.

[31] D. Derickson, R. Helkey, A. Mar, J. Karin, J. Wasserbauer, J. Bowers, Short pulse generation using multisegment mode-locked semiconductor lasers, IEEE J. Quantum Electron. 28 (10) (1992) 2186–2202, https://doi.org/10.1109/3.159527.

[32] U. Keller, K. Weingarten, F. Kartner, D. Kopf, B. Braun, I. Jung, R. Fluck, C. Honninger, N. Matuschek, J. Au, Semiconductor saturable absorber mirrors (SESAM's) for femtosecond to nanosecond pulse generation in solid-state lasers, IEEE J. Sel. Top. Quantum Electron. 2 (3) (1996) 435–453, https://doi.org/10.1109/2944.571743.

[33] N. Rizvi, P. French, J. Taylor, Continuously self-mode-locked Ti:sapphire laser that produces sub-50-fs pulses, Opt. Lett. 17 (1992) 279–281, https://doi.org/10.1364/OL.17.000279.

[34] N. Doran, D. Wood, Nonlinear-optical loop mirror, Opt. Lett. 13 (1988) 56–58, https://doi.org/10.1364/OL.13.000056.

[35] M. Fermann, F. Haberl, M. Hofer, H. Hochreiter, Nonlinear amplifying loop mirror, Opt. Lett. 15 (1990) 752–754, https://doi.org/10.1364/OL.15.000752.

[36] S. Smirnov, S. Kobtsev, A. Ivanenko, A. Kokhanovskiy, A. Kemmer, M. Gervaziev, Layout of NALM fiber laser with adjustable peak power of generated pulses, Opt. Lett. 42 (9) (2017) 1732–1735, https://doi.org/10.1364/OL.42.001732.

[37] A. Kokhanovskiy, S. Kobtsev, A. Ivanenko, S. Smirnov, Properties of artificial saturable absorbers based on NALM with two pumped active fibres, Laser Phys. Lett. 15 (12) (2018) 125101, https://doi.org/10.1088/1612-202X/aae21c.

[38] W. Lai, P. Shum, L. Binh, NOLM-NALM fiber ring laser, IEEE J. Quantum Electron. 41 (7) (2005) 986–993, https://doi.org/10.1109/JQE.2005.847901.

[39] Z. Yan, H. Wang, K. Zhou, Y. Wang, C. Li, W. Zhao, L. Zhang, Soliton mode locking fiber laser with an all-fiber polarization interference filter, Opt. Lett. 37 (2012) 4522–4524, https://doi.org/10.1364/OL.37.004522.

[40] V. Matsas, W. Loh, D. Richardson, Self-starting, passively mode-locked Fabry-Perot fiber soliton laser using nonlinear polarization evolution, IEEE Photonics Tech. Lett. 5 (5) (1993) 492–494, https://doi.org/10.1109/68.215258.

[41] A. Hasegawa, F. Tappert, Transmission of stationary nonlinear optical pulses in dispersive dielectric fibers. II. Normal dispersion, Appl. Phys. Lett. 23 (4) (1973) 171–172, https://doi.org/10.1063/1.1654847.

[42] K. Sala, M. Richardson, N. Isenor, Passive mode locking of lasers with the optical Kerr effect modulator, IEEE J. Quantum Electron. 13 (11) (1977) 915–924, https://doi.org/10.1109/JQE.1977.1069251.

[43] J. Herrmann. Theory of Kerr-lens mode locking: role of self-focusing and radially varying gain. J. Opt. Soc. Am. B, v. 11, 498-512 (1994).11, 498-512 (1994). https://doi.org/10.1364/JOSAB.11.000498.

[44] S. Yefet, A. Peer, A review of cavity design for Kerr lens mode-locked solid-state lasers, Appl. Sci. 3 (4) (2013) 694–724, https://doi.org/10.3390/app3040694.

[45] W. Long. Fiber based mode locked fiber laser using Kerr effect. Thesis (Dr. Ph.). University of Dayton, 147 p., 2016. Publication Number: AAT 10145279, ISBN: 978-1-36-900813-5.

[46] K. Shtyrkova, P. Callahan, M. Watts, E. Ippen, F. Kärtner. Integrated artificial saturable absorber based on Kerr nonlinearity in silicon nitride. In Conference on Lasers and Electro-Optics, OSA Technical Digest (online) (Optical Society of America, 2017), paper AF1B.6. https://doi.org/10.1364/CLEO_AT.2017.AF1B.6.

[47] U. Keller, T. Chiu, J. Ferguson, Self-starting femtosecond mode-locked Nd:glass laser that uses intracavity saturable absorbers, Opt. Lett. 18 (1993) 1077–1079, https://doi.org/10.1364/OL.18.001077.

[48] M. Piché, Mode locking through nonlinear frequency broadening and spectral filtering, Proc. SPIE 2041 (1994) 358–365, https://doi.org/10.1117/12.165631.

[49] V. Mamyshev. All-optical data regeneration based on self-phase modulation effect. Proc. 24th European Conference on Optical Communication (ECOC '98), pp. 475–476, Madrid, Spain, September 1998. https://doi.org/10.1109/ECOC.1998.732666.

[50] S. Regelskis, J. Želudevicius, K. Viskontas, G. Raciukaitis, Ytterbium-doped fiber ultrashort pulse generator based on self-phase modulation and alternating spectral filtering, Opt. Lett. 40 (22) (2015) 5255–5258, https://doi.org/10.1364/OL.40.005255.

[51] Z. Liu, Z.M. Ziegler, L.G. Wright, F.W. Wise, Megawatt peak power from a Mamyshev oscillator, Optica 4 (6) (2017) 649, https://doi.org/10.1364/OPTICA.4.00064910.1364/OPTICA.4.000649.s001.

[52] I. Samartsev, A. Bordenyuk, V. Gapontsev, Environmentally stable seed source for high power ultrafast laser, Proc. SPIE 10085 (2017) 100850S, https://doi.org/10.1117/12.2250641.

[53] W. Liu, R. Liao, J. Zhao, J. Cui, Y. Song, C. Wang, M. Hu, Femtosecond Mamyshev oscillator with 10-MW-level peak power, Optica 6 (2019) 194–197, https://doi.org/10.1364/OPTICA.6.000194.

[54] E. Poeydebat, F. Scol, O. Vanvincq, G. Bouwmans, E. Hugonnot, All-fiber Mamyshev oscillator with high average power and harmonic mode-locking, Opt. Lett. 45 (2020) 1395–1398, https://doi.org/10.1364/OL.389522.

[55] C. Ma, A. Khanolkar, Y. Zang, A. Chong, Ultrabroadband, few-cycle pulses directly from a Mamyshev fiber oscillator, Photon. Res. 8 (2020) 65–69, https://doi.org/10.1364/PRJ.8.000065.

[56] C. Gordón, R. Guzmán, X. Leijtens, G. Carpintero, On-chip mode-locked laser diode structure using multimode interference reflectors, Photon. Res. 3 (2015) 15–18, https://doi.org/10.1364/PRJ.3.000015.

[57] M. Jung, J. Lee, W. Song, Y.L. Lee, J.H. Lee, W. Shin, A passively mode locked thulium doped fiber laser using bismuth telluride deposited multimode interference, Laser Phys. Lett. 13 (5) (2016) 055103, https://doi.org/10.1088/1612-2011/13/5/055103.

[58] L.G. Wright, D.N. Christodoulides, F.W. Wise, Spatiotemporal mode-locking in multimode fiber lasers, Science 358 (6359) (2017) 94–97, https://doi.org/10.1126/science.aao0831.

[59] T. Chen, Q. Zhang, Y. Zhang, X. Li, H. Zhang, W. Xia, All-fiber passively mode-locked laser using nonlinear multimode interference of step-index multimode fiber, Photon. Res. 6 (2018) 1033–1039, https://doi.org/10.1364/PRJ.6.001033.

[60] X. Jiang, B.-M. Mao, Y. Wei, D. Chen, L. She, G. Feng, J. Yang, Wavelength-tunable all-fiber mode-locked laser based on supermode interference in a seven-core fiber, Appl. Opt. 57 (2018) 6768–6771, https://doi.org/10.1364/AO.57.006768.

[61] K. Zhao, H. Jia, P. Wang, J. Guo, X. Xiao, C. Yang, Free-running dual-comb fiber laser mode-locked by nonlinear multimode interference, Opt. Lett. 44 (2019) 4323–4326, https://doi.org/10.1364/OL.44.004323.

[62] K. Zhao, Y. Li, X. Xiao, C. Yang, Nonlinear multimode interference-based dual-color mode-locked fiber laser, Opt. Lett. 45 (2020) 1655–1658, https://doi.org/10.1364/OL.388314.

[63] N. Li, W.Y. Zhang, J. Zhang, M. Guo, Z.X. Guo, Mode-locked Er-doped fiber laser based on nonlinear multimode interference, Laser Phys. Lett. 17 (8) (2020) 085105, https://doi.org/10.1088/1612-202X/ab9f40.

[64] U. Teğin, B. Rahmani, E. Kakkava, D. Psaltis, C. Moser, All-fiber spatiotemporally mode-locked laser with multimode fiber-based filtering, Opt. Express 28 (2020) 23433–23438, https://doi.org/10.1364/OE.399668.

[65] K. Zhang, M. Rochette. Thulium-doped fiber laser mode-locked from nonlinear ultimode interference in chalcogenide fiber. 2020 Conference on Lasers and Electro-Optics (CLEO), San Jose, CA, USA, 2020, 1-2. https://doi.org/10.1364/CLEO_SI.2020.STh4F.6.

[66] Z. Dong, J. Lin, H. Li, Y. Zhang, C. Gu, P. Yao, L. Xu, Er-doped mode-locked fiber lasers based on nonlinear polarization rotation and nonlinear multimode interference, Opt. Laser Technol. 130 (2020) 106337, https://doi.org/10.1016/j.optlastec.2020.106337.

[67] Y. Gan, Q. Wu, Y. Yao, C. Liu, Y. Fu, Y. Yang, J. Tian, K.e. Xu, Generation of high-order solitons with order continuously adjustable in a fiber laser based on GIMF–SIMF–GIMF saturable absorber, Opt. Commun. 479 (2021) 126441, https://doi.org/10.1016/j.optcom.2020.126441.

[68] S. Kim, Y. Kim, J. Park, S. Han, S. Park, Y.J. Kim, S.-W. Kim, Hybrid mode-locked Er-doped fiber femtosecond oscillator with 156 mW output power, Opt. Express 20 (14) (2012) 15054–15060, https://doi.org/10.1364/OE.20.015054.

[69] B. Xu, A. Martinez, S.Y. Set, C.S. Goh, S. Yamashita, Polarization maintaining, nanotube-based mode-locked lasing from figure of eight fiber laser, IEEE Photonic. Tech. Lett. 26 (2) (2014) 180–182, https://doi.org/10.1109/LPT.2013.2291405.

[70] S.A. Filatova, V.A. Kamynin, N.R. Arutyunyan, A.S. Pozharov, A.I. Trikshev, I. V. Zhluktova, I.O. Zolotovskii, E.D. Obraztsova, V.B. Tsvetkov, Hybrid mode locking of an all-fiber holmium laser, J. Opt. Soc. Am. B 35 (2018) 3122–3125, https://doi.org/10.1364/JOSAB.35.003122.

[71] P. Tzenov, I. Babushkin, R. Arkhipov, M. Arkhipov, N. Rosanov, U. Morgner, C. Jirauschek, Passive and hybrid mode locking in multi-section terahertz quantum cascade lasers, New J. Phys. 20 (5) (2018) 053055, https://doi.org/10.1088/1367-2630/aac12a.

[72] R. Huber, M. Wojtkowski, J.G. Fujimoto, Fourier Domain Mode Locking (FDML): A new laser operating regime and applications for optical coherence tomography, Opt. Express 14 (8) (2006) 3225, https://doi.org/10.1364/OE.14.00322510.1364/OE.14.003225.m00110.1364/OE.14.003225.m002.

[73] R. Guenard, K. Krupa, R. Dupiol, M. Fabert, A. Bendahmane, V. Kermene, A. Desfarges, J.L. Berthelemot, A. Auguste, A. Tonello, G. Barthélémy, S. Millot, V.C. Wabnitz, Nonlinear beam self-cleaning in a coupled cavity composite laser based on multimode fiber, Opt. Express 25 (2017) 22219–22227, https://doi.org/10.1364/OE.25.022219.

[74] F. Zhao, H. Wang, Y. Wang, X. Hu, T. Zhang, R. Pan, Observation of various bound states based on a graded index multimode fiber saturable absorber, Laser Phys. Lett. 17 (2) (2020) 025105, https://doi.org/10.1088/1612-202X/ab63da.

[75] W. Fu, L.G. Wright, P. Sidorenko, S. Backus, F.W. Wise, Several new directions for ultrafast fiber lasers [Invited], Opt. Express 26 (8) (2018) 9432–9463, https://doi.org/10.1364/OE.26.009432.

[76] D.C. Kirsch, S. Chen, R. Sidharthan, Y. Chen, S. Yoo, M. Chernysheva, Short-wave IR ultrafast fiber laser systems: Current challenges and prospective applications, J. Appl. Phys. 128 (18) (2020) 180906, https://doi.org/10.1063/5.0023936.

[77] J. Peng, S. Boscolo, Z. Zhao, H. Zeng. Breathing dissipative solitons in mode-locked fiber lasers. Science Advances, v. 5 (11), eaax1110 (2019). https://doi.org/10.1126/sciadv.aax1110.

[78] L. Dong, B. Samson. Fiber lasers: basics, technology, and applications. CRC Press, 340p., 2016. ISBN 978-1-49-872554-5.

[79] Fiber lasers: advances in research and applications (ed. M. C. Paul). Nova Science Pub Inc., 384p., 2017. ISBN 978-1-53-612162-9.

[80] B. Nayar, N. Doran, D. Forrester. “Nonlinear optical fiber loop mirror device,” in Conference on Lasers and Electro-Optics, R. Bartolini, P. Liao, J. Bufton, W. Krupke, eds., v. 11 of OSA Technical Digest (Optical Society of America, 1989), 12-14, paper ME2. ISBN 1-55752-105-0.

[81] D. Richardson, A. Grudinin, D. Payne. Fifty-fs pulse generation in an integrated erbium-doped fiber-laser/amplifier module. In Digest of Conference on Optical Fiber Communication, Vol. 5 of 1992 OSA Technical Digest Series (Optical Society of America, 1992), paper TuG6. https://doi.org/10.1364/OFC.1992.TuG6.

[82] K. Smith, N. Doran, P. Wigley. Pulse shaping, compression, and pedestal suppression employing a nonlinear-optical loop mirror. Opt. Lett., v. 15, 1294-1296 (1990). https://doi.org/10.1364/OL.15.001294; D. Richardson, R. Laming, D. Payne. Very low threshold Sagnac switch incorporating an erbium doped fibre amplifier. El. Letters, v. 26 (21) (1990) 1779–1781. https://doi.org/10.1049/el:19901142.

[83] S. Wu, J. Strait, R. Fork, T. Morse, High-power passively mode-locked Er-doped fiber laser with a nonlinear optical loop mirror, Opt. Lett. 18 (1993) 1444–1446, https://doi.org/10.1364/OL.18.001444.

[84] F. Ilday, F. Wise, T. Sosnowski, High-energy femtosecond stretched-pulse fiber laser with a nonlinear optical loop mirror, Opt. Lett. 27 (17) (2002) 1531–1533, https://doi.org/10.1364/OL.27.001531.

[85] Y. Zhong, Z. Zhang, X. Tao, Passively mode-locked fiber laser based on nonlinear optical loop mirror with semiconductor optical amplifier, Laser Phys. 20 (2010) 1756–1759, https://doi.org/10.1134/S1054660X10150193.

[86] L.M. Zhao, A.C. Bartnik, Q.Q. Tai, F.W. Wise, Generation of 8 nJ pulses from a dissipative-soliton fiber laser with a nonlinear optical loop mirror, Opt. Lett. 38 (2013) 1942–1944, https://doi.org/10.1364/OL.38.001942.

[87] J. Szczepanek, T.M. Kardaś, M. Michalska, C. Radzewicz, Y. Stepanenko, Simple all-PM-fiber laser mode-locked with a nonlinear loop mirror, Opt. Lett. 40 (2015) 3500–3503, https://doi.org/10.1364/OL.40.003500.

[88] W. Hänsel, H. Hoogland, M. Giunta, S. Schmid, T. Steinmetz, R. Doubek, P. Mayer, S. Dobner, C. Cleff, M. Fischer, R. Holzwarth, All polarization-maintaining fiber laser architecture for robust femtosecond pulse generation, Appl. Phys. B 123 (2017) 41, https://doi.org/10.1007/s00340-016-6598-2.

[89] H. Ahmad, S.N. Aidit, S.I. Ooi, Z.C. Tiu, Mode-locked thulium-fluoride fibre laser with an adjustable pulse width using a nonlinear optical loop mirror, Quantum Electron. 49 (2) (2019) 111–114, https://doi.org/10.1070/QEL16770.

[90] M. Michalska, J. Swiderski, All-fiber thulium-doped mode-locked fiber laser and amplifier based on nonlinear fiber loop mirror, Opt. Laser Technol. 118 (2019) 121–125, https://doi.org/10.1016/j.optlastec.2019.05.016.

[91] W. Pan, J. Zhou, L. Zhang, Y. Feng, Raman dissipative soliton fiber laser mode locked by a nonlinear optical loop mirror, Opt. Express 27 (2019) 17905–17911, https://doi.org/10.1364/OE.27.017905.

[92] J. Zhao, J. Zhou, Y. Jiang, L. Li, D. Shen, A. Komarov, L. Su, D. Tang, M. Klimczak, L. Zhao, Nonlinear absorbing-loop mirror in a Holmium-doped fiber laser, J. Lightwave Technol. 38 (2020) 6069–6075, https://doi.org/10.1109/JLT.2020.3005611.

[93] S. Ou, G. Liu, D. Qiu, L. Guo, Q. Zhang, All-polarization-maintaining, all-normal-dispersion mode-locked fiber laser with spectral filtering in a nonlinear optical loop mirror, Opt. Express 28 (2020) 23670–23678, https://doi.org/10.1364/OE.399701.

[94] H. Ahmad, M. Ahmed, M. Samion, Generation of modelocked noise-like pulses in double-clad Tm-doped fibre laser with nonlinear optical loop mirror, J. Mod. Opt. 67 (2) (2020) 146–152, https://doi.org/10.1080/09500340.2019.1699969.

[95] T. Zhang, Y. Pan, L. Yang, Z. Tian, W. Liu, J. Miao, Q. Dong, NOLM-based mode-locked Yb-doped fiber laser with wide-spectrum, Proc. SPIE 11437 (2020) 1143706, https://doi.org/10.1117/12.2542238.

[96] A. Malfondet, A. Parriaux, K. Krupa, G. Millot, P. Tchofo-Dinda, Optimum design of NOLM-driven mode-locked fiber lasers, Opt. Lett. 46 (6) (2021) 1289–1292, https://doi.org/10.1364/OL.418281.

[97] A. Borodkin, P. Honzátko, High-energy all-PM Yb-doped fiber laser with a nonlinear optical loop mirror, Opt. Laser Technol. 143 (2021) 107353, https://doi.org/10.1016/j.optlastec.2021.107353.

[98] M. Durán-Sánchez, B. Posada-Ramírez, R.I. Álvarez-Tamayo, M. Bello-Jiménez, Y. A. García-Flores, I. Armas-Rivera, E. Montiel-Piña, E.A. Kuzin, B. Ibarra-Escamilla, Switchable dissipative soliton resonance and noise like pulses regimes in a mode-locked double-clad thulium doped fiber laser, Laser Phys. 31 (2021) 015102, https://doi.org/10.1088/1555-6611/abd3f6.

[99] F. Zhou, X. Zhou, M. Bi, G. Yang, M. Hu, Y. Lu, Study of the output characteristics of nonlinear optical loop mirror on an erbium-doped mode-locked fiber laser, Optoelectron. Lett. 17 (5) (2021) 283–288, https://doi.org/10.1007/s11801-021-0082-x.

[100] Y. Ma, S. Salman, C. Li, C. Mahnke, Y. Hua, S. Droste, J. Fellinger, A. Mayer, O. Heckl, C. Heyl, I. Hartl, Compact, all-PM fiber integrated and alignment-free ultrafast Yb:fiber NALM laser with sub-femtosecond timing jitter, J. Lightwave Technol. 39 (2021) 4431–4438, https://doi.org/10.1109/JLT.2021.3070208.

[101] H. Chu, S. Zhao, G. Li, M. Li, D. Li, Mode-locked femtosecond polarization-maintaining Yb-doped fiber laser with a figure-nine configuration, Opt. Commun. 482 (2021) 126595, https://doi.org/10.1016/j.optcom.2020.126595.

[102] D. Kim, D. Kwon, B. Lee, J. Kim, Polarization-maintaining nonlinear-amplifying-loop-mirror mode-locked fiber laser based on a 3 × 3 coupler, Opt. Lett. 44 (2019) 1068–1071, https://doi.org/10.1364/OL.44.001068.

[103] G. Gao, H. Zhang, Y. Li, D. Deng, All-normal-dispersion fiber laser with NALM: power scalability of the single-pulse regime, Laser Phys. Lett. 15 (2018) 035106, https://doi.org/10.1088/1612-202X/aa9da1.

[104] Y. Ke, L. Yi-Ming, W. Yan-Bin, Z. Xin, J. Tian, Self-starting all-fiber PM Er:laser mode locked by a biased nonlinear amplifying loop mirror, Chin. Phys. B 28 (12) (2019) 124203, https://doi.org/10.1088/1674-1056/ab4d42.

[105] A. Khegai, M. Melkumov, K. Riumkin, V. Khopin, S. Firstov, E. Dianov, NALM-based bismuth-doped fiber laser at 1.7 μm, Opt. Lett. 43 (2018) 1127–1130, https://doi.org/10.1364/OL.43.001127.

[106] Z. Guo, Q. Hao, J. Peng, H. Zeng, Environmentally stable Er-fiber mode-locked pulsegeneration and amplification by spectrally filtered and phase-biased nonlinear amplifying long-loop mirror, High Power Laser Sci. Eng. 7 (2019) e47, https://doi.org/10.1017/hpl.2019.29.

[107] D. Schmieder, P. Swart, A. Booysen, Figure-eight fibre lasers with NALM loops consisting of highly nonlinear dispersion shifted fibres for dense wavelength division multiplexing, AFRICON 2007 (2007) 1–7, https://doi.org/10.1109/AFRCON.2007.4401621.

[108] A. Mayer, W. Grosinger, J. Fellinger, G. Winkler, L. Perner, S. Droste, S. Salman, C. Li, C. Hey, I. Hart, O. Heckl, Flexible all-PM NALM Yb:fiber laser design for frequency comb applications: operation regimes and their noise properties, Opt. Express 28 (2020) 18946–18968, https://doi.org/10.1364/OE.394543.

[109] H. Ahmad, S. Aidit, S. Ooi, M. Samion, S. Wang, Y. Wang, J. Sahu, A. Zamzuri, 1.3 μm dissipative soliton resonance generation in Bismuth doped fiber laser, Sci. Rep. 11 (2021) 6356, https://doi.org/10.1038/s41598-021-85423-y.

[110] M. Kues, C. Reimer, B. Wetzel, P. Roztocki, B. Little, S. Chu, T. Hansson, E. Viktorov, D. Moss, R. Morandotti, Passively mode-locked laser with an ultra-narrow spectral width, Nat. Photon. 11 (2017) 159–162, https://doi.org/10.1038/nphoton.2016.271.

[111] Q. Deng, K. Yin, J. Zhang, X. Zheng, T. Jiang. A 200 MHz compact environmentally-stable mode-locked figure-9 fiber laser. IEEE Photonics J., v. 13 (4), 1500605 (2021). https://doi.org/10.1109/JPHOT.2021.3095159.

[112] N. Seong, D. Kim, Experimental observation of stable bound solitons in a figure-eight fiber laser, Opt. Lett. 27 (15) (2002) 1321–1323, https://doi.org/10.1364/OL.27.001321.

[113] W. Tian, R. Xu, L. Zheng, X. Tian, D. Zhang, X. Xu, J. Zhu, J. Xu, Z. Wei, 10-W-scale Kerr-lens mode-locked Yb:CALYO laser with sub-100-fs pulses, Opt. Lett. 46 (2021) 1297–1300, https://doi.org/10.1364/OL.419370.

[114] S.V. Smirnov, S.M. Kobtsev, S.K. Turitsyn. Wide variability of generation regimes in mode-locked fiber lasers. Chapter 14 in "Shaping Light in Nonlinear Optical Fibers" (eds. S. Boscolo, C. Finot). Wiley, 504p., 2017. ISBN 978-1-119-08812-7.

[115] I.N. Duling III, C.-J. Chen, P.K.A. Wai, C.R. Menyuk, Operation of a nonlinear loop mirror in a laser cavity, IEEE J. Quantum Electron. 30 (1) (1994) 194–199, https://doi.org/10.1109/3.272080.

[116] I.H. Baek, H.W. Lee, S. Bae, B.H. Hong, Y.H. Ahn, D. Yeom, F. Rotermund, Efficient mode-locking of sub-70-fs Ti: Sapphire laser by graphene saturable absorber, Appl. Phys. Express 5 (2012) 032701, https://doi.org/10.1143/APEX.5.032701.

[117] J. Jeon, J. Lee, J.H. Lee, Numerical study on the minimum modulation depth of a saturable absorber for stable fiber laser mode locking, J. Opt. Soc. Am. B 32 (1) (2015) 31–37, https://doi.org/10.1364/JOSAB.32.000031.

[118] B. Nyushkov, S. Kobtsev, A. Antropov, D. Kolker, V. Pivtsov, Femtosecond 78-nm tunable Er:fibre laser based on drop-shaped resonator topology, J. Light. Technol. 37 (5) (2019) 1359–1363, https://doi.org/10.1109/JLT.2019.2893291.

[119] F.M. Mitschke, L.F. Mollenauer, Ultrashort pulses from the soliton laser, Opt. Lett. 12 (6) (1987) 407–409, https://doi.org/10.1364/OL.12.000407.

[120] N. Davoudzadeh, G. Ducourthial, B. Q. Spring. Custom fabrication and modelocked operation of a femtosecond fiber laser for multiphoton microscopy. Sci. Rep., v. 9 (1), 4233 (2019). https://doi.org/10.1038/s41598-019-40871-5.

[121] W. Hansel, H. Hoogland, M. Giunta, S. Schmid, T. Steinmetz, R. Doubek, P. Mayer, S. Dobner, C. Cleff, M. Fischer, R. Holzwarth. All polarization-maintaining fiber laser architecture for robust femtosecond pulse generation. Chapter 18 in book "Exploring the World with the Laser" (eds. D. Meschede, T. Udem, T. Esslinger). Springer, 812p., 2018. ISBN 978-3-319-64345-8.

[122] G. P. Agrawal. Nonlinear fiber optics (6th ed.). Academic Press, 728p., 2019. ISBN 978-0-12-817042-7.

[123] J. Sun, Y. Zhou, Y. Dai, J. Li, F. Yin, J. Dai, K. Xu, All-fiber polarization-maintaining erbium-doped dispersion-managed fiber laser based on a nonlinear amplifying loop mirror, Appl. Opt. 57 (6) (2018) 1492–1496, https://doi.org/10.1364/AO.57.001492.

[124] V. J. Matsas, T. P. Newson, D. J. Richardson, D. N. Payne. Selfstarting passively mode-locked fibre ring soliton laser exploiting nonlinear polarisation rotation. Electronics Lett., v. 28 (15), Issue 15, 1391-1393 (1992). https://doi.org/10.1049/el:19920885.

[125] H. Jiang, Y. Huang, Z. Zhao, T. Shirahata, L. Jin, S. Yamashita, S.Y. Set, Laser mode locking using a single-mode-fiber coil with enhanced polarization-dependent loss, Opt. Lett. 45 (2020) 2866–2869, https://doi.org/10.1364/OL.393093.

[126] F. Meng, J.M. Dudley, Toward a self-driving ultrafast fiber laser, Light Sci. Appl. 9 (2020) 26, https://doi.org/10.1038/s41377-020-0270-7.

[127] G. Genty, L. Salmela, J.M. Dudley, D. Brunner, A. Kokhanovskiy, S. Kobtsev, S. Turitsyn, Machine learning and applications in ultrafast photonics, Nat. Photon. 15 (2021) 91–101, https://doi.org/10.1038/s41566-020-00716-4.

[128] S. Kobtsev, S. Smirnov, Fiber lasers mode-locked due to nonlinear polarization evolution: golden mean of cavity length, Laser Phys. 21 (2) (2011) 272–276, https://doi.org/10.1134/S1054660X11040050.

[129] L.Q. Zhang, Z. Zhuo, Z. Pan, Y. Wang, J. Zhao, J. Wang, Investigation of pulse splitting behaviour in a dissipative soliton fibre laser, Laser Phys. Lett. 10 (2013), 105104, https://doi.org/10.1088/1612-2011/10/10/105104.

[130] S. Kobtsev, S. Smirnov, S. Kukarin, S. Turitsyn, Mode-locked fiber lasers with significant variability of generation regimes, Opt. Fiber Technol. 20 (6) (2014) 615–620, https://doi.org/10.1016/j.yofte.2014.07.009.

[131] S.O. Leonov, V.S. Voropaev, A.A. Krylov, Pump- and temperature-induced repetition frequency response study in hybrid mode-locked erbium fiber laser with distributed polarizer, Appl. Phys. B 125 (2019) 39, https://doi.org/10.1007/s00340-019-7148-5.

[132] M. Yu, Z. Cheng, C. Hong, Y. Shi, Z. Peng, P. Wang, Investigation of dispersion-managed, all-polarization-maintaining-fiber Yb-doped laser mode-locked by nonlinear polarization evolution, Proc. SPIE 11437 (2020) 114370K, https://doi.org/10.1117/12.2548820.

[133] F.Ö. Ilday, J.R. Buckley, H. Lim, F.W. Wise, W.G. Clark, Generation of 50-fs, 5-nJ pulses at 1.03 μm from a wave-breaking-free fiber laser, Opt. Lett. 28 (2003) 1365–1367, https://doi.org/10.1364/OL.28.001365.

[134] A. Chong, W.H. Renninger, F.W. Wise, Environmentally-stable all-normal-dispersion femtosecond fiber laser, Opt. Lett. 33 (2008) 1071–1073, https://doi.org/10.1364/OL.33.001071.

[135] W. Jun-Li, W. Xue-Ling, H. Bo-Rong, W. Yong-Gang, Z. Jiang-Feng, W. Zhi-Yi. High-pulse-energy all-normal-dispersion Yb-doped fiber laser based on nonlinear polarization evolution. Chin. Phys. Lett., v. 32 (11), 114202 (2015). https://doi.org/10.1088/0256-307X/32/11/114202.

[136] W. Liu, L. Pang, H. Han, W. Tian, H. Chen, M. Lei, P. Yan, Z. Wei, 70-fs mode-locked erbium-doped fiber laser with topological insulator, Sci. Rep. 6 (2016) 19997, https://doi.org/10.1038/srep19997.

[137] J. Szczepanek, T.M. Kardaś, C. Radzewicz, Y. Stepanenko, Nonlinear polarization evolution of ultrashort pulses in polarization maintaining fibers, Opt. Express 26 (2018) 13590–13604, https://doi.org/10.1364/OE.26.013590.

[138] Z. Wang, J. Chen, T. Zhu, D.N. Wang, F. Gao, Graded index fiber as an all-fiber saturable absorber for large energy conventional soliton and dissipative soliton generation, Photon. Res. 7 (2019) 1214–1220, https://doi.org/10.1364/PRJ.7.001214.

[139] E. Yoshida, Y. Kimura, Y. Kimura, M. Nakazawa, M. Nakazawa, Femtosecond Erbium-doped fiber laser with nonlinear polarization rotation and its soliton compression, Jpn. J. Appl. Phys. 33 (1994) 5779, https://doi.org/10.1143/JJAP.33.5779.

[140] X. Liu, Q. Li, D. Pan, F. Ye, B. Malomed, H. Fu, A robust and novel linear fiber laser mode-locked by nonlinear polarization evolution in all-polarization-maintaining fibers, J. Lightwave Technol. (2021), https://doi.org/10.1109/JLT.2021.3117000.

[141] Z. Wu, Q. Wei, P. Huang, S. Fu, D. Liu, T. Huang. Nonlinear polarization evolution mode-locked YDFL based on all-PM fiber cavity. IEEE Photonics J., v. 12 (2), 1501807 (2020). https://doi.org/10.1109/JPHOT.2020.2979327.

[142] W. Znang, Y. Liu, C. Wang, Z. Zhu, D. Luo, C. Gu, W. Li, Ultrafast PM fiber ring laser mode-locked by nonlinear polarization evolution with short NPE section segments, Opt. Express 26 (7) (2018) 7934–7941, https://doi.org/10.1364/OE.26.007934.

[143] X. Shen, W. Li, M. Yan, H. Zeng, Electronic control of nonlinear-polarization-rotation mode locking in Yb-doped fiber lasers, Opt. Lett. 37 (2012) 3426–3428, https://doi.org/10.1364/OL.37.003426.

[144] Y. Wang, L. Zhang, Z. Zhuo, S. Guo, Cross-splicing method for compensating fiber birefringence in polarization-maintaining fiber ring laser mode locked by nonlinear polarization evolution, Appl. Opt. 55 (2016) 5766–5770, https://doi.org/10.1364/AO.55.005766.

[145] X. Li, X. Yu, Z. Sun, Z. Yan, B. Sun, Y. Cheng, X. Yu, Y. Zhang, Q.J. Wang, High-power graphene mode-locked Tm/Ho co-doped fiber laser with evanescent field interaction, Sci. Rep. 5 (2015) 16624, https://doi.org/10.1038/srep16624.

[146] L. Miao, G. Jiang, L. Du, B. Huang, W. Hu, C. Zhao, S. Wen, Erbium-doped fiber laser mode-locked by halide perovskite via evanescent field interaction, IEEE Photon. Technol. Lett. 30 (6) (2018) 577–580, https://doi.org/10.1109/LPT.2018.2807979.

[147] Y. Gladush, A. Mkrtchyan, D. Kopylova, A. Ivanenko, B. Nyushkov, S. Kobtsev, A. Kokhanovskiy, A. Khegai, M. Melkumov, M. Burdanova, M. Staniforth, J. Lloyd-Hughes, A. Nasibulin, Ionic liquid gated carbon nanotube saturable absorber for switchable pulse generation, Nano Lett. 19 (9) (2019) 5836–5843, https://doi.org/10.1021/acs.nanolett.9b01012.

[148] N. Li, W. Zhang, J. Zhang, M. Guo, Z. Guo, Mode-locked Er-doped fiber laser based on nonlinear multimode interference, Laser Phys. Lett. 17 (2020) 085105, https://doi.org/10.1088/1612-202X/ab9f40.

[149] Z. Dong, S. Li, R. Chen, H. Li, C. Gu, P. Yao, L. Xu, Mode-locked ytterbium-doped fiber laser based on offset-spliced graded index multimode fibers, Opt. Laser Technol. 119 (2019) 105576, https://doi.org/10.1016/j.optlastec.2019.105576.

[150] W. Pan, L. Jin, J. Wang, R. Wang, H. Zhang, X. Yingtian, X. Zhao, Y. Li, X. Ma, All-normal-dispersion dissipative soliton fiber laser using an offset-splicing graded-index-multimode-fiber-based saturable absorber, Appl. Opt. 60 (2021) 923–928, https://doi.org/10.1364/AO.413601.

[151] K. Zhang, M. Rochette, All-Fiber saturable absorber using nonlinear multimode interference in a chalcogenide fiber, J. Lightwave Technol. 38 (2020) 6321–6326, https://doi.org/10.1109/JLT.2020.3010356.

[152] J. Zheng, S. Yang, K. Lau, Z. Zhu, L. Li, Recent research progress of Mamyshev oscillator for high energy and ultrashort pulse generation, Opt. Fiber Technol. 67 (2021) 102691, https://doi.org/10.1016/j.yofte.2021.102691.

[153] P. V. Mamyshev. Method and apparatus for all-optical data regeneration. Patent USA 6141129 (Oct. 31, 2000). H04B 10/00, H04B 10/12. https://patents.google.com/patent/US6141129.

[154] K. Sun, M. Rochette, L.R. Chen, Output characterization of a selfpulsating and aperiodic optical fiber source based on cascaded regeneration, Opt. Express 17 (2009) 10419–10432, https://doi.org/10.1364/OE.17.010419.

[155] I. Samartsev, A. Bordenyuk. Passively mode-locked fiber ring generator. Patent WO 2016/100330 Al (23.06.2016). H01S 3/098, H01S 3/067. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2016100330.

[156] P. Sidorenko, W. Fu, L.G. Wright, M. Olivier, F.W. Wise, Self-seeded, multi-megawatt, Mamyshev oscillator, Opt. Lett. 43 (2018) 2672–2675, https://doi.org/10.1364/OL.43.002672.

[157] C. Ma, A. Khanolkar, Y. Zang, A. Chong. Generation of 17 fs pulses from a Mamyshev oscillator with intra-cavity photonic crystal fiber. Conference on Lasers and Electro-Optics, OSA Technical Digest (Optical Society of America, 2019), paper STu3L.1. https://doi.org/10.1364/CLEO_SI.2019.STu3L.1.

[158] V. Boulanger, M. Olivier, F. Guilbert-Savary, F. Trépanier, M. Bernier, M. Piché, All-fiber Mamyshev oscillator enabled by chirped fiber Bragg gratings, Opt. Lett. 45 (2020) 3317–3320, https://doi.org/10.1364/OL.396218.

[159] D. Yan, X. Li, S. Zhang, J. Liu, Pulse dynamic patterns in a self-starting Mamyshev oscillator, Opt. Express 29 (2021) 9805–9815, https://doi.org/10.1364/OE.419948.

[160] X. Luo, T.H. Tuan, T.S. Saini, H.P.T. Nguyen, T. Suzuk, Y. Ohishi, All-fiber mode-locked laser based on Mamyshev mechanism with high-energy pulse generation at 1550 nm, J. Lightwave Technol. 38 (6) (2020) 1468–1473, https://doi.org/10.1109/JLT.2019.2954488.

[161] Y. Chen, P. Sidorenko, R. Thorne, F. Wise, Starting dynamics of a linear-cavity femtosecond Mamyshev oscillator, J. Opt. Soc. Am. B 38 (2021) 743–748, https://doi.org/10.1364/JOSAB.415276.

[162] 127. F. Wise. High Peak Power Mamyshev oscillators. In Optical Fiber Communication Conference (OFC) 2019, OSA Technical Digest (Optical Society of America, 2019), paper W3C.1. https://doi.org/10.1364/OFC.2019.W3C.1.

[163] P. Repgen, D. Wandt, U. Morgner, J. Neumann, D. Kracht, Sub-50 fs, μJ-level pulses from a Mamyshev oscillator–amplifier system, Opt. Lett. 44 (2019) 5973–5976, https://doi.org/10.1364/OL.44.005973.

[164] V. P. Gapontsev, L. E. Samartsev. High-power fiber laser. In Advanced Solid State Lasers, G. Dube, ed., v. 6 of OSA Proceedings Series (Optical Society of America, 1990), paper LSR1. https://doi.org/10.1364/ASSL.1990.LSR1.

[165] J. Limpert, F. Roser, T. Schreiber, A. Tunnermann, High-power ultrafast fiber laser systems, IEEE J. Sel. Top. Quantum Electron. 12 (2) (2006) 233–244, https://doi.org/10.1109/JSTQE.2006.872729.

[166] M.E. Fermann, I. Hartl, Ultrafast fibre lasers, Nat. Photon. 7 (2013) 868–874, https://doi.org/10.1038/nphoton.2013.280.

[167] L. Zhao, D. Li, L. Li, X. Wang, Y. Geng, D. Shen, L. Su, Route to larger pulse energy in ultrafast fiber lasers, IEEE J. Sel. Top. Quantum Electron. v. 24 (3) (2018) 8800409, https://doi.org/10.1109/JSTQE.2017.2771739.

[168] M. Rusdi, A. Jafry, A. Latiff, A. Rosol, M. Rahman, N. Kasim, M. Khudus, H. Harun, Generation of Q-switched fiber laser at 1.0-, 1.55- and 2.0-μm employing a spent coffee ground based saturable absorber, Opt. Fiber Technol. 61 (2021) 102434, https://doi.org/10.1016/j.yofte.2020.102434.

[169] Z. Wang, L. Zhan, J. Wu, Z. Zou, L. Zhang, K. Qian, L. He, X. Fang, Self-starting ultrafast fiber lasers mode-locked with alcohol, Opt. Lett. 40 (2015) 3699–3702, https://doi.org/10.1364/OL.40.003699.

[170] C. Ma, W. Huang, Y. Wang, J. Adams, Z. Wang, J. Liu, Y. Song, Y. Ge, Z. Guo, L. Hu, H. Zhang, MXene saturable absorber enabled hybrid mode-locking technology: a new routine of advancing femtosecond fiber lasers performance, Nanophotonics 9 (8) (2020) 2451–2458, https://doi.org/10.1515/nanoph-2019-0527.

[171] X. Li, D. Wang, J. Chen, Saturable absorber based on a hybrid structure of graded-index multimode fiber and graphene for a passive mode-locked erbium-doped fiber laser, J. Opt. Soc. Am. B 38 (2021) 2112–2117, https://doi.org/10.1364/JOSAB.423137.

[172] A. Donodin, V. Voropaev, D. Batov, D. Vlasov, V. Lazarev, M. Tarabrin, A. Khegai, M. Likhachev, Numerical model of hybrid mode-locked Tm-doped all-fibre laser, Sci. Rep. 10 (2020) 17396, https://doi.org/10.1038/s41598-020-74194-7.

[173] Z. Shi, X. Li, Y. Zhang, H. Li, Y. Zhao, P. Guo, Y. Guo, Graphdiyne for ultrashort pulse generation in an Erbium-doped hybrid mode-locked fiber laser, Front. Phys. 7 (2019) 150, https://doi.org/10.3389/fphy.2019.00150.

[174] Y. Feng, L. Du, Y. He, Q. Yi, J. Li, Q. Duan, S. Chen, L. Miao, C. Zhao, Robust hybrid mode-locking operation with bulk-like transition metal pentatellurides, J. Mater. Chem. C 9 (2021) 6445–6451, https://doi.org/10.1039/D1TC00903F.

[175] Z. Wen, B. Lu, K. Wang, S. Chen, J. Bai, Generating narrow bandwidth pulses in a hybrid mode-locked fiber laser, Opt. Lett. 46 (2021) 1097–1100, https://doi.org/10.1364/OL.414145.

[176] G. Pu, L. Yi, L. Zhang, W. Hu, Intelligent programmable mode-locked fiber laser with a human-like algorithm, Optica 6 (2019) 362–369, https://doi.org/10.1364/OPTICA.6.000362.