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ULTRASHORT PULSE FIBER LASER INCORPORATING NICKEL-BASED METAL-ORGANIC FRAMEWORK SATURABLE ABSORBER

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By

AMIR MURAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Chairman : Professor Mohd Adzir bin Mahdi, PhD
Faculty : Engineering

Ultrashort pulse fiber lasers have drawn considerable research interest owing to their capabilities in providing research solutions for numerous advanced academic and industrial applications. The passive mode-locking method, using real saturable absorbers (SAs), has the prospect of constructing a simple, compact, robust and stable ultrashort pulse source. Until now, various materials have been successfully demonstrated for the fabrication of ultrashort pulse fiber lasers. However, the properties of these materials strictly depend on their intrinsic properties which require fine control and a deeper understanding of material properties. Therefore, this work demonstrates the fabrication of metal-organic framework (MOF)-based SA for ultrashort pulse generation. MOFs have developed an important class of crystalline, porous and hybrid materials with vast possible combinations, synergistic effects and tunable characteristics.

This work involves the fabrication of SA using nickle-1,3,5 benzene tricarboxylic acid (Ni-H_3BTC) MOF by varying metal to ligand ratio. Five different concentration samples were synthesized by increasing the metal ratio from 0.5 to 4.0 with respect to the fixed ligand ratio of 1.0. The prepared samples were characterized for structural, optical, electrical, dielectric and nonlinear saturable absorption properties. The properties of the prepared samples varied proportionally with increasing metal-to-ligand ratio. The prepared samples were further explored for ultrashort pulse generation. The composite of prepared materials and polydimethylsiloxane polymer was prepared and spin-coated on tapered fiber. The tapered fiber with adiabatic (AD) and non-adiabatic (nAD) characteristics were fabricated by varying the up/down taper length while maintaining the waist diameter and length. Among different concentration samples only Sample 2, having metal-to-ligand ratio of 2:1, established the desired modulation depth (MD) of around 5%, which was then inserted in erbium-doped and thulium-doped fiber lasers. At first, a ring cavity erbium-doped fiber laser (EDFL) was designed, having net group velocity dispersion (GVD) in anomalous dispersion regime. The GVD was then shifted to near zero dispersion regime by increasing the erbium-doped fiber length. A conventional soliton mode-locked pulse with Kelly sidebands was observed with 8 m

length of erbium-doped fiber for both SAs, prepared through composite deposition on AD and nAD tapered fiber. The mode-locked fiber laser (MLFL) in the EDFL cavity demonstrated stable characteristics observed during power development with no indication of multi-pulsing or instabilities. The oscilloscope traces and radio frequency (RF) spectrum were observed at a fundamental frequency of 9.9 MHz for both SAs. Moreover, ultrashort pulses with pulse duration of 810 fs and 845 fs were obtained with nAD and AD SA, respectively. When the length of erbium-doped fiber increased to 10 m, noise-like pulse was observed having autocorrelation trace of narrow spike riding on the broad pedestal operating at a fundamental repetition rate of 9 MHz. The pedestal pulse width of 13.9 ps and 26.7 ps were obtained with nAD and AD SA, respectively. The corresponding pulse width of spike was 164 fs and 148 fs, respectively. Likewise, the cavity with both conventional soliton and noise-like pulse demonstrated good operational stability for two hours. The AD SA performed better with high pulse energy, average output power, and RF characteristics, whereas the nAD SA possessed the smallest pulse width, higher spectral bandwidth and higher MD.

A ring cavity thulium-doped fiber laser (TDFL) was constructed with 3 m length of thulium-doped fiber only. All the components used for the proposed TDFL cavity were consisted of fibers having an anomalous dispersion. Therefore, the variation in the length of thulium doped fiber would not change the operating regime of MLFL. The optical spectrum with 3-dB bandwidth of 4.47 nm centered at 1933.25 nm was obtained with nAD SA. Whereas for the AD SA, the 3-dB bandwidth and center wavelength of 4.21 nm and 1935.26 nm were observed, respectively. Moreover, ultrashort pulse, having pulse duration of 1.19 ps and 985 fs were obtained with nAD and AD SA, respectively. The power development spectra demonstrated a stable performance of MLFL, operating at fundamental frequency of 14.7 MHz without any pulse breaking or instabilities. The proposed passive MLFL in TDFL cavity demonstrated ultrashort pulse with signal-to-noise ratio greater than 50 dB and remained stable for 2 hours stability measurement.

Generally, this work involves optimization of Ni-H_3BTC MOF for ultrashort pulse generation; conventional soliton and noise-like mode-locked pulses. These findings suggest the viability of Ni-H_3BTC-MOF as a new light-absorbing material for ultrashort pulse generations that might assist as a footing for exploring different types of available MOFs and their properties for the purpose. This work infers that MOF-based saturable absorbers can be an alternative material for generating ultrashort pulses.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

LASER GENTIAN DENYUT ULTRA-PENDEK MENGGABUNGKAN PENYERAP BOLEH TEPU BERASASKAN KERANGKA LOGAM ORGANIK NIKEL

Oleh

AMIR MURAD

Julai 2022

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Laser gentian denyut ultra-pendek telah menarik minat penyelidikan yang besar kerana keupayaan mereka dalam menyediakan penyelesaian penyelidikan untuk pelbagai aplikasi akademik dan perindustrian termaju. Kaedah penguncian mod pasif, menggunakan penyerap boleh tepu (SA) sebenar, mempunyai prospek untuk membina sumber denyut ultra-pendek yang mudah, padat, teguh dan stabil. Sehingga kini, pelbagai bahan telah berjaya ditunjukkan untuk pembuatan laser gentian denyut ultra-pendek. Walau bagaimanapun, sifat bahan ini bergantung sepenuhnya pada sifat intrinsiknya yang memerlukan kawalan halus dan pemahaman yang lebih mendalam tentang sifat bahan. Oleh itu, kerja ini menunjukkan pemfabrikatan SA berasaskan kerangka logam-organik (MOF) untuk penjanaan denyut ultra-pendek. MOF telah membangunkan kelas penting bahan kristal, berliang dan hibrid dengan kemungkinan gabungan yang luas, kesan sinergistik dan ciri boleh tala.

Kerja ini melibatkan pemfabrikatan SA menggunakan asid trikarboksilik nikel-1,3,5 benzena (Ni-H_3BTC) MOF dengan mengubah nisbah logam kepada ligan. Lima sampel berkepekatan yang berbeza telah disintesis dengan meningkatkan nisbah logam daripada 0.5 kepada 4.0 berkenaan dengan nisbah ligan tetap 1.0. Sampel yang disediakan telah dicirikan untuk ciri-ciri struktur, optik, elektrik, dielektrik dan penyerapan boleh tepu tak linear. Sifat-sifat sampel yang telah disediakan berubah secara berkadar dengan peningkatan nisbah logam kepada ligan. Sampel yang disediakan telah diterokai selanjutnya untuk penjanaan denyut ultra-pendek. Komposit bahan dan polimer polidimetilsiloksana telah disediakan dan disalut secara putaran pada gentian tirus. Gentian tirus dengan ciri adiabatik (AD) dan tidak adiabatik (nAD) telah difabrikasi dengan mengubah tirus panjang atas/bawah manakala diameter dan panjang pinggang dikekalkan. Di antara sampel kepekatan yang berbeza, hanya Sampel 2, yang mempunyai nisbah logam kepada ligan 2:1, mempunyai kedalaman modulasi (MD) sekitar 5%, yang kemudiannya dimasukkan ke dalam laser gentian terdop erbium dan terdop tulium. Pada mulanya, laser gentian terdop erbium (EDFL) rongga cincin telah direka bentuk,

mempunyai penyebaran halaju kumpulan bersih (GVD) dalam rejim penyebaran beranomali. GVD kemudiannya dialihkan kepada rejim penyebaran hampir sifar dengan meningkatkan panjang gentian terdop erbium. Denyut terkunci mod soliton konvensional dengan jalur sisi Kelly telah diperhatikan dengan gentian terdop erbium sepanjang 8 m untuk kedua-dua SA yang telah disediakan melalui pemendapan komposit pada gentian tirus AD dan nAD. Laser gentian terkunci mod (MLFL) dalam rongga EDFL menunjukkan ciri-ciri stabil yang diperhatikan semasa pembangunan kuasa tanpa tanda-tanda berbilang denyut atau ketidakstabilan. Surih osiloskop dan spektrum frekuensi radio (RF) diperhatikan pada frekuensi asas 9.9 MHz untuk kedua-dua SA. Tambahan lagi, denyut ultra-pendek dengan tempoh denyutan masing-masing 810 fs dan 845 fs diperolehi dengan nAD dan AD SA. Apabila panjang gentian terdop erbium meningkat kepada 10 m, denyutan seperti hingar diperhatikan mempunyai kesan autokorelasi pancang sempit yang menunggang pada kekaki luas yang beroperasi pada kadar pengulangan asas 9 MHz. Lebar denyut kekaki masing-masing 13.9 ps dan 26.7 ps diperolehi dengan nAD dan AD SA. Lebar denyut pancang adalah masing-masing 164 fs dan 148 fs. Begitu juga, rongga dengan kedua-dua soliton konvensional dan denyutan seperti hingar menunjukkan kestabilan operasi yang baik selama dua jam. AD SA berprestasi lebih baik dengan tenaga denyutan tinggi, purata kuasa keluaran dan ciri RF, manakala nAD SA mempunyai lebar denyut terkecil, lebar jalur spektrum dan MD yang lebih tinggi.

Laser gentian terdop tulium (TDFL) rongga cincin telah dibina dengan gentian terdop tulium sepanjang 3 m sahaja. Semua komponen yang digunakan untuk rongga TDFL yang dicadangkan terdiri daripada gentian optik yang mempunyai penyebaran beranomali. Oleh itu, variasi dalam panjang gentian terdop tulium tidak akan mengubah rejim operasi MLFL. Spektrum optik dengan lebar jalur 3-dB adalah 4.47 nm berpusat pada 1933.25 nm diperolehi dengan nAD SA. Manakala untuk AD SA, lebar jalur 3-dB dan panjang gelombang tengah telah diperhatikan pada 4.21 nm dan 1935.26 nm masing-masing. Selain itu, denyut ultra-pendek yang mempunyai tempoh denyut 1.19 ps dan 985 fs masing-masing diperolehi dengan nAD dan AD SA. Spektrum pembangunan kuasa menunjukkan prestasi stabil MLFL, beroperasi pada frekuensi asas 14.7 MHz tanpa sebarang perpecahan denyutan atau ketidakstabilan. MLFL pasif yang dicadangkan dalam rongga TDFL menunjukkan denyut ultra-pendek dengan nisbah isyarat kepada bunyi lebih daripada 50 dB dan kekal stabil selama 2 jam pengukuran kestabilan.

Secara amnya, kerja ini melibatkan pengoptimuman Ni-H_3BTC MOF untuk penjanaan denyut ultra-pendek; soliton konvensional dan denyutan terkunci mod seperti hingar. Penemuan ini mencadangkan keberkesanan Ni-H_3BTC-MOF sebagai bahan penyerap cahaya baharu untuk penjanaan denyut ultra-pendek yang mungkin membantu sebagai asas kepada penerokaan pelbagai jenis MOF yang sedia ada dan sifatnya untuk tujuan tersebut. Kerja ini menyimpulkan bahawa penyerap tepu berasaskan MOF boleh menjadi bahan alternatif untuk menjana denyut ultra-pendek.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	Adiabatic
ASE	Amplified spontaneous emission
BET	Brunauer–Emmett–Teller
BP	Black phosphorus
CNT	Carbon nanotube
CSD	Cambridge Structure Database
CSD	Coordination polymers
CW	Continuous wave
DSF	Dispersion-shifted fiber
EDF	Erbium-doped fiber
EDFL	Erbium-doped fiber laser
EDX	Energy dispersive X-ray
EIS	Electrical impedance spectroscopy
EYDFA	Erbium-ytterbium doped fiber amplifier
FESEM	Field emission scanning electron microscopy
FSR	Free spectral range
FTIR	Fourier transform infrared spectroscopy
FWHM	Full width at half maximum
FWM	Four-wave mixing
GVD	Group velocity dispersion
HF	Hydrofluoric acid
IPA	Isopropyl alcohol
I_{sat}	Saturation Intensity
Laser	Light amplification by the stimulated emission of radiation

LD	Laser diode
MD	Modulation depth
MLCT	Metal-to-ligand charge transfer
MLFL	Mode-locked fiber laser
MMF	Multi-mode fiber
MOF	Metal-organics framework
nAD	non-adiabatic
NIR	Near-infrared
NLP	Noise like pulse
NLSA	Nonlinear saturable absorption
NOLM	Nonlinear optical loop mirror
NPR	Nonlinear polarization rotation
OSA	Optical spectrum analyzer
PC	Polarization controller
PDL	Polarization dependent loss
PDMS	Polydimethylsiloxane
PLS	Pulsed laser source
RBW	Resolution bandwidth
SA	Saturable absorber
SD	Standard deviation
SESAM	Semiconductor saturable absorber mirror
SMF	Single-mode fiber
SNR	Signal to noise ratio
SPM	Self-phase modulation
TBP	Time bandwidth product

TDF	Thulium-doped fiber
TDFL	Thulium-doped fiber laser
TMD	Transition metal di-chalcogenide
T_{ns}	Non saturable loss
TPA	Two photon absorption
VBW	Video bandwidth
VOA	Variable optical attenuator
WDM	Wavelength division multiplexer
XPM	Cross-phase modulation
XRD	X-ray diffraction

CHAPTER 1

INTRODUCTION

1.1 Background

A laser is an electronic device that works on stimulated emissions to emit a narrow beam of light. The characteristics of the light emitted by a laser vary significantly from those produced by a traditional source, such as an incandescent light bulb or a fluorescent light tube. The fundamental difference between laser and other light sources is that it generates a coherent narrow beam of high-intensity light. In 1916, Albert Einstein suggested that under appropriate conditions, atoms can release the excess of energy in the form of light, naturally or when stimulated by light [1]. This led to the foundation for evolution of lasers almost one decade ago.

Nevertheless, stimulated emissions were first observed by German physicist Rudolf Walther Ladenburg in 1928, although the invention was called negative absorption and was considered of little practical significance by scientists at that time. Since the name of laser was coined by Gould in 1958, the first breakthrough was achieved at Hughes Research Laboratories by Theodore H. Maiman in 1960, where he invented the first laser from crystals of synthetic ruby [2]. He successfully produced a laser having red pulses of about fingertip size. After that, different types of lasers like helium-neon and semiconductor lasers were developed that demonstrated commercial success and became standard equipment in many diverse applications.

After Maiman invented the laser in 1960 and the subsequent invention of optical fibers, a new era of optical communication began. In single-mode fiber (SMF), the low loss region extends from 1200-1600 nm, equivalent to more than 30 THz of bandwidth. The current standard for long-haul optical communications is up to 40 Gbit/s, and in the next few years, it will begin to move towards 400 Gbit/s by mitigating limitations of nonlinearity and dispersion in fiber at a high bit rate. These advancement in optical fibers technology has enabled it as a desired medium for many applications. Optical fibers offer an applicable platform for the advancement and monolithic integration of laser system; therefore, fiber laser has a substantial prospect in the field of laser engineering.

Fiber laser is synthesized by doping optical fiber with rare earth elements such as erbium, praseodymium, ytterbium, terbium, and thulium. One of the main advantages of fiber laser over its other counterparts is that light can be amplified and delivered by the same flexible medium. Also, it enables amplification of light signal without converting into an electrical signal, ensuring all-optical architecture. The amplified optical wavelengths depict usable gain, which is determined by dopant properties, the structure of fiber and pump power.

Monochromatic light produced by laser does not comprise a pure single frequency; nevertheless, the light produced has some inherent bandwidth. This bandwidth is determined by the type of gain medium and bandwidth. The second element in deciding the emission frequency of a laser is the resonant cavity. Lightwave propagating in the resonant cavity will interfere constructively or destructively with itself, leading to standing waves or modes in the cavity. In an ordinary laser, these modes oscillate independently without any fixed relationship to each other. The interference in these modes produces average output intensity. However, when a fixed relationship is established between modes, all modes will constructively interfere, forming an intense pulse of light instead of random average output intensity. Such a phenomenon is called mode-locking. Mode-locking in lasers can be achieved via two methods, active and passive mode-locking. An external electro-optic component is employed in the active method to realize mode-locking, whereas, in the passive method, an element is implanted in the laser cavity to modulate light for mode-locking. The mode-locked pulses having pulse width in the range of picosecond or less is referred to as ultrashort fiber laser.

1.2 Overview

Ultrashort fiber laser realized through passive mode-locking has attracted significant research interest due to its wide applications, ranging from fundamental research to advanced industrial processing. For instance; medical diagnosis, materials characterization, energy application, remote sensing, micro matching, optical communications, metrology and laser range determination are performed with this type of laser [3]–[7]. Mode-locked fiber lasers possess considerable advantages compared to continuous-wave (CW) lasers. It enables clear and precise cutting in laser surgeries, accurate measurement for remote sensing and cleanser ablation of materials, and several other advantages.

The development of ultrashort pulse fiber lasers with pulse widths in the range of pico- and femto-second has been evolving, accenting on the gain medium and nonlinear characteristics to achieve ultrashort pulse generation. Laser emissions at the near and mid-infrared region (1-2 μm) are now well established by rare-earth doped fibers. Erbium-doped fiber (EDF) provides amplification around 1.55 μm wavelength region is highly desirable for telecommunication, micro-matching, industrial applications and materials surface modification [8]. Also, silica glass fibers have a low loss window at the same wavelength, emerging as a strong candidate for the fabrication of passive mode-locked fiber laser (MLFL). Similarly, thulium-doped fiber (TDF) provides amplification around 1.9 μm has driven research interest owing to their broad-bandwidth around 400 nm, which makes TDF an attractive gain medium for ultrashort pulse generation. TDF lasers are desired for several applications including military, medicine and spectroscopy [9].

Ultrashort pulse laser realized through passive mode-locking is preferred owing to its compact and simple structure, reliable performance and nominal price range [10], [11], which can be realized by either real or artificial saturable absorber (SA). SA is an important nonlinear optical modulating component for generating ultrashort pulses through passive mode-locking or Q-switching. Whereas the mode-locking can be achieved through phase locking the longitudinal modes propagating in the cavity and Q-switching is succeeded by modulating the cavity losses (Q-factor) through SA. In general, SAs can be classified as real SA and artificial SA. The artificial SAs i.e. nonlinear polarization rotation (NPR) and nonlinear optical loop mirror (NOLM) are based on nonlinear effects in the laser cavity [12]. Besides having advantages of low cost and high damage threshold, the performance of artificial SAs is affected by high saturation intensity, difficulty in self-starting and performance degradation by environmental perturbation [13]. On the other hand, the real SAs are based on the saturation effect of the material's resonance transition. In fact, as long as the laser operates within the material's resonance absorption wavelength range, most light-absorbing materials can be utilized as the SA. Besides these several other characteristics like operating wavelength, saturation intensity, damage threshold, and stability are also important determinants for any materials to be used as SA.

Fabrication of real SA to realize passive MLFL in the EDF and TDF laser cavities are of significant research interest owing to its lasing in mid-infrared wavelength region, which is desired for many applications. So far, various materials have been developed for the fabrication of SA. Initially, semiconductor saturable absorber mirror (SESAM) was widely used SA, which rapidly penetrates commercial systems [14]. However, it is limited in bandwidth and requires complex fabrications procedures due to its semiconductor-based structures, which compel the researchers to search for new materials for simple SA fabrication. Recently, low dimensional materials, particularly those with 2D structures and nonlinear properties, have been widely used for the fabrication of SA because they can be easily integrated into various electro-optical components. Carbon nanotube (CNT) [15] possesses nonlinear properties that has been used as SA but has limitations of bandwidth and chirality control, which make it less competent for SA fabrication [16]. Graphene[17] was raised as a potential candidate for SA due to its gap less linear dispersion and Dirac electron property. Due to these properties, graphene and its derivatives were widely reported in the literature [18]–[23]. However, monolayer graphene has a relatively low absorption of 2.3%, which limits its modulation capacity. Transition metal di-chalcogenide (TMD) materials have relatively large bandwidth and possess higher resonant absorption at a particular wavelength [24]–[28], and black phosphorus (BP) [29], [30], having layer dependent tunable bandgap structure has recently joined the family of 2D nanomaterials used for fabrication of SA. However, TMDs require firm control of material thickness [31]. The performance of BP-SA is hampered by its performance degradation in the ambient environment [32]. Several other materials i.e., silver and other metal nanoparticles [33], [34], palladium ditelluride [35], alcohol [36], chalcogenides [37] and metal oxide were also reported for SA fabrication [38]. However, the bandwidth and operating wavelength of these materials is limited, which hamper their photonics application in wideband wavelength region. Thus, the identification of new novel materials having tunable, nonlinear properties, easy fabrication methods, stable and operating in wideband wavelength region is still a long-standing research goal.

In this regard, it is of research interest to explore new functional materials as a mode-locker with desired characteristics [39]. Recently, metal-organics frameworks (MOFs) have emerged as an important class of hybrid crystalline porous materials, which is a functional material with many intriguing properties like ultra-high surface area, tunable bandgap, nano-meter sized spaces, high optical transparency, and mature fabrication methods, leading to broad applications in divisional fields [40]. Besides these, MOF structures retain enhanced stability, crystallinity, and tunability, leading to more than 20,000 structures, as reported by the Cambridge Structure Database (CSD) [41]. MOF also possesses nonlinear properties which can be optimized for efficient mode-locking performance by fine-tuning one or more MOF properties. These properties can be optimized by judicious choice of metal, ligands and synthetic conditions for the desired applications [42], which can be further enhanced by encapsulation in pores, calcination, composites formation, and doping [43]. Moreover, MOFs are ideal materials due to their mature fabrication methods, versatility and synergistic effects to identify desired characteristics for different applications. Furthermore, the wide range of characterization techniques applicable for MOFs enables a wide range of experiments to reveal underlying performance determinants and provide critical information for developing novel functional materials. Also, the plethora of possible combinations will level the path to relate the effect of materials properties on mode-locked laser characteristics.

1.3 Problem statement

Exploration of new MOFs for ultrashort pulse generations is still at the infancy stage. Even though several reported MOFs possess desired properties for SA fabrication, i.e., a third-order nonlinear phenomenon [44], [45], and second harmonic susceptibilities [46]–[48], only a few MOFs and their derivative have been reported for SA fabrication [49]–[51]. These reports open a new avenue to explore MOF for ultrashort pulse generation. However, the effect of different MOF structures on mode-locked laser performance is still obscure. Though, it has been reported that ligand plays a vital role in deciding the characteristics, properties and functionalities of MOFs [52]. Therefore, to further explore MOFs enticing characteristics, different types of ligands during materials synthesis compared to the previous reported MOF are investigated for ultrashort pulse generation. Also, the synthetic conditions are important to decide the final properties of materials for prospective application, which needs to be optimized. However, the lack of information and ways to get the requisite ordered features is a substantial barrier in the application of MOFs. Due to the large range of possible architectures, one of the fundamental research difficulties in this sector is determining the effect of various parameters on the characteristic properties for prospective applications. Recent research on the synthesis of diverse MOFs has made significant progress in characterizing and optimizing them for desired applications. Therefore, the effect of various MOF properties on the ultrashort laser performance is still vague.

Moreover, for reported ultrashort fiber laser using MOF on a tapered fiber, a direct deposition technique was employed. This technique can be achieved either optical deposition or drop-casting, the objective is to transfer materials on fiber or glass substrate. However, these methods have certain shortcomings. The optical deposition requires optimization of light power for each sample individually to ensure the uniform distribution of materials on the fiber surface. However, the uniform distribution of materials with optical deposition is still debatable and requires several trial-and-error experiments. On the other hand, the drop-casting method is straightforward; however, the repeatability is of serious concern as the uniform coating and thickness of materials are not well controlled. In addition, the MOFs were deposited directly without any protective polymer support to attach them to the fiber surface, which also made it prone to environmental and mechanical disturbances and requires dedicated operational conditions. The protective composite facilitates the attachment of materials to the tapered fiber and increases the lifetime of SA by protecting it from disturbances. The development of MOF based SA can be further optimized by spin-coating the materials embedded in polymer composite on tapered fiber to ensure uniform thickness of deposited materials and increase the shelf life of fabricated SA.

Furthermore, from the viewpoint of microfiber dimension, which affects the adiabatic nature of tapered fiber that leads to the performance of pulse generation. In general, adiabatic (AD) tapered fiber is the trusted transducer due to its low loss propagation of light due to its strong confinement effect. However, its counterpart which is non-adiabatic (nAD) tapered fiber offers stronger evanescent light interaction with surroundings but at the expense of higher transmission loss. The evanescent field interaction can be optimized by controlling the tapered angle to analyze its effect on mode-locked pulse characteristics.

1.4 Objective of the study

The main objective of this PhD work is to fabricate passive MLFL by incorporating MOF-based SA, in EDF and TDF ring cavity lasers. To accomplish this, the following objectives have been outlined:

1. To synthesize and characterize MOF using nickel as metal cations and trimesic acid as ligands, through the solvothermal method.

2. To fabricate and characterize SA utilizing as-synthesized MOF on AD and nAD tapered fibers.

3. To analyze the performance of the fabricated SAs in the ring cavity erbium-doped fiber laser (EDFL) for ultrashort pulse generation.

4. To analyze the performance of the fabricated SAs in the ring cavity thulium-doped fiber laser (TDFL) for ultrashort pulse generation.

1.5 Scope of the Study

The scope of this doctoral work is summarized in Figure 1.1. The highlighted subsets are the focus of this research. In this work, passively mode-locked fiber lasers were utilized to generate ultrashort pules in all fiber ring cavity. Two different rare-earth doped fibers namely erbium and thulium are selected to emit lasing wavelength at 1.56 μm and 1.9 μm region, respectively. The passive mode-locking using real SA is a simple mode-locking mechanism that is not affected by environmental perturbations as compared to artificial SAs. Next, a tapered fiber is selected as a substrate for SA fabrication due to its robustness to handle thermal damage. Both AD and nAD type of tapered fibers are chosen to investigate the ultrashort pulse generation. In this case, the light propagation properties in the tapered region are different based on the adiabaticity feature. Next, the SA is fabricated by spin coating the composite material of MOF and Polydimethylsiloxane (PDMS) on the tapered fibers. In this work, we use Ni-H_3BTC MOF and optimize its synthesis by varying metal to ligand ratio to explore its effect on nonlinear saturable absorption (NLSA) properties to generate ultrashort pulses. The PDMS composite safeguards the materials contact with tapered fiber and increases the shelf life of SA compared to direct deposition method. Finally, the fabricated SA is characterized for linear.

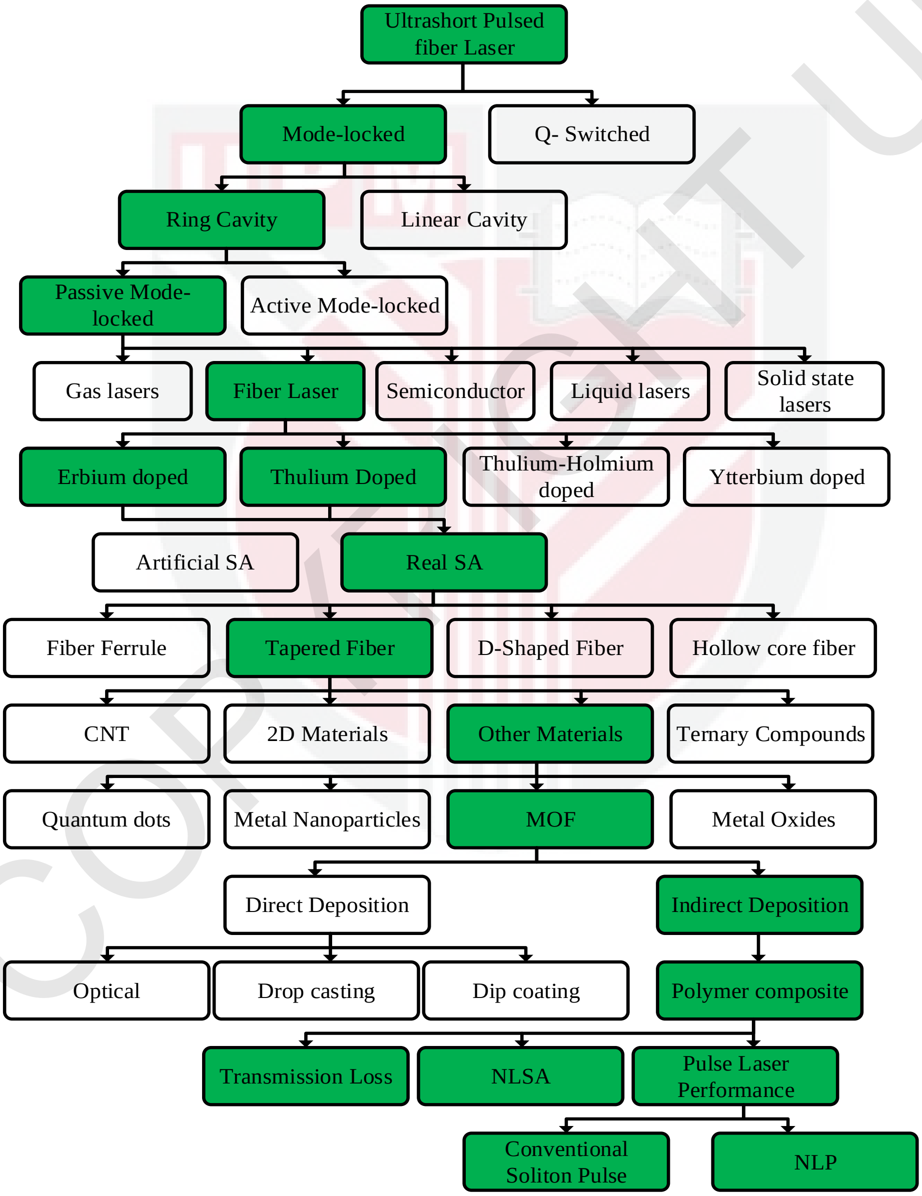

Figure 1.1: Scope of the research work

and nonlinear transmission measurement and subsequently, pulse fiber laser performance is analyzed. Both conventional soliton and noise like pulse (NLP) were observed in ring cavity EDFL. The ultrashort pulse performance of fiber laser using the fabricated SA is analyzed in optical domain, time domain and frequency domain.

1.6 Thesis outline

The content of the thesis is organized into six chapters. Chapter 1 refers to the introduction of thesis. It contains background of lasers, overview of mode-locked fiber lasers, research gap, scope and research objective. A comprehensive literature review on materials, theoretical background and basic principles of passive mode-locking, related nonlinear effects occurring in fiber laser cavities and recent development in fabrication of SA, are listed in Chapter 2. Chapter 3 describes materials, synthesis and characterization of materials for structural, electro-optical and nonlinear properties. The SA fabrication and its characterization for linear and nonlinear properties are also presented in this chapter. Chapter 4 evaluates the performance of passive MLFL in EDFL ring cavity with the fabricated MOF-based SA. Whereas, Chapter 5 describes performance characteristics of the fabricated MOF-based SA in TDFL ring cavity. Chapter 6 concludes the results of research work and recommendations for further improvements.

REFERENCES

[1] J. Hecht, “Short history of laser development,” *Opt. Eng.*, vol. 49, no. 9, p. 091002, Sep. 2010, doi: 10.1117/1.3483597.

[2] C. Chongbin, H. Junmin, and S. Hongqing, “Birth of the First Ruby Laser in China [Scanning Our Past],” *Proc. IEEE*, vol. 109, no. 10, pp. 1753–1763, Oct. 2021, doi: 10.1109/JPROC.2021.3103559.

[3] K. C. Cossel, E. M. Waxman, I. A. Finneran, G. A. Blake, J. Ye, and N. R. Newbury, “Gas-phase broadband spectroscopy using active sources: progress, status, and applications [Invited],” *J. Opt. Soc. Am. B*, vol. 34, no. 1, p. 104, Jan. 2017, doi: 10.1364/josab.34.000104.

[4] D. T. Reid *et al.*, “Roadmap on ultrafast optics,” *J. Opt. (United Kingdom)*, vol. 18, no. 9, p. 093006, Sep. 2016, doi: 10.1088/2040-8978/18/9/093006.

[5] T. Seeger, T. Dreier, W. Chen, S. Kearny, and W. Kulatilaka, “Laser applications to chemical, security, and environmental analysis: introduction to the feature issue,” *Appl. Opt.*, vol. 56, no. 11, p. LAC1, Apr. 2017, doi: 10.1364/ao.56.00lac1.

[6] S. A. Hussain *et al.*, “Cell viability and shock wave amplitudes in the endothelium of porcine cornea exposed to ultrashort laser pulses,” *Graefe’s Arch. Clin. Exp. Ophthalmol.*, vol. 255, no. 5, pp. 945–953, May 2017, doi: 10.1007/s00417-017-3583-3.

[7] A. D. Anastasiou *et al.*, “Exogenous mineralization of hard tissues using photo-absorptive minerals and femto-second lasers; the case of dental enamel,” *Acta Biomater.*, vol. 71, pp. 86–95, Apr. 2018, doi: 10.1016/j.actbio.2018.02.012.

[8] S. Pavlova, M. E. Yagci, S. Koray Eken, E. Tunckol, and I. Pavlov, “High power microsecond fiber laser at 1.5 μm,” *Opt. Express*, vol. 28, no. 12, p. 18368, 2020, doi: 10.1364/OE.377751.

[9] S. D. Jackson, “Towards high-power mid-infrared emission from a fibre laser,” *Nat. Photonics 2012 67*, vol. 6, no. 7, pp. 423–431, Jun. 2012, doi: 10.1038/nphoton.2012.149.

[10] Y. Zhang *et al.*, “Sub-15-ns Passively Q-Switched Er:YSGG Laser at 2.8 μm With Fe:ZnSe Saturable Absorber,” *IEEE Photonics Technol. Lett.*, vol. 31, no. 7, pp. 565–568, Apr. 2019, doi: 10.1109/LPT.2019.2902473.

[11] T. Feng *et al.*, “121 W passively mode-locked Tm:LuAG laser,” *Opt. Express*, vol. 23, no. 9, p. 11819, May 2015, doi: 10.1364/oe.23.011819.

[12] X. Liu, Q. Gao, Y. Zheng, D. Mao, and J. Zhao, “Recent progress of pulsed fiber lasers based on transition-metal dichalcogenides and black phosphorus saturable absorbers,” *Nanophotonics*, vol. 9, no. 8, pp. 2215–2231, Mar. 2020, doi: 10.1515/nanoph-2019-0566.

[13] L. Huang, Y. Zhang, and X. Liu, “Dynamics of carbon nanotube-based mode-locking fiber lasers,” *Nanophotonics*, vol. 9, no. 9, pp. 2731–2761, Sep. 2020, doi: 10.1515/NANOPH-2020-0269.

[14] Y. Mashiko, E. Fujita, and M. Tokurakawa, “Tunable noise-like pulse generation in mode-locked Tm fiber laser with a SESAM,” *Opt. Express*, vol. 24, no. 23, p. 26515, Nov. 2016, doi: 10.1364/oe.24.026515.

[15] L. Dai *et al.*, “Carbon nanotube mode-locked fiber lasers: recent progress and perspectives,” *Nanophotonics*, vol. 10, no. 2, pp. 749–775, Jan. 2020, doi: 10.1515/NANOPH-2020-0446/XML.

[16] Z. Sun, T. Hasan, and A. C. Ferrari, “Ultrafast lasers mode-locked by nanotubes and graphene,” *Phys. E Low-dimensional Syst. Nanostructures*, vol. 44, no. 6, pp. 1082–1091, Mar. 2012, doi: 10.1016/J.PHYSE.2012.01.012.

[17] Q. Bao *et al.*, “Monolayer graphene as a saturable absorber in a mode-locked laser,” *Nano Res.*, vol. 4, no. 3, pp. 297–307, Mar. 2011, doi: 10.1007/s12274-010-0082-9.

[18] L. Ding, C. Xu, B. Xu, and J. Huang, “Characterization and saturable absorption property of graphene oxide on optical fiber by optical deposition,” *J. Wuhan Univ. Technol. Sci. Ed.*, vol. 32, no. 4, pp. 882–887, 2017, doi: 10.1007/s11595-016-1684-9.

[19] D. Steinberg *et al.*, “Graphene oxide and reduced graphene oxide as saturable absorbers onto D-shaped fibers for sub 200-fs EDFL mode-locking,” *Opt. Mater. Express*, vol. 8, no. 1, p. 144, 2018, doi: 10.1364/OME.8.000144.

[20] Q. Bao *et al.*, “Atomic-Layer Graphene as a Saturable Absorber for Ultrafast Pulsed Lasers,” *Adv. Funct. Mater.*, vol. 19, no. 19, pp. 3077–3083, Oct. 2009, doi: 10.1002/adfm.200901007.

[21] P. L. Huang *et al.*, “Stable mode-locked fiber laser based on CVD fabricated graphene saturable absorber,” *Opt. Express*, vol. 20, no. 3, p. 2460, Jan. 2012, doi: 10.1364/OE.20.002460.

[22] Q. Sheng *et al.*, “Actively manipulation of operation states in passively pulsed fiber lasers by using graphene saturable absorber on microfiber,” *Opt. Express*, vol. 21, no. 12, p. 14859, Jun. 2013, doi: 10.1364/OE.21.014859.

[23] Y. Wu *et al.*, “Four-Wave Mixing in a Microfiber Attached Onto a Graphene Film,” *IEEE Photonics Technol. Lett.*, vol. 26, no. 3, pp. 249–252, Feb. 2014, doi: 10.1109/LPT.2013.2291897.

[24] K. Wang *et al.*, “Ultrafast Saturable Absorption of Two-Dimensional MoS_2 Nanosheets,” *ACS Nano*, vol. 7, no. 10, pp. 9260–9267, Oct. 2013, doi: 10.1021/nn403886t.

[25] Q. H. Wang, K. Kalantar-Zadeh, A. Kis, J. N. Coleman, and M. S. Strano, “Electronics and optoelectronics of two-dimensional transition metal

dichalcogenides," *Nat. Nanotechnol.*, vol. 7, no. 11, pp. 699–712, Nov. 2012, doi: 10.1038/nnano.2012.193.

[26] S. Wang *et al.*, "Broadband Few-Layer MoS_2 Saturable Absorbers," *Adv. Mater.*, vol. 26, no. 21, pp. 3538–3544, Jun. 2014, doi: 10.1002/adma.201306322.

[27] H. Zhang *et al.*, "Molybdenum disulfide (MoS_2) as a broadband saturable absorber for ultra-fast photonics," *Opt. Express*, vol. 22, no. 6, p. 7249, Mar. 2014, doi: 10.1364/OE.22.007249.

[28] M. Zhang *et al.*, "Solution processed MoS_2-PVA composite for sub-bandgap mode-locking of a wideband tunable ultrafast Er:fiber laser," *Nano Res.*, vol. 8, no. 5, pp. 1522–1534, May 2015, doi: 10.1007/s12274-014-0637-2.

[29] L. Li *et al.*, "Black phosphorus field-effect transistors," *Nat. Nanotechnol.*, vol. 9, no. 5, pp. 372–377, May 2014, doi: 10.1038/nnano.2014.35.

[30] H. Liu *et al.*, "Phosphorene: An Unexplored 2D Semiconductor with a High Hole Mobility," *ACS Nano*, vol. 8, no. 4, pp. 4033–4041, Apr. 2014, doi: 10.1021/nn501226z.

[31] J. Mohanraj, V. Velmurugan, and S. Sivabalan, "Transition metal dichalcogenides based saturable absorbers for pulsed laser technology," *Opt. Mater. (Amst).*, vol. 60, pp. 601–617, Oct. 2016, doi: 10.1016/j.optmat.2016.09.007.

[32] Y. Huang *et al.*, "Interaction of black phosphorus with oxygen and water," *Chem. Mater.*, vol. 28, no. 22, pp. 8330–8339, Nov. 2016, doi: 10.1021/acs.chemmater.6b03592.

[33] X. Sun, Y. Jia, H. Nie, F. Ren, B. Zhang, and F. Chen, "Near-Surface Buried Plasmonic Nanoparticles in Glass as Novel Nonlinear Saturable Absorbers for Ultrafast Lasers," *Adv. Opt. Mater.*, vol. 10, no. 1, p. 2101664, Jan. 2022, doi: 10.1002/adom.202101664.

[34] C. Voisin, N. Del Fatti, D. Christofilos, and F. Vallée, "Ultrafast Electron Dynamics and Optical Nonlinearities in Metal Nanoparticles," *J. Phys. Chem. B*, vol. 105, no. 12, pp. 2264–2280, Mar. 2001, doi: 10.1021/jp0038153.

[35] P. K. Cheng *et al.*, "Nonlinear optical properties of two-dimensional palladium ditelluride ($PdTe_2$) and its application as aerosol jet printed saturable absorbers for broadband ultrafast photonics," *Appl. Mater. Today*, vol. 26, p. 101296, Mar. 2022, doi: 10.1016/j.apmt.2021.101296.

[36] Z. Wang *et al.*, "Self-starting ultrafast fiber lasers mode-locked with alcohol," *Opt. Lett.*, vol. 40, no. 16, p. 3699, Aug. 2015, doi: 10.1364/OL.40.003699.

[37] Z. Hui, W. Xu, X. Li, P. Guo, Y. Zhang, and J. Liu, "Cu_2S nanosheets for ultrashort pulse generation in the near-infrared region," *Nanoscale*, vol. 11, no. 13, pp. 6045–6051, Mar. 2019, doi: 10.1039/C9NR00080A.

[38] P. Loiko *et al.*, “Oriented zinc oxide nanorods: A novel saturable absorber for lasers in the near-infrared,” *Beilstein J. Nanotechnol.*, vol. 9, no. 1, pp. 2730–2740, 2018, doi: 10.3762/BJNANO.9.255.

[39] A. Martinez and Z. Sun, “Nanotube and graphene saturable absorbers for fibre lasers,” *Nat. Photonics*, vol. 7, no. 11, pp. 842–845, Nov. 2013, doi: 10.1038/nphoton.2013.304.

[40] O. M. Yaghi, M. O’Keeffe, N. W. Ockwig, H. K. Chae, M. Eddaoudi, and J. Kim, “Reticular synthesis and the design of new materials,” *Nature*, vol. 423, no. 6941. pp. 705–714, Jun. 2003. doi: 10.1038/nature01650.

[41] M. Lismont, L. Dreesen, and S. Wuttke, “Metal-Organic Framework Nanoparticles in Photodynamic Therapy: Current Status and Perspectives,” *Advanced Functional Materials*, vol. 27, no. 14. Wiley-VCH Verlag, p. 1606314, Apr. 2017. doi: 10.1002/adfm.201606314.

[42] V. V Butova, M. A. Soldatov, A. A. Guda, K. A. Lomachenko, and C. Lamberti, “Metal-organic frameworks: structure, properties, methods of synthesis and characterization,” *Russ. Chem. Rev.*, vol. 85, no. 3, pp. 280–307, Mar. 2016, doi: 10.1070/rcr4554.

[43] Y. Xue, S. Zheng, H. Xue, and H. Pang, “Metal-organic framework composites and their electrochemical applications,” *Journal of Materials Chemistry A*, vol. 7, no. 13. Royal Society of Chemistry, pp. 7301–7327, 2019. doi: 10.1039/C8TA12178H.

[44] M. Liu, H. S. Quah, S. Wen, Z. Yu, J. J. Vittal, and W. Ji, “Efficient Third Harmonic Generation in a Metal-Organic Framework,” *Chem. Mater.*, vol. 28, no. 10, pp. 3385–3390, May 2016, doi: 10.1021/acs.chemmater.6b00632.

[45] R.-J. Niu *et al.*, “Morphology-dependent third-order optical nonlinearity of a 2D Co-based metal–organic framework with a porphyrinic skeleton,” *Chem. Commun.*, vol. 55, no. 33, pp. 4873–4876, 2019, doi: 10.1039/C9CC01363F.

[46] R. Medishetty *et al.*, “Multi-Photon Absorption in Metal-Organic Frameworks,” *Angew. Chemie Int. Ed.*, vol. 56, no. 46, pp. 14743–14748, Nov. 2017, doi: 10.1002/anie.201706492.

[47] H. S. Quah *et al.*, “Multiphoton harvesting metal-organic frameworks,” *Nat. Commun.*, vol. 6, pp. 1–7, 2015, doi: 10.1038/ncomms8954.

[48] S. Mendiratta, C.-H. Lee, M. Usman, and K.-L. Lu, “Metal-organic frameworks for electronics: emerging second order nonlinear optical and dielectric materials,” *Sci. Technol. Adv. Mater.*, vol. 16, no. 5, p. 54204, 2015, doi: 10.1088/1468-6996/16/5/054204.

[49] X. Jiang *et al.*, “Ultrathin Metal-Organic Framework: An Emerging Broadband Nonlinear Optical Material for Ultrafast Photonics,” *Adv. Opt. Mater.*, vol. 6, no. 16, p. 1800561, Aug. 2018, doi: 10.1002/adom.201800561.

[50] J. Huang *et al.*, "Broadband and enhanced nonlinear optical modulation characteristics of CuBTC for pulsed lasers," *Opt. Mater. Express*, vol. 11, no. 10, p. 3546, Oct. 2021, doi: 10.1364/OME.437408.

[51] Y. Zhao *et al.*, "Functional Porous MOF-Derived CuO Octahedra for Harmonic Soliton Molecule Pulses Generation," *ACS Photonics*, vol. 7, no. 9, pp. 2440–2447, Sep. 2020, doi: 10.1021/acsphotonics.0c00520.

[52] F. A. A. Paz, J. Klinowski, S. M. F. Vilela, J. P. C. Tomé, J. A. S. Cavaleiro, and J. Rocha, "Ligand design for functional metal–organic frameworks," *Chem. Soc. Rev.*, vol. 41, no. 3, pp. 1088–1110, Jan. 2012, doi: 10.1039/C1CS15055C.

[53] H.-C. Zhou, J. R. Long, and O. M. Yaghi, "Introduction to Metal–Organic Frameworks," *Chem. Rev.*, vol. 112, no. 2, pp. 673–674, Feb. 2012, doi: 10.1021/cr300014x.

[54] P. G. Boyd *et al.*, "Data-driven design of metal-organic frameworks for wet flue gas CO_2 capture," *Nature*, vol. 576, no. 7786, pp. 253–256, Dec. 2019, doi: 10.1038/s41586-019-1798-7.

[55] L. Liu, Y. Zhou, S. Liu, and M. Xu, "The Applications of Metal−Organic Frameworks in Electrochemical Sensors," *ChemElectroChem*, vol. 5, no. 1, pp. 6–19, Jan. 2018, doi: 10.1002/celc.201700931.

[56] R. Ramachandran, C. Zhao, D. Luo, K. Wang, and F. Wang, "Morphology-dependent electrochemical properties of cobalt-based metal organic frameworks for supercapacitor electrode materials," *Electrochim. Acta*, vol. 267, pp. 170–180, Mar. 2018, doi: 10.1016/j.electacta.2018.02.074.

[57] C. A. Downes and S. C. Marinescu, "Electrocatalytic Metal-Organic Frameworks for Energy Applications," *ChemSusChem*, vol. 10, no. 22, pp. 4374–4392, Nov. 2017, doi: 10.1002/cssc.201701420.

[58] M. Al Sharabati, R. Sabouni, and G. A. Husseini, "Biomedical Applications of Metal−Organic Frameworks for Disease Diagnosis and Drug Delivery: A Review," *Nanomaterials*, vol. 12, no. 2, p. 277, Jan. 2022, doi: 10.3390/nano12020277.

[59] B. Li, H.-M. Wen, Y. Cui, W. Zhou, G. Qian, and B. Chen, "Emerging Multifunctional Metal-Organic Framework Materials," *Adv. Mater.*, vol. 28, no. 40, pp. 8819–8860, Oct. 2016, doi: 10.1002/adma.201601133.

[60] S. Salam *et al.*, "Ultrafast soliton mode-locked fiber laser at 1560 nm based onZnq$_2$ as a saturable absorber," *Appl. Opt. Vol. 60, Issue 11, pp. 3149-3154*, vol. 60, no. 11, pp. 3149–3154, Apr. 2021, doi: 10.1364/AO.418760.

[61] E. A. Dolgopolova, A. M. Rice, C. R. Martin, and N. B. Shustova, "Photochemistry and photophysics of MOFs: steps towards MOF-based sensing enhancements," *Chem. Soc. Rev.*, vol. 47, no. 13, pp. 4710–4728, Jul. 2018, doi: 10.1039/C7CS00861A.

[62] J. Yu *et al.*, “Confinement of pyridinium hemicyanine dye within an anionic metal-organic framework for two-photon-pumped lasing,” *Nat. Commun.*, vol. 4, no. 1, p. 2719, Dec. 2013, doi: 10.1038/ncomms3719.

[63] S. M. Shin, M. S. Lee, J. H. Han, and N. Jeong, “Assessing the guest-accessible volume in MOFs using two-photon fluorescence microscopy,” *Chem. Commun.*, vol. 50, no. 3, pp. 289–291, Dec. 2013, doi: 10.1039/C3CC44008G.

[64] X. Zhou *et al.*, “Novel Binary Ni-Based Mixed Metal-Organic Framework Nanosheets Materials and Their High Optical Power Limiting,” *ACS Omega*, vol. 7, no. 12, pp. 10429–10437, Mar. 2022, doi: 10.1021/ACSOMEGA.1C07196/ASSET/IMAGES/LARGE/AO1C07196_0007.JPEG.

[65] L. Zhang, H. Li, H. He, Y. Yang, Y. Cui, and G. Qian, “Structural Variation and Switchable Nonlinear Optical Behavior of Metal–Organic Frameworks,” *Small*, vol. 17, no. 6, p. 2006649, Feb. 2021, doi: 10.1002/smll.202006649.

[66] T. N. Nguyen, F. M. Ebrahim, and K. C. Stylianou, “Photoluminescent, upconversion luminescent and nonlinear optical metal-organic frameworks: From fundamental photophysics to potential applications,” *Coord. Chem. Rev.*, vol. 377, pp. 259–306, Dec. 2018, doi: 10.1016/j.ccr.2018.08.024.

[67] K. K. Gangu, S. Maddila, and S. B. Jonnalagadda, “The pioneering role of metal–organic framework-5 in ever-growing contemporary applications – a review,” *RSC Adv.*, vol. 12, no. 22, pp. 14282–14298, May 2022, doi: 10.1039/D2RA01505F.

[68] J. L. C. Rowsell and O. M. Yaghi, “Metal-organic frameworks: A new class of porous materials,” *Microporous and Mesoporous Materials*, vol. 73, no. 1–2. Elsevier, pp. 3–14, Aug. 2004. doi: 10.1016/j.micromeso.2004.03.034.

[69] G. S. He, L.-S. Tan, Q. Zheng, and P. N. Prasad, “Multiphoton absorbing materials: molecular designs, characterizations, and applications.,” *Chem. Rev.*, vol. 108, no. 4, pp. 1245–330, Apr. 2008, doi: 10.1021/cr050054x.

[70] R. Medishetty, J. K. Zaręba, D. Mayer, M. Samoć, and R. A. Fischer, “Nonlinear optical properties, upconversion and lasing in metal-organic frameworks,” *Chem. Soc. Rev.*, vol. 46, no. 16, pp. 4976–5004, Aug. 2017, doi: 10.1039/c7cs00162b.

[71] R. Seetharaj, P. V. Vandana, P. Arya, and S. Mathew, “Dependence of solvents, pH, molar ratio and temperature in tuning metal organic framework architecture,” *Arab. J. Chem.*, vol. 12, no. 3, pp. 295–315, Mar. 2019, doi: 10.1016/j.arabjc.2016.01.003.

[72] A. A. Yakovenko, Z. Wei, M. Wriedt, J. R. Li, G. J. Halder, and H. C. Zhou, “Study of guest molecules in metal-organic frameworks by powder X-ray diffraction: Analysis of difference envelope density,” *Cryst. Growth Des.*, vol. 14, no. 11, pp. 5397–5407, Nov. 2014, doi: 10.1021/cg500525g.

[73] L. Li, S. Wang, T. Chen, Z. Sun, J. Luo, and M. Hong, "Solvent-dependent formation of Cd(II) coordination polymers based on a C 2-symmetric tricarboxylate linker," *Cryst. Growth Des.*, vol. 12, no. 8, pp. 4109–4115, Aug. 2012, doi: 10.1021/cg300617h.

[74] P. Pachfule, R. Das, P. Poddar, and R. Banerjee, "Solvothermal synthesis, structure, and properties of metal organic framework isomers derived from a partially fluorinated link," *Cryst. Growth Des.*, vol. 11, no. 4, pp. 1215–1222, Apr. 2011, doi: 10.1021/cg101414x.

[75] M. L. Cheng, E. Zhu, Q. Liu, S. C. Chen, Q. Chen, and M. Y. He, "Two coordinated-solvent directed zinc(II) coordination polymers with rare gra topological 3D framework and 1D zigzag chain," *Inorg. Chem. Commun.*, vol. 14, no. 1, pp. 300–303, Jan. 2011, doi: 10.1016/j.inoche.2010.11.020.

[76] D. Banerjee *et al.*, "Synthesis and structural characterization of magnesium based coordination networks in different solvents," *Cryst. Growth Des.*, vol. 11, no. 6, pp. 2572–2579, Jun. 2011, doi: 10.1021/cg200327y.

[77] P. Cui *et al.*, "Two solvent-dependent zinc(II) supramolecular isomers: Rare kgd and Lonsdaleite network topologies based on a tripodal flexible ligand," *Cryst. Growth Des.*, vol. 11, no. 12, pp. 5182–5187, Dec. 2011, doi: 10.1021/cg201181s.

[78] M. Mazaj, T. Birsa Čelič, G. Mali, M. Rangus, V. Kaučič, and N. Zabukovec Logar, "Control of the crystallization process and structure dimensionality of Mg-benzene-1,3,5-tricarboxylates by tuning solvent composition," *Cryst. Growth Des.*, vol. 13, no. 8, pp. 3825–3834, Aug. 2013, doi: 10.1021/cg400929z.

[79] W. H. Huang *et al.*, "Solvent influence on sizes of channels in three new Co(II) complexes, exhibiting an active replaceable coordinated site," *Cryst. Growth Des.*, vol. 13, no. 1, pp. 66–73, Jan. 2013, doi: 10.1021/cg301146u.

[80] Y. C. He, J. Guo, H. M. Zhang, J. F. Ma, and Y. Y. Liu, "Tuning the void volume in a series of isomorphic porous metal-organic frameworks by varying the solvent size and length of organic ligands," *CrystEngComm*, vol. 16, no. 24, pp. 5450–5457, Jun. 2014, doi: 10.1039/c4ce00347k.

[81] J. Gu, Z. Gao, and Y. Tang, "PH and auxiliary ligand influence on the structural variations of 5(2′-carboxylphenyl) nicotate coordination polymers," *Cryst. Growth Des.*, vol. 12, no. 6, pp. 3312–3323, Jun. 2012, doi: 10.1021/cg300442b.

[82] L. Luo, G. C. Lv, P. Wang, Q. Liu, K. Chen, and W. Y. Sun, "PH-Dependent cobalt(II) frameworks with mixed 3,3′,5,5′- tetra(1H-imidazol-1-yl)-1,1′-biphenyl and 1,3,5-benzenetricarboxylate ligands: Synthesis, structure and sorption property," *CrystEngComm*, vol. 15, no. 45, pp. 9537–9543, Dec. 2013, doi: 10.1039/c3ce41056k.

[83] I. Chi-Duran *et al.*, "pH-controlled assembly of 3D and 2D zinc-based metal-organic frameworks with tetrazole ligands," *ACS Omega*, vol. 3, no. 1, pp. 801–807, Jan. 2018, doi: 10.1021/acsomega.7b01792.

[84] M. C. Bernini *et al.*, “The Effect of Hydrothermal and Non-Hydrothermal Synthesis on the Formation of Holmium(III) Succinate Hydrate Frameworks,” *Eur. J. Inorg. Chem.*, vol. 2007, no. 5, pp. 684–693, Feb. 2007, doi: 10.1002/ejic.200600860.

[85] K. L. Zhang *et al.*, “Temperature and auxiliary ligand-controlled supramolecular assembly in a series of Zn(ii)-organic frameworks: Syntheses, structures and properties,” *CrystEngComm*, vol. 14, no. 2, pp. 590–600, Jan. 2012, doi: 10.1039/c1ce05577a.

[86] P. Sarawade, H. Tan, and V. Polshettiwar, “Shape- and Morphology-Controlled Sustainable Synthesis of Cu, Co, and In Metal Organic Frameworks with High CO_2 Capture Capacity,” *ACS Sustain. Chem. Eng.*, vol. 1, no. 1, pp. 66–74, Jan. 2013, doi: 10.1021/sc300036p.

[87] N. Sahiner, K. Sel, O. F. Ozturk, S. Demirci, and G. Terzi, “Facile synthesis and characterization of trimesic acid-Cu based metal organic frameworks,” *Appl. Surf. Sci.*, vol. 314, pp. 663–669, 2014, doi: 10.1016/j.apsusc.2014.07.023.

[88] J. Enríquez, C. Manquian, I. Chi-Duran, F. Herrera, and D. P. Singh, “Controlled Growth of the Noncentrosymmetric Zn(3-ptz) 2 and Zn(OH)(3-ptz) Metal−Organic Frameworks,” vol. 4, p. 57, 2019, doi: 10.1021/acsomega.9b00236.

[89] Y. Liu, S. Liu, A. A. S. Gonçalves, and M. Jaroniec, “Effect of metal-ligand ratio on the CO_2 adsorption properties of Cu-BTC metal-organic frameworks,” *RSC Adv.*, vol. 8, no. 62, pp. 35551–35556, Oct. 2018, doi: 10.1039/c8ra07774f.

[90] G. S. Martin E. Fermann, Almantas Galvanauskas, *Ultrafast Lasers Technology and Applications*, 1st ed. CRC Press, 2002.

[91] M. A. Sharif and K. Ashabi, “From chaos to stability in soliton mode-locked fibre laser system,” *Rev. Mex. Física*, vol. 67, no. 6 Nov-Dec, pp. 1–6, Sep. 2021, doi: 10.31349/RevMexFis.67.061301.

[92] M. H. M. Ahmed *et al.*, “Ultrashort pulse thulium-doped fiber laser with molybdenum trioxide on tapered fiber,” *Optik (Stuttg).*, vol. 257, p. 168736, May 2022, doi: 10.1016/j.ijleo.2022.168736.

[93] S. A. Hussain, “Discovery of Several New Families of Saturable Absorbers for Ultrashort Pulsed Laser Systems,” *Sci. Rep.*, vol. 9, no. 1, p. 19910, Dec. 2019, doi: 10.1038/s41598-019-56460-5.

[94] S. M. Kobtsev, “Artificial saturable absorbers for ultrafast fibre lasers,” *Opt. Fiber Technol.*, vol. 68, p. 102764, Jan. 2022, doi: 10.1016/j.yofte.2021.102764.

[95] R. Akbari and A. Major, “Kerr-lens mode locking of a diode-pumped Yb:KGW laser using an additional intracavity Kerr medium,” *Laser Phys. Lett.*, vol. 15, no. 8, p. 085001, Aug. 2018, doi: 10.1088/1612-202X/aac97a.

[96] T. Dong, J. Lin, Y. Zhou, C. Gu, P. Yao, and L. Xu, "Noise-like square pulses in a linear-cavity NPR mode-locked Yb-doped fiber laser," *Opt. Laser Technol.*, vol. 136, p. 106740, Apr. 2021, doi: 10.1016/J.OPTLASTEC.2020.106740.

[97] A. Malfondet, A. Parriaux, K. Krupa, G. Millot, G. Millot, and P. Tchofo-Dinda, "Optimum design of NOLM-driven mode-locked fiber lasers," *Opt. Lett. Vol. 46, Issue 6, pp. 1289-1292*, vol. 46, no. 6, pp. 1289–1292, Mar. 2021, doi: 10.1364/OL.418281.

[98] C.-H. Cheng and G.-R. Lin, "Carbon Nanomaterials Based Saturable Absorbers for Ultrafast Passive Mode-Locking of Fiber Lasers," *Curr. Nanosci.*, vol. 16, no. 3, pp. 441–457, Nov. 2019, doi: 10.2174/1573413715666191114150100.

[99] Y. Ling *et al.*, "Intracavity birefringence-controlled GHz-tuning range passively harmonic mode-locked fiber laser based on NPR," *Appl. Opt.*, vol. 59, no. 22, p. 6724, Aug. 2020, doi: 10.1364/AO.398960.

[100] J. Wang, Y. Wang, S. Liu, G. Li, G. Zhang, and G. Cheng, "Nonlinear Optical Response of Reflective MXene Molybdenum Carbide Films as Saturable Absorbers," *Nanomaterials*, vol. 10, no. 12, p. 2391, Nov. 2020, doi: 10.3390/nano10122391.

[101] J. Lee, S. Kwon, and J. H. Lee, "Influence of the Saturable Absorber Recovery Time on Fiber Laser Mode-Locking," Aug. 2020. doi: 10.1364/CLEOPR.2020.P1_14.

[102] A. Urrutia, J. Goicoechea, and F. J. Arregui, "Optical Fiber Sensors Based on Nanoparticle-Embedded Coatings," *J. Sensors*, vol. 2015, pp. 1–18, 2015, doi: 10.1155/2015/805053.

[103] G. Sobon *et al.*, "Er-Doped Fiber Laser Mode-Locked by CVD-Graphene Saturable Absorber," *J. Light. Technol. Vol. 30, Issue 17, pp. 2770-2775*, vol. 30, no. 17, pp. 2770–2775, Sep. 2012.

[104] C. Zhao *et al.*, "Ultra-short pulse generation by a topological insulator based saturable absorber," *Appl. Phys. Lett.*, vol. 101, no. 21, p. 211106, Nov. 2012, doi: 10.1063/1.4767919.

[105] M. I. Hussain, B. V. Cunning, L. S. Booth, M. J. Petrasiunas, and C. L. Brown, "Effects of flake size on mode-locking behavior for flake-graphene saturable absorber mirrors," *Optik (Stuttg).*, vol. 198, p. 163232, Dec. 2019, doi: 10.1016/j.ijleo.2019.163232.

[106] J. Xu, J. Liu, S. Wu, Q.-H. Yang, and P. Wang, "Graphene oxide mode-locked femtosecond erbium-doped fiber lasers," *Opt. Express*, vol. 20, no. 14, p. 15474, Jul. 2012, doi: 10.1364/oe.20.015474.

[107] G. Jiang, Y. Zhou, L. Wang, and Y. Chen, "PMMA Sandwiched Bi 2 Te 3 Layer as a Saturable Absorber in Mode-Locked Fiber Laser," 2018, doi: 10.1155/2018/7578050.

[108] H. H. Liu, Y. Yang, and K. K. Chow, "Enhancement of thermal damage threshold of carbon-nanotube-based saturable absorber by evanescent-field interaction on fiber end," *Opt. Express*, vol. 21, no. 16, p. 18975, Aug. 2013, doi: 10.1364/oe.21.018975.

[109] M. Zhang *et al.*, "2D Black Phosphorus Saturable Absorbers for Ultrafast Photonics," *Adv. Opt. Mater.*, vol. 7, no. 1, p. 1800224, Jan. 2019, doi: 10.1002/adom.201800224.

[110] Z. Chen *et al.*, "Improved optical damage threshold graphene Oxide/SiO 2 absorber fabricated by sol-gel technique for mode-locked erbium-doped fiber lasers," *Carbon N. Y.*, vol. 144, pp. 737–744, 2019, doi: 10.1016/j.carbon.2018.12.110.

[111] A. A. Melo, M. F. S. Santiago, T. B. Silva, C. S. Moreira, and R. M. S. Cruz, "Investigation of a D-Shaped Optical Fiber Sensor with Graphene Overlay," *IFAC-PapersOnLine*, vol. 51, no. 27, pp. 309–314, Jan. 2018, doi: 10.1016/j.ifacol.2018.11.623.

[112] J. D. Zapata, D. Steinberg, L. A. M. Saito, R. E. P. De Oliveira, A. M. Cárdenas, and E. A. T. De Souza, "Efficient graphene saturable absorbers on D-shaped optical fiber for ultrashort pulse generation," *Sci. Rep.*, vol. 6, no. 1, pp. 1–8, Feb. 2016, doi: 10.1038/srep20644.

[113] B. Nizamani *et al.*, "Indium tin oxide coated D-shape fiber as saturable absorber for passively Q-switched erbium-doped fiber laser," *Opt. Laser Technol.*, vol. 124, p. 105998, Apr. 2020, doi: 10.1016/j.optlastec.2019.105998.

[114] E. J. Aiub, D. Steinberg, E. A. Thoroh de Souza, and L. A. M. Saito, "200-fs mode-locked Erbium-doped fiber laser by using mechanically exfoliated MoS_2 saturable absorber onto D-shaped optical fiber," *Opt. Express*, vol. 25, no. 9, p. 10546, May 2017, doi: 10.1364/oe.25.010546.

[115] M. Kowalczyk *et al.*, "Sb_2Te_3-deposited D-shaped fiber as a saturable absorber for mode-locked Yb-doped fiber lasers," *Opt. Mater. Express*, vol. 6, no. 7, p. 2273, Jul. 2016, doi: 10.1364/ome.6.002273.

[116] H. Ahmad, R. Safaei, M. Rezayi, and I. S. Amiri, "Novel D-shaped fiber fabrication method for saturable absorber application in the generation of ultra-short pulses," *Laser Phys. Lett.*, vol. 14, no. 8, p. 085001, Jul. 2017, doi: 10.1088/1612-202X/AA7729.

[117] X. Bao *et al.*, "Ytterbium-doped fiber laser passively mode locked by evanescent field interaction with $CH_3NH_3SnI_3$ perovskite saturable absorber," *J. Phys. D. Appl. Phys.*, vol. 51, no. 37, p. 375106, Aug. 2018, doi: 10.1088/1361-6463/AAD71D.

[118] L. Li *et al.*, "Femtosecond passively Er-doped mode-locked fiber laser with WS_2 solution saturable absorber," *IEEE J. Sel. Top. Quantum Electron.*, vol. 23, no. 1, Jan. 2017, doi: 10.1109/JSTQE.2016.2538640.

[119] F. A. A. Rashid *et al.*, "Using a black phosphorus saturable absorber to generate dual wavelengths in a Q-switched ytterbium-doped fiber laser," *Laser Phys. Lett.*, vol. 13, no. 8, p. 085102, Jul. 2016, doi: 10.1088/1612-2011/13/8/085102.

[120] M. Jung, J. Lee, J. Park, J. Koo, Y. M. Jhon, and J. H. Lee, "Mode-locked, 194-μm, all-fiberized laser using WS_2-based evanescent field interaction," *Opt. Express*, vol. 23, no. 15, p. 19996, Jul. 2015, doi: 10.1364/oe.23.019996.

[121] E. K. Ng *et al.*, "Saturable absorber incorporating graphene oxide polymer composite through dip coating for mode-locked fiber laser," *Opt. Mater. (Amst).*, vol. 100, p. 109619, Feb. 2020, doi: 10.1016/j.optmat.2019.109619.

[122] K. Kashiwagi and S. Yamashita, "Deposition of carbon nanotubes around microfiber via evanascent light," *Opt. Express*, vol. 17, no. 20, p. 18364, Sep. 2009, doi: 10.1364/oe.17.018364.

[123] J. Wang *et al.*, "Evanescent-light deposition of graphene onto tapered fibers for passive Q-switch and mode-locker," *IEEE Photonics J.*, vol. 4, no. 5, pp. 1295–1305, 2012, doi: 10.1109/JPHOT.2012.2208736.

[124] H. Ahmad, M. J. Faruki, M. Z. A. Razak, Z. C. Tiu, and M. F. Ismail, "Evanescent field interaction of tapered fiber with graphene oxide in generation of wide-bandwidth mode-locked pulses," *Opt. Laser Technol.*, vol. 88, pp. 166–171, Feb. 2017, doi: 10.1016/j.optlastec.2016.09.005.

[125] R. Zhang *et al.*, "Tunable Q-Switched Fiber Laser Based on a Graphene Saturable Absorber Without Additional Tuning Element," *IEEE Photonics J.*, vol. 11, no. 1, pp. 1–10, Feb. 2019, doi: 10.1109/JPHOT.2019.2892646.

[126] H. Ahmad, R. Ramli, N. Yusoff, S. A. Reduan, A. K. Zamzuri, and K. Thambiratnam, "Performance of Nb_2C MXene coated on tapered fiber as saturable absorber for the generation of Mode-Locked Erbium-Doped fiber laser," *Infrared Phys. Technol.*, vol. 114, p. 103647, May 2021, doi: 10.1016/j.infrared.2021.103647.

[127] A. Martinez *et al.*, "Low-loss saturable absorbers based on tapered fibers embedded in carbon nanotube/polymer composites," *APL Photonics*, vol. 2, no. 12, p. 126103, Dec. 2017, doi: 10.1063/1.4996918.

[128] R. Jarzebinska, C. S. Cheung, S. W. James, and R. P. Tatam, "Response of the transmission spectrum of tapered optical fibres to the deposition of a nanostructured coating," *Meas. Sci. Technol.*, vol. 20, no. 3, 2009, doi: 10.1088/0957-0233/20/3/034001.

[129] K. Mullaney, R. Correia, S. E. Staines, S. W. James, and R. P. Tatam, "Monitoring techniques for the manufacture of tapered optical fibers," *Appl. Opt.*, vol. 54, no. 28, p. 8531, Oct. 2015, doi: 10.1364/ao.54.008531.

[130] J. M. Ward, A. Maimaiti, V. H. Le, and S. N. Chormaic, "Contributed Review: Optical micro- and nanofiber pulling rig," *Rev. Sci. Instrum.*, vol. 85, no. 11, p. 111501, Nov. 2014, doi: 10.1063/1.4901098.

[131] S. Sidhik, J. V Ittiarah, and T. K. Gangopadhyay, “Modelling of chemically etched and biconically tapered fiber for evanescent-field based chemical sensor,” *Am. J. Electron. Commun.*, vol. II, no. 2, pp. 27–31, 2015, doi: 10.15864/ajec.v2i2.106.

[132] B. Musa, Y. Mustapha Kamil, M. H. Abu Bakar, A. S. M. Noor, A. Ismail, and M. A. Mahdi, “Effects of taper parameters on free spectral range of non-adiabatic tapered optical fibers for sensing applications,” *Microw. Opt. Technol. Lett.*, vol. 58, no. 4, pp. 798–803, Apr. 2016, doi: 10.1002/mop.29674.

[133] J. D. Love, W. M. Henry, W. J. Stewart, R. J. Black, S. Lacroix, and F. Gonthier, “Tapered single-mode fibres and devices Part 1. Adiabaticity criteria,” *IEE proceedings. Part J, Optoelectron.*, vol. 138, no. 5, pp. 343–354, 1991, doi: 10.1049/ip-j.1991.0060.

[134] R. Nagai and T. Aoki, “Ultra-low-loss tapered optical fibers with minimal lengths,” *Opt. Express*, vol. 22, no. 23, p. 28427, Nov. 2014, doi: 10.1364/oe.22.028427.

[135] S. Ravets, J. E. Hoffman, P. R. Kordell, J. D. Wong-Campos, S. L. Rolston, and L. A. Orozco, “Intermodal energy transfer in a tapered optical fiber: optimizing transmission,” *J. Opt. Soc. Am. A*, vol. 30, no. 11, p. 2361, Nov. 2013, doi: 10.1364/JOSAA.30.002361.

[136] M. Ahmad and L. L. Hench, “Effect of taper geometries and launch angle on evanescent wave penetration depth in optical fibers,” *Biosens. Bioelectron.*, vol. 20, no. 7, pp. 1312–1319, Jan. 2005, doi: 10.1016/j.bios.2004.04.026.

[137] P. W. Milonni and J. H. Eberly, *Laser Physics*. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2010. doi: 10.1002/9780470409718.

[138] D. A. Korobko, D. A. Stoliarov, P. A. Itrin, M. A. Odnoblyudov, A. B. Petrov, and R. V. Gumenyuk, “Harmonic mode-locking fiber ring laser with a pulse repetition rate up to 12 GHz,” *Opt. Laser Technol.*, vol. 133, p. 106526, Jan. 2021, doi: 10.1016/j.optlastec.2020.106526.

[139] N. J. Zabusky and M. D. Kruskal, “Interaction of ‘solitons’ in a collisionless plasma and the recurrence of initial states,” *Phys. Rev. Lett.*, vol. 15, no. 6, pp. 240–243, Aug. 1965, doi: 10.1103/PHYSREVLETT.15.240/FIGURE/1/THUMB.

[140] N. Nishizawa, L. Jin, H. Kataura, and Y. Sakakibara, “Dynamics of a Dispersion-Managed Passively Mode-Locked Er-Doped Fiber Laser Using Single Wall Carbon Nanotubes,” *Photonics 2015, Vol. 2, Pages 808-824*, vol. 2, no. 3, pp. 808–824, Jul. 2015, doi: 10.3390/PHOTONICS2030808.

[141] R. I. Woodward, “Dispersion engineering of mode-locked fibre lasers,” *J. Opt.*, vol. 20, no. 3, p. 033002, Mar. 2018, doi: 10.1088/2040-8986/aaa9f5.

[142] R. Woodward, “Exploiting nonlinearity in optical fibres and nanomaterials for short-pulse laser technology,” Imperial college london, 2015.

[143] P. Grelu and N. Akhmediev, "Dissipative solitons for mode-locked lasers," *Nat. Photonics 2012 62*, vol. 6, no. 2, pp. 84–92, Feb. 2012, doi: 10.1038/nphoton.2011.345.

[144] G. P. Agrawal, *Nonlinear Fiber Optics*, 9th ed. Academic Press Inc., 2019.

[145] R. W. Boyd, *Nonlinear Optics*. Academic Press, 2020.

[146] G. Keiser, "Optical Fiber Communications," Hoboken, NJ, USA: John Wiley & Sons, Inc., 2003. doi: 10.1002/0471219282.eot158.

[147] G. Agrawal, *Nonlinear Fiber Optics*, 4th ed. 2006.

[148] C. Y. Tai, J. S. Wilkinson, N. Perney, M. C. Netti, and J. J. Baumberg, "Self-phase modulation induced spectral broadening of ultrashort laser pulses in tantalum pentoxide (Ta2O5) rib waveguide.," 2003.

[149] L. Cheng *et al.*, "Linear and nonlinear optical properties modulation of Sb 2 Te 3 /GeTe bilayer film as a promising saturable absorber," *Results Phys.*, vol. 13, p. 102282, Jun. 2019, doi: 10.1016/j.rinp.2019.102282.

[150] Y. J. Yuechen Jia and F. C. Feng Chen, "Compact solid-state waveguide lasers operating in the pulsed regime: a review [Invited]," *Chinese Opt. Lett.*, vol. 17, no. 1, p. 012302, 2019, doi: 10.3788/COL201917.012302.

[151] M. Pawliszewska, A. Dużyńska, M. Zdrojek, and J. Sotor, "Metallic carbon nanotube-based saturable absorbers for holmium-doped fiber lasers," *Opt. Express*, vol. 27, no. 8, p. 11361, Apr. 2019, doi: 10.1364/OE.27.011361.

[152] E. K. Ng *et al.*, "L-band femtosecond fiber laser based on a reduced graphene oxide polymer composite saturable absorber," *Opt. Mater. Express*, vol. 11, no. 1, p. 59, Jan. 2021, doi: 10.1364/OME.404238.

[153] L. Li, L. Pang, Q. Zhao, Y. Wang, and W. Liu, "Niobium disulfide as a new saturable absorber for an ultrafast fiber laser," *Nanoscale*, vol. 12, no. 7, pp. 4537–4543, Feb. 2020, doi: 10.1039/C9NR10873D.

[154] X. Wu *et al.*, "Ultrafast fiber laser based on $HfSe_2$ saturable absorber," *Nanotechnology*, vol. 31, no. 24, p. 245204, Mar. 2020, doi: 10.1088/1361-6528/ab7a2f.

[155] H. Zhang, P. Ma, M. Zhu, W. Zhang, G. Wang, and S. Fu, "Palladium selenide as a broadband saturable absorber for ultra-fast photonics," *Nanophotonics*, vol. 9, no. 8, pp. 2557–2567, Aug. 2020, doi: 10.1515/NANOPH-2020-0116/ASSET/GRAPHIC/J_NANOPH-2020-0116_FIG_006.JPG.

[156] L. Li, L. Pang, Q. Zhao, W. Liu, and Y. Su, "VSe_2 nanosheets for ultrafast fiber lasers," *J. Mater. Chem. C*, vol. 8, no. 3, pp. 1104–1109, 2020, doi: 10.1039/C9TC06159B.

[157] Z. Wang *et al.*, "Two-dimensional tin diselenide nanosheets pretreated with an alkaloid for near- and mid-infrared ultrafast photonics," *Photonics Res. Vol. 8, Issue 11, pp. 1687-1696*, vol. 8, no. 11, pp. 1687–1696, Nov. 2020, doi: 10.1364/PRJ.398203.

[158] H. Ahmad, R. Ramli, M. Z. Samion, and N. Yusoff, "Mode-locked thulium/holmium co-doped fiber laser using WTe_2-covered tapered fiber," *Optik (Stuttg).*, vol. 245, p. 167723, Nov. 2021, doi: 10.1016/j.ijleo.2021.167723.

[159] H. Ahmad, R. Ramli, N. N. Ismail, S. N. Aidit, N. Yusoff, and M. Z. Samion, "Passively mode locked thulium and thulium/holmium doped fiber lasers using MXene Nb_2C coated microfiber," *Sci. Reports 2021 111*, vol. 11, no. 1, pp. 1–12, Jun. 2021, doi: 10.1038/s41598-021-90978-x.

[160] M. H. M. Ahmed, W. A. Khaleel, S. A. Sadeq, M. A. W. Abdul Hadi, N. H. Zainol Abidin, and M. A. Mahdi, "Mode-locked thulium doped fiber laser utilizing tungsten trioxide saturable absorber," *Opt. Laser Technol.*, vol. 136, p. 106730, Apr. 2021, doi: 10.1016/J.OPTLASTEC.2020.106730.

[161] F. D. Muhammad, S. A. S. Husin, E. K. Ng, K. Y. Lau, C. A. C. Abdullah, and M. A. Mahdi, "Zinc-oxide/PDMS-clad tapered fiber saturable absorber for passively mode-locked erbium-doped fiber laser*," *Chinese Phys. B*, vol. 30, no. 5, p. 054204, May 2021, doi: 10.1088/1674-1056/abd76e.

[162] H. Yuan *et al.*, "Generation of ultra-fast pulse based on bismuth saturable absorber," *Acta Phys. Sin.*, vol. 69, no. 9, p. 094203, May 2020, doi: 10.7498/aps.69.20191995.

[163] G. Liu *et al.*, "Ultrathin 2D Nonlayered Tellurene Nanosheets as Saturable Absorber for Picosecond Pulse Generation in All-Fiber Lasers," *IEEE J. Sel. Top. Quantum Electron.*, vol. 27, no. 2, pp. 1–6, Mar. 2021, doi: 10.1109/JSTQE.2020.2992625.

[164] X. Li *et al.*, "CoS_2 with 3D valence electron shell structure for pulsed laser application," *ACS Appl. Nano Mater.*, vol. 3, no. 10, pp. 9663–9668, Oct. 2020, doi: 10.1021/ACSANM.0C01621.

[165] Q. Zhang, X. Jiang, M. Zhang, X. Jin, H. Zhang, and Z. Zheng, "Wideband saturable absorption in metal–organic frameworks (MOFs) for mode-locking Er- and Tm-doped fiber lasers," *Nanoscale*, vol. 12, no. 7, pp. 4586–4590, 2020, doi: 10.1039/C9NR09330C.

[166] N. Xu *et al.*, "Tellurene-based saturable absorber to demonstrate large-energy dissipative soliton and noise-like pulse generations," *Nanophotonics*, vol. 9, no. 9, pp. 2783–2795, Jul. 2020, doi: 10.1515/nanoph-2019-0545.

[167] Z. Dong, J. Tian, R. Li, Y. Cui, W. Zhang, and Y. Song, "Conventional Soliton and Noise-Like Pulse Generated in an Er-Doped Fiber Laser with Carbon Nanotube Saturable Absorbers," *Appl. Sci.*, vol. 10, no. 16, p. 5536, Aug. 2020, doi: 10.3390/app10165536.

[168] Z. Wang *et al.*, “Noise-like pulses generated from a passively mode-locked fiber laser with a WS_2 saturable absorber on microfiber,” *Laser Phys. Lett.*, vol. 15, no. 8, p. 085103, Aug. 2018, doi: 10.1088/1612-202X/aac551.

[169] Y. Chen *et al.*, “The formation of various multi-soliton patterns and noise-like pulse in a fiber laser passively mode-locked by a topological insulator based saturable absorber,” *Laser Phys. Lett.*, vol. 11, no. 5, p. 055101, May 2014, doi: 10.1088/1612-2011/11/5/055101.

[170] Ran Zheng, Lilin Yi, Weixiong Li, Haiyan Nan, Zhenghua Ni, and Weisheng Hu, “Noise-like pulse generation by gold-coated graphene covered D-shape fibre as both saturable absorber and polarizer,” in *2014 13th International Conference on Optical Communications and Networks (ICOCN)*, Nov. 2014, no. 1, pp. 1–3. doi: 10.1109/ICOCN.2014.6987137.

[171] P. Maniam and N. Stock, “Investigation of Porous Ni-Based Metal–Organic Frameworks Containing Paddle-Wheel Type Inorganic Building Units via High-Throughput Methods,” *Inorg. Chem.*, vol. 50, no. 11, pp. 5085–5097, Jun. 2011, doi: 10.1021/ic200381f.

[172] C. Gao, S. Liu, L. Xie, Y. Ren, J. Cao, and C. Sun, “Design and construction of a microporous metal–organic framework based on the pillared-layer motif,” *CrystEngComm*, vol. 9, no. 7, pp. 545–547, Jul. 2007, doi: 10.1039/B704433J.

[173] S. Gao, Y. Sui, F. Wei, J. Qi, Q. Meng, and Y. He, “Facile synthesis of cuboid Ni-MOF for high-performance supercapacitors,” *J. Mater. Sci.*, vol. 53, no. 9, pp. 6807–6818, May 2018, doi: 10.1007/s10853-018-2005-1.

[174] B. S. Pilgrim and N. R. Champness, “Metal-Organic Frameworks and Metal-Organic Cages - A Perspective.,” *Chempluschem*, vol. 85, no. 8, pp. 1842–1856, Aug. 2020, doi: 10.1002/cplu.202000408.

[175] S. R. Venna, J. B. Jasinski, and M. A. Carreon, “Structural evolution of zeolitic imidazolate framework-8,” *J. Am. Chem. Soc.*, vol. 132, no. 51, pp. 18030–18033, Dec. 2010, doi: 10.1021/ja109268m.

[176] F.-X. Ma *et al.*, “Formation of Uniform Fe_3O_4 Hollow Spheres Organized by Ultrathin Nanosheets and Their Excellent Lithium Storage Properties,” *Adv. Mater.*, vol. 27, no. 27, pp. 4097–4101, Jul. 2015, doi: 10.1002/adma.201501130.

[177] L. Yaqoob, T. Noor, N. Iqbal, H. Nasir, and N. Zaman, “Development of Nickel-BTC-MOF-Derived Nanocomposites with rGO Towards Electrocatalytic Oxidation of Methanol and Its Product Analysis,” *Catalysts*, vol. 9, no. 10, p. 856, Oct. 2019, doi: 10.3390/catal9100856.

[178] S. K. Papageorgiou, E. P. Kouvelos, E. P. Favvas, A. A. Sapalidis, G. E. Romanos, and F. K. Katsaros, “Metal-carboxylate interactions in metal-alginate complexes studied with FTIR spectroscopy,” *Carbohydr. Res.*, vol. 345, no. 4, pp. 469–473, Feb. 2010, doi: 10.1016/j.carres.2009.12.010.

[179] W. Liang, H. Chevreau, F. Ragon, P. D. Southon, V. K. Peterson, and D. M. D'Alessandro, "Tuning pore size in a zirconium-tricarboxylate metal-organic framework," *CrystEngComm*, vol. 16, no. 29, pp. 6530–6533, Aug. 2014, doi: 10.1039/c4ce01031k.

[180] J. Yang, P. Xiong, C. Zheng, H. Qiu, and M. Wei, "Metal-organic frameworks: A new promising class of materials for a high performance supercapacitor electrode," *J. Mater. Chem. A*, vol. 2, no. 39, pp. 16640–16644, Oct. 2014, doi: 10.1039/c4ta04140b.

[181] A. Carton, A. Mesbah, T. Mazet, F. Porcher, and M. François, "Ab initio crystal structure of nickel(II) hydroxy-terephthalate by synchrotron powder diffraction and magnetic study," *Solid State Sci.*, vol. 9, no. 6, pp. 465–471, Jun. 2007, doi: 10.1016/j.solidstatesciences.2007.04.003.

[182] I. S. Imaduddin *et al.*, "Fabrication of Co_3O_4 from Cobalt/2,6-Napthalenedicarboxylic Acid Metal-Organic Framework as Electrode for Supercapacitor Application," *Materials (Basel).*, vol. 14, no. 3, p. 573, Jan. 2021, doi: 10.3390/ma14030573.

[183] T. P. Mofokeng, A. K. Ipadeola, Z. N. Tetana, and K. I. Ozoemena, "Defect-Engineered Nanostructured Ni/MOF-Derived Carbons for an Efficient Aqueous Battery-Type Energy Storage Device," *ACS Omega*, vol. 5, no. 32, pp. 20461–20472, Aug. 2020, doi: 10.1021/acsomega.0c02563.

[184] H. Qiao, Z. Wei, H. Yang, L. Zhu, and X. Yan, "Preparation and Characterization of NiO Nanoparticles by Anodic Arc Plasma Method," *J. Nanomater.*, vol. 2009, pp. 1–5, 2009, doi: 10.1155/2009/795928.

[185] Q. Wang, Q. Wang, B. Xu, F. Gao, F. Gao, and C. Zhao, "Flower-shaped multiwalled carbon nanotubes@nickel-trimesic acid MOF composite as a high-performance cathode material for energy storage," *Electrochim. Acta*, vol. 281, pp. 69–77, 2018, doi: 10.1016/j.electacta.2018.05.159.

[186] L. Qin, S. Zhao, C. Fan, and Q. Ye, "A photosensitive metal–organic framework having a flower-like structure for effective visible light-driven photodegradation of rhodamine B," *RSC Adv.*, vol. 11, no. 30, pp. 18565–18575, 2021, doi: 10.1039/D1RA02746H.

[187] S. Kaushal, G. Kaur, J. Kaur, and P. P. Singh, "First transition series metal–organic frameworks: synthesis, properties and applications," *Mater. Adv.*, vol. 2, no. 22, pp. 7308–7335, Nov. 2021, doi: 10.1039/D1MA00719J.

[188] X. Zhang *et al.*, "Shape-controlled synthesis of Ni-based metal-organic frameworks with albizia flower-like spheres@nanosheets structure for high performance supercapacitors," *J. Colloid Interface Sci.*, vol. 575, pp. 347–355, Sep. 2020, doi: 10.1016/j.jcis.2020.04.127.

[189] Y. Han, T. Yang, and Y. Chen, "A perspective on morphology controlled synthesis of powder by tuning chemical diffusion and reaction," *Adv. Powder Technol.*, vol. 31, no. 3, pp. 922–925, Mar. 2020, doi: 10.1016/j.apt.2019.12.008.

[190] Y. Han, H. Yang, and X. Guo, "Synthesis Methods and Crystallization of MOFs," in *Synthesis Methods and Crystallization*, IntechOpen, 2020. doi: 10.5772/intechopen.90435.

[191] H. M. Yang, X. L. Song, T. L. Yang, Z. H. Liang, C. M. Fan, and X. G. Hao, "Electrochemical synthesis of flower shaped morphology MOFs in an ionic liquid system and their electrocatalytic application to the hydrogen evolution reaction," *RSC Adv.*, vol. 4, no. 30, pp. 15720–15726, 2014, doi: 10.1039/C3RA47744D.

[192] C. Chen *et al.*, "Formation of bimetallic metal-organic framework nanosheets and their derived porous nickel-cobalt sulfides for supercapacitors," *Dalt. Trans.*, vol. 47, no. 16, pp. 5639–5645, 2018, doi: 10.1039/c8dt00464a.

[193] R. J. Niu *et al.*, "Morphology-dependent third-order optical nonlinearity of a 2D Co-based metal-organic framework with a porphyrinic skeleton," *Chem. Commun.*, vol. 55, no. 33, pp. 4873–4876, 2019, doi: 10.1039/C9CC01363F.

[194] P. Du, Y. Dong, C. Liu, W. Wei, D. Liu, and P. Liu, "Fabrication of hierarchical porous nickel based metal-organic framework (Ni-MOF) constructed with nanosheets as novel pseudo-capacitive material for asymmetric supercapacitor," *J. Colloid Interface Sci.*, vol. 518, pp. 57–68, May 2018, doi: 10.1016/j.jcis.2018.02.010.

[195] Q. Gan, H. He, K. Zhao, Z. He, and S. Liu, "Morphology-dependent electrochemical performance of anode material for Li-ion batteries," *J. Colloid Interface Sci.*, vol. 530, pp. 127–136, 2018, doi: 10.1016/j.jcis.2018.06.057.

[196] J. Zou, Q. Ruan, X. Zhang, B. Xu, Z. Cai, and Z. Luo, "Visible-wavelength pulsed lasers with low-dimensional saturable absorbers," *Nanophotonics*, vol. 9, no. 8, pp. 2273–2294, Mar. 2020, doi: 10.1515/nanoph-2020-0022.

[197] B. E. Conway, V. Birss, and J. Wojtowicz, "The role and utilization of pseudocapacitance for energy storage by supercapacitors," *J. Power Sources*, vol. 66, no. 1–2, pp. 1–14, 1997, doi: 10.1016/S0378-7753(96)02474-3.

[198] W. Wang *et al.*, "Hydrous Ruthenium Oxide Nanoparticles Anchored to Graphene and Carbon Nanotube Hybrid Foam for Supercapacitors," *Sci. Rep.*, vol. 4, no. 1, p. 4452, May 2015, doi: 10.1038/srep04452.

[199] B.-A. Mei, J. Lau, T. Lin, S. H. Tolbert, B. S. Dunn, and L. Pilon, "Physical Interpretations of Electrochemical Impedance Spectroscopy of Redox Active Electrodes for Electrical Energy Storage," *J. Phys. Chem. C*, vol. 122, p. 55, 2018, doi: 10.1021/acs.jpcc.8b05241.

[200] J. H. Joshi, D. K. Kanchan, M. J. Joshi, H. O. Jethva, and K. D. Parikh, "Dielectric relaxation , complex impedance and modulus spectroscopic studies of mix phase rod like cobalt sulfide nanoparticles," *Mater. Res. Bull.*, vol. 93, pp. 63–73, 2017, doi: 10.1016/j.materresbull.2017.04.013.

[201] S. Mendiratta, C. H. Lee, M. Usman, and K. L. Lu, "Metal-organic frameworks for electronics: Emerging second order nonlinear optical and dielectric materials," *Sci. Technol. Adv. Mater.*, vol. 16, no. 5, p. 054204, Oct. 2015, doi: 10.1088/1468-6996/16/5/054204.

[202] P. Yihlih and L. Warren, "Tapered fiber holder," 09/765,382, Jan. 2001

[203] D. A. Stoliarov *et al.*, "Saturable absorber based on the fiber coupler coated by CNTs," *Opt. Fiber Technol.*, vol. 63, p. 102524, May 2021, doi: 10.1016/j.yofte.2021.102524.

[204] B. A. Taha *et al.*, "Comprehensive Review Tapered Optical Fiber Configurations for Sensing Application: Trend and Challenges," *Biosensors*, vol. 11, no. 8, p. 253, Jul. 2021, doi: 10.3390/bios11080253.

[205] B. Musa, Y. M. Kamil, M. H. A. Bakar, A. S. M. Noor, A. Ismail, and M. A. Mahdi, "INVESTIGATING THE EFFECT OF TAPER LENGTH ON SENSITIVITY OF THE TAPERED-FIBER BASED TEMPERATURE SENSOR," *J. Teknol.*, vol. 78, no. 3, pp. 135–140, Feb. 2016, doi: 10.11113/JT.V78.7479.

[206] J. Jeon, J. Lee, and 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*, vol. 32, no. 1, p. 31, Jan. 2015, doi: 10.1364/JOSAB.32.000031.

[207] H. H. Liu and K. K. Chow, "Enhanced stability of dispersion-managed mode-locked fiber lasers with near-zero net cavity dispersion by high-contrast saturable absorbers," *Opt. Lett.*, vol. 39, no. 1, p. 150, Jan. 2014, doi: 10.1364/ol.39.000150.

[208] G. Sobon, J. Sotor, I. Pasternak, A. Krajewska, W. Strupinski, and K. M. Abramski, "Multilayer graphene-based saturable absorbers with scalable modulation depth for mode-locked Er- and Tm-doped fiber lasers," *Opt. Mater. Express*, vol. 5, no. 12, p. 2884, Dec. 2015, doi: 10.1364/ome.5.002884.

[209] F. Wang *et al.*, "Wideband-tuneable, nanotube mode-locked, fibre laser," *Nat. Nanotechnol.*, vol. 3, no. 12, pp. 738–742, 2008, doi: 10.1038/nnano.2008.312.

[210] Y.-H. Lin, C.-Y. Yang, S.-F. Lin, and G.-R. Lin, "Triturating versatile carbon materials as saturable absorptive nano powders for ultrafast pulsating of erbium-doped fiber lasers," *Opt. Mater. Express*, vol. 5, no. 2, p. 236, 2015, doi: 10.1364/ome.5.000236.

[211] A. Krajewska, G. Sobon, I. Pasternak, J. Sotor, K. M. Abramski, and W. Strupinski, "Multilayer graphene-based saturable absorbers with scalable modulation depth for mode-locked Er- and Tm-doped fiber lasers," *Opt. Mater. Express, Vol. 5, Issue 12, pp. 2884-2894*, vol. 5, no. 12, pp. 2884–2894, Dec. 2015, doi: 10.1364/OME.5.002884.

[212] A. Chong, W. H. Renninger, and F. W. Wise, "Properties of normal-dispersion femtosecond fiber lasers," *J. Opt. Soc. Am. B*, vol. 25, no. 2, p. 140, Feb. 2008,

[213] D. Yan *et al.*, "Route to stable dispersion-managed mode-locked Yb-doped fiber lasers with near-zero net cavity dispersion," *Opt. Express*, vol. 28, no. 20, p. 29766, Sep. 2020, doi: 10.1364/OE.403456.

[214] K. Y. Lau *et al.*, "Passively mode-locked ultrashort pulse fiber laser incorporating multi-layered graphene nanoplatelets saturable absorber," *J. Phys. Commun.*, vol. 2, no. 7, p. 075005, Jul. 2018, doi: 10.1088/2399-6528/AACDBE.

[215] E. P. Ippen, H. A. Haus, K. Tamura, and L. E. Nelson, "77-fs pulse generation from a stretched-pulse mode-locked all-fiber ring laser," *Opt. Lett. Vol. 18, Issue 13, pp. 1080-1082*, vol. 18, no. 13, pp. 1080–1082, Jul. 1993, doi: 10.1364/OL.18.001080.

[216] A. Chong, F. Wise, J. Buckley, and W. Renninger, "All-normal-dispersion femtosecond fiber laser," *Opt. Express, Vol. 14, Issue 21, pp. 10095-10100*, vol. 14, no. 21, pp. 10095–10100, Oct. 2006, doi: 10.1364/OE.14.010095.

[217] D. Y. Tang, L. M. Zhao, and B. Zhao, "Soliton collapse and bunched noise-like pulse generation in a passively mode-locked fiber ring laser," *Opt. Express*, vol. 13, no. 7, p. 2289, Apr. 2005, doi: 10.1364/OPEX.13.002289.

[218] D. Y. Tang, J. Wu, L. M. Zhao, S. C. Wen, and X. Q. Fu, "Noise-like pulse in a gain-guided soliton fiber laser," *Opt. Express, Vol. 15, Issue 5, pp. 2145-2150*, vol. 15, no. 5, pp. 2145–2150, Mar. 2007, doi: 10.1364/OE.15.002145.

[219] M. A. Ismail, S. W. Harun, H. Ahmad, and M. C. Paul, "Passive Q-switched and Mode-locked Fiber Lasers Using Carbon-based Saturable Absorbers," in *Fiber Laser*, InTech, 2016. doi: 10.5772/61703.

[220] R. H. Stolen and C. Lin, "Self-phase-modulation in silica optical fibers," *Phys. Rev. A*, vol. 17, no. 4, p. 1448, Apr. 1978, doi: 10.1103/PhysRevA.17.1448.

[221] Y. Ge *et al.*, "Revision on fiber dispersion measurement based on Kelly sideband measurement," *Microw. Opt. Technol. Lett.*, vol. 58, no. 1, pp. 242–245, Jan. 2016, doi: 10.1002/MOP.29532.

[222] C.-Y. Yang, G.-R. Lin, S.-F. Lin, and Y.-H. Lin, "Triturating versatile carbon materials as saturable absorptive nano powders for ultrafast pulsating of erbium-doped fiber lasers," *Opt. Mater. Express, Vol. 5, Issue 2, pp. 236-253*, vol. 5, no. 2, pp. 236–253, Feb. 2015, doi: 10.1364/OME.5.000236.

[223] J. Huang, M. Pang, X. Jiang, W. He, and P. S. Russell, "Route from single-pulse to multi-pulse states in a mid-infrared soliton fiber laser," *Opt. Express*, vol. 27, no. 19, p. 26392, Sep. 2019, doi: 10.1364/oe.27.026392.

[224] N. Li *et al.*, "Cavity-length optimization for high energy pulse generation in a long cavity passively mode-locked all-fiber ring laser," *Appl. Opt.*, vol. 51, no. 17, p. 3726, Jun. 2012, doi: 10.1364/AO.51.003726.

[225] C.-K. Lee, J. H. Lee, B.-T. Zhang, and J.-L. He, "Topological insulators and applications," in *2D Materials for Nanophotonics*, Elsevier, 2021, pp. 81–138. doi: 10.1016/B978-0-12-818658-9.00007-7.

[226] S. Boscolo, J. Peng, and C. Finot, "Design and Applications of In-Cavity Pulse Shaping by Spectral Sculpturing in Mode-Locked Fibre Lasers," *Appl. Sci. 2015, Vol. 5, Pages 1379-1398*, vol. 5, no. 4, pp. 1379–1398, Nov. 2015, doi: 10.3390/APP5041379.

[227] S. Salam, A. H. H. Al-Masoodi, P. Wang, and S. W. Harun, "Femtosecond mode-locked erbium-doped fibre laser with Alq_3 saturable absorber," *IET Optoelectron.*, vol. 14, no. 5, pp. 234–241, Oct. 2020, doi: 10.1049/iet-opt.2019.0171.

[228] D. Popa *et al.*, "74-fs nanotube-mode-locked fiber laser," *Appl. Phys. Lett.*, vol. 101, no. 15, p. 153107, Oct. 2012, doi: 10.1063/1.4757293.

[229] Z. Sun, T. Hasan, F. Wang, A. G. Rozhin, I. H. White, and A. C. Ferrari, "Ultrafast stretched-pulse fiber laser mode-locked by carbon nanotubes," *Nano Res.*, vol. 3, no. 6, pp. 404–411, Jun. 2010, doi: 10.1007/s12274-010-1045-x.

[230] R. Paschotta, "Encyclopedia of laser physics and technology," *Encyclopedia of laser physics and technology*. Weinheim: Wiley-VCH, 2008.

[231] H. Kee *et al.*, "Zinc selenide saturable absorber for ultrashort pulse fiber laser generation in C – band region," *Opt. Mater. (Amst).*, vol. 107, no. May, p. 110100, 2020, doi: 10.1016/j.optmat.2020.110100.

[232] W. D. Tan, C. Y. Su, R. J. Knize, G. Q. Xie, L. J. Li, and D. Y. Tang, "Mode locking of ceramic Nd:yttrium aluminum garnet with graphene as a saturable absorber," *Appl. Phys. Lett.*, vol. 96, no. 3, p. 031106, Jan. 2010, doi: 10.1063/1.3292018.

[233] G. Jiang *et al.*, "Bismuth Telluride nanocrystal: broadband nonlinear response and its application in ultrafast photonics OPEN," vol. 8, p. 2355, 2018, doi: 10.1038/s41598-018-20559-y.

[234] A. P S, M. Srivastava, B. Srinivasan, and D. Venkitesh, "Numerical studies of the operating regimes of a passively mode-locked Thulium doped fiber laser," *OSA Contin.*, vol. 4, no. 8, p. 2193, Aug. 2021, doi: 10.1364/OSAC.431551.

[235] P. Yan *et al.*, "Passively mode-locked fiber laser by a cell-type WS2 nanosheets saturable absorber," *Sci. Rep.*, vol. 5, no. 1, p. 12587, Dec. 2015, doi: 10.1038/srep12587.

[236] P. Zhang, K. Dimyati, B. Nizamani, M. M. Najm, M. Yasin, and S. Wadi Harun, "Ultrashort pulse generation in All-fiber Erbium-doped fiber cavity with thulium doped fiber saturable absorber," *Opt. Laser Technol.*, vol. 149, p. 107888, May 2022, doi: 10.1016/j.optlastec.2022.107888.

[237] X. Ma *et al.*, "Passively mode-locked thulium doped fiber laser based on SnSe nanoparticles as a saturable absorber," *Opt. Laser Technol.*, vol. 138, p. 106870, Jun. 2021, doi: 10.1016/j.optlastec.2020.106870.

[238] A. Murad *et al.*, "Effect of nickel ion concentration on structural, optical and electrical properties towards Ni–H_3BTC-MOF formation for nonlinear saturable absorption phenomenon," *J. Phys. Chem. Solids*, vol. 167, p. 110743, Aug. 2022, doi: 10.1016/j.jpcs.2022.110743.

[239] A. Murad, N. Mohd Yusoff, J. Y. C. Liew, M. H. Yaacob, C. S. Goh, and M. A. Mahdi, "Nickel 1,3,5-benzene-tricarboxylic acid-metal organic framework polymer composite saturable absorber for femtosecond pulse generation," *Results Phys.*, vol. 41, p. 105881, Oct. 2022, doi: 10.1016/j.rinp.2022.105881.