SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Semarak International Journal of Electronic System Engineering

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sijese/index
ISSN: 3030-5519

Exploring Organic-Based Saturable Absorption Focusing on Spider Silk in Q-Switched Pulse Fiber Laser Applications: A Mini Review

Nur Ainnaa Mardhiah Muhammad [1,*], Noor Azura Awang[1], Agus Muhamad Hatta[2]

[1] Photonics Devices Sensors Research (PDSR), Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, KM1 Jalan Panchor, 84600 Panchor, Johor, Malaysia
[2] Department of Engineering Physics, Institut Teknologi Sepuluh Nopember,Surabaya, Indonesia

ARTICLE INFO

Article history:
Received 6 November 2024
Received in revised form 18 November 2024
Accepted 2 December 2024
Available online 20 December 2024

Keywords:
Erbium-doped fiber laser; fiber optic communication; natural biological material; optical pulse fiber sensor; organic-based saturable absorbers; passively Q-switched; spider silk

ABSTRACT

The fiber laser combines the fiber gain medium's function as a fiber amplifier, transforming it into laser output through integration within a cavity configuration. Meanwhile, a pulsed fiber laser is capable of generating short bursts of laser emission characterized by high peak power levels. This concept is known as Q-switching. A saturable absorber material is essential for passive Q-switching, as it is integrated into the laser cavity to produce an instantaneously Q-switched pulse fiber laser. While these materials have been effective in generating pulsed lasers, they often come with unresolved issues, such as long-term exposure to two-dimensional materials can pose health risks. To address this gap, researchers have shifted their interest toward natural or organic materials in the quest for new saturable absorbers. This mini-review provides a comprehensive overview of the saturable absorber mechanism, including essential theoretical equations and key measurement parameters. The next section continues by exploring the fundamentals and early development of saturable absorbers, followed by an in-depth explanation of the Q-switched pulse generation process using erbium-doped fiber as the gain medium and saturable absorber. Critical parameters influencing the performance of Q-switched pulse fiber lasers are discussed, with special attention given to recent advancements in organic-based saturable absorbers for Q-switching. The potential of spider silk as an innovative saturable absorber in Q-switched pulse fiber laser applications is highlighted. Finally, the review delves into the wide-ranging applications of these lasers, including tunable and switchable dual-wavelength fiber lasers with sensor for temperature measurement and to detect adulteration in pure kelulut honey and sucrose solution.

1. Introduction

The fiber laser combines the fiber gain medium's function as a fiber amplifier, transforming it into laser output through integration within a cavity configuration. Meanwhile, a pulsed fiber laser is capable of generating short bursts of laser emission characterized by high peak power levels. Since its establishment by Fred J. McClung in 1962, the idea of pulse creation in lasers has gained significant

[*] *Corresponding author.*
E-mail address: researchainnaa@gmail.com

https://doi.org/10.37934/sijese.4.1.4378

traction, leading to a proliferation of research in the field of pulsed laser technology. His theory is referred to as Q-switching. Initially, this technique involved the utilization of Kerr cell shutters to generate significant pulses, resulting in peak power approximately 100 times greater than that produced by ruby lasers [1]. The foundations of both active and passive approaches are also recognized [2–4]. Using passive saturable absorbers has been regarded as a viable approach for achieving narrow pulse widths and broad spectral ranges [5]. The investigation of high-performance saturable absorbers is widely pursued in the field of ultrafast photonics research. High-performance saturable absorbers possess notable attributes such as efficient heat dissipation, a high threshold for laser damage, and wavelength independence. In addition, their compact size makes them suitable for analyzing small-scale samples and accessing limited or hard-to-reach areas [6,7]. A saturable absorber material is essential for passive Q-switching, as it is integrated into the laser cavity to produce an instantaneously Q-switched pulse fiber laser. While these materials have been effective in generating pulsed lasers, however, they often come with some unresolved issues such as the challenging and expensive fabrication processes for transition metal dichalcogenides material [8–10], and their low damage threshold [11–15]. Additionally, long-term exposure to two-dimensional materials, including topological insulators, can pose health risks [16–18].

To address this gap, researchers have shifted their interest towards natural or organic material in the quest for new saturable absorber. Therefore, this mini review exploring organic-based saturable absorbers, focusing on spider silk to generate the Q-switched pulse erbium-doped fiber laser source. Natural spider silk is a protein-based biological material produced by spiders naturally through silk glands in their bodies [19]. Interestingly, these silks serve as photon carriers, with light guiding through dragline silk recently proven to have transmission losses of only a few dB/cm [20–22], paves the way for its incorporation as natural biological saturable absorber to generate Q-switched pulse fiber laser applications.

2. Saturable Absorber

2.1 Saturable Absorber Mechanism

A saturable absorber is an optical device or material that exhibits a nonlinear response to incident light. It is essential for passively Q-switched fiber lasers as it facilitates the formation of optical pulses (initiating operation in the pulsed state), regulates the output intensity of lasers, and controls characteristics such as repetition rate, pulse width, and pulse energy. It significantly contributes to stabilizing laser output by reducing fluctuations and providing consistent pulse parameters. It is characterized by its ability to modulate the light intensity passing through it, depending on the intensity of the incident light. The mechanism of a saturable absorber is based on the concept of intensity-dependent transmission or absorption of light [23]. Specifically, understanding this mechanism relates to the framework of the saturable absorber material's energy levels and their interaction with light.

When saturable absorber material is placed within the laser cavity under low light intensity, it remains in its ground state with relatively high absorption. During this stage, most electrons are in the ground state and absorb photons at low intensity, exciting them to higher energy levels. As the intensity of the incident light continues to increase, the electrons within the saturable absorber material continues to excite, transitioning to higher energy states, resulting in a decrease in the saturable absorber material's absorption. At sufficiently high light intensities, the absorption becomes saturated due to the fully-occupied of electrons in higher level.

2.2 Saturable Absorber Parameters

As discussed in Subsection 2.1, saturable absorption is a phenomenon that occurs in certain materials or devices, wherein the degree of light absorption relies on the optical intensity of the incoming light, causing a decrease as the light intensity increases. Understanding the parameters of a saturable absorber is important for assessing the desired performance of the resulting laser output. The nonlinear behaviour exhibited by saturable absorber material can be effectively characterized by utilizing a straightforward two-level saturable absorption model. This model serves as a resource for identifying the significant parameters such as the saturable absorption, non-saturation absorption, saturation intensity, and recovery time. The expression of the two-level saturable absorption model is given by Wang *et al.,* and Xing *et al.,* [24,25]:

$$\alpha(I) = \frac{\alpha_s}{1+\frac{I}{I_{sat}}} + \alpha_{ns} \tag{1}$$

where $\alpha(l)$ denotes the absorption coefficient that is dependent on the intensity of the incident light, α_s is the linear limit of saturable absorption (modulation depth), I is the input laser intensity, I_{sat} is the saturation intensity, and α_{ns} is the non-saturable absorption coefficient.

Saturable absorption, also known as modulation depth, can be experimentally measured using the twin-detector method, also known as the twin-balanced or balanced twin-detector technique [26–30], Z-scan measurement [31], and P-scan measurement [32]. The experiment for the twin-detector method is carried out with the help of an ultrafast pulse source of a specific wavelength transmitted into a saturable absorber. The modulation depth is determined by measuring the maximum change that can occur in the induced optical loss. A saturable absorber with a modulation depth of 10 % or higher is preferred, as this allows for a more stable pulse laser function [33–35]. In addition, a saturable absorber with a larger modulation depth can produce significant pulse shaping, which is necessary for achieving short pulse durations. The only disadvantage of a saturable absorber with high modulation depth is its propensity towards Q-switched instabilities. Furthermore, saturable absorption can be expressed as:

$$\alpha_s = \alpha_{sg} N \tag{2}$$

where α_{sg} is the absorption cross-section at the ground state of the saturable absorber and N is the concentration of the saturable absorber material. The saturable absorption is determined by the relative number of photons absorbed per unit distance by the saturable absorber material. A high saturable absorption coefficient means more photons are absorbed by the saturable absorber rather than penetrating deeper, over a relatively short distance. This concept is illustrated in Figure 1, which shows the distance, X for two different absorption coefficient values versus photon intensity, l_{v0}.

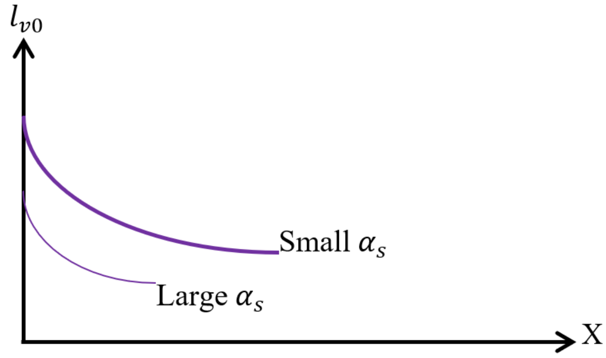


Fig. 1. The distance for two different absorption coefficient values versus photon intensity

Meanwhile, the loss that cannot be saturated by the saturable absorber material, known as non-saturable absorption, is expressed as a percentage of linear absorption due to normalization [36]. This loss can be attributed to transmission loss, free carrier absorption, Auger recombination, and scattering loss. Scattering loss can occur due to surface roughness of the material, lattice defects, and rough interfaces. Additionally, the modulation depth of the saturable absorber material is related to the minimum pulse width of the Q-switched laser, which is regulated by the properties of saturable absorption and non-saturable loss.

The optical peak intensity that equates to a 50 % reduction of the saturated region of its absorption is known as the saturation intensity. Additionally, the Eq. (1) for saturation intensity, represents the intensity required in a steady state to reduce the absorption to half of its unsaturated value:

$$l_s = \frac{hf}{\sigma_{sg}\tau_{se}} \quad (3)$$

where h is Plank's constant, f is the light frequency of operation, σ_{sg} is the absorption cross-section at the ground state of the saturable absorber, and τ_{se} is the absorber recovery time or excited state lifetime. According to Eq. (3), less continuous-wave intensity is needed to saturate the saturable absorber when the excited state lifetime is longer before recombination.

Figure 2 shows a graph of the normalized nonlinear absorption, based on Eq. (1), at different normalized light intensity [37]. According to the Figure 2, the absorption is high, and lasing is disallowed when the laser resonator (pump diode source) light intensity is lower than the saturable absorber saturation intensity ($l < l_s$). The absorption reduces, and transmissivity gradually becomes higher when the light intensity is $l \geq l_s$. Overall, the absorption is saturated when $l \gg l_s$ because of the high Q-value of the resonator, initiating Q-switched laser oscillation. Due to non-saturable loss property, α_{ns} of the saturable absorber, the nonlinear saturable absorption cannot reach 0 %.

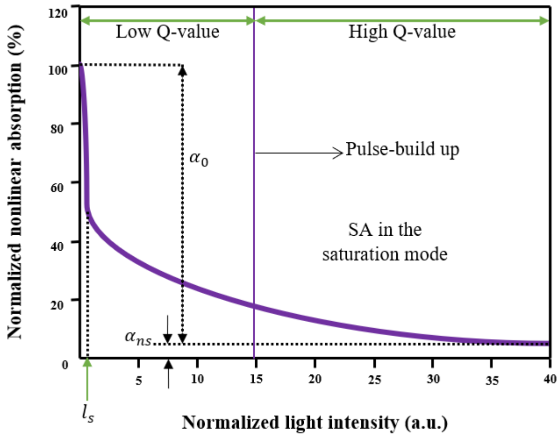


Fig. 2. Light intensity versus nonlinear absorption in Q-switching

3. Overview of the Saturable Absorber

3.1 Graphene

The research on two-dimensional materials has seen rapid development since the first graphene saturable absorber was introduced in 2009 [38,39]. It is ideally suited as a saturable absorber in pulsed fiber laser systems due to its significant fast response times and broad wavelength range [40–45]. Despite its potential, graphene has certain drawbacks, including a low modulation depth, as the absorption per layer is only 2.3 % [46–52]. Apart from that, because graphene is easily oxidized, a hydrogen ambient atmosphere is necessary during its manufacture using chemical vapour deposition [53]. Thus, further investigations into other materials are needed to find high-performing saturable absorbers.

3.2 Topological Insulators

Topological insulator (TI) materials with the formula Y_2X_3, where Y can be either Bi or Sb, and X can be either Te or Se. A HgTe is an example of a two-dimensional material, while Bi_2Te_3, Bi_2Se_3, and Sb_2Te_3 are examples of three-dimensional materials. Hsieh *et al.* reported the initial discovery of three-dimensional TI material in 2008 [54]. Numerous studies have been conducted to generate pulsed fiber laser-based TIs material [55–66]. TIs are quantum states of matter in which the interior is an insulator, whereas the surface states are conductive, allowing electrons to only travel along the surface of the material [67,68]. The electronic configurations of TI films are affected by film thickness due to electron quantum confinement, which drives the TI materials to generate pulsed fiber lasers in the range of visible, near-infrared, and mid-infrared wavelengths [69]. However, there are still challenges to overcome, primarily in understanding how the electronic structure of TI materials works. These materials exhibit intricate electronic structures due to the strong spin-orbit interaction, making it challenging to theoretically predict their bandgap energies and verify them experimentally [69]. Furthermore, the pulse bandwidth and high non-saturable loss are affected not only by the nonlinearity of the fibers, but also by the presence of impurities, defects, and dislocations in the material [69–71]. Additionally, material preparation for compounds such as Bi_2Te_3, Bi_2Se_3, Sb_2Te_3 is complex because they are made of two different elements [72,73]. Moreover, TI saturable absorbers are restricted with a low damage threshold, meaning they can only tolerate a relatively small amount of energy before becoming saturated [11,74,75].

3.3 Transition Metal Dichalcogenides

Transition metal dichalcogenides (TMDs) belong to the category of two-dimensional materials and have attracted attention due to their layer-dependent bandgap, which allows the bandgap to be controlled by manipulating the number of material layers. This property enables saturable absorption over a broad wavelength range and is accompanied by high optical nonlinearity [15,76–81]. TMDs are a family of anisotropic semiconductor materials with the common formula MX_2, where M represents a transition metal element from groups IV to X, including Ti, Zr, and Hf (group IV), group V contains V, Nb, and Ta, group VI involves Mo and W, group VII consists of Mn, Tc and Re, group VIII (Fe, Ru, and Os), group IX (Co, Rh, and Ir), and group X (Ni, Pd, and Pt). The X represents chalcogen elements such as S and Se [82]. TMD materials from groups IV to VII are typically layered, while those from groups VIII to X are often non-layered. The layer-dependent bandgap in TMD materials makes them an appealing target for study in the approach of exploiting saturable absorbers for pulse generation [76,83]. Active research on TMDs-based saturable absorbers and their application in fiber lasers is ongoing. Studies have demonstrated that materials such as titanium trisulfide [84], hafnium sulfide [81], platinum [85], molybdenum ditelluride [86], rhenium disulfide [87], and antimony sulfide [79] act as saturable absorbers to produce Q-switched pulses in an erbium-doped fiber laser cavity. Despite the fact that their bandgaps can be adjusted by changing the layer numbers, their absorption in the mid-infrared wavelength is relatively poor, which might further increase the optical loss [88]. Additionally, TMDs may be inhaled as airborne particles during the fabrication or disposal of two-dimensional TMD-based products, necessitating an evaluation of their biosafety. The preparation methods for TMDs are also somewhat complicated [8–10]. Moreover, these materials are susceptible to low optical damage thresholds [11–15], which can impact their laser generation performance.

3.4 Black Phosphorus

Two-dimensional mono-elemental materials, such as black phosphorus (BP), have piqued the interest of researchers due to their natural characteristics [89–93]. In 2014, experiments conducted by Ye and Zhang independently discovered that BP exhibits anisotropic properties with a variable bandgap [94,95]. Anisotropy refers to materials exhibiting properties that vary with the direction in which they are observed. Along with its layered orthorhombic structure, through which electrons, phonons, and their interactions with photons propagate in an anisotropic manner within the layers' plane. The anisotropic structure of BP thin films is disclosed using angle-resolved Raman and infrared spectroscopies, as well as angle-resolved transport research by Xia *et al.,* [96]. Both theoretical calculations and experimental evidence indicate that BP has direct bandgap characteristics depending on the number of layers (layer-dependent bandgap), with values ranging from 0.10 eV to 0.35 eV for bulk BP and 1.0 eV to 1.7 eV for monolayer BP. Another remarkable aspect of this material, which has garnered considerable research interest, is its ability to absorb light across a wide range of wavelengths, from ultraviolet to infrared [97–99]. In 2021, a Q-switched erbium-doped fiber laser using exfoliated BP as a saturable absorber, was demonstrated by Alghamdi *et al.* achieving a highest pulse energy of 171.7 nJ [72]. Despite its numerous impressive qualities, BP has two major drawbacks that hinder its widespread use. One of these drawbacks is the low stability of two-dimensional BP in ambient conditions. Although the phosphorus allotrope BP is most stable in bulk form, when exfoliated into a few-layer structure, it rapidly reacts with oxygen and moisture in the air, leading to the breakdown of its crystal structure [9,100–103]. Another issue is the difficulty in producing high-quality, large-area few-layer BP using existing synthesis techniques [104,105].

4. Passively Q-Switched Pulse Fiber Laser

A pulsed fiber laser is a subset of fiber laser technology that generates optical pulses, or light pulses, as its output. It can produce more powerful energy than a continuous-wave laser. One technique for generating optical pulses is the passively Q-switched fiber laser, where saturable absorption serves as the essential element [106,107]. Q-switching is a technique used to produce energetic and short pulses, also known as giant pulses. This pulse is not ultrashort. The first experimental works on Q-switched were conducted at Hughes Research laboratories [108]. Hellwarth [109] predicted that a laser would emit short pulses if the loss in an optical resonator was rapidly changed from a high to a low value. This prediction was experimentally confirmed a year later by Collins and Kisliuk [110] and McClung and Hellwarth [111].

By adjusting a laser resonator's quality factor (Q-factor), Q-switching enables the generation of short-duration laser pulses ranging from nanoseconds to picoseconds with high pulse energy. The Q-factor is a dimensionless variable that measures the strength measurement of its oscillation damping. It is determined by:

$$Q = \frac{2\pi f_o \varepsilon}{P} \tag{4}$$

where f_o is the resonant frequency, ε the stored energy in the cavity and $P = -\frac{dE}{dt}$ is the power dissipated.

The quality factor (Q-factor) indicates a laser cavity's ability to preserve its energy. A higher Q-factor signifies lower intracavity losses. The term Q-switching describes the process of switching the laser setup from a low Q to a high Q to create a short pulse duration. Initially, the Q-factor is kept low (with large losses) to prevent lasing. The gain medium provides constant pumping, leading to the accumulation of spontaneous emissions in the cavity, and thereby storing energy. When the Q-factor is suddenly increased to a high level and the necessary amount of energy is collected, the laser pulse begins to build up in the cavity following spontaneous emission, becoming a laser. The pulse intensifies until the losses equal the gain. The laser can no longer oscillate when the pulse peak power is exceeded and the gain is fully depleted. The Q-switch is then opened again (low Q), and the process starts over to build up more inversion for the next consecutive pulse [112].

Passively Q-switched pulse fiber lasers are increasingly useful and relevant in real-life applications. For example, in industrial settings, they are extensively used for precise material processing tasks such as cutting [113,114], engraving [115–119], and marking [120–122]. These lasers deliver high peak powers (ranging from several kilowatts to tens of kilowatts) and short pulse widths (in the nanoseconds range), enabling precise, high-quality processing with minimal thermal effects on ceramics, metals, and polymers. Q-switched pulse fiber lasers are also practical in the aerospace sector [123,124], and electronics industries [125] for manufacturing components with complex designs and precise dimensions. Next, these lasers are highly useful in dermatology [126–130], ophthalmology [131,132], and precision surgery [133–137]. They are employed in operations where meticulous control over energy delivery and minimal thermal damage are essential, such as eye surgery, skin resurfacing, and tattoo removal [138,139]. These lasers enable medical professionals to conduct delicate and precise treatments with little to no damage to surrounding tissues. Additionally, they are used in LIDAR systems for atmospheric research, environmental monitoring, and remote sensing applications [140–144]. In telecommunications, a passively Q-switched pulse fiber laser is necessary for high-speed data transmission, wavelength conversion, signal amplification, signal processing, and data routing [145]. Their stability and reliability, combined with their ability to operate continuously, compact size, lightweight design due to the use of optical fiber as the gain medium, and high efficiency in converting a significant portion of input light energy into laser output, help reduce operating costs and power consumption. These attributes make them indispensable components in fiber optic networks and communication systems, supporting the growing demands of modern telecommunications technologies. Passively Q-switched pulse fiber lasers can create high-energy pulses with good temporal characteristics and narrow linewidths over long distances, making them applicable for military and security devices. These applications include target designation, range finding, and active imaging, all of which require intense bursts of energy [146–148]. In scientific research, this technique is used by researchers to explore ultrafast processes, analyze material properties, and carry out accurate spectroscopic analyzes. It is instrumental in broadening the understanding of basic scientific ideas and opening doors for innovations across various fields of study. Passively Q-switched pulse fiber lasers offer additional key advantages that make them highly desirable, including relatively low maintenance requirements compared to other laser types. They do not require frequent sophisticated component repairs or replacements, resulting in minimized downtime and reduced operational costs over the long term [149,150]. This laser exhibits high beam quality, characterized by strong focusing ability, low divergence, and a well-defined mode structure [130,151–153]. The high beam quality ensures accurate and precise material processing, measurement, and imaging, making them appropriate for applications requiring high spatial resolution and beam manipulation. Passively Q-switched pulse fiber lasers are comparatively easy to operate, unlike several other types of lasers that require complex external modulators [154]. They have a simpler design and are less prone to failure because they do not require alignment to generate a Q-switched pulse [155,156].

4.1 The Principal Process in Generating Q-Switched Pulse Fiber Laser with Saturable Absorber

The generation of Q-switched pulses occurred when a photon of light entered the core of the erbium-doped fiber. This erbium-doped fiber served as the gain medium in the laser cavity to amplify the light. Erbium ions in the fiber absorbed the energy supplied by the pump diode, transferring the energy to the erbium ions and creating a population inversion. This means that the exceeded ions were in a higher state rather than the ground state ions.

The pump diode continuously supplied energy to the gain medium, thus maintaining the population inversion. Following that, the light passed through the area containing the saturable absorber material. The saturable absorber material was designed to have high absorption, creating significant losses within the laser cavity and thus inhibiting lasing from occurring.

As mentioned before, the pump diode continuously supplied energy to the gain medium. After a specific time, the energy within the gain medium achieved a threshold value higher than the loss in the cavity created by the saturable absorber. This caused the absorption of the saturable absorber to suddenly become saturated and then transition to a transparent state.

At that moment, the loss of the cavity was reduced, and the accumulated energy in the gain medium was released, forming the Q-switched pulse with high energy and short duration (Figure 3).

After the pulse was generated, the saturable absorber entered the recovery phase, preparing for the next round of lasing. During this time, the saturable absorber returned to its high absorption state, causing high losses of the cavity and inhibiting lasing. The pump diode continued to supply energy to the gain medium, preparing for the next cycle.

The entire process repeated itself. As the saturable absorber recovered, the loss in the cavity increased, inhibiting lasing. The energy in the gain medium continued to accumulate until it reached the threshold value, at which point the saturable absorber switched states, leading to the generation of the Q-switched pulses.

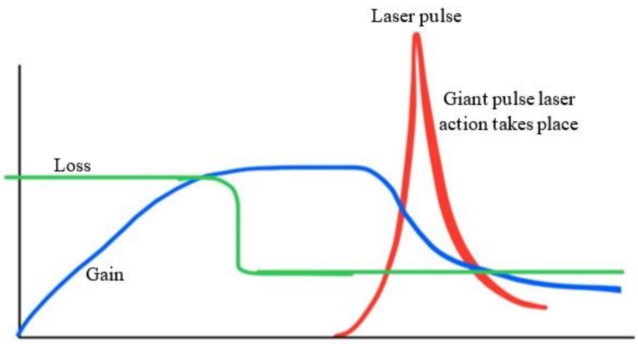


Fig. 3. A visualization depicting the creation of a Q-switched pulse

4.2 Q-Switched Pulse Fiber Laser Key Parameters

The temporal characteristics of Q-switched pulse fiber laser is typically characterized by several key parameters, such as repetition rate, pulse width, pulse energy, and peak power (Figure 4), measured using an oscilloscope.

The first parameter, repetition rate, indicates the number of pulses emitted by the laser within a given time interval, often measured in seconds. This repetition rate can be simply measured from the oscilloscope by monitoring the duration between the output pulse trains. The Q-switched pulse repetition rate typically ranges from a few kilohertz to 100 kHz, representing its fundamental feature [157–159].

Secondly, the pulse width, also known as pulse duration, is identified as the full width at half-maximum, which represents 50 % of the time interval between the rising edge-marking the initiation of the pulse and a drop edge, signifying the end point of the pulse, within the framework of laser pulses. According to Herda *et al.,* the pulse width exhibits a decreasing trend with an increase in pump power [160]. Typically, the pulse width occurs within the microseconds range [10,161].

The term pulse energy pertains to the amount of energy encapsulated within each pulse produced by the laser. It is calculated by dividing the average power by the repetition rate. The measurement of pulse energy is commonly expressed in units of nanojoules [162–164].

Another criterion of a Q-switched pulse is peak power. The peak power of an optical pulse refers to the maximum optical intensity that the pulse can achieve. Peak power is commonly measured in milliwatts or decibel-milliwatts [165].

Meanwhile, an optical spectrum analyzer is used to measure the spectral properties of the laser output, including the main wavelength at which the laser operates. This helps identify the lasing medium and assess the tuning capabilities of the Q-switched laser.

The manipulation of pump power induces noteworthy effects on the Q-switched parameters. As the pump power increases, more energy becomes available for the gain medium in the fiber laser, leading to faster population inversion and quicker recovery of the gain medium. This allows for a higher repetition rate as the laser system can undergo more cycles of energy storage and release in a given period. Simultaneously, the pulse width decreases. Increased pump power accelerates the build-up of energy in the gain medium, resulting in a higher inversion level in the gain medium that allows for quicker release of stored energy during the Q-switched process. Quicker release of energy results in shorter pulse durations, leading to a decrease in pulse width. Furthermore, the pulse energy exhibits a notable increase, as the augmented pump power provides more energy for storage in the gain medium, resulting in a more substantial release during the Q-switched operation. Finally, the higher pump power leads to more stimulated emission events, contributing to a more intense laser output and, consequently, an increase in the overall output power, owing to the combined effects of higher repetition rates and increased pulse energy.

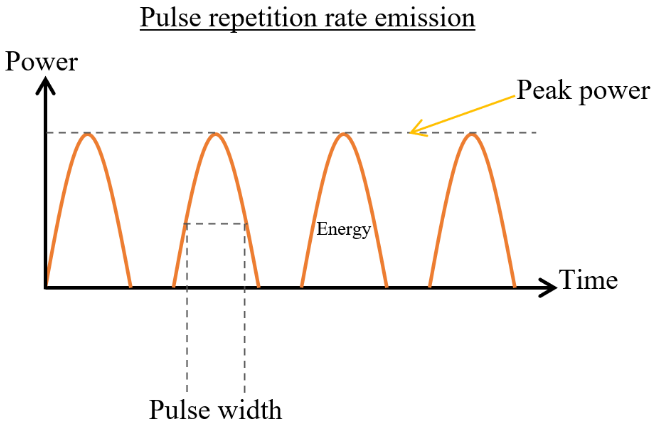


Fig. 4. An illustration of the pulse laser emission

5. Organic Based Saturable Absorber

Currently, the market for various saturable absorbers has been growing, including organic-based saturable absorbers from different classes, which have been successfully used to generate pulsed laser output in erbium-doped fiber laser systems. Over the past five years (since 2021), organic semiconductor material was made from Poly(3-hexylthiophene-2,5-diyl) regioregular, which was used to drive Q-switched pulse generation at maximum repetition rate of 78.63 kHz. In the same year (2021), the Q-switched laser output using 8-Hydroxyquonolino cadmium chloride hydrate as saturable absorber were realized in two different erbium-doped fiber laser's cavity configurations having different output couplers. Najm *et al.,* demonstrated a modulation depth of 11 % as shown in Figure 5. They prepared as saturable absorber by mechanical exfoliation technique and demonstrated Q-switched pulse output of 136 kHz using 50/50 optical coupler. In addition, the same group also used 8-Hydroxyquonolino cadmium chloride hydrate as a saturable absorber using 95/5 optical coupler, achieved 173 kHz Q-switched pulse output. Later, researchers prepared 8-Hydroxyquinolino cadmium chloride hydrate material as a saturable absorber in the thin-film form, exhibit modulation depth of 18 % which enabled Q-switched pulse generation at 150 kHz and 143 kHz, respectively. These studies suggest that organic-based saturable absorber materials can be effectively engineered to generate a broader pulse range.

The operation of the organic-based saturable absorbers was extended by using turmeric material, prepared by embedding turmeric powder into polyvinyl alcohol (PVA) film. A stable Q-switched pulse with a pulse width of 0.725 us and a repetition rate of 90.09 kHz was obtained at a central wavelength of 1566.96 nm (Figure 6).

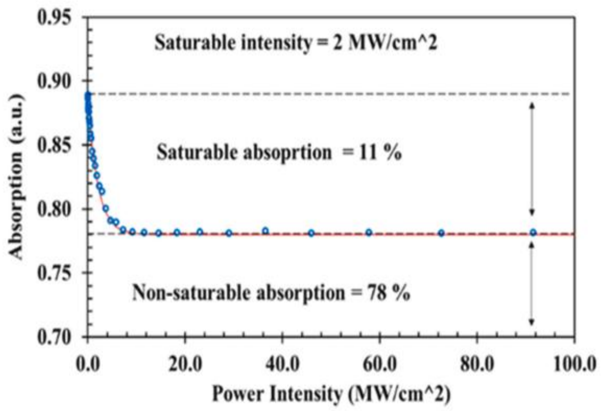


Fig. 5. The nonlinear absorption response of 8-Hydroxyquonolino cadmium chloride hydrate [166]

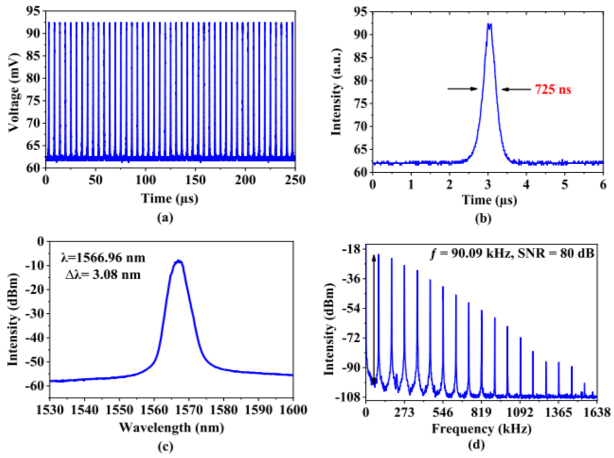


Fig. 6. (a) Pulses train, (b) single pulse envelop, (c) output spectrum, and (d) radio frequency spectrum [167]

Due to the optical response of poly (3,4 ethylenedioxythiophene): poly (4-styrenesulfonate), organic conducting material, Al-Hiti *et al.,* were fabricated thin-film saturable absorber by mixing poly (3,4 ethylenedioxythiophene): poly (4-styrenesulfonate) with polyvinyl alcohol (PVA), prepared by simple solution casting and spin-coating method. From the balanced twin detector measurement revealed that it has potential to be performed as a pulse initiator in 1.5 µm region as it owns moderate of saturable absorption of 50 % and 22 % respectively.

Natural dyes, considered among the organic-based materials, are colorants acquired from plants, minerals, and/or invertebrates. Henna (Lawsonia inermis) is one such dye material, obtained from the leaves of the plant, traditionally used to create intricate designs on women's hands. The leaves of the plant are dried, crushed, and then boiled with water to extract the dye. The potential of lawsone-based saturable absorbers has been highlighted due to their nonlinear optical properties at low input power. Soboh *et al.,* in 2021 reported the generation of stable Q-switched pulses at a central wavelength of 1564 nm, with the highest repetition rate of 80 kHz, and the lowest pulse width of 1.7 µs, utilizing lawsone as the saturable absorber [168].

Furthermore, phthalocyanines based saturable absorber allow for the operation wavelength for instance, S. Wadi *et al.,* demonstrated a modulation depth of 8.8 % at 1532.1 nm with repetition rate of 77.2 kHz. Additionally, the same group also used phthalocyanines film as saturable absorption (9.5 %) achieving 48.6 kHz pulse repetition rate.

Ahmad *et al.,* (2024) practically using Polyacrylonitrile film as a saturable absorber for generating Q-switched pulses with the combination of Polyacrylonitrile, a resin material, and polyvinyl alcohol. Polyacrylonitrile is a synthetic polymer derived from the monomer acrylonitrile, and it is structurally composed of a linear polymer featuring repeating units of acrylonitrile monomers. This organic polymer exhibits a semicrystalline nature and is characterized by the chemical formula $[C_3H_3N]n$, with a nitrile (CN) functional group attached to its polyethylene backbone as the fundamental unit structure. The nitrile group, acting as a hydrogen bonding acceptor, possesses a large dipole moment between the electron-deficient carbon atom and the electron-rich nitrogen atom, facilitating relatively strong attractive interactions. The Polyacrylonitrile film saturable absorber, fabricated via a casting approach, was generated Q-switched laser pulses at a central wavelength of 1572.0 nm. The highest repetition rate and the lowest pulse width achieved was 66.1 kHz and 2.43 µs, respectively.

Q-switched pulse generation-based Poly(9-vinylcarbazole) saturable absorber was validated by Samsamnun *et al.,* Poly(9-vinylcarbazole) has a bandgap energy of about 3.4 eV and it has been used to investigated the nonlinear optical properties of Poly(9-vinylcarbazole) thin film fabricated by spin-coating approach. The highest pulse obtained at 1562 nm band characterizes a pulse width of 395 us at a repetition rate of 77.2 kHz.

Spider silk, with its exceptional all-encompassing characteristics, has become one of the most sought-after natural biological materials among researchers. Natural spider silk is a type of protein-based biological material produced naturally by the spider through the silk gland in its body [19,169]. Spider silk shows high transmittance and sparkles in the sunlight, prompting researchers to delve deeper into its optical transmission potential. In 2013, Huby *et al.,* proved that natural spider silk can be utilized as a sustainable and efficient optical fiber, capable of propagating light. A straight spider silk fiber was found to have an attenuation coefficient of 10.5 dB/cm in air. The propagation of light was further confirmed through various arrangements, including spider silk arranged in a loop configuration, silk submerged in a physiological liquid, and the integration of silk fiber into photonic chips via a hybridization process involving synthetic polymers (photoresist) and natural silk fibers [21].

In addition, Tow *et al.,* implemented spider dragline silk as a means to use as a chemically active optical fiber to measure ambient relative humidity levels. The proposed concept was validated by a polarimetric setup consisting of a laser, polarization controller, single-mode fiber, gas chamber with controlled temperature and humidity levels, dragline silk, and polarization analyzer. They applied a polarization analyzer to measure the phase change of the transmitted light. They have demonstrated that spider silk possesses the inherent ability to effectively direct light within a certain range of wavelengths, spanning from the visible spectrum to around 1400 nm. This light-guiding capability is accompanied by minimal signal attenuation, with propagation losses measuring below 1 dB/mm. The aforementioned characteristics enable the employment of silk as a means of transmitting light, serving as a chemically responsive protein thread that functions as a fiber-optic sensor for quantifying the level of ambient relative humidity [170,171]. Those studies describe the uses of spider silk as an efficient light guide, as biological media in an integrated photonic chip, and as an optical sensor.

5.1 The Specific Properties of Spider Silk That Make It Suitable for Use as A Saturable Absorber

Natural spider silk is featured by the composition of the protein that makes up the silk. The amino acid composition, produced by the major ampullate glands of the spider and used as the primary structural material of its web, consists predominantly of glycine (30%-40%) and alanine (20%-30 %). The glutamine content exceeds 10 %, while the proline content is about 5 %, suggesting that the silk possesses both hydrophobic and hydrophilic properties [172]. Silk protein sequences exhibit a distinctive structural characteristic in which they are arranged into two types of domain sections. The first type is a β-sheet block, consisting of small repetitive units that are typically hydrophobic and form the crystalline portion of the silk. The second type is organized in α-helices, consisting of the non-repetitive hydrophilic part of the core sequence, which constitutes the amorphous regions [173,174]. The silk is a protein thread made up of repeated arrays of polypeptides that have both separate and distinct crystalline and non-crystalline sections. These sections align along the axis of the silk. The attachment between these two sections is maintained by reversible hydrogen bonds (see Figure 7), which can be modified by various types of molecules. This property makes them well-suited for detecting modifying agents including water molecules, acids, and bases. Molecules that interact will either attach to the amino acids in the α-helical section, impacting the silk ability to elongate, or attach to the amino acids in the β-sheet blocks, altering the silk crystallinity or the orientation of the crystalline blocks. These unique conformational events result in changes in the optical characteristics of the light passing through the silk [170].

The optical abilities combined with unique biocompatibility, and tensile strength of spider silk enable its manipulation for advanced optical investigations and pave the way for its incorporation as a natural biological saturable absorber material to generate pulsed fiber laser [21,170,175–194].

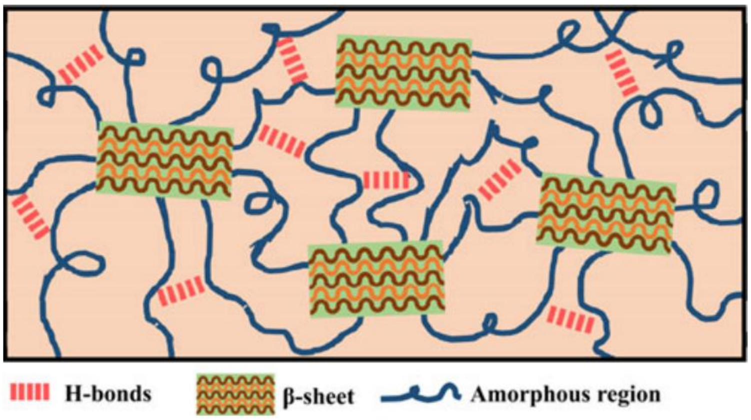


Fig. 7. This diagram illustrates the structure of silk protein, with the β-sheets (crystalline region) enclosed within the amorphous region. The crystal orientation is maintained along the silk axis by reversible hydrogen bonds (red lines) [170]

5.2 Experimental Findings

According to Muhammad *et al.,* 2024, they quantified the nonlinear absorption of spider silk saturable absorber which is evident from the fitting curve given in Figure 8 that spider silk functioning as a saturable absorber exhibits a modulation depth of 26 ± 8 % and a saturation intensity of 0.02 ± 0.01 WM/cm^2. Additionally, in the design of the Q-switched erbium-doped fiber laser, Figure 9 demonstrated that the pulse width decreased as the pump power increased, while the repetition rate concurrently increased. The maximum output power and pulse energy were 0.04 ± 0.01 mW and 1.4 ± 0.3 nJ in Figure 10, respectively. The output spectrum wavelength of 1569 ± 23 nm was determined using an optical spectrum analyzer (Yokogawa, AQ6370D), with a 2 nm resolution having a wavelength range of 600 - 1700 nm, as shown in Figure 11. The pulse characteristics were observed utilizing a InGaAs biased detector (Thorlabs, DET08CFC/ M) with a 5 GHz bandwidth connected to an oscilloscope (Tektronix, MDO3104). These observations indicated that when the pump power was set at 200 mW, the minimum pulse width recorded was 10 ± 5 µs, which occurred simultaneously with the maximum pulse repetition rate of 29 ± 6 kHz. A stable pulse train was observed across varying time scales, as illustrated in Figure 12, through the use of an oscilloscope. These experimental results demonstrate the effectiveness of spider silk as a saturable absorber which provide practical insights and validate the theoretical claims.

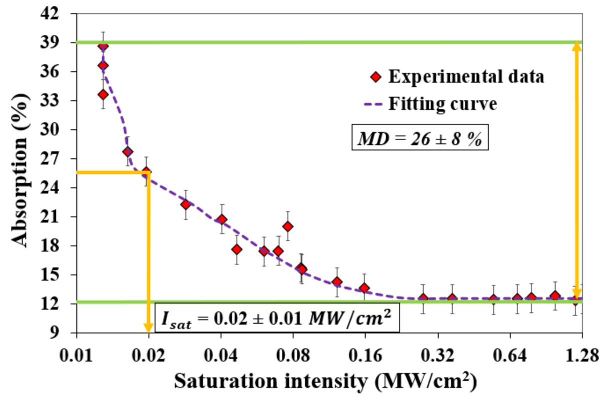


Fig. 8. The nonlinear absorption of the spider silk-based saturable absorber [195]

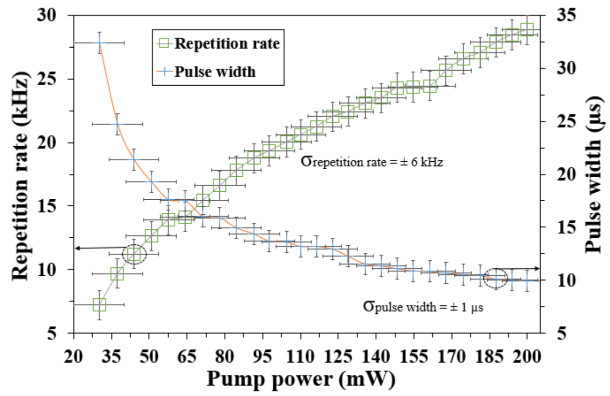


Fig. 9. Repetition rate and pulse width depends on pump power [195]

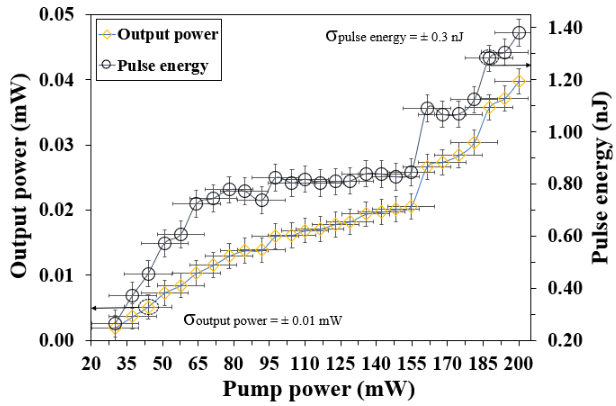


Fig. 10. Output power and pulse energy influenced by pump power [195]

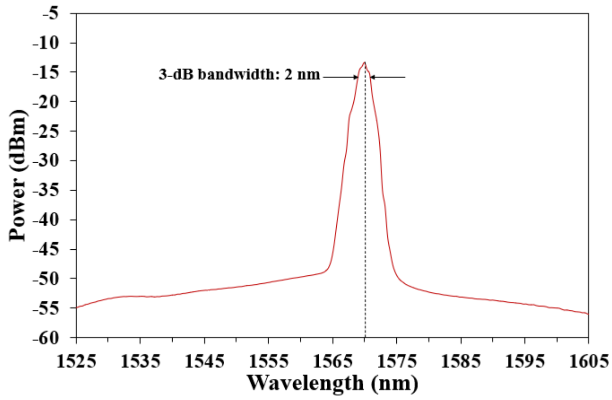


Fig. 11. The output spectrum of the Q-switched pulse fiber laser at a pump power of 200 mW with a 3-dB bandwidth of 2 nm and a central wavelength of 1569 ± 23 nm [195]

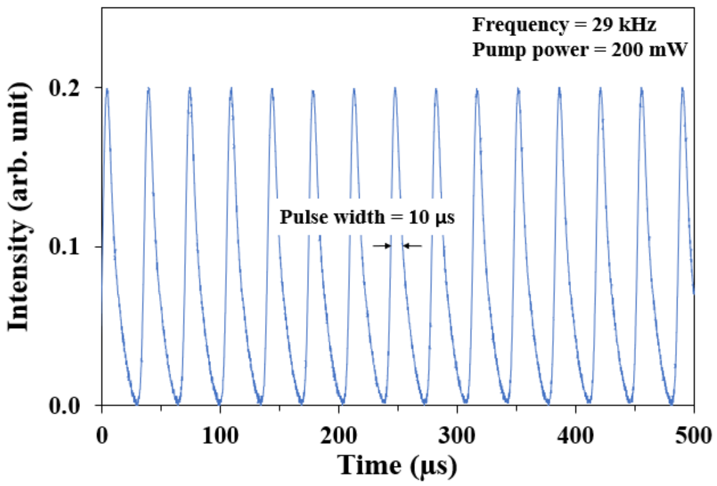


Fig. 12. A stable pulse train at the highest pump power [195]

Table 1 below shows the summarize of the results on the performance of Q-switched pulse fiber laser exploiting different organic-based saturable absorbers.

Table 1
Summarization results on the performance of Q-switched pulse fiber laser exploiting different organic-based saturable absorbers

SA category	SA material	MD (%)	Saturation intensity (MW/cm^2)	L_{EDF} (m)	PP_T (mW)	λ_C (nm)	Max. RR (kHz)	Min. PW (µs)	SNR (dB)	PE (nJ)	Ref.
Organic material (semiconductor)	Poly(3-hexylthiophene-2,5-diyl) regioregular	11	80.45	2.4	63	1562	78.63	3.79	49.72	15	[16]
Organic material	8-Hydroxyquonolino cadmium chloride hydrate (50/50 OC)	11	2	1	50	1530.49	136	2.076	81	172	[166]
Organic material	8-Hydroxyquonolino cadmium chloride hydrate (95/5 OC)	11	2	1	101	1530.49	173	1.66	75	10	[166]
Organic material	8-Hydroxyquinolino cadmium chloride hydrate	18	0.1	1	101	1530	150	726 ns	72	4.5	[196]
Organic material	Turmeric	23	0.16	2	119	1566.96	90.09	0.725	80	150.96	[167]
Organic material	Poly(3,4 ethylenedioxythiophene): poly (4-styrenesulfonate)	50	0.14	2	113	1568.03	108.69	9.2	79	192.11	[8]
Organic material (natural dye)	Lawsone (2-hydroxy-1,4-naphthoquinone)	12	3.5	2.4	26	1564	80	1.7	71	53.7	[168]
Organic material	Poly(3,4- ethylenedioxythiophene): poly(styrenesulfonate)	22	0.21	2	87	1563.3	85.91	1.97	65	155.51	[197]
Organic compound	Copper phthalocyanines	8.8	7	2.4	66.3	1532.1	77.2	3.95	55.4	49.2	[15]
Organic compound	Iron phthalocyanines	9.5	0.01	1.8	35.2	1531.3	48.6	4.34	60.28	53.6	[198]
Organic thin film	8-$HQCdCl_2H_2O$	18	0.1	1	71	1531	143	1.85	82	167	[199]
Organic polymer	Polyacrylonitrile	11.4	20	0.7	113.3	1572	66.1	2.43	52.1	52	[200]
Organic semiconductor	Poly (9-vinylcarbazole)	4	202.07	2.4	63.4	1562	91.91	3.43	51.14	8.73	[201]
Organic (natural biological)	Spider silk	26 ± 8	0.02 ± 0.01	3	30 ± 1	1569 ± 23	29 ± 6	10 ± 5	54 ± 14	1.4 ± 0.3	[195]

6. Q-Switched Pulse Fiber Laser Applications

Q-switched pulse fiber laser is versatile tools with a wide range of applications. It can be tuned to different wavelengths, which is useful as tunable laser source. It also supports dual-wavelength switching. In temperature sensing, Q-switched laser provide accurate measurements by detecting subtle changes in temperature. Additionally, it is used to detect adulteration in pure kelulut honey, offering a quick and non-invasive method to ensure its purity. These applications highlight the adaptability and precision of Q-switched pulse fiber laser, making them a focus of ongoing research and innovation.

6.1 Tunable and Switchable Dual-Wavelength
6.1.1 Wavelength tunable

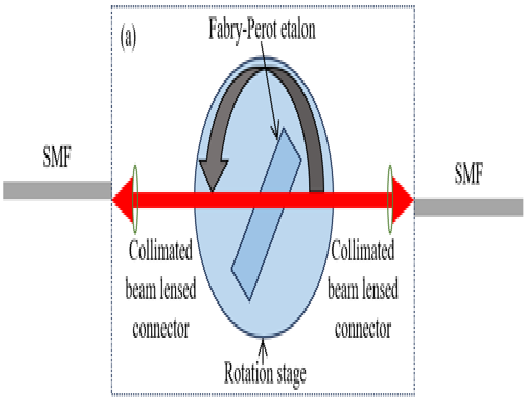
Wavelength tunable refers to the ability of a laser to adjust its output to various specific wavelengths within a certain range. This adjustment can be achieved using different tunable filters, which are frequently used to tune the wavelength of the pulsed laser. Examples include curved multimode fiber [202], fiber Bragg grating (FBG) [203], multimode interference filter [204], rotating mirrors in combination with a diffraction grating [205,206], Sagnac interferometer [207,208], tilted fiber Bragg grating [209], and tunable bandpass filter (TBF) [28,210–219]. A wavelength tunable laser is imperative in applications where the precise matching of the laser wavelength to specific absorption lines or material properties is necessary. Such lasers are extensively applied in the treatment of pigmented lesions, teeth whitening procedures, and multiphoton microscopy technology.

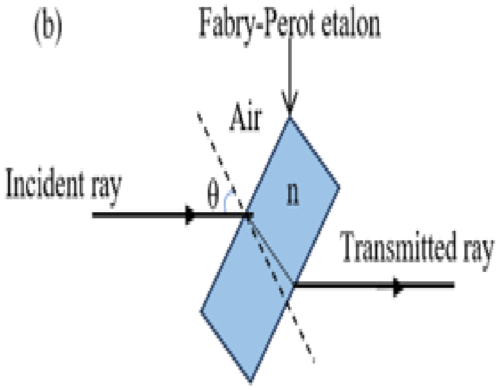
A wavelength-tunable device using TBF has been designed to possess an adjustable transmission band, enabling it to selectively transmit light within a certain range of wavelengths. The operational mechanism of the TBF has its foundation based on the Fabry-Perot interferometer, as described by Frankel *et al.,* [220]. To modify the incident angle of the beam, the wavelength must be identified according to the expression given below [220]:

$$\lambda = (\frac{2nL}{m})(\cos\theta) \quad (5)$$

The variables in the Eq. (5) are defined as follows: λ is the wavelength of interest, n represents the refractive index of the etalon, L represents the thickness of the etalon filter, m is an integer, and θ represents the angle between the incident beam and the normal axis. The model of the fiber-coupled TBF is shown in Figure 13 (a), whereas Figure 13 (b) depicts the light propagation via the Fabry-Perot etalon filter. The light beam emitted by the single-mode fiber is directed through a collimator. The light subsequently passes through a region of free space, which serves as a filter when it encounters a Fabry-Perot etalon. Before entering the second single-mode fiber, the propagating beam recombines in the second collimator. By adjusting the Fabry-Perot etalon, it is possible to change the angle at which the beam propagates, allowing for the selection of a specific wavelength. The adjustability of the TBF allows for precise tuning to select any desired wavelength within its operational range. This adjustment results in the rotation of the Fabry-Perot etalon, resulting in the desired output.

In another view, the tuning of wavelength to various specific wavelengths within a certain range is achieved with the support of a tunable bandpass filter. The operational mechanism of the tunable bandpass filter is based on the Fabry-Perot etalon, an optical device, in the experimental setup. This Fabry-Perot etalon is designed with two parallel mirrors that are partially reflective and separated by a spacer. When light enters the etalon, a portion of it is partially reflected while the rest is transmitted at each mirror. Constructive interference occurs when the optical path difference (the distance between two light paths) between the reflected beams multiple with an integer of the wavelength, leading to reinforcement and the creation of a bright fringe. Destructive interference, on the other hand, occurs when the optical path difference between the reflected beams is multiple with half of the integer wavelength, causing the waves to cancel out and resulting in a dark fringe. Next, the desired wavelength is selected by adjusting the spacer thickness (distance), which is designed to be adjustable. Adjusting this spacer thickness changes the interference, thereby producing the desired wavelength output. Overall, the measurement of the resulting tunable wavelength is caused by the light transmitting through the etalon, which produces interference fringes. By analyzing these fringes, the desired output of a wavelength-tunable Q-switched pulse erbium-doped fiber laser is achieved.





(a) (b)

Fig. 13. (a) The model of fiber-coupled tunable bandpass filter; (b) The propagation of light via the Fabry-Perot etalon filter

6.1.2 Switchable dual-wavelength

Switchable dual-wavelength refers to the ability to rapidly and discretely adjust the laser emission from one fixed wavelength to another dominant wavelength. This feature is beneficial in applications where swift switching between different wavelengths is demanded, such as in modern communication networks, including terahertz signals [221]. It facilitates the effective and adaptable administration of optical signals, particularly in situations where multiple channels must be accessed consecutively for data transmission or processing.

To obtain switchable dual-wavelength operation, the polarization controller is required to manipulate the polarization state of light, impacting the Q-switched operation with two fiber Bragg gratings [222]. This assists in generating dual-wavelength pulses by reflecting different wavelengths. A fiber Bragg grating operates as a wavelength-selective mirror, carefully structured with distinct grating periods that align with the targeted wavelengths at which they reflect light [223,224]. The fiber Bragg grating's design parameters, such as the period and amplitude of the refractive index variation, determine the specific wavelength that the grating reflects. When light travels through an optical fiber, the fiber Bragg grating causes the reflection of the Bragg wavelength, leading to a distinct reflection peak at that specific wavelength while transmitting all others.

6.2 Sensor Applications

The pulse generated remains stable due to the gain and modulated loss of the saturable absorber. At the same time, the pulse can detect external stimuli, such as changes in temperature or the presence of adulterants in honey solutions, making it function as an optical sensor. This can be achieved by integrating sensing elements like side-polished fiber or fiber Bragg grating within the cavity.

6.2.1 Sensing element
6.2.1.1 Side-polished fiber

The investigation of side-polished fiber (SPF) has spanned four decades since its initial development by Bergh *et al.,* in 1980 [225]. Side-polished fiber provides a flexible and adaptable framework for developing optical fiber devices and sensors. It exhibits dependable mechanical features and effective immunity to electromagnetic interference, making it suitable for various applications, including temperature sensing [226]. Figure 14 portrays the structure of side-polished fiber, which comprises three distinct segments: the lead-in and lead-out optical fiber (the transitional area), and the flat area. During the fabrication of side-polished fiber, it is necessary to remove a portion of the cladding through polishing. The distance between the polished surface and the core is typically on the order of a few microns, so the evanescent field of the light propagating through the fiber will escape or leak from this polished region [227]. The flat area is in the middle of the polished region, situated between the two transition regions. The residual thickness refers to the measurement of the distance between the polished surface and the bottom surface of the fiber. This parameter identifies the interaction strength between the transmitted light in the side-polished fiber and the surrounding media [228].

Side-polished fiber is prevalently used as a sensing device to detect temperature variation. As mentioned earlier, the surface of the side-polished fiber is partially polished in the centre area to facilitate the propagation of light. The polished region acts as a sensing area, confining light within the core due to the high refractive index of the core. However, when the side-polished fiber is immersed in hot water, for example, a portion of light leaks from the core to the cladding or surrounding medium. The outcome of this process leads to the formation of an evanescent wave [229]. An evanescent wave is a near-field electromagnetic wave that exhibits an exponential decay as it propagates into a medium [226]. It is a unique characteristic of wave propagation that occurs when a wave, such as light, moves from a medium with a higher refractive index to one with a lower refractive index. This occurs when the angle of incidence surpasses the critical angle [230]. When this happens, instead of being transmitted over the interface, a fraction of the wave's energy is preserved and propagates along the interface in the form of an evanescent wave. The evanescent wave undergoes interaction with the external medium, and variations in the surrounding environment, such as fluctuations in temperature due to immersion in hot water, can affect this interaction [231]. The changes in the properties of the evanescent wave due to temperature changes can be identified and measured such as monitoring the wavelength or radio frequency change of the light that is transmitted through the fiber.

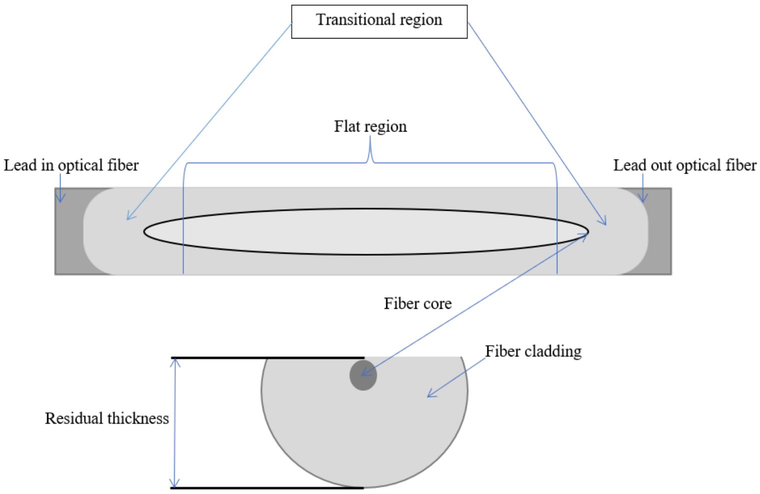


Fig. 14. The polished area's cross-section and top view of the side-polished fiber

6.2.1.2 Fiber Bragg grating

A fiber Bragg grating is a type of fiber optic component that incorporates a distributed Bragg reflector within a tiny section of the fiber core. This section is manufactured and incorporated within the optical fiber using an ultraviolet lithography technique. It is designed to selectively reflect a particular range of wavelengths associated with the guided modes while allowing the transmission of all other wavelengths. Figure 15 portrays the basic structural arrangement of fiber Bragg grating, which is manufactured with a periodically uniform grating structure. This grating constitutes the core of the optical fiber, characterized by refractive index variation with constant segments from one grating to another. These gratings are recognized as fundamental components in the manufacture of most Bragg grating structures, which periodically modulate the phase or intensity of a light wave that is reflected or transmitted by them [232–235].

Fiber Bragg grating works based on constructive interference, meaning that as the incident light travels along the fiber Bragg grating and matches with the Bragg condition (twice the grating spacing multiplied by the effective refractive index of the core), a portion of the incident light will undergo reflection. However, due to destructive interference (when the incident light travelling along the fiber Bragg grating does not match the Bragg condition), the light continues to be transmitted along the fiber. The incident wavelength that satisfies the Bragg condition, or the Bragg wavelength, is denoted as λ_B. The effective refractive index of the mode propagating in the fiber is denoted as n_{eff}, and the grating period, Λ has an impact on the Bragg wavelength. The wavelength at which a significant reflection will occur is determined by Eq. (6), [236]. The reflection of light can be attributed to changes in refractive index, which can be comprehended through a physical perspective. If the reflections from points that are spaced apart by a spatial period are in phase, then the cumulative reflections combine coherently to produce a robust reflection. Eq. (6) indicates that any change in the physical or mechanical properties of the grating region has an impact on the reflected wavelength, λ_B. The Bragg wavelength experiences a shift due to perturbations of the external medium that surrounds the fiber.

$$\lambda_B = 2\Lambda n_{eff} \tag{6}$$

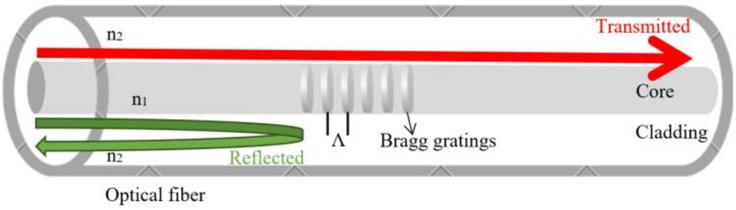


Fig. 15. The basic structure of fiber Bragg grating [237]

6.2.2 Temperature Sensor

Temperature monitoring is prominent in several industries such as the aerospace domain, metallurgical sector, medical profession, and nuclear energy generation [238,239]. The implementation of temperature monitoring inside the turbines and combustion chambers of an aircraft or aero-engine can contribute to the prolongation of its operational lifespan [240–242]. On the contrary, monitoring the interior temperature of high-temperature boilers in the metallurgical industry is critical for accurately assessing the combustion rate and ensuring safety measures are in place [243,244]. In recent times, there has been a significant surge in attention given to temperature monitoring instruments within the medical sector. This heightened interest is mostly attributed to the emergence of COVID-19, which has necessitated the constant monitoring of individuals' temperatures in public areas [245,246].

Fiber temperature sensors have the flexibility to endure challenging conditions of higher temperatures and pressures, as well as the potential to perform distributed remote measurements [247]. They are also beneficial in terms of compact size and immunity to electromagnetic interference [248]. Temperature sensing often depends on either the wavelength shift or radio frequency shift of the transmission spectrum or the fluctuation of transmitted power. To date, different techniques have been employed for temperature sensing, encompassing standard fiber types such as single-mode fiber and multi-mode fiber [249], photonic crystal fiber [250], fibers based on gratings structure such as fiber Bragg grating [251], long-period grating, and tilted fiber Bragg grating [252], Fabry-Perot interferometer fiber [253], as well as side-polished fiber [254]. In comparison to alternative fiber optics for sensor measurement, grating-based and side-polished fiber as the sensing element exhibit advantages such as excellent linearity and stable operation. Consequently, these sensors have found extensive use in commercial applications. Muhammad *et al.,* (2024) proposed and demonstrated temperature sensing device incorporating side-polished fiber and fiber Bragg grating as the sensing element within the passively Q-switched pulse fiber laser source [255]. The structure converts the continuous wave generated by a self-constructed erbium-doped fiber ring cavity with a spider silk saturable absorber into a pulsed laser of Q-switched. The Q-switched laser shows good characteristics, including a high damage threshold and resistance to oxidization, deformation, or environmental factors. The side-polished fiber and fiber Bragg grating temperature sensing area are inserted into the ring cavity, whose characteristics are experimentally investigated by monitoring the oscilloscope trace of the pulse train and radio frequency shifts, as well as assessing the stability, sensitivity, and linearity of the device.

6.2.3 Detection of Adulteration in Pure Kelulut Honey

Pure kelulut honey is highly valued in Malaysia as a versatile health supplement. Numerous claims are associated with it, including its potential as an antibacterial agent, antidiabetic compound, anti-inflammatory substance, antioxidant, and antitumor agent. These observed effects are due to the numerous bioactive constituents, which include acids, flavonoids, minerals, and phenolics [256–260].

In addition, the presence of trehalulose has been discovered in kelulut honey, which is widely distributed in kelulut bee farms in Malaysia. Trehalulose, an infrequent disaccharide, is an isomer of sucrose that has a lower glycemic index [261]. These facts support the traditional claim that kelulut honey is suitable for consumption by diabetics, as it has the potential to help lower blood glucose levels [262].

The constituents of pure kelulut honey include minerals, proteins, natural sugars, and water [263] However, in order to profit through unethical means, the purity of honey is compromised by adding various cheaper ingredients such as beetroot sugar, cane sugar, or other sugar derivatives such as high fructose corn syrup, high fructose inulin syrup, or invert sugar syrup [264–268]. These compounds alter the biochemical properties and flavour of honey and have a negative impact on its nutritional composition, which in turn affects human health negatively [269–271].

In response to the growing need for robust methods to detect adulteration in pure honey, researchers have been working intensively on this aspect [272–274]. A variety of techniques have been developed to detect adulteration in pure honey. These include Fourier transform infrared spectroscopy [275], Fourier transforms Raman spectroscopy [276], gas chromatography [277], liquid chromatography [278,279], liquid chromatography coupled with isotope ratio mass spectrometry [280], near-infrared spectroscopy [281–283], nuclear magnetic resonance spectroscopy [284], stable carbon isotope ratio mass spectrometry [285,286], and thermal analysis [287]. Despite their effectiveness, these methods require specialized laboratory equipment and labour-intensive sample preparation, time-consuming procedures, and incur significant costs [288]. Therefore, it is imperative to develop and implement a robust method for the detection of adulteration in pure honey that not only ensures the quality, safety, and reliability of pure honey but is also stable and easy to use.

The application of fiber optic structures has been extensively researched for detecting various adulterants and contaminants in food. They represent a compelling alternative to other methods that address the challenges [289–291]. Techniques such as fiber Bragg grating [292], lossy resonance [293,294], and surface plasmon resonance have been investigated [295].

In 2024, Muhammad *et al.* presents the development of pulse fiber laser sensor structure for the detection of adulteration in pure kelulut honey using fiber Bragg grating technology as the sensing element [237]. The sensor is based on a Q-switched pulse erbium-doped fiber laser and uses spider silk as the base material. The functionality of the proposed sensor is based on the principles of Bragg grating fiber, wherein the Bragg wavelength is determined by the grating period and the effective refractive index of the fiber. Changes in the concentration of the adulterated analyte result in changes in the composition of the solution, leading to a shift in the refractive index of the adulteration solution [296,297]. Variations in the refractive index of the adulteration solution affect the overall effective refractive index, producing a response in the form of a resonance shift in the fiber Bragg grating curve. The resonance shift is influenced by different frequencies associated with the different optical wavelengths, altering the resonance angle and half-width of the fiber Bragg grating. This intricate interplay between the optical parameters enables a detailed understanding of the sensor's response to changes in adulterant concentrations in kelulut honey solutions, ranging from 0 % to 50 %. This dual mathematical and optical analysis greatly improves the precision and sensitivity of the proposed pulse fiber sensor, making it a valuable tool for detecting subtle changes in complex solutions.

7. Limitations

The use of spider silk as a saturable absorber brings intriguing possibilities, but it is not without limitations. One significant issue is related to material sourcing. Natural spider silk is difficult to obtain in large quantities due to spiders' territorial and cannibalistic nature, making large-scale production impractical. Although synthetic production methods, such as genetic engineering in bacteria or plants, offer promise, ensuring scalability and uniformity remains a challenge. Additionally, integration challenges further complicate the use of spider silk as a saturable absorber. Its delicate and fibrous nature makes handling and incorporation into optical systems more complex, often requiring additional treatments to ensure compatibility and durability. These extra steps can increase production costs and complicate the manufacturing process. These challenges highlight the need for further research and development to address the limitations of spider silk and enhance its potential as a viable saturable absorber.

8. Conclusions

In conclusion, we were driven by the need for novel solutions in the realm of Q-switched pulse fiber laser applications. Traditional approaches often rely on saturable absorbers of synthetic origin or inorganic material, presenting limitation in terms of environmental impact. The exploration of organic-based saturable absorber such as spider silk stemmed from its unique properties, including its biocompatibility, potential for cost-effective material without compromising the pulse fiber laser generation, and interestingly, it has been proved that this spider silk served as photon carriers and light guiding with transmission losses of a few dB/cm. Recognizing these attributes, researcher were inspired to investigate its viability within the context of Q-switched pulse fiber lasers, aiming to not only advance the field of photonics but also contribute to environmentally friendly and sustainable technologies. This motivation guided our research endeavours, propelling us to explore innovative avenues in the use of saturable absorber material for Q-switched pulse fiber laser development.

Acknowledgement
This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Research Enhancement Graduate Grant (RE-GG) (UTHM/PS/500-19/7/4) (grant number, Q058).

References
[1] McClung, Fred J., and Robert W. Hellwarth. "Giant optical pulsations from ruby." *Applied Optics* 1, no. 101 (1962): 103-105.https://doi.org/10.1364/AO.1.S1.000103
[2] Haus, Hermann A. "Theory of mode locking with a fast saturable absorber." *Journal of Applied Physics* 46, no. 7 (1975): 3049-3058. https://doi.org/10.1063/1.321997
[3] Haus, Hermann. "Theory of mode locking with a slow saturable absorber." IEEE Journal of Quantum Electronics 11, no. 9 (1975): 736-746. https://doi.org/10.1109/JQE.1975.1068922
[4] Haus, H. "A theory of forced mode locking." *IEEE Journal of Quantum Electronics* 11, no. 7 (1975): 323-330. https://doi.org/10.1109/JQE.1975.1068636
[5] Liu, Xueming, Yudong Cui, Dongdong Han, Xiankun Yao, and Zhipei Sun. "Distributed ultrafast fibre laser." *Scientific reports* 5, no. 1 (2015): 9101. https://doi.org/10.1038/srep09101
[6] Paiva, Joana S., Pedro AS Jorge, Carla C. Rosa, and João PS Cunha. "Optical fiber tips for biological applications: from light confinement, biosensing to bioparticles manipulation." *Biochimica et Biophysica Acta (BBA)-General Subjects* 1862, no. 5 (2018): 1209-1246. https://doi.org/10.1016/j.bbagen.2018.02.008
[7] Muhammad, Nur Ainnaa Mardhiah, Noor Azura Awang, and Hatijah Basri. "Recent advancements review in zinc oxide and titanium dioxide saturable absorber for ultrafast pulsed fiber laser." *Optik* 283 (2023): 170855. https://doi.org/10.1016/j.ijleo.2023.170855
[8] Al-Hiti, Ahmed Shakir, Retna Apsari, Moh Yasin, and Sulaiman Wadi Harun. "Nanosecond Q-switched pulse generation using poly (3, 4 ethylenedioxythiophene): Poly (4-styrenesulfonate) thin film as saturable absorber." *Infrared Physics & Technology* 116 (2021): 103788.. https://doi.org/10.1016/j.infrared.2021.103788
[9] Zulkipli, Nur Farhanah, Afiq Arif Aminuddin Jafry, Retna Apsari, Farina Saffa Mohamad Samsamnun, Malathy Batumalay, M. I. M. A. Khudus, Hamzah Arof, and Sulaiman Wadi Harun. "Generation of Q-switched and mode-locked pulses with Eu2O3 saturable absorber." *Optics & laser technology* 127 (2020): 106163. https://doi.org/10.1016/j.optlastec.2020.106163

[10] Chen, Yu, Guobao Jiang, Shuqing Chen, Zhinan Guo, Xuefeng Yu, Chujun Zhao, Han Zhang et al. "Mechanically exfoliated black phosphorus as a new saturable absorber for both Q-switching and mode-locking laser operation." *Optics express* 23, no. 10 (2015): 12823-12833. https://doi.org/10.1364/OE.23.012823

[11] Zhang, Liying, and Fang Wang. "Stannic oxide saturable absorbers for generating Q-switched erbium-doped fiber lasers." *Optical Fiber Technology* 80 (2023): 103469. https://doi.org/10.1016/j.yofte.2023.103469

[12] Najm, M. M., B. Nizamani, P. Zhang, H. Arof, A. S. Al-Hiti, A. H. A. Rosol, M. C. Paul, M. Yasin, and S. W. Harun. "Chromium aluminum carbide as Q-switcher for the near-infrared erbium-doped fiber laser." *Optik* 250 (2022): 168362. https://doi.org/10.1016/j.ijleo.2021.168362

[13] Li, Lu, Jiawei Cheng, Qiyi Zhao, Jinniu Zhang, Huiran Yang, Yaming Zhang, Zhanqiang Hui, Feng Zhao, and Wenjun Liu. "Chromium oxide film for Q-switched and mode-locked pulse generation." *Optics Express* 31, no. 10 (2023): 16872-16881. https://doi.org/10.1364/OE.491792

[14] Latiff, A. A., N. A. Kadir, E. I. Ismail, H. Shamsuddin, H. Ahmad, and S. W. Harun. "All-fiber dual-wavelength Q-switched and mode-locked EDFL by SMF-THDF-SMF structure as a saturable absorber." *Optics Communications* 389 (2017): 29-34. https://doi.org/10.1016/j.optcom.2016.12.011

[15] Wadi, Nurul Izzah S., Rosmalini Ab Kadir, Zulzilawati Jusoh, Norizan Ahmed, Muhammad Imran MA Khudus, and Sameer Salam. "Q-switched EDFL with copper phthalocyanines saturable absorber." *Optik* 296 (2024): 171547. https://doi.org/10.1016/j.ijleo.2023.171547

[16] Samsamnun, Farina Saffa Mohamad, Nur Farhanah Zulkipli, Mohd Arif Mohd Sarjidan, Sulaiman Wadi Harun, W. H. A. Majid, Muhammad Imran Mustafa Abdul Khudus, Ahmad Shuhaimi et al. "Poly (3-hexylthiophene-2, 5-diyl) regioregular (P3HT) thin film as saturable absorber for passively Q-switched and mode-locked erbium-doped fiber laser." *Optical fiber technology* 54 (2020): 102073. https://doi.org/10.1016/j.yofte.2019.102073

[17] Shakaty, Aseel A., Jassim K. Hmood, Bushra R. Mahdi, R. I. Mahdi, and Alabbas A. Al-Azzawi. "Q-switched erbium-doped fiber laser based on nanodiamond saturable absorber." *Optics & Laser Technology* 146 (2022): 107569. https://doi.org/10.1016/j.optlastec.2021.107569

[18] Nel, Andre, Tian Xia, Lutz Madler, and Ning Li. "Toxic potential of materials at the nanolevel." *science* 311, no. 5761 (2006): 622-627. https://doi.org/10.1126/science.1114397

[19] Kiseleva, Aleksandra P., Pavel V. Krivoshapkin, and Elena F. Krivoshapkina. "Recent advances in development of functional spider silk-based hybrid materials." *Frontiers in Chemistry* 8 (2020): 554. https://doi.org/10.3389/fchem.2020.00554

[20] Tow, Kenny Hey, Desmond M. Chow, Fritz Vollrath, Isabelle Dicaire, Tom Gheysens, and Luc Thévenaz. "Spider silk: a novel optical fibre for biochemical sensing." In *24th International Conference on Optical Fibre Sensors*, vol. 9634, pp. 988-991. SPIE, 2015. https://doi.org/10.1117/12.2192427

[21] Huby, Nolwenn, Véronique Vié, Anne Renault, Sylvie Beaufils, Thierry Lefèvre, François Paquet-Mercier, Michel Pézolet, and Bruno Bêche. "Native spider silk as a biological optical fiber." *Applied Physics Letters* 102, no. 12 (2013). https://doi.org/10.1063/1.4798552

[22] Chow, Desmond M., Kenny Hey Tow, Fritz Vollrath, Isabelle Dicaire, Tom Gheysens, and Luc Thévenaz. "Shedding light on the optical properties of spider silk fiber." In *2015 IEEE Photonics Conference (IPC)*, pp. 333-334. IEEE, 2015. https://doi.org/10.1109/IPCon.2015.7323526

[23] Kashiwagi, Ken, and Shinji Yamashita. "Optical deposition of carbon nanotubes for fiber-based device fabrication." *Frontiers in Guided Wave Optics and Optoelectronics* 647 (2010). https://doi.org/10.5772/39546

[24] Wang, Frank, A. G. Rozhin, V. Scardaci, Z. Sun, F. Hennrich, I. H. White, William I. Milne, and Andrea C. Ferrari. "Wideband-tuneable, nanotube mode-locked, fibre laser." *Nature nanotechnology* 3, no. 12 (2008): 738-742. https://doi.org/10.1038/nnano.2008.312

[25] Xing, Guichuan, Hongchen Guo, Xinhai Zhang, Tze Chien Sum, and Cheng Hon Alfred Huan. "The physics of ultrafast saturable absorption in graphene." Optics express 18, no. 5 (2010): 4564-4573. https://doi.org/10.1364/OE.18.004564

[26] Zalkepali, N. U. H. H., N. A. Awang, B. K. Ghosh, K. A. Mohamad, A. Alias, N. N. H. E. N. Mahmud, A. Z. M. Zamri, and N. A. M. Muhammad. "Tunable performance of indium tin oxide-zinc oxide as Q-switcher." *Optik* 281 (2023): 170852. https://doi.org/10.1016/j.ijleo.2023.170852

[27] Jafry, A. A. A., G. Krishnan, N. Kasim, N. F. Zulkipli, F. S. M. Samsamnun, R. Apsari, et al. "MXene $Ti_3C_2T_x$ as a Passive Q-Switcher for Erbium-Doped Fiber Laser." *Optical Fiber Technology* 58 (2020): 102289. https://doi.org/10.1016/j.yofte.2020.102289

[28] Rizman, Z. I., M. F. M. Rusdi, M. Yasin, P. Yupapin, and S. W. Harun. "Q-Switched Tunable Fiber Laser Utilizing Silver Nanoparticles Deposited onto PVA Film as Saturable Absorber." *Indian Journal of Physics* 95 (2021): 141–45. https://doi.org/10.1007/s12648-019-01675-5

[29] Ahmad, H., S. A. Reduan, S. N. Aidit, N. Yusoff, M. J. Maah, M. F. Ismail, et al. "Ternary $MoWSe_2$ Alloy Saturable Absorber for Passively Q-Switched Yb-, Er-, and Tm-Doped Fiber Laser." *Optics Communications* 437 (2019): 355–62. https://doi.org/10.1016/j.optcom.2019.01.009

[30] Mahmud, N. N. H. E. N., N. A. Awang, N. U. H. H. Zalkepali, A. A. Latif, N. A. M. Muhammad, and A. Z. M. Zamri. "The Influence of Au-NP Thickness Coated on Side-Polished Fiber on the Properties of Mode-Locked Erbium-Doped Fiber Laser." *Infrared Physics & Technology* 130 (2023): 104616. https://doi.org/10.1016/j.infrared.2023.104616

[31] Xu, N., and Q. Wen. "Single Element Material Sulfur Quantum Dots Nonlinear Optics and Ultrafast Photonic Applications." *Optics & Laser Technology* 138 (2021): 106858. https://doi.org/10.1016/j.optlastec.2020.106858

[32] Liu, Shunxiang, Jinsheng Lu, Hongfu Huang, Ning Xu, Junle Qu, and Qiao Wen. "Ultrafast photonics applications based on evanescent field interactions with 2D molybdenum carbide (Mo 2 C)." *Journal of Materials Chemistry C* 9, no. 19 (2021): 6187-6192. https://doi.org/10.1039/D1TC00628B

[33] Herda, Robert, Oleg G. Okhotnikov, Edik U. Rafailov, Wilson Sibbett, Paul Crittenden, and Andrei Starodumov. "Semiconductor quantum-dot saturable absorber mode-locked fiber laser." *IEEE Photonics Technology Letters* 18, no. 1 (2005): 157-159. https://doi.org/10.1109/LPT.2005.860376

[34] Rozhin, Aleksey G., Youichi Sakakibara, Shu Namiki, Madoka Tokumoto, Hiromichi Kataura, and Yohji Achiba. "Sub-200-fs pulsed erbium-doped fiber laser using a carbon nanotube-polyvinylalcohol mode locker." *Applied physics letters* 88, no. 5 (2006).. https://doi.org/10.1063/1.2172398

[35] Going, R., D. Popa, F. Torrisi, Z. Sun, T. Hasan, F. Wang, and A. C. Ferrari. "500 fs wideband tunable fiber laser mode-locked by nanotubes." *Physica E: Low-Dimensional Systems and Nanostructures* 44, no. 6 (2012): 1078-1081. https://doi.org/10.1016/j.physe.2012.01.014

[36] Bao, Q., H. Zhang, Z. Ni, Y. Wang, L. Polavarapu, Z. Shen, et al. "Monolayer Graphene as a Saturable Absorber in a Mode-Locked Laser." *Nano Research* 4 (2011): 297–307. https://doi.org/10.1007/s12274-010-0082-9

[37] Zulkifli, A. Z. "Fabrication and Characterisation of Graphene Oxide Saturable Absorber for Q-Switched Fiber Laser Generation." PhD diss., Universiti Malaya, 2015.

[38] Bao, Q., H. Zhang, Y. Wang, Z. Ni, Y. Yan, Z. X. Shen, et al. "Atomic-Layer Graphene as a Saturable Absorber for Ultrafast Pulsed Lasers." *Advanced Functional Materials* 19 (2009): 3077–83. https://doi.org/10.1002/adfm.200901007

[39] Luo, Z., Y. Li, M. Zhong, Y. Huang, X. Wan, J. Peng, et al. "Nonlinear Optical Absorption of Few-Layer Molybdenum Diselenide ($MoSe_2$) for Passively Mode-Locked Soliton Fiber Laser." *Photonics Research* 3, no. A79 (2015): A79. https://doi.org/10.1364/PRJ.3.000A79

[40] Ismail, M. A., F. Ahmad, S. W. Harun, H. Arof, and H. Ahmad. "A Q-Switched Erbium-Doped Fiber Laser with a Graphene Saturable Absorber." *Laser Physics Letters* 10 (2013): 025102. https://doi.org/10.1088/1612-2011/10/2/025102

[41] Kasim, N., C. L. Anyi, H. Haris, F. Ahmad, N. M. Ali, H. Ahmad, et al. "Q-Switched Erbium-Doped Fiber Laser Using Multi-Layer Graphene-Based Saturable Absorber." *Journal of Nonlinear Optical Physics and Materials* 23 (2014): 1–8. https://doi.org/10.1142/S021886351450009X

[42] Yuzaile, Y. R., N. A. Awang, Z. Zakaria, N. U. H. H. Zalkepali, A. A. Latif, A. N. Azmi, et al. "Graphite Saturable Absorber for Q-Switched Fiber Laser." *International Journal of Engineering & Technology* 7 (2018): 334. https://doi.org/10.14419/ijet.v7i4.30.22303

[43] Peng, X., and Y. Yan. "Graphene Saturable Absorbers Applications in Fiber Lasers." *Journal of the European Optical Society-Rapid Publications* 17 (2021). https://doi.org/10.1186/s41476-021-00163-w

[44] Rosdin, R. Z. R. R., N. M. Ali, S. W. Harun, F. Ahmad, and H. Arof. "Q-Switched Er-Doped Fiber Laser with Low Pumping Threshold Using Graphene Saturable Absorber." *Chinese Optics Letters* 12, no. 9 (2014): 091404. https://doi.org/10.3788/COL201412.091404

[45] Jasni, N. A. H., S. N. F. Zuikafly, F. Ahmad, M. Abdullah, W. M. F. W. Nawawi, and H. Yahaya. "Graphene-Based Saturable Absorber for Passive Q-Switching Erbium-Doped Fiber Laser." *IEEE International Conference on Semiconductor Electronics Proceedings (ICSE)* (2020): 124–27. https://doi.org/10.1109/ICSE49846.2020.9166857

[46] Meng, Y., Y. Li, Y. Xu, and F. Wang. "Carbon Nanotube Mode-Locked Thulium Fiber Laser with 200 nm Tuning Range." *Scientific Reports* 7 (2017): 1–7. https://doi.org/10.1038/srep45109

[47] Li, Jianfeng, Hongyu Luo, Bo Zhai, Rongguo Lu, Zhinan Guo, Han Zhang, and Yong Liu. "Black phosphorus: a two-dimension saturable absorption material for mid-infrared Q-switched and mode-locked fiber lasers." *Scientific reports* 6, no. 1 (2016): 30361. https://doi.org/10.1038/srep30361

[48] Chen, Jin-Hui, Bi-Cai Zheng, Guang-Hao Shao, Shi-Jun Ge, Fei Xu, and Yan-Qing Lu. "An all-optical modulator based on a stereo graphene–microfiber structure." *Light: Science & Applications* 4, no. 12 (2015): e360-e360. https://doi.org/10.1038/lsa.2015.133

[49] Lin, Yuan-Yao, Peng Lee, Jin-Long Xu, Chung-Lun Wu, Che-Min Chou, Chao-Yang Tu, Mitch MC Chou, and Chao-Kuei Lee. "High-pulse-energy topological insulator Bi 2 Te 3-based passive Q-switched solid-state laser." *IEEE Photonics Journal* 8, no. 4 (2016): 1-10. https://doi.org/10.1109/JPHOT.2016.2581490
[50] Azooz, S. M., M. H. M. Ahmed, F. Ahmad, B. A. Hamida, S. Khan, and H. Ahmad. "Passively Q-Switched Fiber Lasers Using a Multi-Walled Carbon Nanotube Polymer Composite-Based Saturable Absorber." *Optik (Stuttgart)* 126 (2015): 2950–54. https://doi.org/10.1016/j.ijleo.2015.07.065
[51] Zhang, F., S. Han, Y. Liu, Z. Wang, and X. Xu. "Dependence of the Saturable Absorption of Graphene upon Excitation Photon Energy." *Applied Physics Letters* 106 (2015): 1–6. https://doi.org/10.1063/1.4913607
[52] Mohd Yusoff, N., C. A. C. Abdullah, M. A. W. Abdul Hadi, E. K. Ng, H. K. Lee, N. H. Zainol Abidin, et al. "Low Threshold Q-Switched Fiber Laser Incorporating Titanium Dioxide Saturable Absorber from Waste Material." *Optik (Stuttgart)* 218 (2020): 164998. https://doi.org/10.1016/j.ijleo.2020.164998
[53] Peng, Kaung-Jay, Yung-Hsiang Lin, Chung-Lun Wu, Sheng-Fong Lin, Chun-Yu Yang, Shih-Meng Lin, Din-Ping Tsai, and Gong-Ru Lin. "Dissolution-and-reduction CVD synthesis of few-layer graphene on ultra-thin nickel film lifted off for mode-locking fiber lasers." *Scientific Reports* 5, no. 1 (2015): 13689. https://doi.org/10.1038/srep13689
[54] Hsieh, David, Dong Qian, Lewis Wray, Yiman Xia, Yew San Hor, Robert Joseph Cava, and M. Zahid Hasan. "A topological Dirac insulator in a quantum spin Hall phase." *Nature* 452, no. 7190 (2008): 970-974. https://doi.org/10.1038/nature06843
[55] Price, H., Y. Chong, A. Khanikaev, H. Schomerus, L. J. Maczewsky, M. Kremer, et al. "Roadmap on Topological Photonics." *Journal of Physics: Photonics* 4, no. 3 (2022): 032501. https://doi.org/10.1088/2515-7647/ac4ee4
[56] Rider, M. S., S. J. Palmer, S. R. Pocock, X. Xiao, P. Arroyo Huidobro, and V. Giannini. "A Perspective on Topological Nanophotonics: Current Status and Future Challenges." *Journal of Applied Physics* 125, no. 12 (2019): 120901. https://doi.org/10.1063/1.5086433
[57] Blanco-Redondo, A. "Topological Nanophotonics: Toward Robust Quantum Circuits." *Proceedings of the IEEE* 108, no. 5 (2020): 837–849. https://doi.org/10.1109/JPROC.2019.2939987
[58] Wang, X., W. Zhao, H. Zhang, S. Elshahat, and C. Lu. "Magnetic-Optic Effect-Based Topological State: Realization and Application." *Frontiers in Materials* 8 (2022): 588. https://doi.org/10.3389/fmats.2021.816877
[59] Segev, Mordechai, and Miguel A. Bandres. "Topological photonics: Where do we go from here?." *Nanophotonics* 10, no. 1 (2020): 425-434. https://doi.org/10.1515/nanoph-2020-0441
[60] Yan, Qiuchen, Xiaoyong Hu, Yulan Fu, Cuicui Lu, Chongxiao Fan, Qihang Liu, Xilin Feng, Quan Sun, and Qihuang Gong. "Quantum topological photonics." *Advanced Optical Materials* 9, no. 15 (2021): 2001739. https://doi.org/10.1002/adom.202001739
[61] Smirnova, D., D. Leykam, Y. Chong, and Y. Kivshar. "Nonlinear Topological Photonics." *Applied Physics Reviews* 7, no. 2 (2020): 021306. https://doi.org/10.1063/1.5142397
[62] Wu, Y., C. Li, X. Hu, Y. Ao, Y. Zhao, and Q. Gong. "Applications of Topological Photonics in Integrated Photonic Devices." *Advanced Optical Materials* 5, no. 17 (2017): 1700357. https://doi.org/10.1002/adom.201700357
[63] Ota, Yasutomo, Kenta Takata, Tomoki Ozawa, Alberto Amo, Zhetao Jia, Boubacar Kante, Masaya Notomi, Yasuhiko Arakawa, and Satoshi Iwamoto. "Active topological photonics." *Nanophotonics* 9, no. 3 (2020): 547-567.https://doi.org/10.1515/nanoph-2019-0376
[64] Ozawa, Tomoki, Hannah M. Price, Alberto Amo, Nathan Goldman, Mohammad Hafezi, Ling Lu, Mikael C. Rechtsman et al. "Topological photonics." *Reviews of Modern Physics* 91, no. 1 (2019): 015006. https://doi.org/10.1103/RevModPhys.91.015006
[65] Khanikaev, A. B., and G. Shvets. "Two-Dimensional Topological Photonics." *Nature Photonics* 11, no. 12 (2017): 763–773. https://doi.org/10.1038/s41566-017-0048-5
[66] Lu, L., J. D. Joannopoulos, and M. Soljačić. "Topological Photonics." *Nature Photonics* 8, no. 11 (2014): 821–829. https://doi.org/10.1038/nphoton.2014.248
[67] Hasan, M. Z., and C. L. Kane. "Colloquium: Topological Insulators." *Reviews of Modern Physics* 82, no. 4 (2010): 3045–3067. https://doi.org/10.1103/RevModPhys.82.3045
[68] Moore, J. E. "The Birth of Topological Insulators." *Nature* 464, no. 7286 (2010): 194–198. https://doi.org/10.1038/nature08916
[69] Mondal, Shyamal, Rounak Ganguly, and Krishnakanta Mondal. "Topological insulators: an in-depth review of their use in modelocked fiber lasers." *Annalen der Physik* 533, no. 6 (2021): 2000564. https://doi.org/10.1002/andp.202000564
[70] Pereira, Vanda M., Chi-Nan Wu, Katharina Höfer, Arnold Choa, Cariad-A. Knight, Jesse Swanson, Christoph Becker et al. "Challenges of topological insulator research: Bi2Te3 thin films and magnetic heterostructures." *physica status solidi (b)* 258, no. 1 (2021): 2000346. https://doi.org/10.1002/pssb.202000346
[71] Lee, Chao-Kuei, Ju Han Lee, Bai-Tao Zhang, and Jing-Liang He. "Topological insulators and applications." In *2D Materials for Nanophotonics*, pp. 81-138. *Elsevier*, 2021. https://doi.org/10.1016/B978-0-12-818658-9.00007-7

[72] Alghamdi, Turki Ali, Somaya Adwan, Hamzah Arof, and Sulaiman Wadi Harun. "Application of black phosphorus for pulse generation in erbium-doped fiber laser." *Results in Optics* 4 (2021): 100091. https://doi.org/10.1016/j.rio.2021.100091
[73] Hazirah Hani Zalkepali, Noor Ummi, Muwafaq Mohammed Bakr Alsaady, Mustafa Mudhafar, Nik Noor Haryatul Eleena Nik Mahmud, Nur Ainnaa Mardhiah Muhammad, Ain Zamira Muhammad Zamri, and Noor Azura Awang. "Inorganic Material of Magnesium Nitrate Mg (NO 3) 2 Film as Q-Switcher in the C-Band Region." *Pertanika Journal of Science & Technology* 32, no. 2 (2024). https://doi.org/10.47836/pjst.32.2.22
[74] Zhao, Chujun, Han Zhang, Xiang Qi, Yu Chen, Zhiteng Wang, Shuangchun Wen, and Dingyuan Tang. "Ultra-short pulse generation by a topological insulator based saturable absorber." *Applied Physics Letters* 101, no. 21 (2012). https://doi.org/10.1063/1.4767919
[75] Nasir, A. M. M., M. F. A. Rahman, S. A. Anuar, A. A. Latiff, A. H. A. Rosol, and A. H. H. Al-Masoodi. "Generation of Q-switched erbium-doped fiber laser using MAX phase titanium aluminum nitride Ti4AlN3." *Optik* 295 (2023): 171488. https://doi.org/10.1016/j.ijleo.2023.171488
[76] Ruppert, Claudia, Burak Aslan, and Tony F. Heinz. "Optical properties and band gap of single-and few-layer MoTe2 crystals." *Nano letters* 14, no. 11 (2014): 6231-6236. https://doi.org/10.1021/nl502557g
[77] Mak, Kin Fai, Changgu Lee, James Hone, Jie Shan, and Tony F. Heinz. "Atomically thin MoS 2: a new direct-gap semiconductor." *Physical review letters* 105, no. 13 (2010): 136805. https://doi.org/10.1103/PhysRevLett.105.136805
[78] Sun, Zhipei, Amos Martinez, and Feng Wang. "Optical modulators with 2D layered materials." *Nature Photonics* 10, no. 4 (2016): 227-238. https://doi.org/10.1038/nphoton.2016.15
[79] Yao, Xuehui, Ya Liu, Sijia Liu, Qiang Zhang, and Guoqing Hu. "Passively Q-switched and mode-locking fiber laser based on Sb2S3 saturable absorber." *Optical Fiber Technology* 82 (2024): 103616. https://doi.org/10.1016/j.yofte.2023.103616
[80] Liu, Xing, Qun Gao, Yang Zheng, Dong Mao, and Jianlin Zhao. "Recent progress of pulsed fiber lasers based on transition-metal dichalcogenides and black phosphorus saturable absorbers." *Nanophotonics* 9, no. 8 (2020): 2215-2231. https://doi.org/10.1515/nanoph-2019-0566
[81] Pang, Lihui, Lu Li, Wenjun Liu, Rongqian Wu, and Yi Lv. "Hafnium sulfide nanosheets for large energy passively Q-switched fiber laser application." *Optical Materials* 102 (2020): 109784. https://doi.org/10.1016/j.optmat.2020.109784
[82] Bhattacharyya, Swastibrata, and Abhishek K. Singh. "Semiconductor-metal transition in semiconducting bilayer sheets of transition-metal dichalcogenides." *Physical Review B—Condensed Matter and Materials Physics* 86, no. 7 (2012): 075454. https://doi.org/10.1103/PhysRevB.86.075454
[83] Sahin, H., Sefaattin Tongay, S. Horzum, W. Fan, J. Zhou, J. Li, J. Wu, and F. M. Peeters. "Anomalous Raman spectra and thickness-dependent electronic properties of WSe 2." *Physical Review B—Condensed Matter and Materials Physics* 87, no. 16 (2013): 165409. https://doi.org/10.1103/PhysRevB.87.165409
[84] Hou, Huanran, Tianqi You, Qin Zhou, Mengli Liu, Yuyi Ouyang, Ximei Liu, and Wenjun Liu. "Q-switched all-fiber laser based on titanium trisulfide." *Optik* 205 (2020): 164234. https://doi.org/10.1016/j.ijleo.2020.164234
[85] Yuzaile, Y. R., Z. Zakaria, N. A. Awang, and N. U. H. H. Zalkepali. "Plasma sputtered platinum saturable absorber with variable sputtering time for Q-switched erbium-doped fiber laser." *Optics & Laser Technology* 136 (2021): 106525. https://doi.org/10.1016/j.optlastec.2020.106525
[86] Ahmad, Harith, Nur Fatini Azmy, Norazriena Yusoff, Siti Aisyah Reduan, Siti Nabila Aidit, Leonard Bayang, and Muhamad Zharif Samion. "MoTe2-PVA as saturable absorber for passively Q-switched thulium-doped fluoride and erbium-doped fiber laser." *Optik* 243 (2021): 167157. https://doi.org/10.1016/j.ijleo.2021.167157
[87] Fadhel, Mahmoud Muhanad, Abdulwahhab Essa Hamzah, Norazreen Abd Aziz, Mohd Saiful Dzulkefly Zan, and Norhana Arsad. "Passively Q-switching an all polarization-maintaining erbium-doped fiber laser with a rhenium disulfide (ReS2) saturable absorber." *Heliyon* 9, no. 10 (2023). https://doi.org/10.1016/j.heliyon.2023.e20678
[88] Cheng, Ping Kwong, Chun Yin Tang, Xin Yu Wang, Sainan Ma, Hui Long, and Yuen Hong Tsang. "Passively Q-switched ytterbium-doped fiber laser based on broadband multilayer platinum ditelluride (PtTe2) saturable absorber." *Scientific reports* 9, no. 1 (2019): 10106. https://doi.org/10.1038/s41598-019-46658-y
[89] Zhang, Meng, Qing Wu, Feng Zhang, Lingling Chen, Xinxin Jin, Yuwei Hu, Zheng Zheng, and Han Zhang. "2D black phosphorus saturable absorbers for ultrafast photonics." *Advanced Optical Materials* 7, no. 1 (2019): 1800224. https://doi.org/10.1002/adom.201800224
[90] Guo, Zhinan, Han Zhang, Shunbin Lu, Zhiteng Wang, Siying Tang, Jundong Shao, Zhengbo Sun et al. "From black phosphorus to phosphorene: basic solvent exfoliation, evolution of Raman scattering, and applications to ultrafast photonics." *Advanced Functional Materials* 25, no. 45 (2015): 6996-7002. https://doi.org/10.1002/adfm.201502902

[91] Huang, Mingqiang, Mingliang Wang, Cheng Chen, Zongwei Ma, Xuefei Li, Junbo Han, and Yanqing Wu. "Broadband black-phosphorus photodetectors with high responsivity." *Adv. Mater* 28, no. 18 (2016): 3481-3485. https://doi.org/10.1002/adma.201506352
[92] Xia, Fengnian, Han Wang, and Yichen Jia. "Rediscovering black phosphorus as an anisotropic layered material for optoelectronics and electronics." *Nature communications* 5, no. 1 (2014): 4458. https://doi.org/10.1038/ncomms5458
[93] Wang, Xiaomu, and Shoufeng Lan. "Optical properties of black phosphorus." *Advances in Optics and photonics* 8, no. 4 (2016): 618-655. https://doi.org/10.1364/AOP.8.000618
[94] Li, Likai, Yijun Yu, Guo Jun Ye, Qingqin Ge, Xuedong Ou, Hua Wu, Donglai Feng, Xian Hui Chen, and Yuanbo Zhang. "Black phosphorus field-effect transistors." *Nature nanotechnology* 9, no. 5 (2014): 372-377. https://doi.org/10.1038/nnano.2014.35
[95] Liu, Han, Adam T. Neal, Zhen Zhu, David Tomanek, and Peide D. Ye. "Phosphorene: a new 2D material with high carrier mobility." *arXiv preprint arXiv:1401.4133* (2014).
[96] Guo, Qiushi, Andreas Pospischil, Maruf Bhuiyan, Hao Jiang, He Tian, Damon Farmer, Bingchen Deng et al. "Black phosphorus mid-infrared photodetectors with high gain." *Nano letters* 16, no. 7 (2016): 4648-4655. https://doi.org/10.1021/acs.nanolett.6b01977
[97] Buscema, Michele, Dirk J. Groenendijk, Sofya I. Blanter, Gary A. Steele, Herre SJ Van Der Zant, and Andres Castellanos-Gomez. "Fast and broadband photoresponse of few-layer black phosphorus field-effect transistors." *Nano letters* 14, no. 6 (2014): 3347-3352. https://doi.org/10.1021/nl5008085
[98] Tran, Vy, Ryan Soklaski, Yufeng Liang, and Li Yang. "Layer-controlled band gap and anisotropic excitons in few-layer black phosphorus." *Physical Review* B 89, no. 23 (2014): 235319. https://doi.org/10.1103/PhysRevB.89.235319
[99] Favron, Alexandre, Etienne Gaufrès, Frédéric Fossard, Anne-Laurence Phaneuf-L'Heureux, Nathalie YW Tang, Pierre L. Lévesque, Annick Loiseau, Richard Leonelli, Sébastien Francoeur, and Richard Martel. "Photooxidation and quantum confinement effects in exfoliated black phosphorus." *Nature materials* 14, no. 8 (2015): 826-832. https://doi.org/10.1038/nmat4299
[100] Favron, Alexandre, Etienne Gaufrès, Frédéric Fossard, Anne-Laurence Phaneuf-L'Heureux, Nathalie YW Tang, Pierre L. Lévesque, Annick Loiseau, Richard Leonelli, Sébastien Francoeur, and Richard Martel. "Photooxidation and quantum confinement effects in exfoliated black phosphorus." *Nature materials* 14, no. 8 (2015): 826-832. https://doi.org/10.1038/nmat4299
[101] Zhou, Qionghua, Qian Chen, Yilong Tong, and Jinlan Wang. "Light-induced ambient degradation of few-layer black phosphorus: mechanism and protection." *Angewandte Chemie International Edition* 55, no. 38 (2016): 11437-11441. https://doi.org/10.1002/anie.201605168
[102] Island, Joshua O., Gary A. Steele, Herre SJ van der Zant, and Andres Castellanos-Gomez. "Environmental instability of few-layer black phosphorus." *2D Materials* 2, no. 1 (2015): 011002. https://doi.org/10.1088/2053-1583/2/1/011002
[103] Ooi, Wei Ling, Azura Hamzah, Kawther M. Mustafa, Ahmad Haziq Aiman Rosol, Norliza Mohamed, Nur Najahatul Huda Saris, and Sulaiman Wadi Harun. "Molybdenum gallium carbide saturable absorber as Q-switcher in an erbium-doped fibre laser." *Optical Fiber Technology* 82 (2024): 103612. https://doi.org/10.1016/j.yofte.2023.103612
[104] Castellanos-Gomez, Andres. "Black phosphorus: narrow gap, wide applications." *The journal of physical chemistry letters* 6, no. 21 (2015): 4280-4291. https://doi.org/10.1021/acs.jpclett.5b01686
[105] Khurram, Muhammad, Zhaojian Sun, Ziming Zhang, and Qingfeng Yan. "Chemical vapor transport growth of bulk black phosphorus single crystals." *Inorganic Chemistry Frontiers* 7, no. 15 (2020): 2867-2879. https://doi.org/10.1039/D0QI00582G
[106] Muhammad, N. A. M., N. A. Awang, N. U. H. H. Zalkepali, N. N. H. E. N. Mahmud, and H. Basri. "Q-switched fiber laser using a polysulfone membrane enhanced with biosynthesized zinc oxide and titanium dioxide nanoparticles for use as saturable absorber." *Laser Physics* 32, no. 6 (2022): 065101. https://doi.org/10.1088/1555-6611/ac687d
[107] Zamri, Ain Zamira Muhamad, Noor Ummi Hazirah Hani Zalkepali, Noor Azura Awang, Mun Kok Lim, Nik Noor Haryatul Eleena Nik Mahmud, and Nur Ainnaa Mardhiah Muhammad. "Q-switched erbium-doped fiber lasers with ITO thin film saturable absorbers: A comprehensive cavity configuration study." *Optical Fiber Technology* 82 (2024): 103638. https://doi.org/10.1016/j.yofte.2023.103638
[108] Smith, G. "The early laser years at Hughes Aircraft Company." *IEEE journal of quantum electronics* 20, no. 6 (1984): 577-584. https://doi.org/10.1109/JQE.1984.1072445
[109] Singer, Jay R. "Advances in quantum electronics." *Advances in Quantum Electronics* (1961).
[110] Collins, R. J., and P. Kisliuk. "Control of population inversion in pulsed optical masers by feedback modulation." *Journal of Applied Physics* 33, no. 6 (1962): 2009-2011.https://doi.org/10.1063/1.1728883

[111] McClung, Fred J., and Robert W. Hellwarth. "Giant optical pulsations from ruby." *Applied Optics* 1, no. 101 (1962): 103-105.https://doi.org/10.1063/1.1777174
[112] Digonnet, Michel JF. *Rare-earth-doped fiber lasers and amplifiers, revised and expanded*. CRC press, 2001. https://doi.org/10.1201/9780203904657
[113] Bovatsek, James M., and Rajesh S. Patel. "Highest-speed dicing of thin silicon wafers with nanosecond-pulse 355nm q-switched laser source using line-focus fluence optimization technique." In *Laser-based Micro-and Nanopackaging and Assembly IV*, vol. 7585, pp. 181-192. SPIE, 2010. https://doi.org/10.1117/12.845298
[114] Hong, Lei, Lijun Li, and Chunlei Ju. "Investigation of cutting of engineering ceramics with Q-switched pulse CO2 laser." *Optics and lasers in engineering* 38, no. 5 (2002): 279-289. https://doi.org/10.1016/S0143-8166(01)00171-3
[115] Schaeffer, Ronald. *Fundamentals of laser micromachining*. CRC press, 2012. https://doi.org/10.1117/12.387562
[116] Rizvi, N. H., D. K. Milne, P. T. Rumsby, and M. C. Gower. "Laser Micromachining: New Developments and Applications." *Proceedings of SPIE* 3933 (2000): 261–71. https://doi.org/10.1117/12.387562
[117] Gower, M. C. "Industrial Applications of Laser Micromachining." *Optics Express* 7, no. 2 (2000): 56–67. https://doi.org/10.1364/OE.7.000056
[118] Minami, K., Y. Wakabayashi, T. Matsubara, K. Yoshimi, M. Yoshida, and M. Esashi. "YAG Laser Assisted Etching for Releasing Silicon Microstructure." *IEEE Micro Electro Mechanical Systems* (1993): 53–58. https://doi.org/10.1109/MEMSYS.1993.296951
[119] Leone, C., V. Lopresto, and I. De Iorio. "Wood Engraving by Q-Switched Diode-Pumped Frequency-Doubled Nd:YAG Green Laser." *Optics and Lasers in Engineering* 47 (2009): 161–68. https://doi.org/10.1016/j.optlaseng.2008.06.019
[120] Li, J. L., K. I. Ueda, A. Shirakawa, and L. X. Zhong. "Passively Q-Switched Nd:YAG Microchip Laser Emits Radially and Azimuthally Polarized Light." CLEO/Europe - EQEC (2009): 841–201800. https://doi.org/10.1109/CLEOE-EQEC.2009.5192901
[121] Haupt, O. L. I. V. E. R., and Frank Gaebler. "Short-Pulse Q-Switched Lasers: Enhance Precision Marking Applications." *Photonics Spectra* 47, no. 6 (2013): 45-47.
[122] Woods, Stuart, and Tobias Pfanz. "DPSS lasers rival fiber lasers for marking applications." *Laser focus world* 44, no. 1 (2008).
[123] LinkedIn. "Passive Q-Switch Crystals Market Size, Growth and Forecast from 2023–2030." *LinkedIn.*
[124] Williams, Andrew J., Michael S. Griffith, and Andrew G. McCarthy. "Frequency stability of passively Q-switched non-planar ring oscillator under aircraft vibration." In *Remote Sensing of Clouds and the Atmosphere XXIV*, vol. 11152, pp. 244-254. SPIE, 2019.https://doi.org/10.1117/12.2524876
[125] Zayhowski, J. "Passively Q-Switched Microchip Lasers and Applications." *Review of Laser Engineering* 26 (1998): 841–846. https://doi.org/10.2184/lsj.26.841
[126] Shi, C., Huang, H., Li, M., Bao, Y., and Li, Z. "Passively Q-Switched 3 µm Erbium-Doped Solid State Lasers Using Gold Nanorods as Broadband Saturable Absorber." *Optics and Laser Technology* 160 (2023): 109095. https://doi.org/10.1016/j.optlastec.2022.109095
[127] Wanner, M., Sakamoto, F. H., Avram, M. M., Chan, H. H., Alam, M., Tannous, Z., et al. "Immediate Skin Responses to Laser and Light Treatments Therapeutic Endpoints: How to Obtain Efficacy." *Journal of the American Academy of Dermatology* 74 (2016): 821–833. https://doi.org/10.1016/j.jaad.2015.06.026
[128] Chen, J.-C., Tu, Y.-C., Ho, Y.-W., Liang, H.-C., and Chen, Y.-F. "Highly Efficient Diode-Pumped Passively Q-Switched Nd:YVO4/KGW Raman Lasers at Yellow and Orange Wavelengths." *Optics Express* 31 (2023): 8696. https://doi.org/10.1364/OE.486533
[129] Yi, W. J. "Development of Picosecond Laser for Dermatology Application: Its Changeable Pulse Width and Bundle Pulse Implementation." *Korean Association for Laser Dermatology and Trichology* 1 (2020): 50–56. https://doi.org/10.46738/Aesthetics.2020.1.1.50
[130] Trídico, Lívia Arroyo, and Carlos Roberto Antonio. "Laser quality switched (Q-switched): revisão de suas variações e principais aplicabilidades clínicas." *Surgical & Cosmetic Dermatology* 11, no. 4 (2019): 274-279. https://doi.org/10.5935/scd1984-8773.20191141419
[131] Dupriez, P., and Pierre, C. "Sub-50 fs All-Fiber Source Based on a 100 ps Passively Q-Switched Microchip Laser." *Optics InfoBase Conference Papers* (2014): 1–2. https://doi.org/10.1364/CLEO_SI.2014.SM1O.1
[132] Sun, H., Li, Z., Zhu, Z., Hui, Y., Lei, H., and Li, Q. "1kHz, Er3+/Yb3+: Glass Passively Q-Switched Microchip Laser with Long Time Stable Operation." *Optical Engineering* 11907 (2021): 311–319. https://doi.org/10.1117/12.2602899
[133] Ning, Shougui, Guoying Feng, Shenyu Dai, Hong Zhang, Wei Zhang, Lijuan Deng, and Shouhuan Zhou. "Mid-infrared Fe2+: ZnSe semiconductor saturable absorber mirror for passively Q-switched Er3+-doped ZBLAN fiber laser." *AIP Advances* 8, no. 2 (2018). https://doi.org/10.1063/1.5012847

[134] Li, Jianfeng, Hongyu Luo, Lele Wang, Yong Liu, Zhijun Yan, Kaiming Zhou, Lin Zhang, and Sergei K. Turistsyn. "Mid-infrared passively switched pulsed dual wavelength Ho3+-doped fluoride fiber laser at 3 µm and 2 µm." *Scientific reports* 5, no. 1 (2015): 10770. https://doi.org/10.1063/1.5012847
[135] Rosol, A. H. A., Mahyuddin, M. B. H., Jusoh, Z., and Harun, A. S. W. "Tungsten Disulfide Saturable Absorber for Nanosecond Pulses Generation." *Nonlinear Optics and Quantum Optics* 51 (2019): 161–169.
[136] Korenfeld, A., Sebbag, D., Ben-Ami, U., Shalom, E., Marcus, G., and Noach, S. "High Pulse Energy Passive Q-Switching of a Diode-Pumped Tm:YLF Laser by Cr:ZnSe." *Laser Physics Letters* 12 (2015): 45804. https://doi.org/10.1088/1612-2011/12/4/045804
[137] Kong, L. C., G. Q. Xie, P. Yuan, L. J. Qian, S. X. Wang, H. H. Yu, and H. J. Zhang. "Passive Q-switching and Q-switched mode-locking operations of 2 µm Tm: CLNGG laser with MoS 2 saturable absorber mirror." *Photonics Research* 3, no. 2 (2015): A47-A50.https://doi.org/10.1364/PRJ.3.000A47
[138] Barua, S. "Laser-Tissue Interaction in Tattoo Removal by Q-Switched Lasers." *Journal of Cutaneous and Aesthetic Surgery* 8 (2015): 5. https://doi.org/10.4103/0974-2077.155063
[139] Vogel, Alfred, M. R. Capon, Mary N. Asiyo-Vogel, and Reginald Birngruber. "Intraocular photodisruption with picosecond and nanosecond laser pulses: tissue effects in cornea, lens, and retina." *Investigative ophthalmology & visual science* 35, no. 7 (1994): 3032-3044. https://doi.org/10.1002/lsm.1900150106
[140] Nägele, M., Stoppel, K., and Dekorsy, T. "Passively Q-Switched 914 nm Microchip Laser for Lidar Systems." *Optics Express* 29 (2021): 23799. https://doi.org/10.1364/OE.432340
[141] Mafroos, M. M., Ameelia, N., Jameela, H. H., and Hamzah, A. "Characterizing Passively Q-Switched Fiber Laser in Lidar Application." *International Journal of Integrated Engineering* 15 (2023): 170–176. https://doi.org/10.30880/ijie.2023.15.03.017
[142] Vasil'ev, B. I., and O. Mannoun. "IR Differential-Absorption Lidars for Ecological Monitoring of the Environment." *Quantum Electronics* 36 (2006): 801–20. https://doi.org/10.1070/QE2006v036n09ABEH006577
[144] Shi, W., E. Petersen, N. Moor, A. Chavez-Pirson, and N. Peyghambarian. "All Fiber-Based Single-Frequency Q-Switched Laser Pulses at 2 µm for Lidar and Remote Sensing Applications." *In Nanophotonics and Macrophotonics for Space Environments* V, 81640M. 2011. https://doi.org/10.1117/12.894914
[145] Di Teodoro, F., P. Belden, P. Ionov, N. Werner, and G. Fathi. "Development of Pulsed Fiber Lasers for Long-Range Remote Sensing." *Optical Engineering* 53 (2014): 036105. https://doi.org/10.1117/1.OE.53.3.036105
[146] Rademacher, Georg, Benjamin J. Puttnam, Ruben S. Luís, Tobias A. Eriksson, Nicolas K. Fontaine, Mikael Mazur, Haoshuo Chen et al. "Peta-bit-per-second optical communications system using a standard cladding diameter 15-mode fiber." *Nature Communications* 12, no. 1 (2021): 4238.
[147] Seidel, R. W. "From Glow to Flow: A History of Military Laser Research and Development." *Historical Studies in the Physical and Biological Sciences* 18 (1987): 111–47. https://doi.org/10.2307/27757598
[148] Mohamed, A. "Design and Realization of a Compact and Multi-Purpose Passively Q-Switched ND:YAG Laser System." *Journal of Engineering Science and Military Technologies* 2 (2018): 129–33. https://doi.org/10.21608/ejmtc.2018.479.1018
[149] Chernysheva, Maria, Chengbo Mou, Raz Arif, Mohammed AlAraimi, Mark Rümmeli, Sergei Turitsyn, and Aleksey Rozhin. "High power Q-switched thulium doped fibre laser using carbon nanotube polymer composite saturable absorber." *Scientific reports* 6, no. 1 (2016): 24220. https://doi.org/10.1038/srep24220
[150] Tang, Jingling, Zhenxu Bai, Duo Zhang, Yaoyao Qi, Jie Ding, Yulei Wang, and Zhiwei Lu. "Advances in all-solid-state passively Q-switched lasers based on Cr4+: YAG saturable absorber." In *Photonics*, vol. 8, no. 4, p. 93. Multidisciplinary Digital Publishing Institute, 2021. https://doi.org/10.3390/photonics8040093
[151] Lau, K. Y., and D. Hou. "Recent Research and Advances of Material-Based Saturable Absorber in Mode-Locked Fiber Laser." *Optics and Laser Technology* 137 (2021): 106826. https://doi.org/10.1016/j.optlastec.2020.106826
[152] Martinez, A., K. Fuse, B. Xu, and S. Yamashita. "Optical Deposition of Graphene and Carbon Nanotubes in a Fiber Ferrule for Passive Mode-Locked Lasing." *Optics Express* 18 (2010): 23054. https://doi.org/10.1364/OE.18.023054
[153] Mao, Dong, Xiaoyang She, Bobo Du, Dexing Yang, Wending Zhang, Kun Song, Xiaoqi Cui, Biqiang Jiang, Tao Peng, and Jianlin Zhao. "Erbium-doped fiber laser passively mode locked with few-layer WSe2/MoSe2 nanosheets." *Scientific reports* 6, no. 1 (2016): 23583. https://doi.org/10.1038/srep23583
[154] Ramlan, N. A. A., R. Zakaria, N. F. Zulkifli, N. Kasim, R. A. M. Yusoff, and A. A. A. Jafry. "Indium Selenide as Passive Saturable Absorber for Q-Switching in Erbium-Doped Fiber Lasers." *Optical Fiber Technology* 72 (2022): 102972. https://doi.org/10.1016/j.yofte.2022.102972
[155] Ahmad, H., N. A. Roslan, M. K. A. A. Zaini, and M. Z. Samion. "Tunable Multiwavelength Erbium-Doped Fiber Laser Based on In-Fiber Fabry-Perot Interferometer Fiber Bragg Gratings in Linear and Ring Cavity Configurations." *Optik* 262 (2022): 169359. https://doi.org/10.1016/j.ijleo.2022.169359
[156] Ahmad, H., S. I. Ooi, M. Z. Samion, and S. A. Reduan. "Tunable Mode-Locked Pulsed Laser Generation at Longer 2.0 µm Region." *IEEE Journal of Quantum Electronics* 58 (2022): 1–10. https://doi.org/10.1109/JQE.2022.3195256

[157] Jackson, S. D. "Passively Q-Switched Tm3+-Doped Silica Fiber Lasers." *Applied Optics* 46 (2007): 3311–17. https://doi.org/10.1364/AO.46.003311
[158] Mao, Dong, Xiaoqi Cui, Wending Zhang, Mingkun Li, Tianxian Feng, Bobo Du, Hua Lu, and Jianlin Zhao. "Q-switched fiber laser based on saturable absorption of ferroferric-oxide nanoparticles." *Photonics Research* 5, no. 1 (2017): 52-56. https://doi.org/10.1364/PRJ.5.000052
[159] Wadi, Nurul Izzah S., Rosmalini Ab Kadir, Zulzilawati Jusoh, Norizan Ahmed, Muhammad Imran MA Khudus, and Sameer Salam. "Q-switched EDFL with copper phthalocyanines saturable absorber." *Optik* 296 (2024): 171547. https://doi.org/10.1016/j.ijleo.2023.171547
[160] Herda, R., S. Kivistö, and O. G. Okhotnikov. "Dynamic Gain Induced Pulse Shortening in Q-Switched Lasers." *Optics Letters* 33 (2008): 1011. https://doi.org/10.1364/OL.33.001011
[161] Liu, Yang, Chongyang Xu, Yingtian Xu, Li Li, Yuanyuan Jing, He Zhang, Jie Fan, Liang Jin, Yonggang Zou, and Xiaohui Ma. "High-performance passively Q-switched fiber laser based on CuFeO2/SiO2 as saturable absorber." *Optics Communications* 546 (2023): 129793. https://doi.org/10.1016/j.optcom.2023.129793
[162] Mao, Dong, Xiaoqi Cui, Xuetao Gan, Mingkun Li, Wending Zhang, Hua Lu, and Jianlin Zhao. "Passively Q-switched and mode-locked fiber laser based on an ReS2 saturable absorber." *IEEE Journal of Selected Topics in Quantum Electronics* 24, no. 3 (2017): 1-6. https://doi.org/10.1109/JSTQE.2017.2713641
[163] Ramlan, N. A., R. Zakaria, N. F. Zulkipli, A. A. Jafry, R. Kamarulzaman, and N. Kasim. "Silver Indium Selenide Composite as a Saturable Absorber for Passive Q-Switched and Mode-Locked Pulsed Generation in Erbium-Doped Fiber Laser." *Optik* 292 (2023): 171388. https://doi.org/10.1016/j.ijleo.2023.171388
[164] Yusoff, N. Mohd, C. A. C. Abdullah, MAW Abdul Hadi, E. K. Ng, H. K. Lee, NH Zainol Abidin, N. S. Rosli, and M. A. Mahdi. "Low threshold Q-switched fiber laser incorporating titanium dioxide saturable absorber from waste material." *Optik* 218 (2020): 164998. https://doi.org/10.1016/j.ijleo.2020.164998
[165] Nasir, A. M. M., A. A. Latiff, S. A. Anuar, A. R. Muhammad, and M. F. A. Rahman. "Passively Q-Switched Fiber Laser Utilizing Molybdenum Titanium Aluminum Carbide (Mo2Ti2AlC2) for Pulsed Laser Generation." *Optik* 273 (2023): 170439. https://doi.org/10.1016/j.ijleo.2022.170439
[166] Najm, Mustafa Mohammed, Ahmed Shakir Al-Hiti, Bilal Nizamani, Hamzah Arof, Pei Zhang, Moh Yasin, and Sulaiman Wadi Harun. "Passively Q-switched erbium-doped fiber laser with mechanical exfoliation of 8-HQCDCL2H2O as saturable absorber." *Optik* 242 (2021): 167073. https://doi.org/10.1016/j.ijleo.2021.167073
[167] Al-Hiti, A. S., A. H. H. Al-Masoodi, W. R. Wong, M. Yasin, A. H. H. Al-Masoodi, and S. W. Harun. "Nanosecond Passively Q-Switched Fiber Laser in the 1.5 µm Region Using Turmeric Saturable Absorber." *Optics and Laser Technology* 139 (2021): 106971. https://doi.org/10.1016/j.optlastec.2021.106971
[168] Soboh, Rawan SM, Ahmed HH Al-Masoodi, Fuad NA Erman, Ab HH Al-Masoodi, B. Nizamani, H. Arof, M. Yasin, and S. W. Harun. "Lawsone dye material as potential saturable absorber for Q-switched erbium doped fiber laser." *Optical fiber technology* 64 (2021): 102537. https://doi.org/10.1016/j.yofte.2021.102537
[169] Craig, C. L. "Evolution of Arthropod Silks." Annual Review of Entomology 42 (1997): 231–67. https://doi.org/10.1146/annurev.ento.42.1.231
[170] Hey, Tow K., Chow, D. M., Vollrath, F., Dicaire, I., Gheysens, T., and L. Thévenaz. "Exploring the Use of Native Spider Silk as an Optical Fiber for Chemical Sensing." *Journal of Lightwave Technology* 36 (2018): 1138–44. https://doi.org/10.1109/JLT.2017.2756095
[171] Tow, Kenny Hey, Desmond M. Chow, Fritz Vollrath, Isabelle Dicaire, Tom Gheysens, and Luc Thévenaz. "Towards a new generation of fibre-optic chemical sensors based on spider silk threads." In *2017 25th Optical Fiber Sensors Conference (OFS)*, pp. 1-4. Ieee, 2017. https://doi.org/10.1117/12.2264438
[172] Vollrath, F., and D. P. Knight. "Liquid Crystalline Spinning of Spider Silk." *Nature* 410 (2001): 541–48. https://doi.org/10.1038/35069000
[173] Mita, K., Ichimura, S., and T. C. James. "Highly Repetitive Structure and Its Organization of the Silk Fibroin Gene." *Journal of Molecular Evolution* 38 (1994): 583–92. https://doi.org/10.1007/BF00175878
[174] Hayashi, C. Y., and R. V. Lewis. "Molecular Architecture and Evolution of a Modular Spider Silk Protein Gene." *Science* 287 (2000): 1477–79. https://doi.org/10.1126/science.287.5457.1477
[175] Thirugnanasambantham, K. G., Keerthi Vaasan, R., Kishore, S., Anirudh, S., Bala Kumaran, K., and P. Mathan Kumar. "Spider Silk Fiber: A Brief Review on Molecular Structure, Properties, and Applications of Spider Silk." *AIP Conference Proceedings* 2283 (2020). https://doi.org/10.1063/5.0024918
[176] Li, Jiatian, Sitong Li, Jiayi Huang, Abdul Qadeer Khan, Baigang An, Xiang Zhou, Zunfeng Liu, and Meifang Zhu. "Spider silk-inspired artificial fibers." *Advanced Science* 9, no. 5 (2022): 2103965. https://doi.org/10.1002/advs.202103965
[177] Gu, Y., Yu, L., Mou, J., Wu, D., Zhou, P., and M. Xu. "Mechanical Properties and Application Analysis of Spider Silk Bionic Material." *E-Polymers* 20 (2020): 443–57. https://doi.org/10.1515/epoly-2020-0049

[178] Kujala, S., Mannila, A., Karvonen, L., Kieu, K., and Z. Sun. "Natural Silk as a Photonics Component: A Study on Its Light Guiding and Nonlinear Optical Properties." *Scientific Reports* 6 (2016): 1–9. https://doi.org/10.1038/srep22358
[179] Qiao, Xin, Zhigang Qian, Junjie Li, Hongji Sun, Yao Han, Xiaoxia Xia, Jin Zhou, Chunlan Wang, Yan Wang, and Changyong Wang. "Synthetic engineering of spider silk fiber as implantable optical waveguides for low-loss light guiding." *ACS applied materials & interfaces* 9, no. 17 (2017): 14665-14676. https://doi.org/10.1021/acsami.7b01752
[180] Tao, Hu, Mark A. Brenckle, Miaomiao Yang, Jingdi Zhang, Mengkun Liu, Sean M. Siebert, Richard D. Averitt et al. "Silk-based conformal, adhesive, edible food sensors." *Advanced Materials* 24, no. 8 (2012): 1067-1072. https://doi.org/10.1002/adma.201103814
[181] Gosline, J. M., DeMont, M. E., and M. W. Denny. "The Structure and Properties of Spider Silk." *Endeavour* 10 (1986): 37–43. https://doi.org/10.1016/0160-9327(86)90049-9
[182] Rising, A., Widhe, M., Johansson, J., and M. Hedhammar. "Spider Silk Proteins: Recent Advances in Recombinant Production, Structure-Function Relationships and Biomedical Applications." *Cellular and Molecular Life Sciences* 68 (2011): 169–84. https://doi.org/10.1007/s00018-010-0462-z
[183] Vollrath, F., and D. P. Knight. "Liquid Crystalline Spinning of Spider Silk." *Nature* 410 (2001): 541–48. https://doi.org/10.1038/35069000
[184] Gellynck, K., Verdonk, P., Forsyth, R., Almqvist, K. F., Van Nimmen, E., Gheysens, T., et al. "Biocompatibility and Biodegradability of Spider Egg Sac Silk." *Journal of Materials Science: Materials in Medicine* 19 (2008): 2963–70. https://doi.org/10.1007/s10856-007-3330-0
[185] Allmeling, C. "Use of Spider Silk Fibres as an Innovative Material in a Biocompatible Artificial Nerve Conduit." *Journal of Cellular and Molecular Medicine* 10 (2006). https://doi.org/10.2755/jcmm010.003.18
[186] Vepari, C., and D. L. Kaplan. "Silk as a Biomaterial." *Progress in Polymer Science* 32 (2007): 991–1007. https://doi.org/10.1016/j.progpolymsci.2007.05.013
[187] Shao, Zhengzhong, and Fritz Vollrath. "Surprising Strength of Silkworm Silk." *Nature* 418 (2002): 741. https://doi.org/10.1038/418741a
[188] Du, N., Yang, Z., Liu, X. Y., Li, Y., and H. Y. Xu. "Structural Origin of the Strain-Hardening of Spider Silk." *Advanced Functional Materials* 21 (2011): 772–78. https://doi.org/10.1002/adfm.201001397
[189] Hakimi, O., Knight, D. P., Vollrath, F., and P. Vadgama. "Spider and Mulberry Silkworm Silks as Compatible Biomaterials." *Composites Part B: Engineering* 38 (2007): 324–37. https://doi.org/10.1016/j.compositesb.2006.06.012
[190] Jackman, Skyler L., Christopher H. Chen, Selmaan N. Chettih, Shay Q. Neufeld, Iain R. Drew, Chimuanya K. Agba, Isabella Flaquer et al. "Silk fibroin films facilitate single-step targeted expression of optogenetic proteins." *Cell reports* 22, no. 12 (2018): 3351-3361. https://doi.org/10.1016/j.celrep.2018.02.081
[191] Porter, D., Guan, J., and F. Vollrath. "Spider Silk: Super Material or Thin Fibre?" *Advanced Materials* 25 (2013): 1275–79. https://doi.org/10.1002/adma.201204158
[192] Frinch, H. "Strength and Structure of Glenoidal Bone." *Reviews in Molecular Biotechnology* 74 (1994): 6783. https://doi.org/10.1016/S1389-0352(00)00006-4
[193] Fu, C., Porter, D., and Z. Shao. "Moisture Effects on Antheraea Pernyi Silk's Mechanical Property." *Macromolecules* 42 (2009): 7877–80. https://doi.org/10.1021/ma901321k
[194] Heim, Markus, David Keerl, and Thomas Scheibel. "Spider silk: from soluble protein to extraordinary fiber." *Angewandte Chemie International Edition* 48, no. 20 (2009): 3584-3596. https://doi.org/10.1002/anie.200803341
[195] Muhammad, Nur Ainnaa Mardhiah, Noor Azura Awang, Hatijah Basri, Amirah Abd Latif, Noor Ummi Hazirah Hani Zalkepali, Ain Zamira Muhamad Zamri, and Nik Noor Haryatul Eleena Nik Mahmud. "Steady Q-switched erbium-doped fiber laser pulse generation by exploiting spider silk as a passive saturable absorber." *Optics & Laser Technology* 169 (2024): 110170. https://doi.org/10.1016/j.optlastec.2023.110170
[196] Najm, Mohammed M., Sulaiman W. Harun, Sahar Salam, Hazizan Arof, Bashir Nizamani, and Muhammad Yasin. "8-Hydroxyquinolino Cadmium Chloride Hydrate for Generating Nanosecond and Picosecond Pulses in Erbium-Doped Fiber Laser Cavity." *Optical Fiber Technology* 61 (2021): 102439. https://doi.org/10.1016/j.yofte.2020.102439
[197] Shakir Al-Hiti, Ahmed, Muhammad Yasin, and Sulaiman W. Harun. "Poly(3,4-Ethylenedioxythiophene): Poly(Styrenesulfonate) Spin-Coated onto Polyvinyl Alcohol Film as Saturable Absorber for Generating Q-Switched Laser at 1.5 µm Region." *Optical Fiber Technology* 68 (2022): 102763. https://doi.org/10.1016/j.yofte.2021.102763
[198] Wadi, Nor Idayu Syafitri, Rozzita Abd Kadir, Zarina Jusoh, Noornajhan Ahmed, Mohd Ismail Mohd Abd Khudus, and Sahar Salam. "Utilizing Iron Phthalocyanines Absorber for the Generation of Q-Switched and Mode-Locked Pulses." *Optik* 300 (2024): 171665. https://doi.org/10.1016/j.ijleo.2024.171665

[199] Najm, Mohammed M., Mohd Nazri Abdullah, Abdullah Almukhtar, Banaz Abdul Hamida, Muhammad Yasin, and Sulaiman W. Harun. "8-HQCdCl2H2O as an Organic Q-Switcher in Erbium Laser Cavity." *Optoelectronics Letters* 19 (2023): 681–85. https://doi.org/10.1007/s11801-023-3009-x
[200] Ahmad, Aeriyn D., Sameer Salam, Norrima Mokhtar, Hamzah Arof, Retna Apsari, Belal Ahmed Hamida, and Sulaiman W. Harun. "Q-switched pulse generation in L-band region with polyacrylonitrile saturable absorber." *Physica Scripta* 99, no. 6 (2024): 065562. https://doi.org/10.1088/1402-4896/ad4d22
[201] SAMSAMNUN, FARINA SAFFA BINTI MOHAMAD, NUR FARHANAH BINTI ZULKIPLI, MOHD ARIF BIN MOHD SARJIDAN, AHMAD HAZIQ AIMAN BIN ROSOL, AFIQ ARIF AMINUDDIN JAFRY, MD ASHADI MD JOHARI, AERIYN DWIERNI BINTI AHMAD, MUHAMMAD IMRAN MUSTAFA ABDUL KHUDUS, and SULAIMAN WADI HARUN. "Q-Switched and mode-locked pulse generation with poly (9-vinylcarbazole) saturable absorber." *Optoelectronics and Advanced Materials-Rapid Communications* 18, no. March-April 2024 (2024): 85-92.
[202] Ahmad, H., A. Z. Zulkifli, and K. Thambiratnam. "Tunable Q-Switched Erbium-Doped Fiber Laser Based on Curved Multimode Fiber and Graphene Oxide Saturable Absorber." *Laser Physics* 27 (2017). https://doi.org/10.1088/1555-6611/aa6583
[203] González-García, A., B. Ibarra-Escamilla, O. Pottiez, E. A. Kuzin, F. M. Maya-Ordoñez, and M. Duran-Sánchez. "Compact Wavelength-Tunable Actively Q-Switched Fiber Laser in CW and Pulsed Operation Based on a Fiber Bragg Grating." *Laser Physics* 25, no. 4 (2015): 1–5. https://doi.org/10.1088/1054-660X/25/4/045104
[204] Mohammed, D. Z., W. A. Khaleel, and A. H. Al-Janabi. "Tunable Q-Switched Erbium-Doped Fiber Laser Based on Metal Transition Oxide Saturable Absorber and Refractive Index Characteristic of Multimode Interference Effects." *Optics & Laser Technology* 97 (2017): 106–10. https://doi.org/10.1016/j.optlastec.2017.06.022
[205] Fan, Ya-Xian, Fu-Yun Lu, Shu-Ling Hu, Ke-Cheng Lu, Hong-Jie Wang, Guang-Yin Zhang, and Xiao-Yi Dong. "Narrow-linewidth widely tunable hybrid Q-switched double-clad fiber laser." *Optics letters* 28, no. 7 (2003): 537-539. https://doi.org/10.1364/OL.28.000537
[206] Shin, Woojin, Bong-Ahn Yu, Yeung Lak Lee, Tae Jun Yu, Tae Joong Eom, Young-Chul Noh, Jongmin Lee, and Do-Kyeong Ko. "Tunable Q-switched erbium-doped fiber laser based on digital micro-mirror array." *Optics Express* 14, no. 12 (2006): 5356-5364. https://doi.org/10.1364/OE.14.005356
[207] Song, H., Q. Wang, D. Wang, and L. Li. "Passively Q-Switched Wavelength-Tunable 1-µm Fiber Lasers with Tapered-Fiber-Based Black Phosphorus Saturable Absorbers." *Results in Physics* 8 (2018): 276–80. https://doi.org/10.1016/j.rinp.2017.12.020
[208] Sharma, U., C. S. Kim, J. U. Kang, and N. M. Fried. "Highly Stable Tunable Dual-Wavelength Q-Switched Fiber Laser for DIAL Applications." *Optics InfoBase Conference Papers* 16 (2004): 1277–79. https://doi.org/10.1109/LPT.2004.825991
[209] Ahmad, H., M. Z. Zulkifli, F. D. Muhammad, A. Z. Zulkifli, and S. W. Harun. "Tunable Graphene-Based Q-Switched Erbium-Doped Fiber Laser Using Fiber Bragg Grating." *Journal of Modern Optics* 60, no. 3 (2013): 202–12. https://doi.org/10.1080/09500340.2013.766767
[210] Srivastava, M., D. Venkitesh, and B. Srinivasan. "Effects of Wavelength Filtering on Pulse Dynamics in a Tunable, Actively Q-Switched Fiber Laser." *Optics & Laser Technology* 98 (2018): 190–97. https://doi.org/10.1016/j.optlastec.2017.07.049
[211] Zulkifli, Mohd Zamani, Farah Diana Muhammad, MF Mohd Azri, MK Mohd Yusof, K. Z. Hamdan, Sani Amril Samsudin, and Moh Yasin. "Tunable passively Q-switched ultranarrow linewidth erbium-doped fiber laser." *Results in Physics* 16 (2020): 102949. https://doi.org/10.1016/j.rinp.2020.102949
[212] Ahmad, H., S. A. Reduan, N. E. Ruslan, C. S. J. Lee, M. Z. Zulkifli, and K. Thambiratnam. "Tunable Q-Switched Erbium-Doped Fiber Laser in the C-Band Region Using Nanoparticles (TiO2)." *Optics Communications* 435 (2019): 283–88. https://doi.org/10.1016/j.optcom.2018.11.035
[213] Popa, D., Z. Sun, T. Hasan, F. Torrisi, F. Wang, and A. C. Ferrari. "Graphene Q-Switched, Tunable Fiber Laser." Applied Physics Letters 98, no. 7 (2011): 96–99. https://doi.org/10.1063/1.3552684
[214] Cao, W. J., H. Y. Wang, A. P. Luo, Z. C. Luo, and W. C. Xu. "Graphene-Based, 50 nm Wide-Band Tunable Passively Q-Switched Fiber Laser." *Laser Physics Letters* 9, no. 1 (2012): 54–58. https://doi.org/10.1002/lapl.201110085
[215] Ahmad, H., M. A. M. Salim, K. Thambiratnam, S. F. Norizan, and S. W. Harun. "A Black Phosphorus-Based Tunable Q-Switched Ytterbium Fiber Laser." *Laser Physics Letters* 13, no. 9 (2016): 95103. https://doi.org/10.1088/1612-2011/13/9/095103
[216] Muhammad, A. M. M. N., N. A. Awang, N. N. H. E. Nik Mahmud, N. U. H. H. Zalkepali, Z. M. Zamri, and H. Basri. "Biosynthesized Zinc Oxide and Titanium Dioxide Nanoparticles by Aloe Vera Extract for Tunable Q-Switched Application." *Optical Fiber Technology* 77 (2023): 103276. https://doi.org/10.1016/j.yofte.2023.103276
[217] Zalkepali, N. U. H. H., N. N. H. E. Mahmud, N. A. Awang, and A. Z. M. Zamri. "Influence of Thickness on Tunability Performance of Plasma Sputtered Indium Tin Oxide as Q-Switcher." *Laser Physics* 33, no. 4 (2023): 045104. https://doi.org/10.1088/1555-6611/acbccf

[218] Awang, Noor Azura, Noor Ummi Hazirah Hani Zulkefli, A. Z. M. Zamri, Nik Noor Haryatul Eleena Bt N. Mahmud, and N. A. M. Muhammad. "Enhanced Tunability of Q-Switched Fiber Lasers Using Biogenic Agnps-Cs Saturable Absorber: Optical Deposition vs. Drop Casting." *NAM, Enhanced Tunability of Q-Switched Fiber Lasers Using Biogenic Agnps-Cs Saturable Absorber: Optical Deposition vs. Drop Casting*. https://doi.org/10.2139/ssrn.4585228
[219] Muhammad, N. A. M., N. A. Awang, H. Basri, N. U. H. H. Zalkepali, and M. I. Supaat. "Biological Material Spider Silk by Direct Incorporation onto Fiber Ferrule for Wavelength Tunable Q-Switched Application." *Laser Physics Letters* 21, no. 5 (2024): 055102. https://doi.org/10.1088/1612-202X/ad3a55
[220] Frenkel, A., and C. Lin. "Angle-Tuned Etalon Filters for Optical Channel Selection in High Density Wavelength Division Multiplexed Systems." *Journal of Lightwave Technology* 7, no. 5 (1989): 615–24. https://doi.org/10.1109/50.19087
[221] Kleine-Ostmann, T., and T. Nagatsuma. "A Review on Terahertz Communications Research." *Journal of Infrared, Millimeter, and Terahertz Waves* 32, no. 2 (2011): 143–71. https://doi.org/10.1007/s10762-010-9758-1
[222] Muhammad, N. A. M., N. A. Awang, and M. I. Supaat. "Switchable Dual-Wavelength Q-Switched Erbium-Doped Fibre Laser Using Spider Silk as a Biocompatible and Eco-Friendly Saturable Absorber." *ASM Science Journal* 19 (2024): 1–13. https://doi.org/10.32802/asmscj.2023.1758
[223] Lin, C. Y., G. W. Chern, and L. A. Wang. "Periodical Corrugated Structure for Forming Sampled Fiber Bragg Grating and Long-Period Fiber Grating with Tunable Coupling Strength." *Journal of Lightwave Technology* 19, no. 8 (2001): 1212–21. https://doi.org/10.1109/50.939803
[224] Erdogan, T. "Fiber Grating Spectra." *Journal of Lightwave Technology* 15, no. 8 (1997): 1277–94. https://doi.org/10.1109/50.618322
[225] Belovolov, M. I., E. M. Dianov, A. V. Kuznetsov, and A. M. Prokhorov. "Single-Mode Fiber-Optic Directional Couplers." *Fiber and Integrated Optics* 6, no. 3 (1987): 239–53. https://doi.org/10.1080/01468038708222969
[226] Zhuo, L., J. Tang, W. Zhu, H. Zheng, H. Guan, H. Lu, et al. "Side Polished Fiber: A Versatile Platform for Compact Fiber Devices and Sensors." *Photonic Sensors* 13, no. 1 (2023): 1–24. https://doi.org/10.1007/s13320-022-0661-x
[227] Chen, Z., and C. Bai. "Effect of Overlaid Material on Optical Transmission of Side-Polished Fiber Made by Wheel Side Polishing." *In 2008 1st Asia-Pacific Optical Fiber Sensors Conference*, APOS 2008, 2–5. https://doi.org/10.1109/APOS.2008.5226303
[228] Tseng, S.-M., and C.-L. Chen. "Side-Polished Fibers." *Applied Optics* 31, no. 18 (1992): 3438. https://doi.org/10.1364/AO.31.003438
[229] Kim, K. T., H. K. Kim, S. Hwangbo, S. Choi, B. H. Lee, and K. Oh. "Characterization of Evanescent Wave Coupling in Side-Polished Hollow Optical Fiber and Its Application as a Broadband Coupler." *Optics Communications* 245, no. 1–6 (2005): 145–51. https://doi.org/10.1016/j.optcom.2004.10.008
[230] Koschmieder, T. H. "Evanescent Wave Acceleration." *Fiber Optics and Applications* 48, no. 2 (1994): 75–84.
[231] Yang, Yitao, Kaixin Ge, Pan Tao, Shixun Dai, Xunsi Wang, Wei Zhang, Tiefeng Xu, Yin Wang, Ting-Jung Lin, and Peiqing Zhang. "Mid-infrared evanescent wave sensor based on side-polished chalcogenide fiber." *Ceramics International* 49, no. 1 (2023): 1291-1297. https://doi.org/10.1016/j.ceramint.2022.09.108
[232] Kashyap, Raman. "Fiber Bragg Gratings. Burlington, MA." (2010). https://doi.org/10.1016/B978-0-12-372579-0.00007-7
[233] Agrawal, Govind P. "Nonlinear fiber optics." In *Nonlinear Science at the Dawn of the 21st Century*, pp. 195-211. Berlin, Heidelberg: Springer Berlin Heidelberg, 2000. https://doi.org/10.1007/3-540-46629-0_9
[234] Othonos, A. "Fiber Bragg Gratings." *Review of Scientific Instruments* 68, no. 12 (1997): 4309–41. https://doi.org/10.1063/1.1148392
[235] Arora, D., J. Prakash, H. Singh, and A. Wason. "Reflectivity and Bragg Wavelength in FBG." *International Journal of Engineering* 5, no. 4 (2011): 341–49.
[236] Mahanta, D. K. "Design of Uniform Fiber Bragg Grating Using Transfer Matrix Method." *International Journal of Engineering and Science* 5, no. 2 (2013): 8–13.
[237] Muhammad, N. A. M., N. A. Awang, B. A. Talip, N. U. H. H. Zalkepali, and M. I. Supaat. "Highly Sensitive Adulteration Detection in Kelulut Honey Utilizing Fiber Bragg Grating Technology with Q-Switched Pulse Erbium-Doped Fiber Laser and Innovative Spider Silk Substrate." *Sensors and Actuators A: Physical* 376 (2024): 115656. https://doi.org/10.1016/j.sna.2024.115656
[238] Childs, P. R. N., J. R. Greenwood, and C. A. Long. "Review of Temperature Measurement." *Review of Scientific Instruments* 71 (2000): 2959–78. https://doi.org/10.1063/1.1305516
[239] Ma, Shaonian, Yanping Xu, Yuxi Pang, Xian Zhao, Yongfu Li, Zengguang Qin, Zhaojun Liu, Ping Lu, and Xiaoyi Bao. "Optical fiber sensors for high-temperature monitoring: a review." *Sensors* 22, no. 15 (2022): 5722. https://doi.org/10.3390/s22155722
[240] Gao, Shan, Lixin Wang, and Chi Feng. "Multi-spectral pyrometer for gas turbine blade temperature measurement." In *Photonics Applications for Aviation, Aerospace, Commercial, and Harsh Environments V*, vol. 9202, pp. 327-341. SPIE, 2014. https://doi.org/10.1117/12.2059424

[241] Lee, C. E., and H. F. Taylor. "A Fiber-Optic Pressure Sensor for Internal Combustion Engines." *Sensors* 15 (1998): 20–27. https://doi.org/10.1364/AO.33.001315

[242] Watson, J., and G. Castro. "A Review of High-Temperature Electronics Technology and Applications." *Journal of Materials Science: Materials in Electronics* 26 (2015): 9226–35. https://doi.org/10.1007/s10854-015-3459-4

[243] Yang, Shuo, Daniel Homa, Hanna Heyl, Logan Theis, John Beach, Billy Dudding, Glen Acord, Dwyn Taylor, Gary Pickrell, and Anbo Wang. "Application of sapphire-fiber-Bragg-grating-based multi-point temperature sensor in boilers at a commercial power plant." *Sensors* 19, no. 14 (2019): 3211. https://doi.org/10.3390/s19143211

[244] Willsch, M., T. Bosselmann, P. Flohr, R. Kull, W. Ecke, I. Latka, D. Fischer, and T. Thiel. "Design of fiber optical high temperature sensors for gas turbine monitoring." In *20th International conference on optical fibre sensors*, vol. 7503, pp. 1117-1120. SPIE, 2009. https://doi.org/10.1117/12.835875

[245] Zhang, L., Y. Zhu, M. Jiang, Y. Wu, K. Deng, and Q. Ni. "Body Temperature Monitoring for Regular COVID-19 Prevention Based on Human Daily Activity Recognition." *Sensors* 21 (2021): 1–19. https://doi.org/10.3390/s21227540

[246] Costanzo, Sandra, and Alexandra Flores. "A non-contact integrated body-ambient temperature sensors platform to contrast COVID-19." *Electronics* 9, no. 10 (2020): 1658. https://doi.org/10.3390/electronics9101658

[247] Zhang, Hui, Shecheng Gao, Yunhan Luo, Zhenshi Chen, Songsong Xiong, Lei Wan, Xincheng Huang et al. "Ultrasensitive Mach-Zehnder interferometric temperature sensor based on liquid-filled D-shaped fiber cavity." *Sensors* 18, no. 4 (2018): 1239. https://doi.org/10.3390/s18041239

[248] Pathak, A. K., and C. Viphavakit. "A Review on All-Optical Fiber-Based VOC Sensors: Heading Towards the Development of Promising Technology." *Sensors and Actuators A: Physical* 338 (2022): 113455. https://doi.org/10.1016/j.sna.2022.113455

[249] Wang, Z., D. L. Chen, X. C. Yang, S. X. Liang, and X. H. Sun. "Temperature Sensor of Single-Mode-No-Core-Single-Mode Fiber Structure Coated with PDMS." *Optical Fiber Technology* 68 (2022): 102793. https://doi.org/10.1016/j.yofte.2021.102793

[250] Mollah, M. A., S. M. R. Islam, M. Yousufali, L. F. Abdulrazak, M. B. Hossain, and I. S. Amiri. "Plasmonic Temperature Sensor Using D-Shaped Photonic Crystal Fiber." *Results in Physics* 16 (2020): 102966. https://doi.org/10.1016/j.rinp.2020.102966

[251] Zamri, A. Z. M., N. U. H. H. Zalkepali, N. A. Awang, M. K. Mustafa, N. N. H. E. N. Mahmud, and N. A. M. Muhammad. "Responsiveness of Temperature Using Tunable Dual-Wavelength Q-Switched Fiber Laser." Laser *Physics* 33 (2023): 1–5. https://doi.org/10.1088/1555-6611/acbf3a

[252] Liao, C. R., and D. N. Wang. "Review of Femtosecond Laser Fabricated Fiber Bragg Gratings for High Temperature Sensing." *Photonic Sensors* 3 (2013): 97–101. https://doi.org/10.1007/s13320-012-0060-9

[253] Kim, B., H. Jeong, Y. S. Lee, S. Hong, and K. Oh. "Spatially Selective DNA Deposition on the Fiber Core by Optically Trapping an Aqueous Droplet and Its Application for Ultra-Compact DNA Fabry-Perot Temperature Sensor." *Sensors and Actuators Reports* 3 (2021): 100038. https://doi.org/10.1016/j.snr.2021.100038

[254] Teng, C., P. Shao, S. Li, S. Li, H. Liu, H. Deng, et al. "Double-Side Polished U-Shape Plastic Optical Fiber Based SPR Sensor for the Simultaneous Measurement of Refractive Index and Temperature." *Optics Communications* 525 (2022): 128844. https://doi.org/10.1016/j.optcom.2022.128844

[255] Muhammad, N. A. M., and N. A. Awang. "Spider Silk Biological Material for Q-Switched Temperature Sensor." *Physica Scripta* 99 (2024): 065532. https://doi.org/10.1088/1402-4896/ad474a

[256] Biluca, F. C., J. Bernal, S. Valverde, A. M. Ares, L. V. Gonzaga, A. C. O. Costa, et al. "Determination of Free Amino Acids in Stingless Bee (Meliponinae) Honey." *Food Analytical Methods* 12 (2019): 902–7. https://doi.org/10.1007/s12161-018-01427-x

[257] Ávila, S., P. S. Hornung, G. L. Teixeira, L. N. Malunga, F. B. Apea-Bah, M. R. Beux, et al. "Bioactive Compounds and Biological Properties of Brazilian Stingless Bee Honey Have a Strong Relationship with the Pollen Floral Origin." *Food Research International* 123 (2019): 1–10. https://doi.org/10.1016/j.foodres.2019.01.068

[258] Ranneh, Y., F. Ali, M. Zarei, A. M. Akim, H. A. Hamid, and H. Khazaai. "Malaysian Stingless Bee and Tualang Honeys: A Comparative Characterization of Total Antioxidant Capacity and Phenolic Profile Using Liquid Chromatography-Mass Spectrometry." LWT - *Food Science and Technology* 89 (2018): 1–9. https://doi.org/10.1016/j.lwt.2017.10.020

[259] De Sousa, J. M. B., E. L. De Souza, G. Marques, M. de T. Benassi, B. Gullón, M. M. Pintado, et al. "Sugar Profile, Physicochemical and Sensory Aspects of Monofloral Honeys Produced by Different Stingless Bee Species in Brazilian Semi-Arid Region." LWT - *Food Science and Technology* 65 (2016): 645–51. https://doi.org/10.1016/j.lwt.2015.08.058

[260] Silva, I. A. A., T. M. S. Da Silva, C. A. Camara, N. Queiroz, M. Magnani, and J. S. De Novais. "Phenolic Profile, Antioxidant Activity, and Palynological Analysis of Stingless Bee Honey from Amazonas, Northern Brazil." *Food Chemistry* 141 (2013): 3252–58. https://doi.org/10.1016/j.foodchem.2013.06.072

[261] Fletcher, M. T., N. L. Hungerford, D. Webber, M. Carpinelli de Jesus, J. Zhang, and I. S. J. Stone. "Stingless Bee Honey, a Novel Source of Trehalulose: A Biologically Active Disaccharide with Health Benefits." *Scientific Reports* 10 (2020): 1–8. https://doi.org/10.1038/s41598-020-68940-0
[262] Liu, Huijie, Xueyan Xing, Fuping Lu, and Yu Li. "Functional Modification of the Substrate-Binding Site for Isomaltulose Production Based on Predicted Structure of Sucrose Isomerase from Pantoea dispersa UQ68 J." In *Advances in Applied Biotechnology: Proceedings of the 3rd International Conference on Applied Biotechnology (ICAB2016), November 25-27, 2016, Tianjin, China 3*, pp. 59-68. Springer Singapore, 2018. https://doi.org/10.1007/978-981-10-4801-2_6
[263] Al-Mamary, M., A. Al-Meeri, and M. Al-Habori. "Antioxidant Activities and Total Phenolics of Different Types of Honey." *Nutrition Research* 22, no. 9 (2002): 1041–47. https://doi.org/10.1016/S0271-5317(02)00406-2
[264] Liu, Y., F. Qu, L. Luo, W. Xu, and M. Zhong. "Detection of Rice Syrup from Acacia Honey Based on Lubrication Properties Measured by Tribology Technique." *Tribology International* 129 (2019): 239–45. https://doi.org/10.1016/j.triboint.2018.08.027
[265] Yilmaz, M. T., N. B. Tatlisu, O. S. Toker, S. Karaman, E. Dertli, and O. Sagdic. "Steady, Dynamic and Creep Rheological Analysis as a Novel Approach to Detect Honey Adulteration by Fructose and Saccharose Syrups: Correlations with HPLC-RID Results." *Food Research International* 64 (2014): 634–46. https://doi.org/10.1016/j.foodres.2014.07.009
[266] Oroian, M., S. Ropciuc, and S. Paduret. "Honey Adulteration Detection Using Raman Spectroscopy." *Food Analytical Methods* 11 (2018): 959–68. https://doi.org/10.1007/s12161-017-1072-2
[267] Mehryar, L., and M. Esmaiili. "Honey and Honey Adulteration Detection: A Review." *International Congress on Engineering and Food*, 11th (2011): 1–6.
[268] Naila, A., S. H. Flint, A. Z. Sulaiman, A. Ajit, and Z. Weeds. "Classical and Novel Approaches to the Analysis of Honey and Detection of Adulterants." *Food Control* 90 (2018): 152–65. https://doi.org/10.1016/j.foodcont.2018.02.027
[269] Guler, A., H. Kocaokutgen, A. V. Garipoglu, H. Onder, D. Ekinci, and S. Biyik. "Detection of Adulterated Honey Produced by Honeybee (Apis Mellifera L.) Colonies Fed with Different Levels of Commercial Industrial Sugar (C3 and C4 Plants) Syrups by the Carbon Isotope Ratio Analysis." *Food Chemistry* 155 (2014): 155–60. https://doi.org/10.1016/j.foodchem.2014.01.033
[270] Chen, L., X. Xue, Z. Ye, J. Zhou, F. Chen, and J. Zhao. "Determination of Chinese Honey Adulterated with High Fructose Corn Syrup by Near Infrared Spectroscopy." *Food Chemistry* 128 (2011): 1110–14. https://doi.org/10.1016/j.foodchem.2010.10.027
[271] Zimmet, P., K. G. M. M. Alberti, and J. Shaw. "Global and Societal Implications of the Diabetes Epidemic." *Nature* 414, no. 6865 (2001): 782–87. https://doi.org/10.1038/414782a
[272] Sobrino-Gregorio, L., R. Bataller, J. Soto, and I. Escriche. "Monitoring Honey Adulteration with Sugar Syrups Using an Automatic Pulse Voltammetric Electronic Tongue." *Food Control* 91 (2018): 254–60. https://doi.org/10.1016/j.foodcont.2018.04.003
[273] Wu, Liming, Bing Du, Yvan Vander Heyden, Lanzhen Chen, Liuwei Zhao, Miao Wang, and Xiaofeng Xue. "Recent advancements in detecting sugar-based adulterants in honey–A challenge." *TrAC Trends in Analytical Chemistry* 86 (2017): 25-38. https://doi.org/10.1016/j.trac.2016.10.013
[274] Tosun, Murat. "Detection of adulteration in honey samples added various sugar syrups with 13C/12C isotope ratio analysis method." *Food chemistry* 138, no. 2-3 (2013): 1629-1632. https://doi.org/10.1016/j.foodchem.2012.11.068
[275] Gallardo-Velázquez, Tzayhri, Guillermo Osorio-Revilla, Marlene Zuñiga-de Loa, and Yadira Rivera-Espinoza. "Application of FTIR-HATR spectroscopy and multivariate analysis to the quantification of adulterants in Mexican honeys." *Food Research International* 42, no. 3 (2009): 313-318. https://doi.org/10.1016/j.foodres.2008.11.010
[276] Paradkar, M. M., and J. Irudayaraj. "Discrimination and classification of beet and cane inverts in honey by FT-Raman spectroscopy." *Food chemistry* 76, no. 2 (2002): 231-239. https://doi.org/10.1016/S0308-8146(01)00292-8
[277] Ruiz-Matute, Ana I., Michal Brokl, Ana C. Soria, M. Luz Sanz, and Isabel Martínez-Castro. "Gas chromatographic–mass spectrometric characterisation of tri-and tetrasaccharides in honey." *Food Chemistry* 120, no. 2 (2010): 637-642. https://doi.org/10.1016/j.foodchem.2009.10.050
[278] Cotte, Jean-François, Hervé Casabianca, Barbara Giroud, M. Albert, J. Lheritier, and Marie-Florence Grenier-Loustalot. "Characterization of honey amino acid profiles using high-pressure liquid chromatography to control authenticity." *Analytical and bioanalytical chemistry* 378, no. 5 (2004): 1342-1350. https://doi.org/10.1007/s00216-003-2430-z
[279] Wang, Jinmei, Xiaofeng Xue, Xiaojing Du, Ni Cheng, Lanzhen Chen, Jing Zhao, Jianbin Zheng, and Wei Cao. "Identification of acacia honey adulteration with rape honey using liquid chromatography–electrochemical detection and chemometrics." *Food analytical methods* 7 (2014): 2003-2012. https://doi.org/10.1007/s12161-014-9833-7

[280] CABANero, ANA I., Jose L. Recio, and Mercedes Ruperez. "Liquid chromatography coupled to isotope ratio mass spectrometry: a new perspective on honey adulteration detection." *Journal of agricultural and food chemistry* 54, no. 26 (2006): 9719-9727. https://doi.org/10.1021/jf062067x
[281] Kelly, J. Daniel, Cristina Petisco, and Gerard Downey. "Potential of near infrared transflectance spectroscopy to detect adulteration of Irish honey by beet invert syrup and high fructose corn syrup." *Journal of Near infrared spectroscopy* 14, no. 2 (2006): 139-146. https://doi.org/10.1255/jnirs.599
[282] Li, Shuifang, Xin Zhang, Yang Shan, Donglin Su, Qiang Ma, Ruizhi Wen, and Jiaojuan Li. "Qualitative and quantitative detection of honey adulterated with high-fructose corn syrup and maltose syrup by using near-infrared spectroscopy." *Food chemistry* 218 (2017): 231-236. https://doi.org/10.1016/j.foodchem.2016.08.105
[283] Zhu, Xiangrong, Shuifang Li, Yang Shan, Zhuoyong Zhang, Gaoyang Li, Donglin Su, and Feng Liu. "Detection of adulterants such as sweeteners materials in honey using near-infrared spectroscopy and chemometrics." *Journal of Food Engineering* 101, no. 1 (2010): 92-97. https://doi.org/10.1016/j.jfoodeng.2010.06.014
[284] Lolli, Massimo, Davide Bertelli, Maria Plessi, Anna Gloria Sabatini, and Cinzia Restani. "Classification of Italian honeys by 2D HR-NMR." *Journal of Agricultural and Food Chemistry* 56, no. 4 (2008): 1298-1304. https://doi.org/10.1021/jf072763c
[285] Padovan, Gilberto João, D. De Jong, L. P. Rodrigues, and Julio Sergio Marchini. "Detection of adulteration of commercial honey samples by the 13C/12C isotopic ratio." *Food Chemistry* 82, no. 4 (2003): 633-636. https://doi.org/10.1016/S0308-8146(02)00504-6
[286] Çinar, Serap B., Aziz Ekşi, and İlknur Coşkun. "Carbon isotope ratio (13C/12C) of pine honey and detection of HFCS adulteration." *Food chemistry* 157 (2014): 10-13. https://doi.org/10.1016/j.foodchem.2014.02.006
[287] Sobrino-Gregorio, Lara, María Vargas, Amparo Chiralt, and Isabel Escriche. "Thermal properties of honey as affected by the addition of sugar syrup." *Journal of food engineering* 213 (2017): 69-75. https://doi.org/10.1016/j.jfoodeng.2017.02.014
[288] Zábrodská, Blanka, and Lenka Vorlová. "Adulteration of honey and available methods for detection–a review." Acta Veterinaria Brno 83, no. 10 (2015): 85-102. https://doi.org/10.2754/avb201483S10S85
[289] Kumar, Manish, and Sanjeev Kumar Raghuwanshi. "Design and analysis of surface plasmon resonance (SPR) sensor to check the quality of food from adulteration." *In Physics and Simulation of Optoelectronic Devices* XXVI, vol. 10526, pp. 332-339. SPIE, 2018. https://doi.org/10.1117/12.2289077
[290] Spadavecchia, J., M. G. Manera, F. Quaranta, P. Siciliano, and R. Rella. "Surface plamon resonance imaging of DNA based biosensors for potential applications in food analysis." *Biosensors and Bioelectronics* 21, no. 6 (2005): 894-900. https://doi.org/10.1016/j.bios.2005.02.016
[291] Yakes, B. J., Jos Buijs, C. T. Elliott, and K. Campbell. "Surface plasmon resonance biosensing: Approaches for screening and characterising antibodies for food diagnostics." Talanta 156 (2016): 55-63. https://doi.org/10.1016/j.talanta.2016.05.008
[292] Woyessa, Getinet, Andrea Fasano, Alessio Stefani, Christos Markos, Kristian Nielsen, Henrik K. Rasmussen, and Ole Bang. "Single mode step-index polymer optical fiber for humidity insensitive high temperature fiber Bragg grating sensors." *Optics Express* 24, no. 2 (2016): 1253-1260. https://doi.org/10.1364/OE.24.001253
[293] Wang, Qi, and Wan-Ming Zhao. "A comprehensive review of lossy mode resonance-based fiber optic sensors." *Optics and Lasers in Engineering* 100 (2018): 47-60. https://doi.org/10.1016/j.optlaseng.2017.07.009
[294] Verma, R. K. "Design considerations of a surface plasmon resonance (SPR) based tapered fiber optic bio-sensing probe with graphene-MoS2 over layers." *Optik* 180 (2019): 330-343. https://doi.org/10.1016/j.ijleo.2018.11.081
[295] Verma, Rajneesh K., Payal Suwalka, and Jatin Yadav. "Detection of adulteration in diesel and petrol by kerosene using SPR based fiber optic technique." *Optical Fiber Technology* 43 (2018): 95-100. https://doi.org/10.1016/j.yofte.2018.04.011
[296] Tan, Chan-Yuan, and Yao-Xiong Huang. "Dependence of refractive index on concentration and temperature in electrolyte solution, polar solution, nonpolar solution, and protein solution." *Journal of Chemical & Engineering Data* 60, no. 10 (2015): 2827-2833.https://doi.org/10.1021/acs.jced.5b00018
[297] Singh, Vivek Kumar, Brij Bir Singh Jaswal, Vinay Kumar, Ram Prakash, and Priyanka Rai. "Application of He-Ne laser to study of the variation of refractive index of liquid solutions with the concentration." *Journal of Integrated Science and Technology* 1, no. 1 (2013): 13-18.