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Design Optimization of Fiber Laser for Generation of Femtosecond Optical Pulses

Zahid Muhammad[1*], Ubaid Ullah Khalil[1], Anees Khan[1], Tanweer Ahmed[1], Waqas Khan[1], Samra Naz[1]

[1]Department of Physics, Hazara University Mansehra, Pakistan

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***Corresponding author:** Zahid Muhammad
Department of Physics, Hazara University Mansehra, Pakistan

Abstract **Original Research Article**

The precise coordination of dispersion management, temperature control, mode-locking mechanisms, and gain medium qualities are required in the design and optimization of fiber laser cavities for the generation of femtosecond pulses. The performance and capacities of femtosecond fiber lasers are being enhanced by developments in these fields, opening up new uses for them. The main focus of this research work was to design a lasing cavity for the generation of femtosecond optical pulses. So, we designed a laser cavity having six segments with a total length of 5.4 meters. The first segment is a 100-centimeter-long single mode fiber (SMF), the second one is an active fiber (Yb doped fiber) which is 40-centimeter long, and the third segment is a 70-centimeter-long SMF.A 130 cm free space region(cavity) makes up the fourth segment, which include a collimator, mirror, grating, half wave plate, quarter wave plate, isolator, and polarized beam splitter (PBS). Single-mode fibers of 80 cm and 120 cm in length comprises the fifth and sixth sections respectively. The calculated repetition rate of the laser cavity is 37.06 MHz.. We used the software "Ultrafast Pulse Propagator Version 3.0.0", created by Bilkent University in Ankara, Turkey, to accomplished this task. This application was initially created to examine fiber links, mode-locking, and fiber amplification. The physics of the code is based on the generalized non-linear Schrödinger equation, which includes high order dispersion, bandwidth, gain with restriction, saturation loss, and saturation absorption. For data visualization, this software uses FORTRAN code and MATLAB algorithms. The pulse width increased linearly from 1.2809 to 1.3227 Ps and the spectral width decreased linearly from 2.3841 to 2.2561 nm when the Yb doped fiber's length were changed between 5 and 50 cm. 94729 fs^2 is the total dispersion from the 5.4 m long lasing cavity. In the end, we determined the pulses' repetition rate, which came out to be 37.06 MHz. To create steady, noise-free, ultrashort optical pulses, every parameter including active fiber (Yb) lengths and total cavity lengths are adjusted for the laser cavity design.

Keywords: Fiber Laser, Femtosecond Optical Pulses, dispersion management.

INTRODUCTION

Elias Spitzer created fiber lasers in 1963. This type of solid-state laser uses rare-earth elements like Ytterbium and Neodymium as its main source of gain in fiber. In the field of solid-state lasers, these are the key technologies. The fiber lasers have an active area of several meters, which allows them to produce significant optical gain. Due to its high fiber-to-surface ratio, which enables it to sustain constant power production in the Kw range, it can efficiently cool it.

By following this pattern, it's possible to turn the relatively low brightness pump beam into a higher brightness signal and the major core can be pushed at a stronger intensity than it would have spread to [1,2]. The most primitive design tends to be [3] symmetrical dual circular fibers [4,5]. Shorter fibers have fewer basic and optical pump portions when appropriate cladding is used. Under the right conditions, laser fibers can emit one or more black pulses. We showed that the generation of Dark solitons in the laser resulted in the formation of dark pulses, based on numerical simulations [6].

All kinds of fiber lasers have recently produced multiple wavelength dissipation solitons, which are passively scattered using SESAM lock. It has been discovered that in a bending-dependent laser, one stable wavelength and three times the dissolved wavelength can form. The nature of events can be linked to the mechanisms of his generation [7]. In addition to clamping the fibers in the fiber laser, the pump's light is also transmitted over and over again by the nucleus since the nucleus is wrapped around it like a cord [8]. Since numerous pump generators are used all around the loop, this configuration is appropriate for power growth [9, 10]. Fiber lasers gained an extensive amount of fascination increasingly as power sources of femtosecond pulses due to their great stability, small dimensions, and cost-effectiveness.

In the last two years, significant advancements have been made using Yb-fiber lasers operating at 1 micrometer. With the demonstration [11] of a new mode-locking regime that uses self-similar pulse propagation, these lasers can now regularly produce sub-100 fs pulses with energies greater than 5 nJ at repetition rates ranging from 30 to 50 MHz [12, 33]. Approximately 30 MHz was the normal repetition rate at which these lasers were run [12, 13, 14]. As far as we are aware, only the repetition rate's lower bound resulting from residual birefringence has been examined [15]. Investigating the upper bounds on the repetition rate so appears reasonable.

Furthermore, there is a pragmatic incentive as numerous applications require repetition rates greater than approximately 100 MHz. One prominent instance is optical frequency metrology, where a number of teams are investigating the application of fiber lasers [16, 17, 18, 19]. In this instance, achieving a suitably big comb line spacing requires a high repetition rate (about > 150MHz).

Harmoniously mode-locked lasers can also attain higher repetition rates. Nevertheless, passive harmonic mode-locking is not stable for many applications, while active harmonic mode-locking produces picosecond pulses. Moreover, strong, femtosecond pulses can be produced in conjunction with a Yb fiber amplifier [20], which would be very useful for applications like micro-machining. Thus far, essentially mode-locked fiber lasers with pulse lengths of 100 fs or less have only managed to achieve repetition rates of about 100 MHz at 1m [14] and 130 MHz at 1.55 micro meter [21] (using an Er/Yb co-doped glass waveguide amplifier). Er-fiber lasers have been claimed to exhibit repetition rates of up to 300 MHz; however, the length of the pulses was limited to approximately 500fs [22].

Here, we describe methodically increasing a Yb fiber laser's fundamental repetition rate to 200 MHz while maintaining sub-100 fs pulse durations. Since Yb fiber has the best gain per length among fibers that are easily obtainable, we have selected it as the gain medium. Boosting the repetition rate of fiber lasers faces two unique obstacles: Practically speaking, the cavity length is restricted by the physical dimensions of the laser cavity's constituent parts. More importantly, though, a threshold power is required to start passive mode-locking. The widely-used methods for passively locking the mode of fiber lasers depend on the phase shifts that the pulse accumulates as it passes through the fiber, which are dependent on its intensity. The most popular method is nonlinear polarization evolution (NPE) [23], which has a significant modulation depth (about 50%) and nearly immediate response. Removed from the cavity, the eliminated light can be employed as a useful output port when a polarizing beamsplitter is utilized. The nonlinear optical loop mirror [24] and its variants are further techniques that have been demonstrated to generate brief, high-energy pulses [25]. However, because these technologies require longer fiber lengths, they are not suitable for high repetition rate operation. The peak power of the pulse is limited when the cavity's round-trip time is shortened because less energy is held inside. Furthermore, with a given power, a shorter fiber section results in a less nonlinear phase shift. Consequently, unlike a laser mode-locked by a saturable Reflector Bragg, the pump power threshold for mode-locking increases quadratically with the repetition rate, to first order, with all other parameters remaining unchanged.

Fiber Laser Cavity

Fiber lasers capable of generating femtosecond optical pulses are crucial for a variety of applications, including high-precision manufacturing, medical imaging, and telecommunications. The design and optimization of these lasers' cavities are critical in achieving high peak powers and short pulse durations. Typically, Yb-doped, Er-doped, or Tm-doped fibers are used. The choice depends on the desired wavelength and pulse characteristics.

Pump Sources: Diode lasers or laser diodes that provide energy to excite the gain medium.

Wavelength-Selective Elements: Dichroic mirrors, gratings, and filters to ensure proper mode selection and pulse shaping.

Dispersion Compensators: Such as prisms or diffraction gratings, to manage and compensate for the dispersion within the fiber.

Nonlinear Optical Fiber: For processes such as self-phase modulation and supercontinuum generation.

Nonlinear Crystals: Used for frequency conversion and pulse shaping.

Saturable Absorbers: Such as semiconductor saturable absorber mirrors (SESAMs) or fiber-based saturable absorbers to initiate and maintain mode-locking.

Nonlinear Polarization Rotation (NPR): Utilizes nonlinear interactions to achieve mode-locking.

Ring Cavity: Offers flexibility in adjusting cavity length and is less sensitive to alignment issues.

Linear Cavity: Typically used in multi-stage configurations to achieve specific pulse characteristics.

Normal Dispersion vs. Anomalous Dispersion: Anomalous dispersion is often used to achieve soliton-like pulse shaping. Careful design of the dispersion profile is crucial to maintain pulse compression and avoid pulse broadening.

Cooling Mechanisms: Such as heat sinks or thermoelectric coolers to prevent thermal effects that can degrade performance.

Fiber Length and Pumping: Optimization to balance gain and thermal load.

Adjusting the Cavity Length: Fine-tuning to synchronize with the pulse repetition rate.

Pump Power Optimization: Ensuring sufficient gain without introducing excessive thermal effects.

Mode Field Matching: Between the pump and signal modes to minimize losses and maximize efficiency.

Optical Coatings: High-quality coatings to reduce losses and maximize transmission.

Environmental Control: Minimizing temperature fluctuations and vibrations that can affect cavity stability.

Feedback Systems: Implementing active or passive stabilization methods to ensure consistent performance.

The design and optimization of fiber laser cavities for femtosecond pulse generation involve a careful balance of gain medium properties, mode-locking mechanisms, dispersion management, and thermal control. Advances in these areas continue in order to enhance the efficiency and capabilities of femtosecond fiber-lasers, enabling their use in increasingly demanding applications.

Ytterbium Doped Fiber Laser

An ytterbium-doped fiber laser (YDFL) is a type of solid-state laser that uses ytterbium ions (Yb^{3+}) as the active laser medium. These lasers are popular due to their efficiency, high output power, and broad wavelength range. Yb-doped fiber lasers typically emit light in the range of 1030–1080 nm. The exact wavelength depends on the specific doping concentration and fiber design. The core of the laser where the lasing action occurs. The fiber is doped with ytterbium ions that provide the laser's gain medium. A diode laser is used to excite the ytterbium ions. The pump light is absorbed by the ytterbium ions, which then emit laser light when they return to a lower energy state. Two mirrors, one highly reflective (HR) and one partially reflective (PR)—that form an optical cavity. The mirrors are aligned to allow light to bounce back and forth through the doped fiber, amplifying the light with each pass. The partially reflective mirror allows a portion of the laser light to exit the cavity as the output beam. The reflectivity of this mirror determines the output power and mode characteristics of the laser. The fiber may include additional components like cladding, coatings, and sometimes a fiber Bragg grating to control wavelength and mode.

The diode pump source injects light into the ytterbium-doped fiber, exciting the ytterbium ions to a higher energy state. As the excited ytterbium ions return to their ground state, they emit photons. These photons stimulate further emissions from other excited ions, leading to a cascade effect. The optical resonator, composed of the mirrors, reflects the photons back through the fiber, causing further amplification. Some of the amplified light is transmitted through the partially reflective mirror, producing the laser output.

Ytterbium-doped fiber lasers are known for their excellent performance, including high efficiency, good beam quality, and the ability to operate at high power levels. Yb-doped fiber lasers are used for materials processing, such as cutting and welding. They are utilized in surgical and diagnostic applications due to their high power and precision. They serve as sources for spectroscopy and microscopy. Yb-doped fiber lasers are valued for their high efficiency, robustness, and relatively simple design compared to other fiber lasers.

Experimental Setup and Cavity Design of Ytterbium Doped Fiber Laser

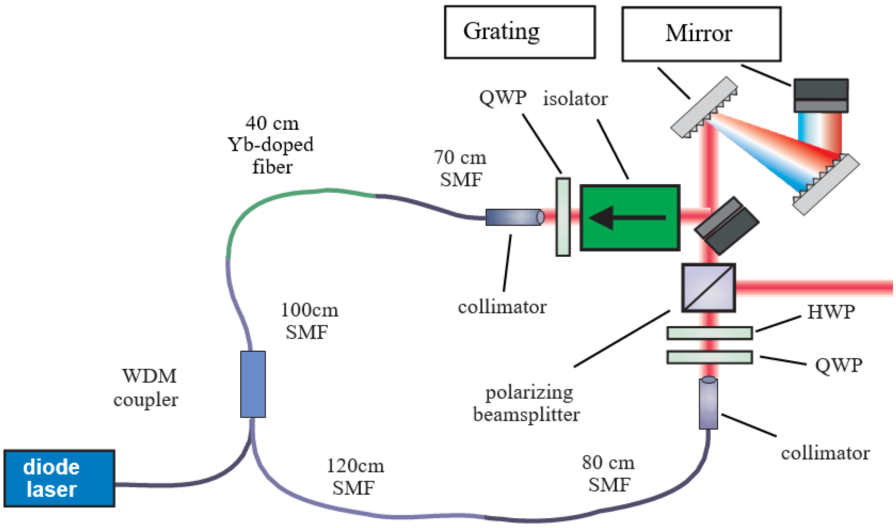


Figure 1 shows how the fiber laser cavity is designed. The overall length of this cavity is 5.4 meters. It is divided into three sectors: SMF, measuring 100 cm in the first part, an active fiber Yb doped, measuring 40 cm in part 2, and SMF, measuring 70 cm in part 3. A 130 cm open space makes up the fourth section, which also includes a variety of optical components such an isolator, grating, mirror, half and quarter plates, and (PBS). Single-mode(SMF) fibers measuring 80 and 120 centimeters in length, make up the fifth and sixth sections. WDM is used to pump active fibers using a diode laser. Through an SMF, the WDM combines the pump and laser wavelengths. The cavity's total "dispersion" is 94729 fs^2. We designed our laser cavity with ultra short pulses in mind, using software to get the desired outcome, based on our understanding of the fundamentals of lasers, mode locking, and ultrashort pulses. An electronic device known as "WDM" merges optical data from various fibers with varying wavelengths onto a single fiber. It is more affordable to expand the capacity existing fiber optic links. WDM pumps active fibers using a diode laser. The WDM uses an SMF to combine the pump and laser wavelengths. The cavity's total "dispersion" is 94729 fs^2. Knowing the basics of lasers, mode locking, and ultrashort pulses, we developed our laser cavity with ultra short pulses in mind, utilizing software to achieve the required result. All of the inputs are combined into a single output fiber via a coupler known as the WDM input. WDM usually has a large number of inputs. Multiplexing is the process of receiving a signal from fiber and multiplexing the light into identical broad beams. When light strikes the grating, it splits into various wavelengths at various angles. Gratings are mirror-like objects with prism-like properties. To produce a different product for every wavelength of light, optics collects and focuses each wavelength in the fiber. Using WDM has a lot of benefits. One common connection can supply wavelengths, allowing the use of already-existing equipment. Selecting the appropriate laser transmitter for WDM multicast is necessary to ensure accurate decoding of every channel at the receiving end. It is projected that upcoming developments will create 80–128 channels. It is possible to mix and match digital signals.

A wave plate or damper is a type of "light device" that alters the “polarization" state of the light that passes through it. The components that make up the wave panels are perforated, such quartz or fiber glass. along one or both of two specified crystallographic axes, the refractive index of which differs from linearly polarized light. Variations in the refractive index, light wavelength, and crystal width all affect how well a wave plate performs. Through the proper selection of the relationship between these parameters, the polarity of the light wave can be altered by entering a controlled phase shift between its two polarizing parts. Wave boards come in two distinct forms.

With the addition of a half-wave plate, linearly polarized radiation can have its polarization direction modified. If the angle is produced by the optical axis and the input polarization θ, then the output polarization is 2θ cyclic. by employing a quarter-wave plate to change the linear polarization of the input beam to round (or oval) polarization. Right "polarized light" is created if the four-wave board optical axis is 45° of rotation away from the incoming "polarized light" axis of optical. Like semiconductors, fiber isolators are passive components used in fibers-optic links.

A light isolator's function as an optical magnetic device is to allow light transmission in just one corridor. This relief prevents the laser source from emitting signals that aren't needed and could cause the laser source to go out, including "frequency offsets," the spot jumps, and capacitance modifications. An isolator is therefore a crucially important and practical technique for reducing these impacts. The Faraday Effect, which describes a process wherein the polarization plane cycles as it travels through the glass subjected to a magnetic field, is what makes a "optical isolator depend" on its function. The "route" of the magnetic field determines the turning path rather than the "route" of "light transmission." There are two kinds of operation modes, depending on various lighting trends. There are two positions: the front position and the back position. Light can enter the "input polarizer" and become "linearly polarized" when it is in the front position. The Faraday axis rotates 45 degrees as the light gets closer to it. As a result, the light maintains its 45° polarization state at the end of the polarizations phase. However, the light enters the final polarizer at the back location by 45 degrees of polarization first. The rotation then proceeds in the same direction for an additional 45 degrees after passing over the Faraday axis. After that, the polarized light turns 90 degrees perpendicular to the "input polarizer," making it difficult for the "isolator" to hold onto the light, which will either reflect or absorb it. The polarized beams splitter (PBS) reflects transverse "polarized light" (90 degrees of polarization) and passes the X-axis "polarized light" (0 degrees of polarization). uses a polarized beam splitter to split the incoming beams into two transverse beams and a polarized beam. The rectangle and slab have slit openings that are the most significant form of slit beams, while there are other varieties as well. They provide a variety of functions. Two of the three glass prisms are joined in the base of the Cube Ray, Cube utilizing polyester epoxies. Rearranging the resin sheet's breadth results in half of the lightbulb being transported and the other half being bounced back through one outlet. One output fiber and one fiber can be combined with the polarizing beam incision. Every input signal will be delivered along a distinct output polarization axis when the device is utilized as a beam collector. Maintaining the fibers is crucial when using these polarized lines.

An optical tool called a collimator is used to emit or reflect parallel light through fibers. It is necessary to transform the light output from optical-fibers into a free-space continuous beam. For this, a parallel-lenses works well. But the conclusion of the "focal length" of the lens is the distance at which the fibers are fixed. Collimators are necessary to convert a divergent "optical fibers light emission into a parallel beam of light. The change in the structure of the fibers provides the basis for two different forms of parallelism. It is possible to apply some collimation straight to bare fibers. This is the most affordable and portable option. The second kind of fiber stabilizers should not be used with bare fibers because they have a mechanical interaction with a fibrous conductor. This is readily affixed to and detached from the fiber's end.

RESULTS AND DISCUSSION

Pulse width refers to the duration of a single pulse emitted by the laser, typically measured in picoseconds (ps) or femtoseconds (fs). In CW mode, there is no distinct pulse width as the laser emits a continuous beam. For mode-locked Ytterbium-doped fiber lasers, pulse widths can range from tens of femtoseconds to several picoseconds. The exact pulse duration depends on factors like the laser cavity design, dispersion management, and the mode-locking technique used. To generate shorter pulses, advanced techniques such as dispersion compensation (using gratings or prisms) and nonlinear effects (like self-phase modulation) are employed. Shorter pulses are generally achieved by optimizing the fiber and cavity design to support mode-locking and manage dispersion effectively. Spectral width, or bandwidth, refers to the range of wavelengths over which the laser pulse's energy is distributed, typically measured in 10^{-9}meters (nm) or terahertz (THz).

Yb-doped fiber lasers can have spectral widths ranging from (10^{-9}) nanometers to several tens of (10^{-9}) nanometers, based on the pulse width and the laser configuration. Shorter pulses (in the femtosecond range) often result in broader spectral widths due to the time-bandwidth product constraint, where shorter pulses have wider spectra.

The spectral width is influenced by factors like the gain medium's emission spectrum, the dispersion in the fiber, and any additional spectral shaping components used in the laser system.

There is an inverse relationship between pulse width and spectral width governed by the Fourier transform relationship. Shorter pulses have wider spectral bandwidths, while longer pulses have narrower spectral bandwidths.

For ytterbium-doped fiber lasers, pulse widths can vary from tens of femtoseconds to picoseconds, and spectral widths can span several nanometers. The pulse width and spectral width are interrelated through the time-bandwidth product, which defines the trade-off between pulse duration and spectral bandwidth**)** we designed our laser cavity for ultra short pulses and used software to obtained the result, we choose the Yb doped fibers. The various factors that effect on pulse duration and spectral broadening are presented here.

Segment Specifications

Section I: The first portion is an SMF and is 100 cm in length. The SMF has a projected fracturing power-rating of 0.95, an unsaturated gain of 0.0, a gain band-width of 30.0 nm, and a Kerr coefficient of 2.7.

Section II: Doped Ytterbium fiber (an active fiber) is the second segment. The YDF's length is measured between 5 and 50 centimeters. The active fibers have a Kerr coefficient of 2.7. Yb-doped fibers provide a potential fraction of 0.98, a gain saturation energy of 10.0 nJ, and zero unsaturated gain within a 30 nm gain bandwidth.

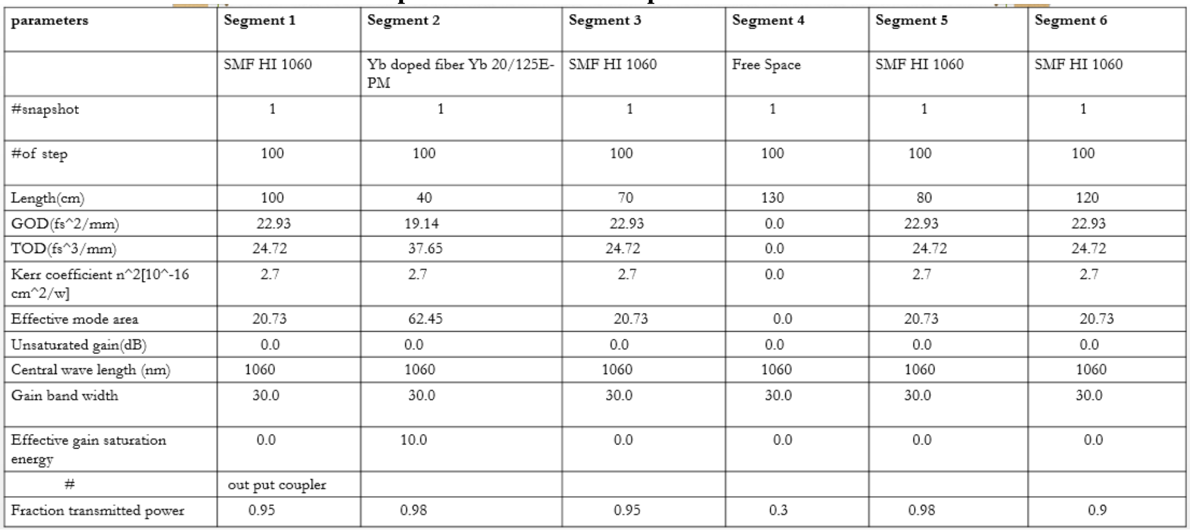
Section III: Additionally, Part 3 is Hi1060 single-mode fiber. Part 3 length is 70 cm. This sector's gain bandwidth is 30 nm, its transmission potential ratio is 0.95, and its Kerr coefficient is 2.7.

Section IV: Section 4 is a 130 cm long Free space. This section contains a variety of optical components, including grids, isolators, half-wave boards, parallel and quadruple wave boards, and polarized beam splitter and mirrors. Each side of the free space is filled with collimators. NPR uses wave retarders to achieve passive locking. The wave boards' angle is automatically calculated by the application. The Kerr coefficient, GVD, For this sector, TOD, unsaturated gain, and effective saturation energy are all 0. There is a 0.3 fraction of energy transmitted.

Section V: Part 5 is again a Hi1060 SMF. In portion 4, the SMF's length is fixed at one meter. The fraction of transmitted energy is 0.98 and the saturation gain is 0 in Sector 5, "Unsaturated Profit" and Energy Efficiency.

Section VI: The final section of the cavity design, Part 6, is 120 cm long and uses SMF yet again. Another time, the coefficient of Kerr is 2.7, with a band-width of 30 nm, a transmitted power output of 0.9. 1060 nm is the primary wavelength used by all sectors. The Table contains all of the sector's information.

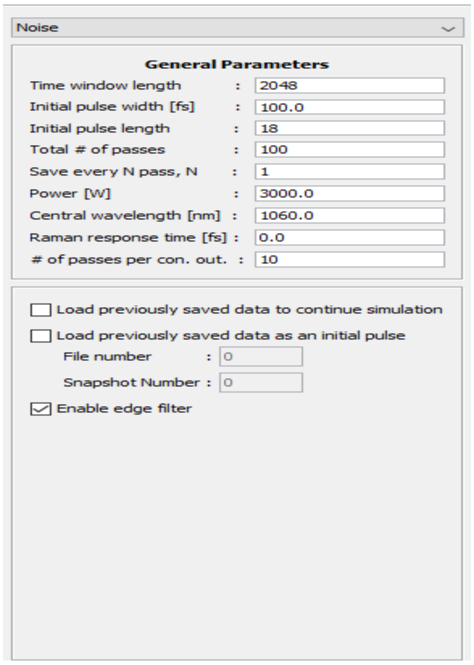
Table 1.: An explanation of each component in the laser chamber



parameters	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6
	SMF HI 1060	Yb doped fiber Yb 20/125E-PM	SMF HI 1060	Free Space	SMF HI 1060	SMF HI 1060
#snapshot	1	1	1	1	1	1
#of step	100	100	100	100	100	100
Length(cm)	100	40	70	130	80	120
GOD(fs^2/mm)	22.93	19.14	22.93	0.0	22.93	22.93
TOD(fs^3/mm)	24.72	37.65	24.72	0.0	24.72	24.72
Kerr coefficient n^2[10^-16 cm^2/w]	2.7	2.7	2.7	0.0	2.7	2.7
Effective mode area	20.73	62.45	20.73	0.0	20.73	20.73
Unsaturated gain(dB)	0.0	0.0	0.0	0.0	0.0	0.0
Central wave length (nm)	1060	1060	1060	1060	1060	1060
Gain band width	30.0	30.0	30.0	30.0	30.0	30.0
Effective gain saturation energy	0.0	10.0	0.0	0.0	0.0	0.0
#	out put coupler					
Fraction transmitted power	0.95	0.98	0.95	0.3	0.98	0.9

General Parameters

The following is a description of the software's general parameters.



General Parameters

Time window length : 2048
Initial pulse width [fs] : 100.0
Initial pulse length : 18
Total # of passes : 100
Save every N pass, N : 1
Power [W] : 3000.0
Central wavelength [nm] : 1060.0
Raman response time [fs] : 0.0
# of passes per con. out. : 10

☐ Load previously saved data to continue simulation
☐ Load previously saved data as an initial pulse
File number : 0
Snapshot Number : 0
☑ Enable edge filter

Figure 2: The general parameter is displayed

GVD and TOD for SMF (Hi1060)

We measure the "GVD, TOD" of a single-mode fiber with a cut-off wavelength of 940 nm, a numerical aperture (NA) of 0.14, and a core-radius (Cr) of 2.57 µm.

The formula can be used to calculate the effective pattern area (A). $A = \pi r^2$The computed mode's effective surface is 20.73 μm^2. Dispersion of group velocity = 22.93 fs^2/mm Dispersion at third order = 24.72 fs^3/mm.

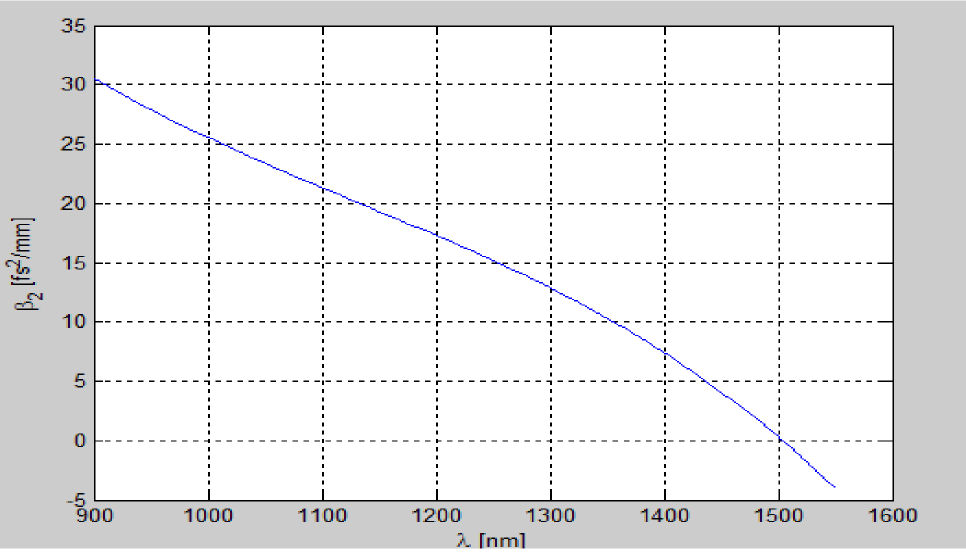


Figure 3: SMF's dispersion coefficient in relation to wavelength

Figure 3 explains how the dispersion decreases with increasing wavelength. It should be noted that the dispersion is zero at a wavelength of 1500 nm. The pulse propagation is positive, and the dispersion in the wavelength is a negative known as anomalous dispersion. This indicates that a longer wavelength moves more slowly than a shorter one. Positive dispersion and negative pulse propagation are present below this wavelength, or 1500 nm, indicating that the longer wavelength is moving more quickly than the shorter wavelength. Natural dispersion is another name for positive dispersion. The normal dispersion will be replaced with the anomalous dispersion in order to get the limited dispersion.

GVD and TOD for (Yb)

We utilize a 0.075 numerical aperture for determining the (Yb)doped fibers' "GVD" and "TOD".

The cutting wavelength is 875 nm, and the basic radius is 4.466µm. Using the formula $A = \pi r^2$, we were able to determine the doped-mode area. The "effective-mode area" after the computation is 62.87μm^2. Dispersion of group velocity = 19.14 fs^2/mm Dispersion of the third order = 37.65 fs^3/mm

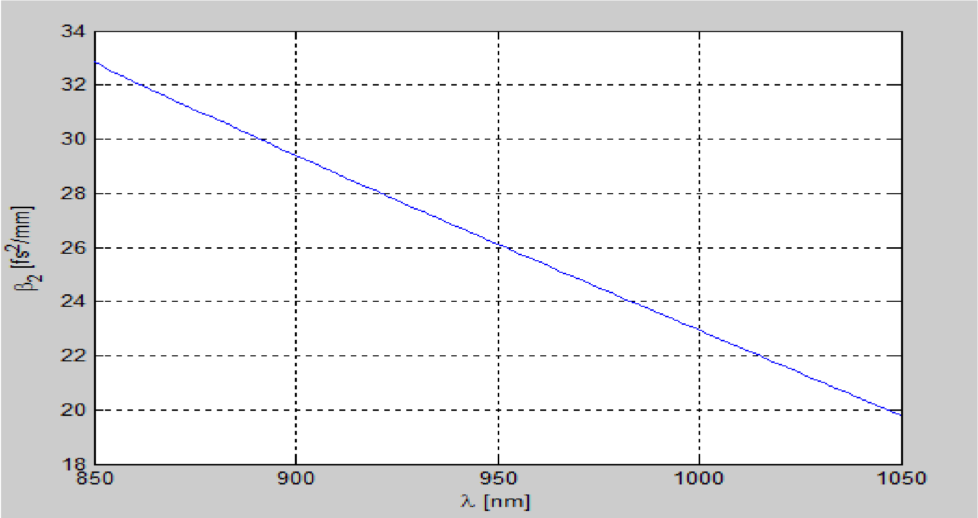


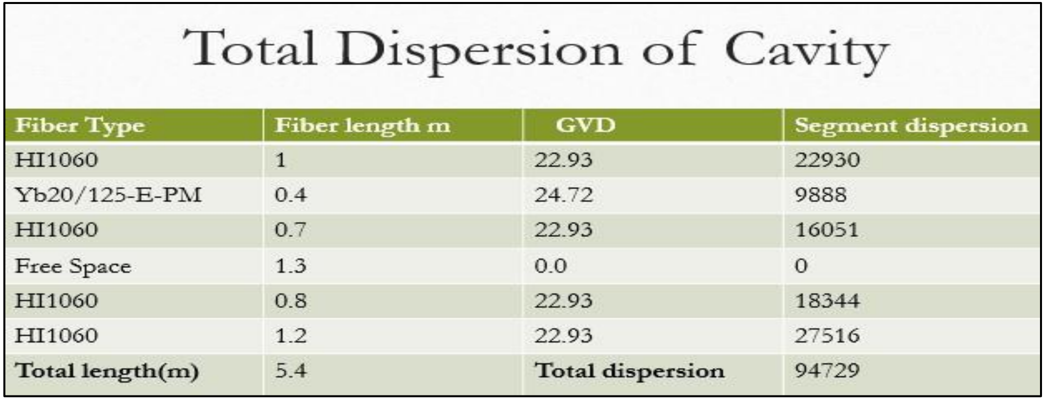
Figure 4: YDF's dispersion coefficient as a "function of wavelength."

Figure 4. illustrates how wavelength affects dispersion. With varying wavelengths, the above figure displays a variable dispersion value. The wavelength decreases in dispersion from 850 nm to 1050 nm, as seen in the graph. However, the graph above does not show a negative number for dispersion.

Computation of the Total Dispersion

We compute the overall dispersion of the cavity for each section that has a fixed length. The "dispersion" of the chamber as a whole as well as the "dispersion" of each sector are shown in the table. Because of the optical component positioning in this sector, the Yb doped fiber has a dispersion of 24.72 while the open space has zero dispersion. The length of free space is 1.3 meters. The distribution of pieces per 10^{-3}m is shown on the third column. The dispersion of each component throughout the unit's whole length is displayed in the fourth column. Thus, 94729 fs^2 is the total scattering in the 5.4 m long laser cavity.

Table 2: Dispersion of each component as well as the cavity's net "dispersion."



Total Dispersion of Cavity

Fiber Type	Fiber length m	GVD	Segment dispersion
HI1060	1	22.93	22930
Yb20/125-E-PM	0.4	24.72	9888
HI1060	0.7	22.93	16051
Free Space	1.3	0.0	0
HI1060	0.8	22.93	18344
HI1060	1.2	22.93	27516
Total length(m)	5.4	**Total dispersion**	94729

Pulse Width Variations with Lengths

We examined the effects of the Yb anesthetic fiber length on the spectral width and pulse duration. When the doped fiber Yb's length is adjusted in increments of five centimeters from 5 cm to 50 cm, the pulse width and spectral width will shift, with all other parameters being measured continuously. The program displays all of the results in the following figure.

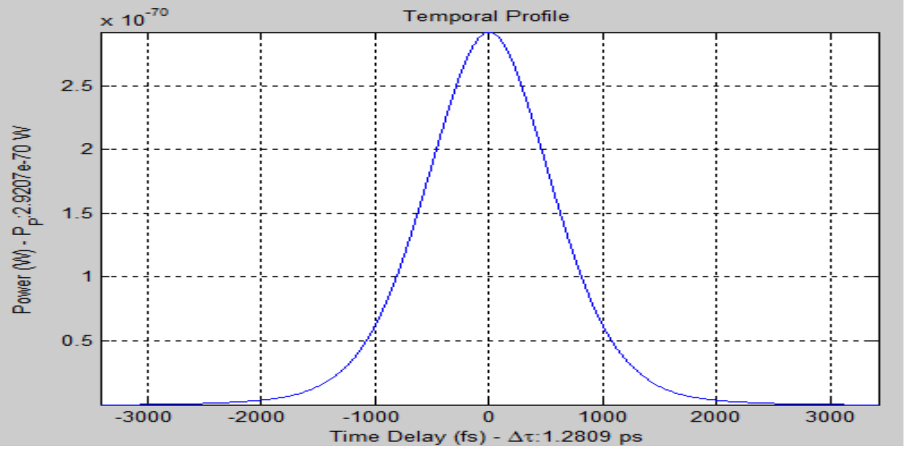


Figure 6: shows a schematic of the 1.2809 ps pulse width for a 5 cm YDF length

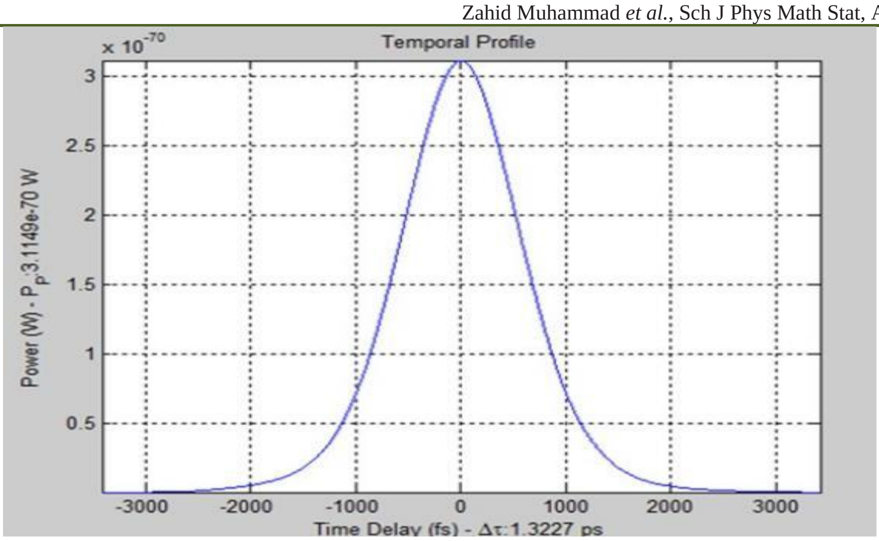


Figure 7: Shows the schematic for a 50 cm YDF length with a pulse width of 1.3227 ps

According to the data, long active fibers measuring 5 cm in length have a pulse duration of 1.2809 points per second, and long active fibers measuring 50 cm have a pulse duration of 1.3227 points per second.

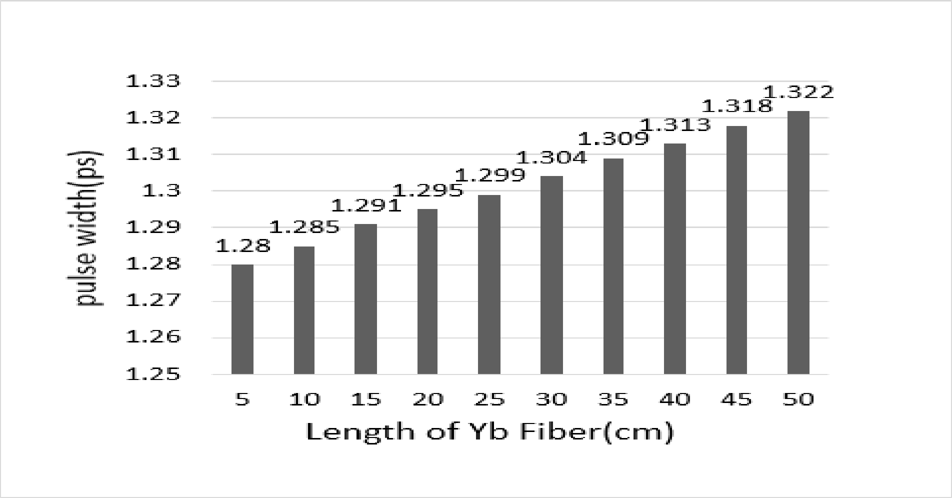


Figure 8: Pulse width vs. YDF length graph

This shows that the pulse width grows linearly with the "length" of the doped fiber Yb. where the pulse duration is measured in picoseconds and the YDF length is measured in centimeters. 5 cm pulse width equals 1.2809 ps points, and 50 cm pulse width equals 1.3227 ps points. An "increase" of 0.5 ps in the pulse-width will result in a 5 cm length increase.

Spectral Width Variation with Length

When the Yb doped-fiber's length increases in stages of 5 cm from 5 cm to 50 cm, the spectral width will alter while maintaining the same other parameters. The numbers below display every outcome that the software planned.

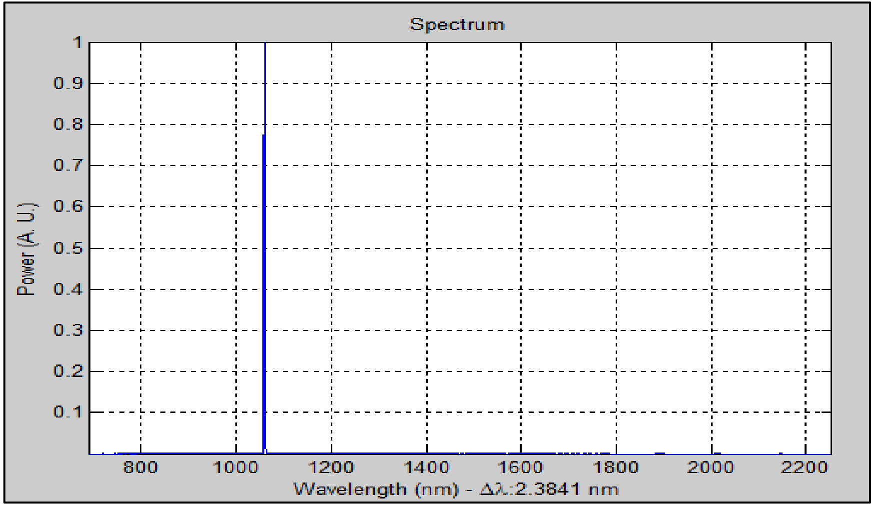


Figure 9: Diagram showing the spectral width (2.3841 nm) for the YDF's 5 cm length

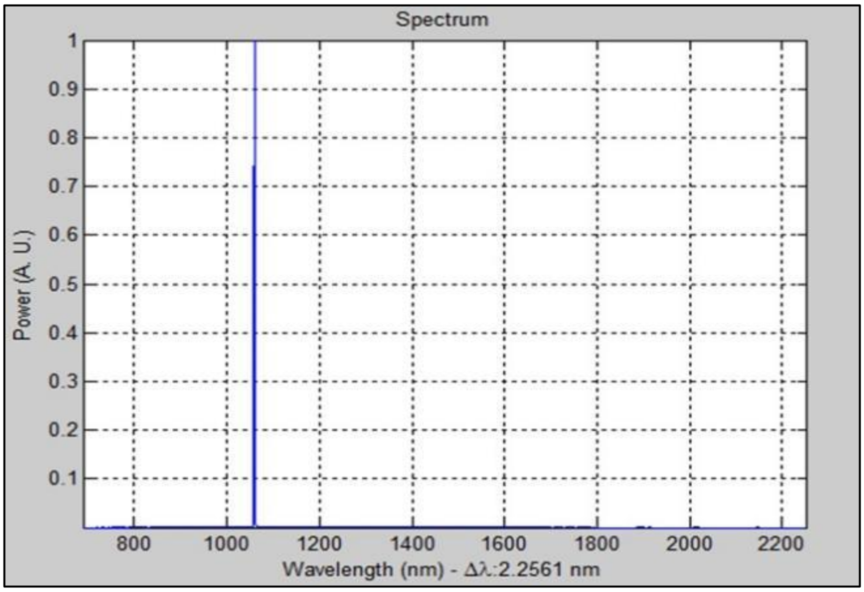


Figure 10: Diagram showing the spectral width (2.2561 nm) for the YDF's 50 cm length.

According to the data, the spectral width of a YDF that is 5 cm long is 2.3841 nm, and a YDF that is 50 cm long is 2.2561 nm. The graph between spectral width and YDF length is plotted in the figure below.

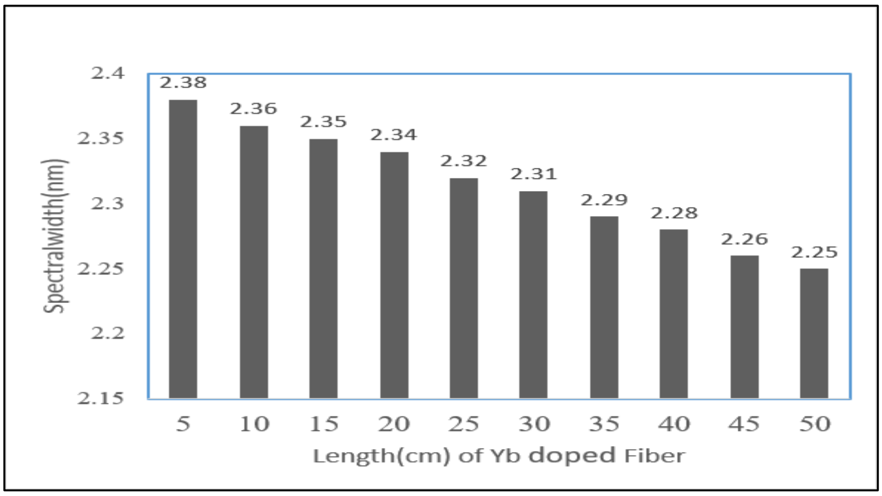


Figure 11: Diagram showing Yb doped fiber length in relation to 'spectral width"

When the length of the Yb doped-fiber increases, there is a related decrease in the "spectral-width. where the spectral-width is measured in 10^{-9}meter and the YDF's length is measured in centimeters. The two have different spectral lengths: 2.3841 nm for a length of 5 cm and 2.2561 nm for a length of 50 cm. The spectral width will drop by 0.01 nm for every 5 cm increase in longitudinal length.

Rate of Repetition of the Designed Laser

When the LASER is working in pulsed mode, the repetition rate indicates how many times the pulses will repeat in a second. Here, we determined the laser's repetition rate using a constant resonator length and a repetition frequency of 37.06 MHZ. The laser cavity's repetition rate is computed using the formula below.

$\boldsymbol{Rep.\ rate = c/nL}$

where L is the cavity's net length, n is the refractive index, and c is the speed of light.

$\boldsymbol{Rep.\ Rate = 3 \times 108 / 1.499 \times 5.4}$

$\boldsymbol{Rep.\ Rate = 37.06 MHz}$

For our planned laser cavity, the periodic frequency is 37.06MHz.

CONCLUSION

Fiber-Based ultrafast lasers are attractive because of probably low cost and alignment free construction. The pulse duration of mode-locked fibers varying from picoseconds to femtoseconds. In this research work ultrafast femtosecond pulses are generated using mode-locking. Ultrafast fiber is a very wide researched field and finds enormous applications in the field of medicine and industry. We employed the "Ultra short Pulse Propagator Version 3.0.0" software, created by Bilkent University in Ankara Turkey to investigate the laser's mode-locking capability. The program offers a wide range of features and can be used for simulation. Software can also be used to measure GVD and TOD. Plotting pulse-width, spectrum-width, and fast frequency can be done using this software. The chamber design is composed of six components: a 100 cm long SMF, a 20 /125-E-PM Yb-doped fiber, and a 70.0 cm long single-mode fiber. With a length of 130 cm, the fourth section is a free space. In this free space segment, the grating plates, half-wave plates, quarter-wave plates, polarization beam splitters, isolators, collimators, and two reflecting mirrors are positioned correctly. This section's wave plates should be modified to generate non-linear polarization rotations in order to accomplish mode-locking. The fifth and sixth segments are composed of "single-mode fibers" that have lengths of 80 and 120 centimeters, respectively. The entire length of the chamber is 5.4 meters. At 1060 nm, designed (Yb)-doped fiber is in operation. The functioning principles of the optical' components are given in detail. The pulsed operation of the laser has been computationally investigated. With the help of software, we were able to measure the GVD and TOD for SMF and Yb-doped fiber. The dispersion of an SMF is 22.93fs^2 / mm, but that of a Yb-doped fiber is 24.72fs^2 / mm. The total dispersion of the designed cavity chamber is 94729 fs^^{2}.

We plot the dispersion graph against wavelength on a curve and analyze it. The YDF length is changed or converted to measure the pulse width and spectral width. With a step size of 5 cm, the length of YDF was varying from 5 cm to 50 cm.

The results obtained make it clear that the pulse-width increases as the Yb doped fiber length increases. However, the results also shows that the spectral-width changes when the Yb doped-fiber length increases, which differs from the 'pulse width'. The spectral-width diminishes as the Yb doped-fiber (20/125-E-PM) lengthens (in centimeters). Software was also used to create the statistics of each part's pulse and spectral width, and their behavior in dissimilar sections was carefully considered.

Ultimately, the overall frequency of the pulse is 37.06 MHz, which was determined using the formula $\boldsymbol{Rep.\ rate = c/nL.}$

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