Dual-Wavelength Self-Similar Pulse Fiber Laser Based On Topological Insulator

Weici Liu*, and Lei Qi

Department of Electronic Information Engineering, Guangzhou College of Technology and Business, Foshan, Guangdong, 528138, China

*Corresponding author’s e-mail: liu-weici@m.scnu.edu.cn, liuweici-2002@126.com

Abstract. Multi wavelength ultrashort pulse is of great significance in the scientific field. The dual-wavelength self-similar (SS) pulse mode-locked fiber laser with topological insulator (TI) is studied in this paper. The study on evolution of dual-wavelength SS pulse is based on Ginzburg-Landau equation (GLE) by split-step Fourier transforms (SSFT). The results have a high theoretical significance and value in practice.

1. Introduction

The development of fiber lasers has a significant impact on research and practice. Multi-wavelength mode-locked fiber lasers are popular in fiber communication, non-linear optics and fiber sensing due to the advantages of wide band, high peak power, ultra-short pulse width and multi wavelength output [1-4]. Passive mode-locked technology based on saturable absorber has the advantages of simple structure, compact structure, no need of modulator and high peak power, which is the key technology to realize multi wavelength mode-locked pulse in fiber laser.

In recent years, topological insulator (TI) has attracted great attention of researchers in physics, chemistry and materials [5, 6]. TI is a new kind of nanometer material which has the advantages of wide operating band, adjustable modulation depth, fast recovery time, low saturation absorption threshold, high nonlinear refractive index and high thermal damage threshold. The devices based on TI are better than those based on metal and graphene. Therefore, the TI can be used as an ideal saturable absorber for multi wavelength mode locking fiber laser.

TIs have attracted extensive attention due to their excellent properties for mode-locked fiber lasers. In August 2012, F. Bernard first studied the saturated absorption characteristics of TI Bi2Te3 at 1550nm wavelength, and predicted that TI can be used as mode-locked device to realize ultrashort pulse mode locking [7]. In December 2013, J. Sotor team realized a soliton mode-locked fiber laser with central wavelength of 1558.6nm, repetition rate of 4.75mhz, pulse width of 1.8ps and pulse energy of 105pj [8]; In March 2014, J. Lee team realized an erbium-doped fiber laser with a pulse width of about 600fs[9].

However, ultrashort pulse is easy to be distorted at high power. Self-similar (SS) pulse has the advantages of keeping the pulse shape unchanged during high power transmission, resisting light wave splitting. It is of great significance for the generation of high-power ultrashort pulse, and has been widely used in high power amplifier system, high efficiency on-line compressor, fiber Bragg grating, fiber communication and so on. Researchers have done a lot of theoretical and experimental studies on SS optical pulses in the past decade. On the other hand, researchers at home and abroad have done a lot of theoretical and experimental studies on parabolic SS optical pulses in the past decade. In foreign
countries, in 2004, F.O. Ilday et al. [10] first proposed the design principle of SS pulse fiber laser. In
the same year, they analysed the possibility of SS pulse laser generated by Ti: sapphire laser [11]. C.K.
Nielsen et al. obtained SS pulse output in ytterbium doped fiber laser in 2005 [12]. In 2014,
Kalashnikov V l et al. showed that Raman scattering limited the increase of SS pulse energy [13]. In
2016, Frank W. wise et al. studied the evolution of SS pulses in fiber lasers with comb dispersion [14].
Lidiya A. Esther proposed low-pedestal, few-cycle ultrashort SS pulses at 800 nm [15].

This paper proposes the schematic of dual-wavelength SS fiber laser based on topological insulator
saturable absorber (TISA), and studies the evolution of dual-wavelength SS pulse based on
Ginzburg-Landau equation by split-step Fourier transforms (SSFT), which is important to the related
micro-nano-devices based on TI.

2. Theoretical Model

Based on the principle of mode locked laser, we used the following Ginzburg-Landau equations
(GLEs) to describe the pulse propagation [10-15]:

\[
\frac{\partial A}{\partial z} + i \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \frac{g}{2\Omega_g^2} \frac{\partial^2 A}{\partial t^2} = i \gamma |A|^2 A + \frac{1}{2} (g - \alpha) A, \tag{1}
\]

Where \(A\) is the envelopes of the optical pulses in the optical fiber, \(\beta_2\) represents the second-order
dispersion coefficient; \(\gamma\) is the nonlinearity of the fiber; \(g\) is the gain coefficient; and \(\Omega_g\) is the
bandwidth of the laser gain.

3. Design and Results analysis

![Figure 1. Schematic of dual-wavelength SS pulse fiber laser based on TISA](image)

The schematic of dual-wavelength SS pulse fiber laser based on TISA is shown as figure 1. TISA is
topological insulator saturable absorber, PC is polarization controller, WDM is wavelength division
multiplexer, LD is pump source, SMF is single-mode fiber with normal dispersion, YDF is
ytterbium-doped fiber with gain.

There is a 980 nm pump source in the fiber ring cavity, which is used to excite the gain medium
that ytterbium-doped fiber provides the gain medium in the resonant cavity to generate the gain
spectrum. Wavelength division multiplexer guides light of different wavelengths into the optical loop.
The function of isolator is to make the directional propagation of light in the cavity. The phase shift of
the output pulse can be controlled by adjusting the polarization state of the pulse in the resonant cavity
by PC, which can be used to obtain the selective wavelengths.

The simulation is as follows. The input Gaussian pulse is with \(\lambda_0=1550\text{nm}\), and \(T_0=0.5\text{ps}\). \(E_{in}\)
$\beta_2 = 6.0 \times 10^{-3} \text{ps}^2/\text{m}$, $\gamma = 1.4 \times 10^{-3} \text{W}^{-1}\text{m}^{-1}$, $g = 0.5 \text{m}^{-1}$, the fiber length is 10m. Figure 2 indicates the stable evolution of dual-wavelength SS pulse.

![Figure 2](image1.png)

**Figure 2.** The evolution of dual-wavelength SS pulse

The stable evolution of dual-wavelength SS pulse is shown as figure 2. We can see the width and amplitude of the evolution of dual-wavelength SS pulse increasing with the propagation distance. Figure 3 which is the frequency spectrum shows a smooth double peak. Figure 4 and figure 5 indicate a stable dual-wavelength achieved.

![Figure 3](image2.png)

**Figure 3.** The frequency spectrum of dual-wavelength SS pulse

![Figure 4](image3.png)

**Figure 4.** The temporal profile of dual-wavelength SS pulse
4. Conclusion
In general, the dual-wavelength SS pulse fiber laser based on TI is proposed in this paper. The study on dual-wavelength SS pulse is based on GLE, and the solution is solved by the split-step Fourier method. Then, the evolution of dual-wavelength SS pulse is simulated and discussed. The results have important scientific research significance and practical application value for fiber laser in generating high energy and ultra-short pulse. They also provide theoretical reference for optimizing optical fiber communication system and promoting the development of optical fiber communication technology.

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