Simulation of dual-wavelength self-similar pulse based on two dimensional material fiber laser

Weici Liu*, Yunting Wu and Lei Qi

Engineering School, Guangzhou College of Technology and Business, Foshan, Guangdong, 528138, China

*Corresponding author’s e-mail: liuweici@m.scnu.edu.cn

Abstract. Multi-wavelength self-similar fiber laser has many advantages that other lasers do not have. It has many applications in industry, sensing, medical, military, communication and other fields. Two dimensional material devices can be used as saturable absorbers to construct dual-wavelength self-similar pulse mode-locked fiber lasers. In this paper, the evolution characteristics of dual-wavelength self-similar pulse based on two dimensional material mode-locked fiber lasers are analysed.

1. Introduction

Ultrafast laser has been an important research hotspot in the field of lasers in the world. As a member of ultrafast fiber laser family, multi-wavelength mode-locked fiber laser has many advantages, such as large number of output wavelengths, short pulse width and high peak power. It has become a key tool in the field of optical fiber communication, nonlinear optics, optical fiber sensing and other fields due to its advantages of high speed, wide operating band, etc., and has gradually become a focus of international scientists [1-9].

The multi-wavelength self-similar pulse laser is different from the cavity structure of the traditional broadening pulse laser. The total dispersion of the laser is positive, and it can work in different modes. The position of the narrowest pulse width is also opposite to the previous broadening pulse laser. This kind of laser can produce self-similar pulse, in which the pulse can be self-similar transmission. The amplitude and phase of the self-similar pulse can keep its shape and have linear chirp during transmission [10-11].

In recent years, graphene, topological insulator and two-dimensional sulfide, which are new two-dimensional nano-materials, have attracted great attention in the fields of physics, chemistry and materials. In addition to electrical properties, topological insulators and sulfides have novel optoelectronic properties, such as saturated absorption, high nonlinearity and limiting properties, which has aroused wide interest of researchers all over the world. Exploring the application of these materials in optical fiber devices has become one of the leading issues in the field of Optoelectronics in the world [7-9]. At present, more attention has been paid to single wavelength mode-locking using the saturated absorption properties of these two-dimensional materials, but less attention has been paid to self-similar pulsed lasers. The results show that the two-dimensional material device can be used as a saturable absorber in the self-similar laser cavity, which may produce multi-wavelength self-similar mode-locked pulses. Its formation mechanism and theoretical model need to be established and improved. In this paper, dual-wavelength pulse propagation and evolution characteristics of self-similar fiber laser based on two-dimensional materials are studied.
2. Theoretical Model

For a two-dimensional material based dual-wavelength self-similar pulsed fiber laser, the fundamental equation of mode locking is as follows

\[
\frac{\partial A}{\partial z} = \frac{(g - \alpha)}{2} \frac{A}{2} + i \gamma |A|^2 A + i \beta_2 \frac{\partial^2 A}{\partial T^2} + \alpha A
\]  

(1)

where \( A \) is the normalized pulse amplitude; \( g \) is the saturation gain in the whole cavity and \( \alpha \) represents the loss of the fiber; \( \beta_2 \) is normal group velocity dispersion; \( \gamma \) is the nonlinearity coefficient, and \( T \) is time scaled.

3. Numerical Simulation Analysis

In this paper, the evolution process of dual-wavelength self-similar pulsed generated by 1550 femtosecond pulse propagating in two-dimensional materials fiber laser are numerically simulated by split-step Fourier method.

The following is the simulations. Fig.1 shows the optical characteristics of the dual-wavelength self-similar pulse with transmission distance, for the \( g_0 = 0.5 \, \text{m}^{-1}, \beta_2 = 3.8 \times 10^{-2} \, \text{ps}^2/\text{m}, \gamma = 5 \times 10^{-3} \, \text{W}^{-1}\text{m}^{-1}, \lambda_0 = 1550 \, \text{nm}, T_0 = 0.5 \, \text{ps}, E_0 = 40 \, \text{pj}. \)

![Figure 1 optical characteristics of the dual-wavelength self-similar pulse with transmission distance](L)

From figure 1, we can see that the pulse broadens faster and the linearity of chirp is better with the increase of transmission distance.

Figure 2 reveals optical characteristics of the dual-wavelength self-similar pulse with input pump energy, for other parameters are as figure 1. The optical characteristics of the dual-wavelength self-similar pulse are similar to those of figure 1.

The optical characteristics of the dual-wavelength self-similar pulse with full width at half maximum (FWHM) are shown in Figure 3. The pulse broadness and the linearity of chirp decreases as FWHM raises.
Figure 2 optical characteristics of the dual-wavelength self-similar pulse with input pump energy

(a) waveform

(b) chirp

Figure 3 optical characteristics of the dual-wavelength self-similar pulse with full width at half maximum (FWHM)

(a) waveform

(b) chirp

Figure 4 optical characteristics of the dual-wavelength self-similar pulse with normal group velocity

(a) waveform

(b) chirp
dispersion

The self-similar evolution occurs in the normal dispersion region, and Figure 4 demonstrates optical characteristics of the dual-wavelength self-similar pulse with normal group velocity dispersion. The results indicate that normal group velocity dispersion is helpful for the formation of self-similar pulse and the linearity of chirp.

4. Conclusion

Multi-wavelength mode-locked fiber laser based on passive mode-locked technology has many advantages, such as large number of output wavelengths, tuneable number of output wavelengths and spectrum position, flat output power and strong stability. In this paper, the evolution characteristics of dual-wavelength self-similar pulse in mode-locked fiber lasers based on two-dimensional materials are studied.

Acknowledgement

This research was financially supported by the Project of Department of Education of Guangdong Province (No.2019KTSCX257) the National College Students' innovation and entrepreneurship training program (No. 202013714003); 2019 Natural Science Project of Guangzhou College of Technology and Business (No. KA201931); Foundation for Distinguished Young Talents in Higher Education of Guangdong, China (No. 2020KQNCX109).

References

[1] Talaverano L , Abad S , Jarabo S , et al. Multiwavelength Fiber Laser Sources with Bragg-Grating Sensor Multiplexing Capability[J]. Journal of Lightwave Technology, 2001, 19(4):553-558.
[2] Pouste A J , Finlayson N , Harper P . Multiwavelength fiber laser using a spatial mode beating filter[J]. Optics Letters, 1994, 19(10):716-8.
[3] Das G , Lit J W Y . L-band multiwavelength fiber laser using an elliptical fiber[J]. IEEE Photonics Technology Letters, 2002, 14(5):606-608.
[4] Zhang Z , Zhan L , Xu K , et al. Multiwavelength fiber laser with fine adjustment, based on nonlinear polarization rotation and birefringence fiber filter[J]. Optics Letters, 2008, 33(4):324-326.
[5] Pinto A M R , Frazao O , Santos J L , et al. Multiwavelength fiber laser based on a photonic crystal fiber loop mirror with cooperative Rayleigh scattering[J]. Applied Physics B, 2010, 99(3):391-395.
[6] Sulaiman A H , Abdullah F , Ismail A , et al. Boosting Output Power of Multiwavelength Fiber Laser with Lyot Filter utilizing Hybrid Amplifier[C]// 2020 IEEE 8th International Conference on Photonics (ICP). IEEE, 2020.
[7] Luo Z Q , Wang J Z , Zhou M , et al. Dual-wavelength mode-locked Yb-doped fiber laser based on the interaction of graphene and fiber-taper evanescent field[J]. Laser Physics Letters, 2012, 9(3):229.
[8] Shisheng, Huang, Yonggang, et al. Tunable and switchable multi-wavelength dissipative soliton generation in a graphene oxide mode-locked Yb-doped fiber laser[J]. Optics Express, 2014.
[9] Zhang A , Sun C , Pan H , et al. Characterization of multi-wavelength Q-switched fiber laser by changing wavelength separation of filter[J]. Optical Fiber Technology, 2020, 58:102297.
[10] Arabanian A S , Salmanian M . Realizing high adjustability of bandwidth and energy of output pulse in a self-similar femtosecond fiber laser[J]. Optical Fiber Technology, 2021, 61:102438.
[11] Zhang Q , Li H , Wu L , et al. Research on evolution region of self-similar pulses in a dispersion-decreasing fiber[J]. Optical and Quantum Electronics, 2019, 51(6):190.1-190.13.