Dual-Wavelength Self-Similar Pulse Microstructure Fiber Laser Based on Graphene Saturable Absorber

Wei-ci LIU¹,²,* , Fa-qiang WANG³ and Rui-sheng LIANG¹,³

¹Department of Electronic Information Engineering, Guangzhou College of Technology and Business, Foshan 528138, China
²School of physics and Telecommunication Engineering, South China Normal University, Guangzhou 510006, China
³Laboratory of Nanophotonic Functional Materials and Devices (SIPSE), and Laboratory of Quantum Engineering and Quantum Materials, South China Normal University, Guangzhou 510006, China

*Corresponding author

Keywords: Dual-wavelength self-similar pulse, Microstructure fiber laser, Graphene saturable absorber, WDM.

Abstract. Based on graphene saturable absorber, the microstructure fiber laser is proposed which can generate dual-wavelength self-similar pulse. The evolution of dual-wavelength self-similar pulse are simulated and analyzed by the coupled Ginzburg-Landau equations. The dual-wavelength self-similar pulse dynamic mechanism of microstructure fiber laser is studied, which is important and valuable for the development of future WDM systems.

Introduction

Internet traffic is making the demand for communication capacity grow faster and faster. In future fiber-optic communication systems, how to increase the transmission capacity is a challenge. Wavelength division multiplexing (WDM) which can expand the bandwidth of already existing fiber transmission networks becomes the most attractive technology, because it can create huge new information pipelines that will bring better service at lower cost[1,2]. Recently, multiwavelength laser source which is significant to minimize the complexity of the WDM network system, has become a scientific research focus[3,4].

However, the system requires very high accuracy and stability of wavelength. Self-similar pulse (SSP) generated in a fiber with normal group velocity dispersion (GVD) and gain is a promising solution owing to its unique features, such as self similarity in shape, resistance to optical wave breaking, enhanced linearity of chirp, and a broad spectrum [5–10]. Graphene has the unique broadband optical characteristics due to its excellent electronic structure and optical properties[4,11]. In this paper, we proposed and demonstrated a scheme of dual-wavelength self-similar pulse laser source based on graphene saturable absorber, which can be potentially used in future WDM systems.

Theoretical Model

In self-similar pulse microstructure fiber laser, based on the principle of mode locked laser, combining the physical characteristics of the graphene saturable absorber and the weakly birefringence in the cavity, we used the following coupled Ginzburg-Landau equations to describe the pulse propagation[5-10]:
\begin{equation}
\frac{\partial u}{\partial z} = i\beta u - \delta \frac{\partial u}{\partial t} - \frac{i\beta_2}{2} \frac{\partial^2 u}{\partial t^2} + i\gamma (|u|^2 + \frac{2}{3} |v|^2)u + \frac{i\gamma}{3} v^2 u^* + \frac{g}{2} u + \frac{g}{2\Omega_s^2} \frac{\partial^2 u}{\partial t^2}
\end{equation}

\begin{equation}
\frac{\partial v}{\partial z} = i\beta u - \delta \frac{\partial v}{\partial t} - \frac{i\beta_2}{2} \frac{\partial^2 v}{\partial t^2} + i\gamma (|v|^2 + \frac{2}{3} |u|^2)v + \frac{i\gamma}{3} u^2 v^* + \frac{g}{2} v + \frac{g}{2\Omega_s^2} \frac{\partial^2 v}{\partial t^2}
\end{equation}

Where \( u \) and \( v \) are the envelopes of the optical pulses in the two orthogonal polarized modes of the optical fiber. \( 2\beta = 2\pi\Delta n/\lambda \) is the wave-number difference between the two modes. \( 2\delta = 2\beta\lambda/2\pi c \) is the inverse group velocity difference. \( \beta_2 \) is the second-order dispersion coefficient; \( \gamma \) represents the nonlinearity of the fiber; \( g \) is the saturable gain coefficient of the microstructure fiber; and \( \Omega_s \) is the bandwidth of the laser gain.

The \( g_s^* \) that is absorption capacity of the graphene can be expressed by Eq. (3) [4,11].

\begin{equation}
\frac{\partial g_s^*}{\partial t} = - \frac{g_s^* - g_0^*}{\tau_{rec}} - \frac{|u|^2 + |v|^2}{E_{sat}} g_s^*
\end{equation}

Where \( g_0^* \) is is the loss of saturable absorber at the condition of thermal equilibrium; \( \tau_{rec} \) is recovery time of saturable absorber; \( E_{sat} \) represents the saturated energy of saturable absorber.

**Design and Results**

Figure 1 shows the proposed configuration of the dual-wavelength SSP microstructure fiber (MF) laser based on graphene saturable absorber. The design is discussed detailedly as follows.

![Figure 1. Schematic of dual-wavelength SSP microstructure fiber laser based on graphene saturable absorber.](image)

The pump source is 980/1060 nm laser through a WDM coupler. The SSP generates in the active medium MF which exhibits novel structure that can easily adjust the normal GVD and nonlinearity coefficient[12], which are responsible for self-similar pulse generation and propagation. The polarization controller (PC) is used to adjust the polarization states of different modes and balance the gain and loss. The graphene saturable absorber(GSA) which has fast responses, a large modulation depth and broadband operation, is favorable for the high-power, long-time stable operation of the dual-wavelength laser[4,11]. Dispersive delay line (DDL) ( \( \beta_2<0 \) ) is for compressing the pulse. The laser output emerges from the optical coupler.
Here the simulation is as follows. The evolution of a Gaussian input pulse in an amplifier with realistic parameters corresponds to those of currently available MF. For the input field a Gaussian pulse with \( \lambda_0=1310\text{nm} \), \( T_0=0.8\text{ps} \), where \( T_0 \) is the half-width (at 1/e-intensity point). \( E_0=35\text{pJ} \), \( \beta_2=7.0\times10^{-3}\text{ps}^2/\text{m} \), \( \gamma=1.3\times10^{-3}\text{W}^{-1}\text{m}^{-1} \), \( g=0.51\text{m}^{-1} \), the fiber length is 10m. Figure 2 indicates the stable evolution of dual-wavelength SSP.

Figure 2. The evolution of dual-wavelength SSP of the microstructure fiber laser based on graphene saturable absorber.

Figure 2 is the evolution of dual-wavelength SSP from Gaussian input pulse to parabolic SSP in 0-10m propagation distance, which indicates the dual-wavelength SSP microstructure fiber laser works well. It is obvious in Figure 2 that is parabolic waveform and self similarity in shape. The width and the amplitude of dual-wavelength SSP increase with the propagation distance Z.

Figure 3. The pulse temporal profile before compressing (dashed line) and after compressing (solid line).

The dashed line in Figure 3 is the dual-wavelength SSP temporal profile before compressing and solid line is compressed SSP. Figure 4 shows the dual-wavelength SSP optical spectrum. Figure 3 and Figure 4 reveal the high-quality pulse compression by DDL.

Figure 4. Dual-wavelength pulses optical spectrum.
Conclusion

In summary, a stable, broadband, compact, microstructure fiber laser that is based on graphene saturable absorber, is investigated to achieve high capacity transmission and high channel count for WDM system by the formation of similariton spectrums. The laser is dual-wavelength selection and flexile control. The results are significant for enriching the laser source in optical fiber communication.

Acknowledgement

This research was financially supported by the National Natural Science Foundation of China (Grants No. 61275059 and No.61774062), and Foundation for Distinguished Young Talents in Higher Education of Guangdong, China (Grant No. 2016KQNCX195).

References


