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Generation of High-Repetition-Rate Pulses Utilizing Cascaded Single Mode Fiber and Semiconductor Optical Amplifier

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Abstract

To generate high-repetition-rate optical pulses, a novel and simple device is demonstrated, in which the cascaded single mode fiber (SMF) with negative third order dispersion and semiconductor optical amplifier (SOA) are adopted. Numerical research results show that let an optical pulse with center wavelength in zero dispersion wavelength of optical fiber transit in SMF for generating an oscillation pulse. Subsequently, the followed SOA is provided for amplification. As a consequence, the high-repetition-rate optical pulses can be obtained.

Key Words: *Optoelectronics, high-repetition-rate optical pulses, single mode fiber, semiconductor optical amplifier.*

1. Introduction

High-repetition-rate optical pulses have become a very key technique for the development of future ultrahigh-speed optical transmission systems and for ultrahigh-speed all-optical signal processing [1]. Many techniques have been recently advanced for generating high-speed optical pulse, such as mode-locking loop fiber ring laser (MLFRL), distributed feedback (DFB) semiconductor laser with electroabsorption modulator, gain switching DFB semiconductor laser and cross phase modulation (XPM) of using continuous wave and pulses in fiber, etc. [2–5]. However, some defects are in existence for these techniques, for example bad stability, larger pulse width, larger chirp and pedestal, and similar problems. In this paper, we bring forward a novel theoretical technique to generate high-repetition-rate optical pulse using cascaded negative third order dispersion single mode fiber (SMF) and semiconductor optical amplifier (SOA). With the transmission equations in fiber and SOA, we demonstrate that a Gaussian seed pulse whose center wavelength is located in zero dispersion wavelength of fiber will begin to oscillate in the leading edge of pulse owing to effect of negative third order dispersion. The generated oscillation pulse may be amplified by SOA, and then, the high-repetition-rate optical pulses can be obtained.

2. Theory Model

When we have ignored fiber loss and assumed that the dispersion length is smaller than by far its nonlinear length, the transmission equation of Gaussian pulse whose center wavelength is equal to the zero dispersion wavelength of fiber can be written as [6]:

$$\frac{\partial A}{\partial Z} = \frac{1}{6}\beta_3 \frac{\partial^3 A}{\partial T^3} \tag{1}$$

where A is amplitude envelope, Z is fiber length, β_3 is third order dispersion coefficient, T is normal time.

Utilizing Fourier method, the amplitude envelope can be obtained after transmitting distance Z

$$A(Z,T) = \frac{1}{2\pi}\int_{-\infty}^{\infty} A(0,\omega)\exp(\frac{i}{6}\beta_3\omega^3 Z - i\omega T)d\omega \tag{2}$$

where $A(0,\omega)$ is the Fourier transform of incidence optical field at $Z = 0$, and is given by

$$A(0,\omega) = \int_{-\infty}^{\infty} A(0,T)\exp(i\omega T)dT. \tag{3}$$

When optical pulse is transmitting in SOA, we take into account the ideal travelling wave SOA. SOA is divided into many segments. In the different location of SOA, the carrier density N and optical power P are be described by [7–9]

$$\frac{\partial N_j}{\partial T} = \frac{I}{qV} - \frac{N_j}{\tau_c} - \frac{\Gamma g_i(N_j)}{\hbar\omega A_{cross}}\bar{P_j} \tag{4}$$

$$\frac{\partial P_j}{\partial Z} = (\Gamma g(N_j) - \alpha_{int})P_j \tag{5}$$

where j is the j^{th} segment, N_j and P_j are the carrier density and optical power in the j^{th} segment, respectively, T(=t-Z/V_g, V_g is group velocity, Z is different location) is normal time, I is the injection current, r is the active volume, q is the election, τ_c is the carrier lifetime, $1/\tau_c$=AN+BN^2+CN^3, A, B and C are nonradiative, bimolecular and Auger recombination constants respectively, Γ is the confinement factor, $\hbar\omega$ is the photon energy, A_{cross} is the cross section mode, α_{int} is the internal loss, $\overline{P_j}$ is the average optical power in jth segment, and can be described by [10]

$$\bar{P_j} = \frac{1}{\Delta L}\int\limits_{(j-1)\Delta L}^{j\Delta L} P_{j-1}e^{(\Gamma g(N_j)-\alpha_{int})}dZ = \frac{G_j - 1}{\ln(G_j)}P_{j-1} \tag{6}$$

where dn/dN is the index with carrier density variation, dg/dN is the gain with carrier density variation, λ is the center wavelength of pulse, ΔL is the length of each section, P_{int} is the output power of the $(j-1)$th section, $g(N_j)$ is the gain described by [11]

$$g(N_j) = a_1(N_j - N_0) - a_2(\lambda - \lambda_N)^2 + a_3(\lambda - \lambda_N)^3 \tag{7}$$

where a_1 is the different gain coefficient, N_0 is the carrier density required for transparency, a_2 and a_3 are the width of gain spectrum and the experience constant of gain asymmetry, λ_N is the wavelength of gain peak related to carrier density described by

$$\lambda_N = \lambda_0 - a_4(N - N_0) \tag{8}$$

where λ_0 is the wavelength of gain peak for transparency, a_4 is the experience constant.

3. Numerical Results & Analysis

A seed input pulse assumed a Gaussian optical pulse with 0.3 mW original peak power is 3 ps width at 1/e intensity point. Time domain shape of the seed pulse is plotted in Figure 1 for $\beta_3 = -0.1$ ps^3/km and $Z = 8L'_D(L'_D = \frac{T_0^3}{|\beta_3|})$. From the Figure 1, we can see that oscillating structures, namely dispersion pulses, appear at the leading edge of pulse owing to negative third-order dispersion effect, but the peak power of dispersion pulse is steadily decreasing.

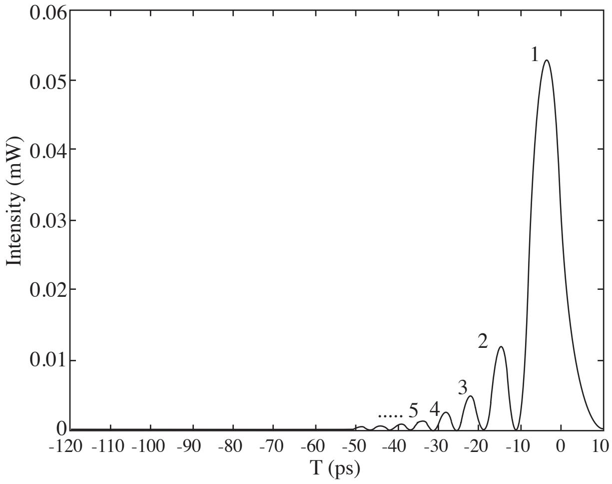

Figure 1. The time domain shape of seed pulse after $8L'_D$.

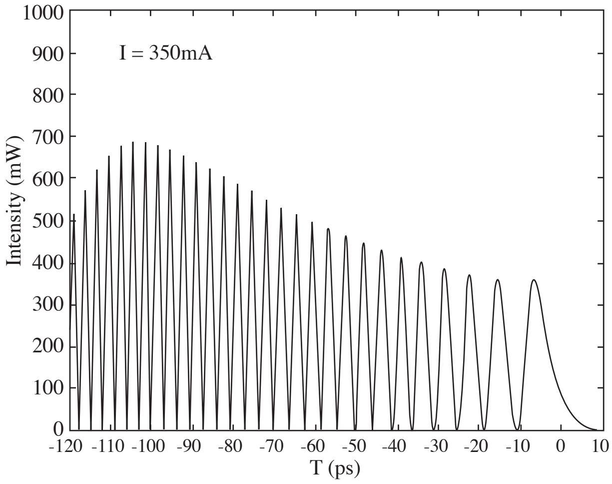

Figure 2. The time domain shapes of dispersion pulses amplified in SOA.

The amplified pulse shapes are plotted in Figure 2. The parameters used in the calculations are $A_{cross} = 0.3$ μm^2, $V = 150$ μm^3, $I = 350$ mA, $N_0 = 0.9\times10^{24}$/m^3, $\Gamma = 0.3$, $A = 2.5\times10^8$ s^{-1}, $B = 1.0\times10^{-16}$ m^3/s, $C = 0.94\times10^{-40}$ m^6/s, $\lambda = 1605$ nm, $\lambda_0 = 1605$ nm, $a_1 = 2.5\times10^{-20}$ m^2, $a_2 = 7.4\times10^{18}$ m^{-3}, $a_3 = 3.155\times10^{25}$ m^{-4}, $a_4 = 3\times10^{-32}$ m^4, $\alpha_{int}= 20$ cm^{-1}, $q = 1.6\times10^{-19}$ C; and SOA is divided into 100 segments. In Figure 2, it is showed that high-repetition-rate optical pulses are generated by the SOA in select time windows. But, front dispersion pulses with little energy cannot invoke SOA gain saturation as they pass through the SOA, thus are amplified effectively, and the peak powers are increased. When the peak power of the dispersion pulse is increased to a certain value, gain saturation occurs in SOA. As a consequence there is a corresponding decrease in the peak power of dispersion pulses.

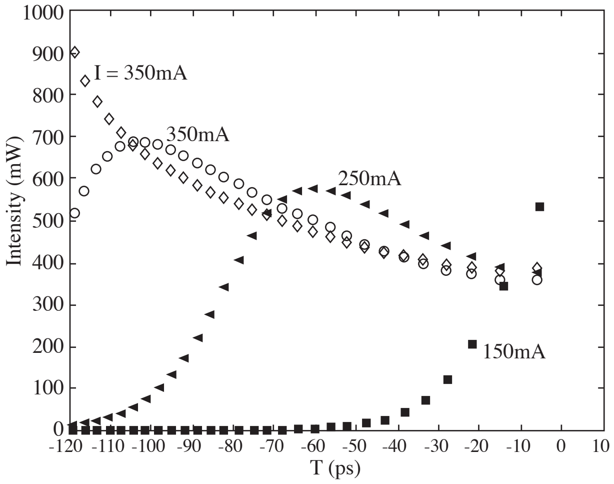

Figure 3. Variety trend of peak power of repetition pulses against different bias currents in SOA.

Figure 3 shows the trend of peak power of amplified repetition pulses for bias currents $I = 150$ mA, 250 mA, 350 mA, and 450 mA. From Figure 3, we can see that the peak power of repetition pulses gradually increase with $I = 150$ mA. The behavior can be explained that, when bias current is lower, the carrier density is also lower. Thereby, the amplification degree of dispersion for the pulse is smaller, and their energy cannot induce the SOA to gain saturation. Consequently, the peak powers of dispersion pulses increase gradually. Conversely, for larger bias currents of SOA, the peak powers of dispersion pulses will first increase then decrease. As a result, high-repetition-rate optical pulses of different length can be obtained by adjusting the bias current.

4. Conclusions

In this paper, we have demonstrated a novel and simple method to generate high-repetition-rate pulse using cascaded single mode fiber and semiconductor optical amplifier. There is an important reference value in practice applications. Research results show that high-repetition-rate optical pulses can be obtained by adjusting the fiber length and bias current of semiconductor optical amplifier.

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