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Design of Highly stable Femto Second Fiber laser in Similariton regime for Optical Communication application

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ABSTRACT: Analyzing the stability of similariton pulse in a passively mode-locked fiber laser. The intracavity elements comprise an Yb doped fiber, a saturable absorber and a single mode fiber. Stability of the pulse has been investigated in the presence of the higher order linear and nonlinear effects of third order dispersion and self-steepening respectively.

KEYWORDS: Mode locked fiber laser, Split step Fourier transform.

1 INTRODUCTION

The generation of ultrashort optical pulses is an extremely exciting and rapidly growing field. A lot of research has been done on ultrafast technology during the last decade and this has created a strong demand for short pulsed laser systems. These lasers find applications in various fields such as optical frequency metrology, terahertz generation, optical coherence tomography, eye laser surgery, dentist drills, micro-machining and marking, high speed soliton transmission and ultrahigh speed OTDM transmission. Of utmost importance in ultrafast optics is the mode-locked laser and development of mode-locked laser is, in itself, a huge research field.

Mode-locked lasers can be of two types: actively mode-locked lasers and passively mode-locked lasers. On the basis of the operation regime, there are three basic classifications: the soliton lasers where the net intracavity dispersion must be anomalous, the stretched pulse fiber laser where dispersion management is used with fiber spans of alternating dispersion, and the similariton (self-similar) lasers where net intracavity dispersion must be normal. The advantage of similariton lasers over the other two types is that self-similar pulses are highly stable and can travel long distances without undergoing wave-breaking. Here, in this paper, we have studied pulse evolution in a passively mode-locked fiber laser in the self-similar regime, and the effect of higher order dispersion and nonlinear terms on the stability of pulses.[1]

2 LASER MODEL

The laser described here consists of a gain fiber, a saturable absorber and a single mode fiber. Propagation of pulses through the gain fiber and the single mode fiber can be described by the extended nonlinear Schrödinger equation given by (1).

$$\frac{\partial A}{\partial z} = -\frac{i}{2}\left(\beta_2 + igT_2{}^2\right)\frac{\partial^2 A}{\partial t^2} + \frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3} + i\gamma|A|^2 A + \frac{1}{2}(g-\alpha)A \qquad (1)$$

where A is the envelope of the field, z is the propagation coordinate, t is time, β_2 is the GVD, β_3 is the TOD, T_2 is the dipole relaxation time, γ is the coefficient of cubic nonlinearity, α is the linear loss and g is the gain coefficient. The gain saturates with total energy according to the equation:

= (2)

Where is the small signal gain, is the saturation energy, and is the pulse energy. The dipole relaxation time is given by:

(3)

Where c is the speed of light in vacuum, is the gain bandwidth, and k is the wave number. The saturable absorber is modeled by its intensity dependent reflectivity given by:

R = + . (1 -) (4)

Where is the unsaturated reflection coefficient, is the saturated reflection coefficient, the saturation power (150W) and P the instantaneous pulse power.

3 Simulation Of The Model

The above model is simulated numerically using the split-step Fourier method. A Gaussian pulse with pulse energy of 200pJ and pulse width equal to 30ps is chosen as the initial pulse. The GVD of the gain fiber is -0.075 , TOD is +0.002 ps^3/m, and the length is 0.4m. γ for both SMF and gain fiber is 0.003$W^{-1}m^{-1}$. The GVD of the SMF is +0.0023ps^2/m and its length is 4m. E_{sat} is 400pJ, g_0 is 7m^{-1}, and the center wavelength of the laser is 1035nm. The resulting net cavity dispersion is +0.062ps^2, i.e., net intracavity dispersion is positive. As expected, the simulation yields steady wave-breaking-free pulses.

4 Results And Discussion

4.1 Pulse Evolution In Presence Of Dispersion And Nonlinearity

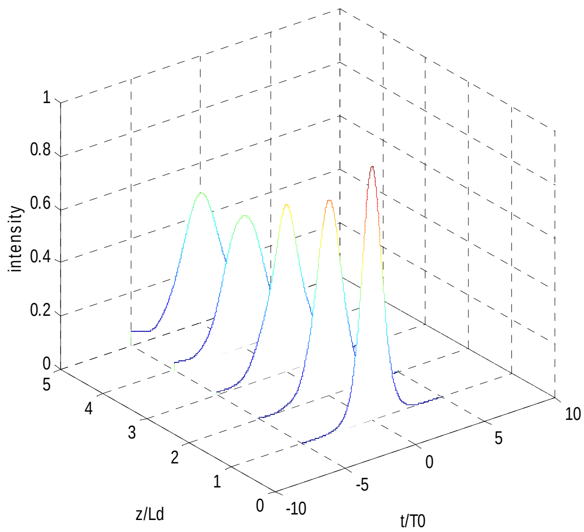

Fig.1: Evolution of pulse in the presence of both dispersion and nonlinearity

Figure 1 shows how the pulse evolves when both GVD and nonlinearity are present. Over here, of importance is the parameter N (called the broadening factor) defined by:

$$N^2 = L_d / L_{NL}$$

Dispersion dominates for N<<1 while self-phase modulation dominates for N>>1. The above graph has been obtained for the condition N=1, i.e. when $L_d = L_{NL}$. Here, both GVD and self-phase modulation are equally effective.

4.2 PULSE EVOLUTION IN AN ALL-FIBER-RING-LASER IN THE WAVE-BREAKING-FREE REGIME [5]

The formation of wave-breaking-free pulses from an initial Gaussian pulse, and the various factors affecting pulse stability have been studied and presented in the following sections.

4.3 BUILD UP OF WAVE-BREAKING FREE PULSE FROM INITIAL GAUSSIAN PULSE

Fig.2: Pulse evolution over 100 roundtrips

Figure 2 shows how the pulse evolves over 100 roundtrips. We have taken Gaussian pulse as the initial pulse. Under normal conditions, the pulse would undergo wave-breaking after few roundtrips. However, here the conditions of self-similar pulse evolution have been met, ensuring that the net intracavity dispersion is positive, whereby parabolic pulses evolve which travel without any change in their shape.

If, however, these conditions are not met and net intracavity dispersion is not positive, then parabolic pulses will not evolve. This would result in wave-breaking, and we will not get stable pulses in that case.

4.4 OUTPUT PULSE PROFILE

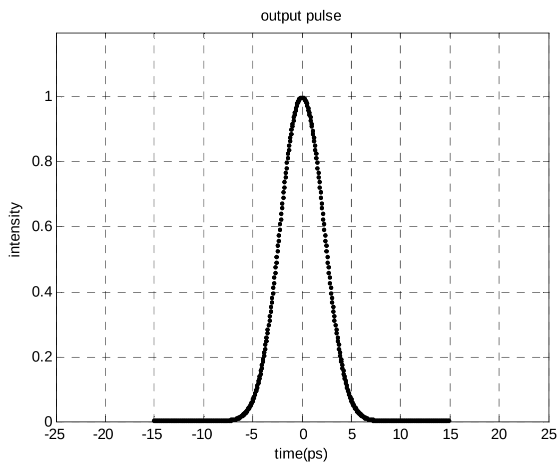

Fig.3: Shape of the output pulse

Figure 3 shows the output pulse profile. The x-axis shows the pulse duration in ps whereas the y-axis shows the normalized pulse intensity. This is the output taken from the cavity. If we use external pulse compression techniques such as prism or grating pairs, then the pulse width can be further reduced.

4.5 EFFECT OF DIFFERENT g_0 VALUES ON PULSE EVOLUTION

The gain of the AS-Yb-PBGF is modeled by:

$$g = \frac{g_0}{1 + {E_{pulse}}/{E_{sat}}}$$

where g_0 gives the small-signal gain, specific to the particular fiber. Thus, g_0 plays a major role in pulse evolution. Presented below are the graphs for different values of g_0. These help us analyze the effect of g_0 on pulse evolution.

Fig.4: Pulse evolution for g_0=7.5

Simulations have been carried out for various values of g_0 and these show that values of g_0 between 7 and 8 are acceptable. Beyond this value, energy saturation occurs. This happens because every gain fiber has a particular value of saturation energy which puts an upper limit on the amount of amplification the fiber would produce. Hence, the gain fiber cannot increase the pulse energy beyond a certain value. This can be seen in the following graphs. The next two graphs show pulse evolution for g_0 values equal to 15 and 20. [2]

g0=15

g0=20

Effect of initial pulse energy on pulse evolution

The initial pulse energy also affects pulse stability. By carrying out simulations with different values of initial pulse energy, it has been observed that initial pulse energy in the range 200pJ to 400pJ is acceptable. Beyond this range, the pulse energy suddenly decreases after the first roundtrip itself. This again happens because of the energy saturation effect in the gain fiber. The next three graphs show pulse evolution for initial pulse energies equal to 300pJ, 600pJ and 1000pJ.

Fig.5: Pulse evolution for initial pulse energy E0=300pJ

Initial pulse energy E0=600pJ

Initial pulse energy E0=1000pJ

4.6 EFFECT OF NONLINEARITY

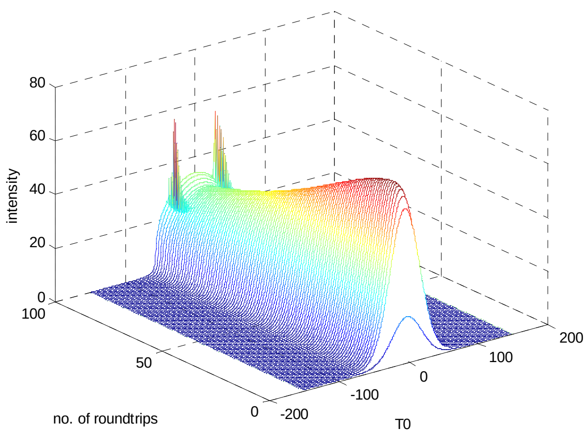

Fig.6 Pulse evolution for increased value of nonlinearity (gamma=0.0075$W^{-1}m^{-1}$)

Figure 6 shows the effect of increasing the fiber nonliearity. As the nonlinearity of the fiber increases, self-phase modulation increases which causes spectral broadening and makes the pulse unstable, with the result that wave-breaking occurs. Nonlinearity becomes more and more dominant as the pulse width decreases. Thus, to avoid the effects of nonlinearity, the pulse width within the cavity should not be reduced to a very short value. We can rather use some external pulse compression techniques to shorten the pulse. We get stable wave-breaking-free pulses for gamma less than $0.005\mathrm{W}^{-1}\mathrm{m}^{-1}$. However, as gamma increases beyond this value, optical wave-breaking occurs. Figure 6 shows pulse evolution for gamma=$0.0075\mathrm{W}^{-1}\mathrm{m}^{-1}$.

4.6 EFFECT OF DISPERSION

Fig.7: Effect of increased dispersion (β_2 of SMF = $0.075ps^2/m$)

Figure 7 shows the effect of increased second order dispersion on pulse evolution. When β_2 of SMF is $0.023\mathrm{ps}^2/\mathrm{m}$, stable pulses are seen to evolve whose shape and intensity remain almost constant. However, when β_2 of SMF is increased to $0.075\mathrm{ps}^2/\mathrm{m}$, the pulses no longer maintain their shape. Broadening of pulses occurs and their intensity is seen to decrease.

5 CONCLUSION

To conclude, modeling of an ultrashort passively mode-locked fiber laser was done using an Yb-doped fiber. Simulations were performed for the case of normal net intracavity dispersion, thereby demonstrating self-similar pulse evolution. The pulses obtained from the laser cavity were further compressed by means of an extra-cavity dispersion compensating fiber.

Stability analysis of the pulses was carried out by varying the system parameters such as gain of the fiber and the initial pulse energy. Besides, the effects of increased nonlinearity and increased second order dispersion, and of including higher order nonlinear and dispersive terms such as self-steepening and third order dispersion were studied.

It was found that values of g_0 between 7 and 8 per meter and initial pulse energy in the range 200pJ to 400pJ is acceptable because beyond this range, energy saturation occurs. Besides, the value of nonlinear parameter γ should not exceed $.005\mathrm{W}^{-1}\mathrm{m}^{-1}$, and β_2 of SMF should remain close to $0.025\mathrm{ps}^2/\mathrm{m}$.

In the presence of third order dispersion, the pulse becomes asymmetric with one of the edges developing an oscillatory structure. Self-steepening also makes the pulse asymmetric. For small values of the self-steepening parameter ‘s’, the pulse remains stable but as the value of s increases, the pulse becomes unstable with its peak shifting towards the trailing edge.

Finally, the effects of using an initially chirped input pulse and using an intracavity DCF were studied. It was found that the effect of initial chirp is to make the pulse unstable. On the other hand, if we use an intracavity DCF then we can greatly improve the output pulse characteristics. We can get a much narrower and sharper pulse from the cavity by using an intracavity dispersion compensating fiber.

The work, in this project, has been done for the case of net normal intracavity dispersion which leads to self-similar pulses. Future work in this field would include the design of an all normal fiber laser. The advantage of an all normal fiber laser is that it would give highly stable pulses with higher pulse energy and peak power.

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