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Pulse Shape of Fiber Mode Lock Laser

1. Ginzburg–Landau Equation
2. Mechanism of Pulse-Stretched 、Similariton Pulses、Dissipative Soliton
3. Comparison of Different Mechanism

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Ginzburg–Landau Equation

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The **modifified nonlinear Schrödinger equation (MNLSE)**, which takes into account **gain** and **losses**, as well as **GVD of different orders**, **nonlinear effects**, and the effect of **saturable absorbers (SA)** and **spectral fifilters[1]:**

$$\frac{\partial A}{\partial z}+i\frac{\beta_2(z)}{2}\frac{\partial^2 A}{\partial T^2}-\frac{\beta_3(z)}{6}\frac{\partial^3 A}{\partial T^3}=i\gamma\left(|A|^2A+\frac{i}{\omega_0}\frac{\partial|A|^2A}{\partial x}-T_RA\frac{\partial|A|^2}{\partial T}\right)-\Gamma A+g(z)A+ \\ +g(z)\tau_g^2\frac{\partial^2 A}{\partial T^2}+\frac{1}{\Omega}\frac{\partial^2 A}{\partial T^2}+\alpha|A|^2A+\delta|A|^4A, \tag{1}$$

Soliton Generation Mode

$$\frac{\partial A}{\partial z}+i\frac{\beta_2(z)}{2}\frac{\partial^2 A}{\partial T^2}=i\gamma(|A|^2A) \tag{2}$$

GVD Coefficient **Nonlinearity Parameter**

$$A(t,z)=A_0\mathrm{sech}(t/T_0)e^{i\varphi} \tag{3}$$

[1]. Haus, H.A. Theory of mode locking with a fast saturable absorber. *J. Appl. Phys.* **1975**, *46*, 3049–3058.

Mechanism of Different Modes

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Nonlinear Phase Shift

$$\Phi^{NL}(t,L) = \frac{\omega}{c}\int_0^L n_2 I(t,z)dz \qquad (4)$$

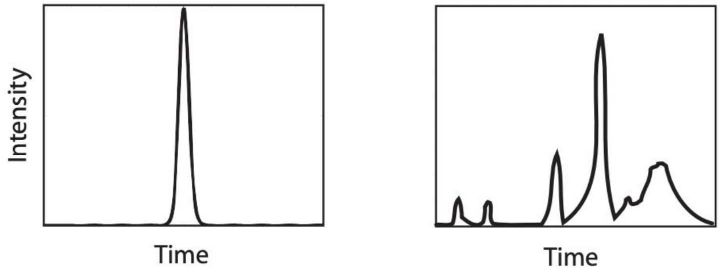

Fig.1 Wave-Breaking of Laser Pulse[2]

$\phi^{NL} \sim \pi$	$A(t) = A_0 exp\left(-\frac{t^2}{2T_0^2}\right) \qquad (5)$ **Stretched Pulses**	The main feature of this generation mode is the **ability to reduce nonlinear effects** by changing the pulse duration inside the cavity.
$\phi^{NL} \gg \pi$	$A(t) = A_0\left[1-\left(\frac{t}{T_0}\right)^2\right]^{1/2} exp\left(-iC\frac{t^2}{2T_0^2}\right) \qquad (6)$ **Similariton Pulses**	For monotonically-chirped solutions of the nonlinear Schrodinger equation, high-intensity wave-breaking-free solutions exist when the **GVD is normal**.
	$A(t,z) = A_0 \mathrm{sech}(t/T_0) e^{i\beta_2 \ln(sech(\frac{t}{T_0}))+i\theta z} \qquad (7)$ **Dissipative Soliton**	The stable generation of a laser in the mode of dissipative solitons **requires a spectral filter** in the cavity to limit the growth of the laser spectrum.

[2]. Wise, F.; Chong, A.; Renninger, W. High-energy femtosecond fiber lasers based on pulse propagation at normal dispersion. *Laser Photonics Rev.* **2008**, *2*, 58–73.

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Comparison of Different Mechanism

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Parameter	Soliton	Stretched Pulses	Similariton	Dissipative Soliton
Total GVD of the resonator elements	<0	close to 0	close to 0	>0
Maximum pulse energy	limited	limited	not limited	not limited
Minimum pulse duration	~1 ps	tens of femtoseconds	tens of femtoseconds	tens of femtoseconds

Table 1. Comparison of the main characteristics of various generation modes in fifiber USP lasers[3].

Based on the analysis of the generation modes of fiber USP lasers, a summary in Table 1 was compiled, which reflects the **main output characteristics** of the radiation and the parameters of laser resonators at various generation modes. Typical values are indicated for each mode. As mentioned above, the main parameter characterizing the stability of time characteristics is the jitter, which depends on the USP laser total GVD.

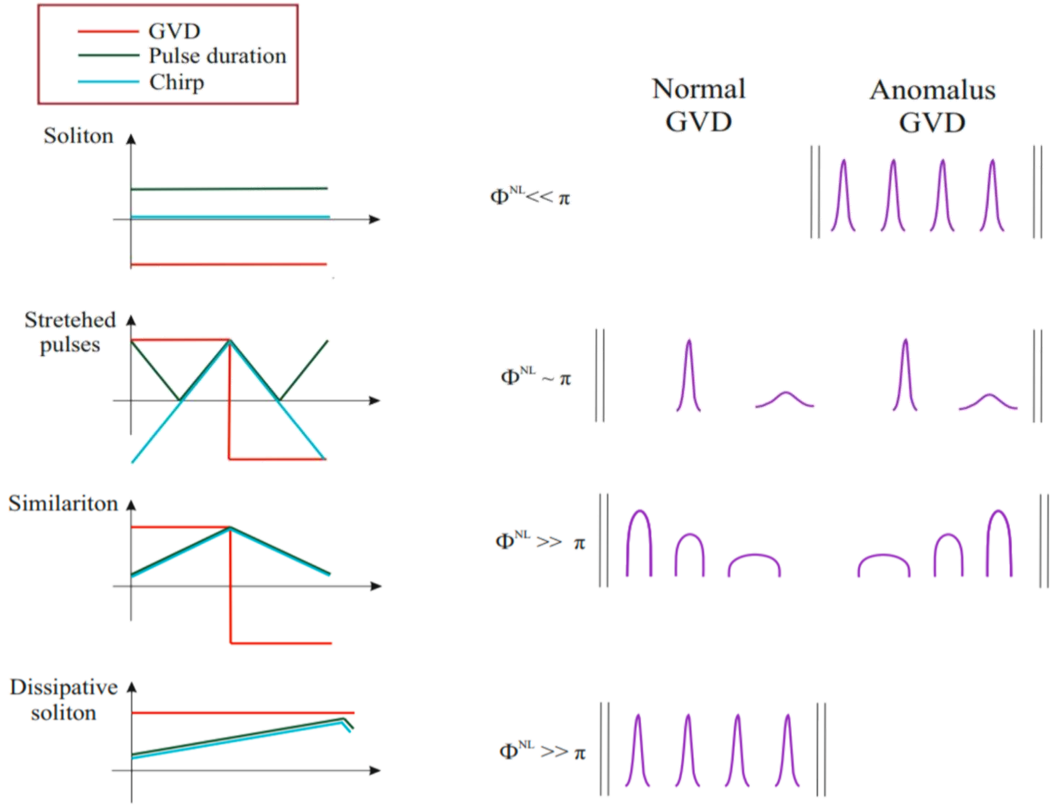

Figure 2. A simplified diagram of the evolution of pulses in resonators of different types[3].

[3]. Sazonkin, S.G.; Orekhov, I.O.; Dvoretskiy, D.A.; Lazdovskaia, U.S.; Ismaeel, A.; Denisov, L.K.; Karasik, V.E. Analysis of the Passive Stabilization Methods of Optical Frequency Comb in Ultrashort-Pulse Erbium-Doped Fiber Lasers. Fibers 2022, 10, 88. https://doi.org/10.3390/fib10100088.

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THANKS!
Q&A