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All-fiber ultrashort pulse laser

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Fibers-The key to femtosecond fiber lasers

- Confinement of pump and laser light.
- Excellent thermal properties.
- Ease to use and robustness.
- Reliable and economical telecom components.
- High electrical to optical efficiency
- Perfect mode profile: TEM_{00}.
- Compact size allowing integration.

Limitations of Ultrashort pulse fiber laser

- Nonlinearity: typically accumulate nonlinearities should be less than π to avoid severe spatial and spectral distortions.
- Maximum usable fiber core size.
- Dispersion: must be matched through third order for pulse recompression.

Development of fiber ring laser

- Soliton fiber laser: all fibers in the ring work in negative dispersion.
- Pulse energy: several hundreds of picojoules.
- Further improvements occurred when it was realized that the presence of anomalous GVD within the laser cavity limits both the width and the energy of pulse.

Development of fiber ring laser

- Stretched-pulse fiber laser: dispersion management or nonlinearity management, which could generate the shortest pulse in fiber laser.
- Pulse energy: its nonlinear phase shift is still limited to $< \pi$, output pulse energy is several nanojoules.

Development of fiber ring laser

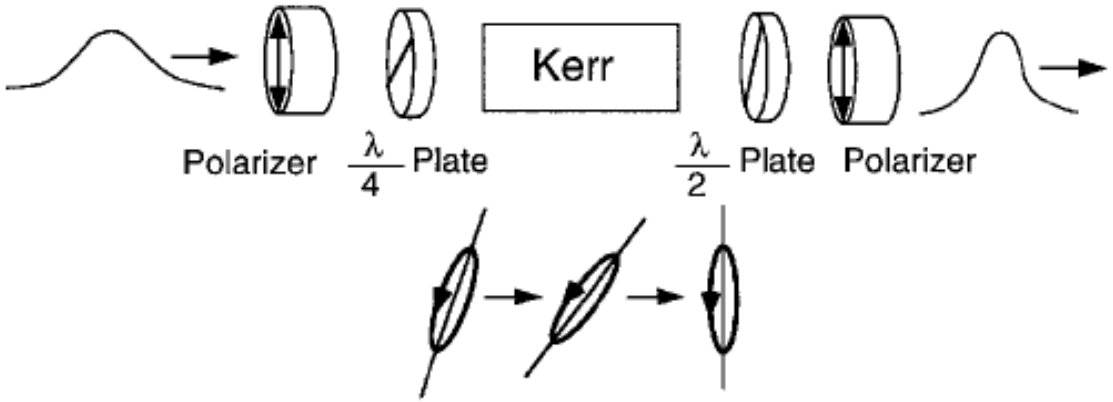
- Self-similar fiber laser: normal dispersion linearizes the chirp produced by self phase modulation, the wave breaking free pulse evolves into a parabolic shape.
- Pulse energy: its sustainable nonlinear phase shift can be as large as 10 π , pulse energy scales up to about fifty nanojoules .

Mode-locking methods of the fiber laser

- Active mode-locking: ~ pulse duration limited to a few picoseconds.
- Passive mode locking:

1. Semiconductor saturable absorber mirror.
2. Nonlinear amplifying loop mirror (NALM or Figure-8).
3. Nonlinear polarization rotation (NPR).

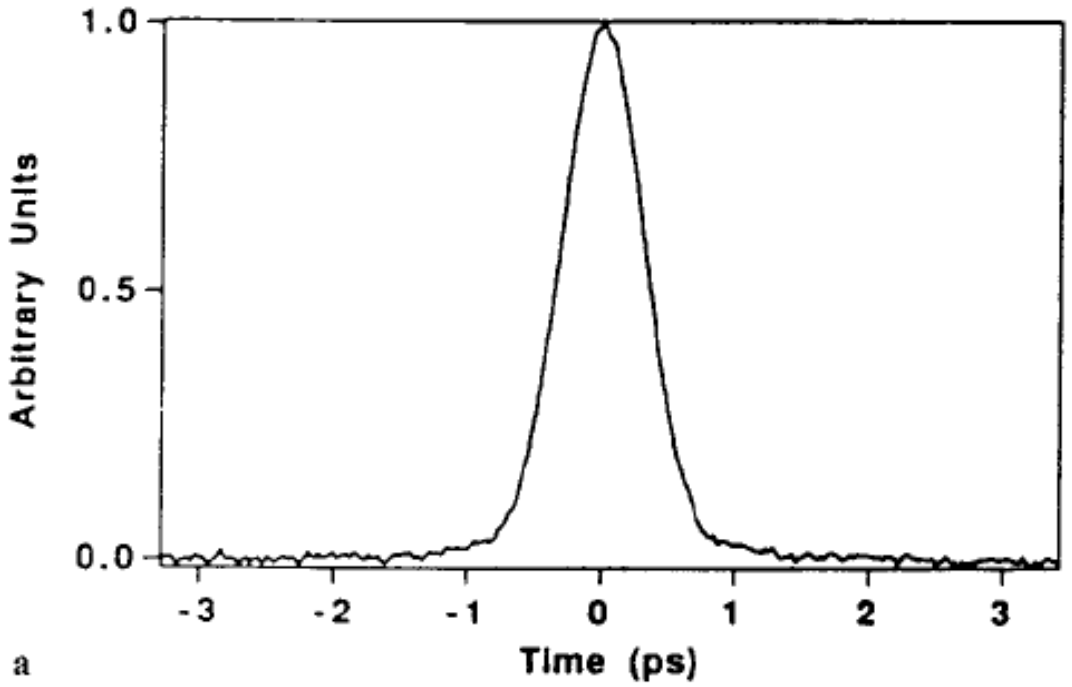
Nonlinear polarization rotation (NPR)



- The NPR technique could generate sub 100-fs pulses if the dispersion management is optimized.

L.E. Nelson et al. Appl. Phys, 1997, B 65 :277～294.

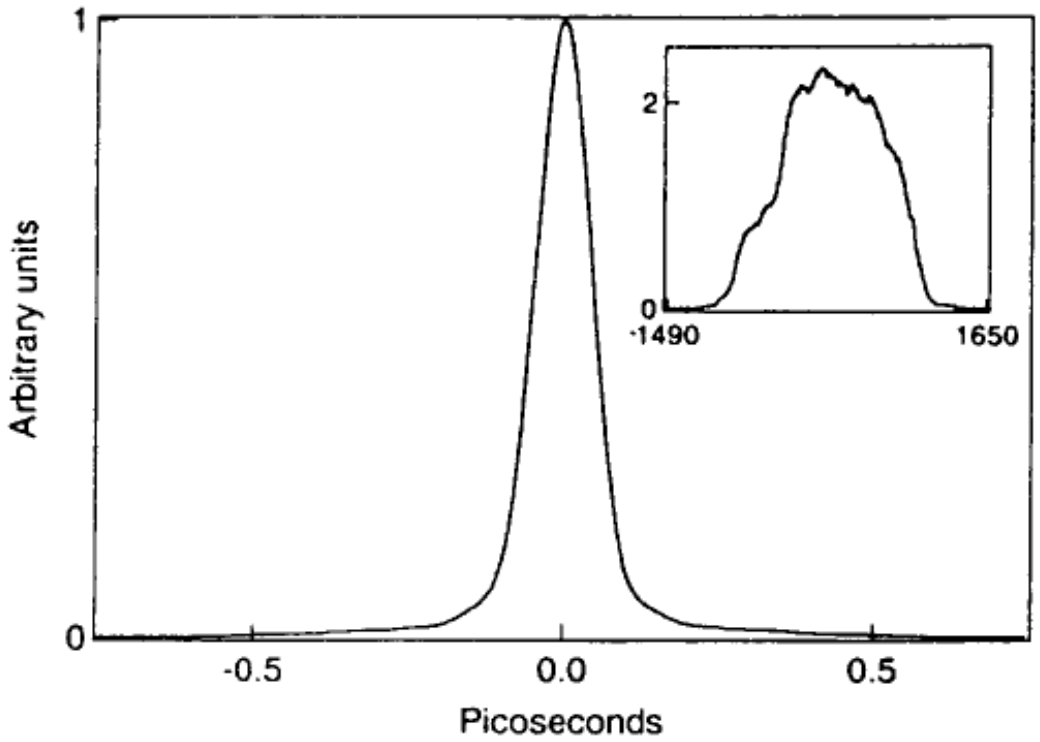
Experiment results in early 1990s



- 450-fs pulse output from the soliton fiber laser was achieved by Tamura et al in 1993.

K. Tamura et al, Electron. Lett. 28, 2226(1992).

Experiment results in early 1990s

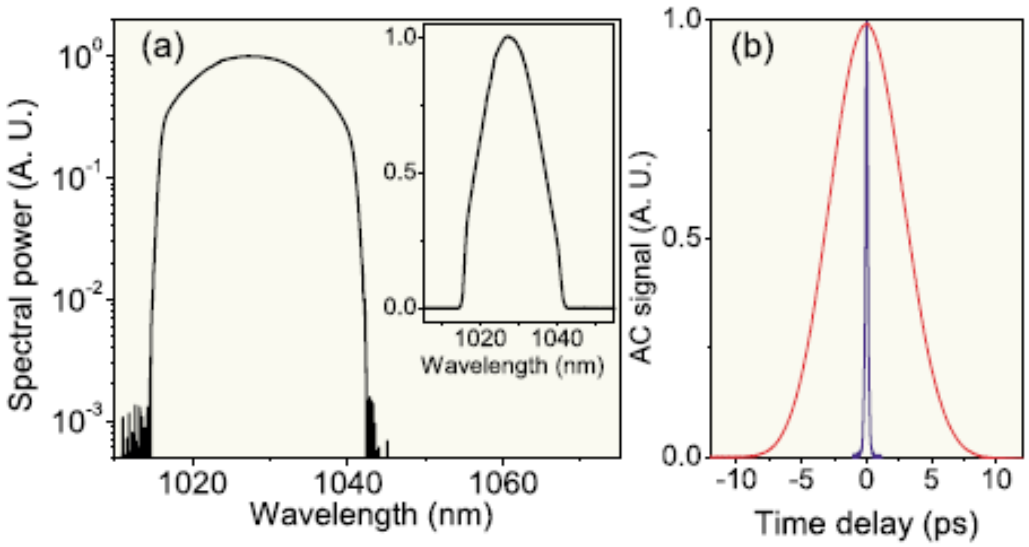


- Stretched-pulse fiber laser achieved 77-fs ultrashort pulse also by Tamura et al in 1993.

K. Tamura et al. Opt. Lett., 1993, 18(13): 1080～1082.

Pulse suffer from wave-breaking when nonlinear phase shift is larger than π .

Wave-breaking free parabolic pulses Yb-doped fiber laser



F. O. Ilday et al, PRL. 92(21), 213902 (2000).

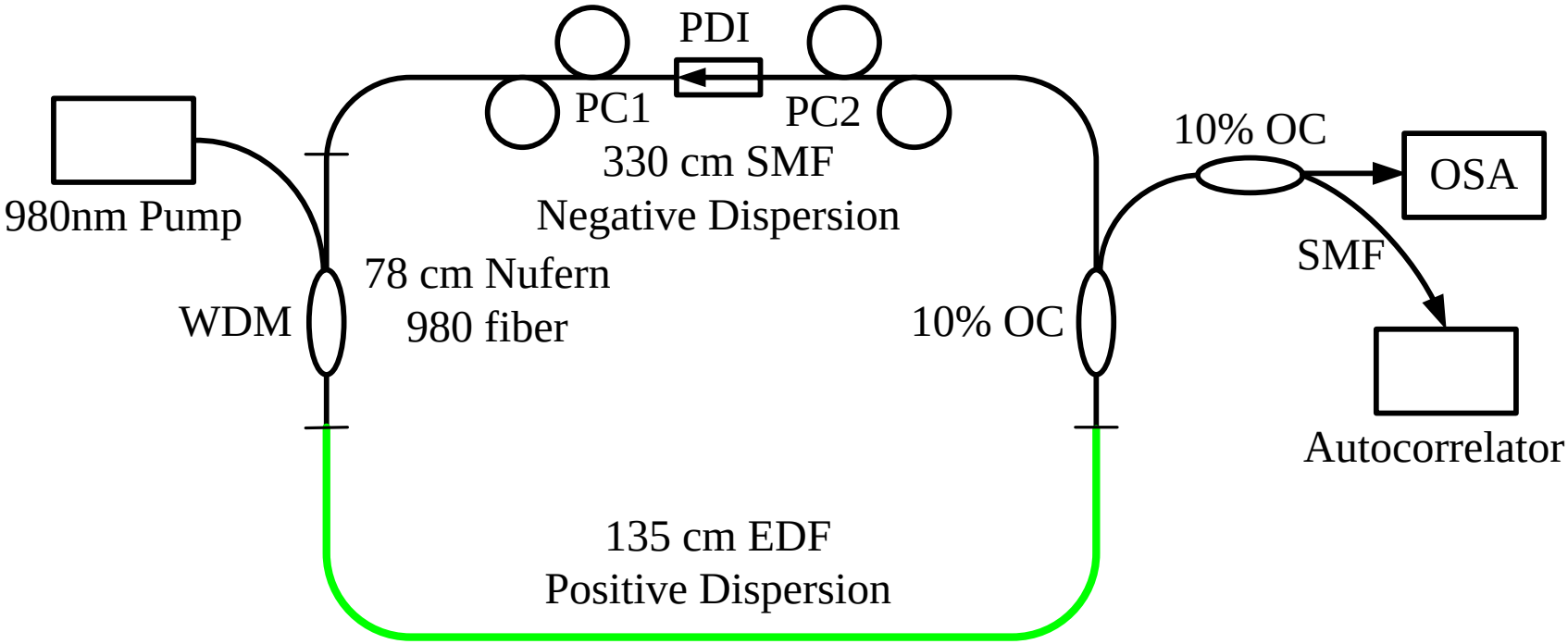
Whether or not we can also get parabolic pulse in erbium-doped fiber laser ?

Not yet.

Because long gain fiber must be used causing strong nonlinearity, so pulse could not develop into parabolic shape.

While wave-breaking free is still possible.

Experiment configuration



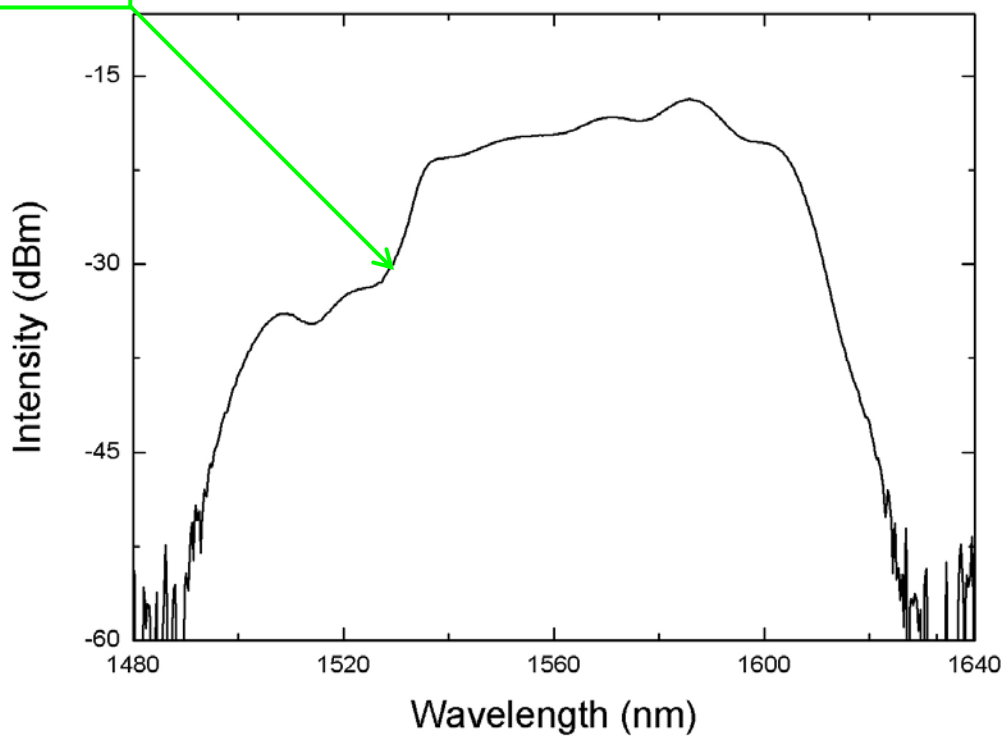
Carefully optimize the cavity length and the gain fiber can make the fiber laser working on the wave-breaking free regime.

Dispersion management

- The GVD parameter of standard single mode fiber is about 18ps/nm/km.
- High-doped EDF has a GVD parameter of about -51ps/nm/km.
- Dispersion was optimized to generate shortest, wave breaking free pulse.

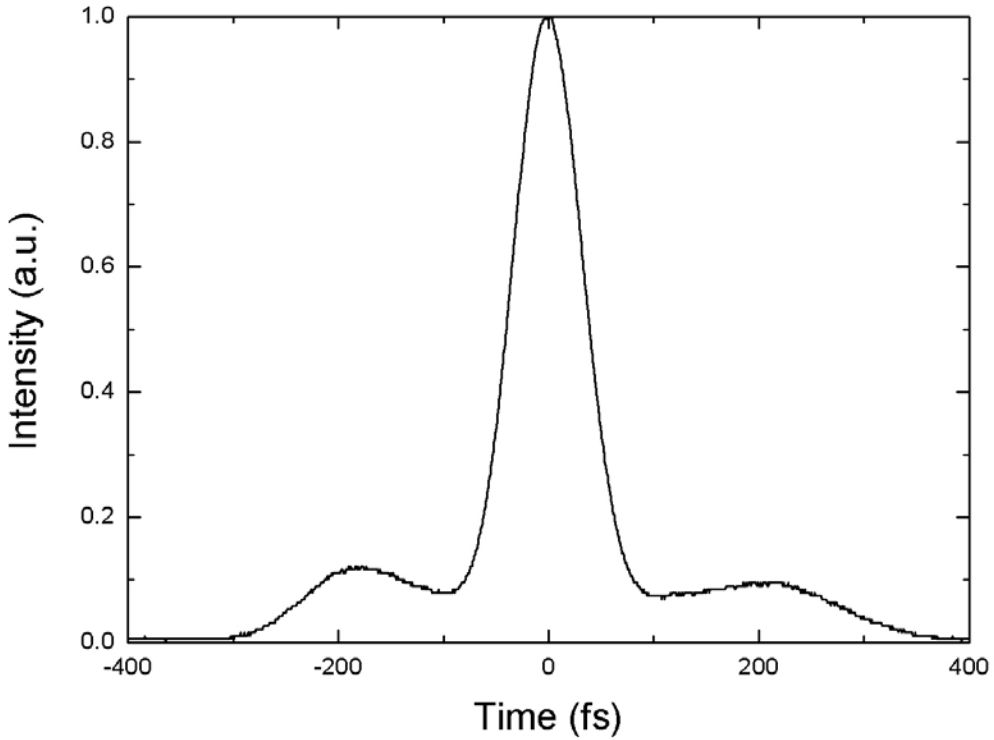
Optical spectrum

Absorption peak of erbium



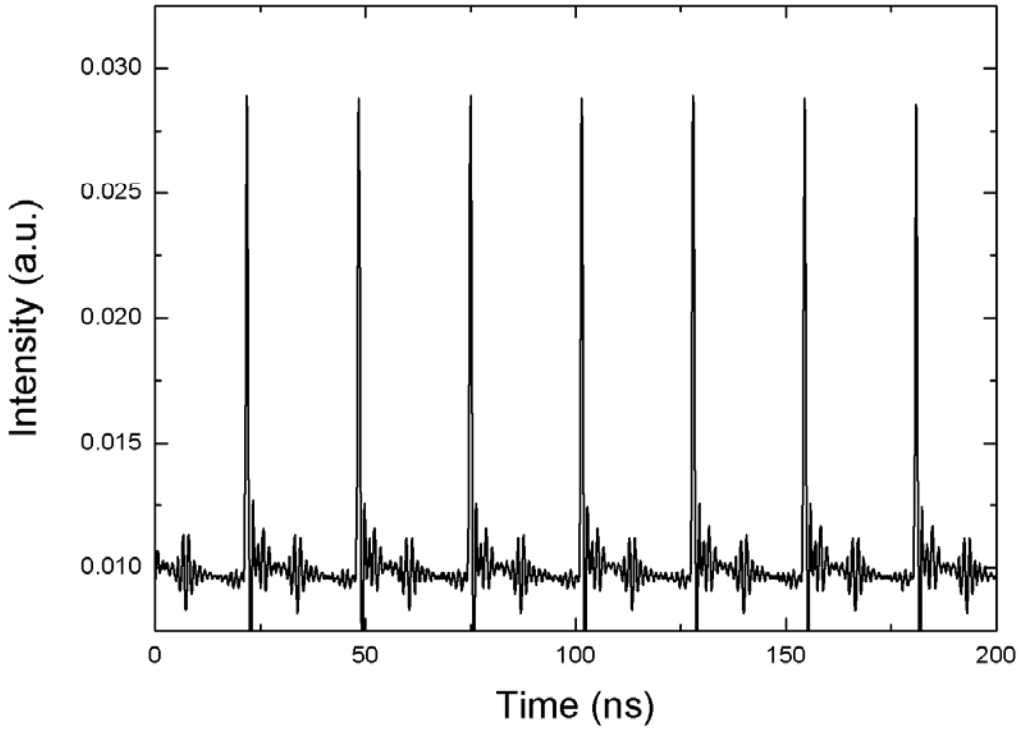
- Without any sidelobe and CW-breakthrough
- spectrum width is 61 nm.

Autocorrelate trace



- 50-fs pulses output from the laser

Pulses train



Time-bandwidth product

- 50-fs output pulse
- 61 nm spectrum width
- Time-bandwidth is 0.37

Output power

- Output average power is 56.4 mW at 330 mW pump power, but limited by available pump power.
- Peak power is about 23 kW

Erbium doped fiber laser working on wave breaking free regime

- Large nonlinear phase shift.
- Scales up energy.
- Efficient recompression.
- High quality single pulse operation.

Thank you!