Title

Stretching Ultrafast Pulses Using Optical Fibers

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Publication Date

2024-06-10

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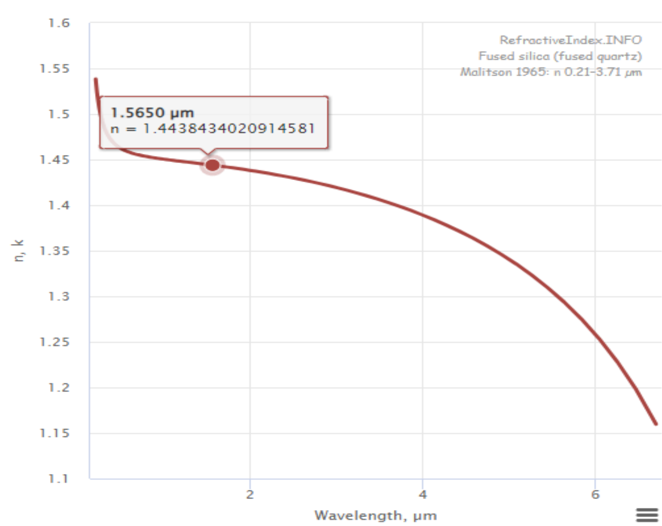
Abstract: Ultrafast pulses can be temporally stretched through the use of optical fibers. By utilizing its dispersion characteristics and varying the propagation length, desired pulse durations can be achieved.

INTRODUCTION

In a mode-locked laser (ML) that uses a cavity to initiate lasing conditions, the resulting pulse duration may be shorter than desired [1]. In the case of ultrafast lasers (femtosecond or picosecond ranges), optical fibers may be used to stretch pulses temporally. The operation is driven by the dispersive characteristics of the optical material, which in this case are optical fibers. By sending a pulse through a fiber with dispersive characteristics, chromatic dispersion can be utilized to temporally stretch the pulse [2]. Chromatic dispersion occurs due to the "dependence of refractive index on frequency," [3] causing different modes to propagate at different velocities. It is also important to note that at higher intensities of the pulse, the refractive index may begin to behave nonlinearly [4]. Some fields that utilize this technique include biomedicine for ultrasound imaging [5], Raman scattering excitation systems to avoid laser-induced plasma sparks [6], and chirped pulse amplifier (CPA) systems.

METHODS

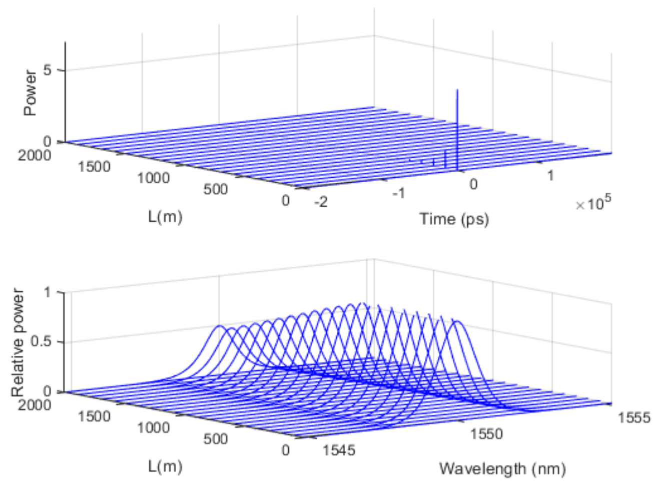
Figure 1. Example of refractive index of fused silica (Ref. [6])



The figure displays the relationship between refractive index and wavelength of fused silica, generally showing a negative correlation. By passing the pulse through a fiber, shorter wavelengths will have higher refractive indexes and thus travel slower according to the simple relation (velocity = speed of light / refractive index), while longer wavelengths, with lower refractive indexes, will travel faster and ultimately result in a stretched pulse.

To simulate the stretching process, I have used MATLAB with base code from Dan T Nguyen [3].

Figure 2. Simulation of pulse stretching from MATLAB code



The input laser was modeled using a hyperbolic secant pulse with a peak power of 5.6910 W and a temporal full-width half max (FWHM) of 1.66 ps. The pulse propagated through an SMF-28 fiber [7] with a dispersion of about 18.0 ps / (nm ` km) and nonlinear refractive index of 2.6e-20 for 2km.

RESULTS AND INTERPRETATION

Table 1. Simulation results of pulse stretching from MATLAB code

Propagation Distance(m)	FWHM (ps)	Peak Power (W)	Energy (pJ)
0	1.6	5.6910	10.5284
1000	266.2658	0.0263	8.5578
2000	1160.89	0.0032	4.3890

The simulations display that significant stretching occurs throughout the optical fiber, with chromatic dispersion evident from the widening of the pulse in the frequency domain.

Additionally, the pulse maintains an energy of 10.0575 pJ and achieves a FWHM of 36.6 ps after 500 meters of propagation. This indicates that substantial stretching is possible without significant energy loss.

CONCLUSIONS

Using MATLAB simulations, it has been shown that pulse stretching using only optical fibers is feasible, with significant stretching achievable without substantial energy loss. However, as these results are based on simulations, future research should involve tests and experiments on actual erbium-doped mode-locked lasers and physical optical fibers. This hands-on research is essential to account for additional physical effects or variables that may not be represented in simulations but could influence the performance of physical devices. It would also be very beneficial to test this process on a variety of inputs with differing FWHM and peak powers to test best operating conditions.

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