The Study of The Pulse Laser Properties in Two Different Photonic Crystal Fiber Materials

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Received on: 27/4/2011 & Accepted on: 2/2/2012

ABSTRACT

This study is to obtain a better understanding of how to shape the pulse laser spectrum by varying the material properties of the photonic crystal fiber (PCF). This includes the ability to obtain spectral power in particular wavelength regions, and obtaining a broad bandwidth.. Numerical modeling of the split step Adaptive Fourier method has been used to solving a form of nonlinear Schrödinger equation, which describes the propagation of pulses in PCF. It was investigated how the spectrum can be controlled through dispersion property. The electromagnetic wave that send from IR laser diode source through the PCF to the observer. the optical properties of this electromagnetic wave, normalized power, intensity, dispersion, and group delay dispersion will be studied for the input, output and observer laser pulse. The compared of the different two materials of PCF (fused silica and Barium-fluoride BaF2) that be used and studies.

Keywords: Fused silica crystal fiber, BaF2 crystal fiber, Observer, IR laser diode source

دراسة خصائص نبضة الليزر لمادتين مختلفتين من الالياف الضوئية الكرستال

الخلاصة

هذه الدراسة هي للحصول على فهم أفضل لكيفية تشكيل طيف نبضة الليزر من خلال تغيير خصائص المواد من الألياف الضوئية الكريستال (PCF). وهذا يشمل القدرة على الحصول على الطاقة الطيفية في مناطق معينة من الطول الموجي، والحصول على عرض النطاق الترددي الواسع. وقد استخدمت النماذج العددية للأسلوب الخطوة تقسيم فورييه على التكيف مع شكل من أشكال حل معادلة شرودنجر غير الخطية ، التي تصف انتشار النبضات في الألياف البصرية. تم التحقيق في كيفية السيطرة على الطيف من خلال خاصية التشتت.ان هذا البحث يتضمن الموجة الكهرومغناطيسية التي ارسلت من مصدر ليزر دايود، تمر عبر الألياف الضوئية الكريستال ثم تصل إلى المراقب. وستتم دراسة الخصائص البصرية لهذه الموجة الكهرومغناطيسية، قوة طبيعية، والكثافة، والتشتت، ومجموعة تشتت تأخير للإدخال والإخراج والمراقب لنبضة الليزر. المقارنة للمادتين مختلفتين من الألياف الضوئية الكريستال (السيليكا و فلوريد الباريوم) التي يمكن استخدامها ودراستها.

INTRODUCTION

The method relies on computing the solution in small steps and on taking into account the linear and nonlinear steps separately. The linear step (dispersion) can be made in either frequency or time domain, while the nonlinear step is made in the time domain.

THEORETICAL BASICS

The method is widely used for studying nonlinear pulse propagation in optical fibers. The electric field of a pulse linearly polarised along the x-axis and propagating in the fundamental mode of an optical fiber can be written as [1]

$$E_A(r,t) = \hat{x}F(x,y)A(z,t)exp[i(\beta_0 z - w_0 t)] \quad (1)$$

where r =(x, y, z), ˆx is the polarization unit vector, F(x, y) describes the transverse field distribution, A(z, t) is the pulse envelope, and β_0 is the mode propagation constant ß(ω) at the centre angular frequency $\omega_0$of the pulse. E_A is scaled to the actual electric field E [V/m] according to $E_A = \sqrt{\frac{1}{2}\epsilon_0 cnE}$, where ϵ_0 is the vacuum permittivity, c is the speed of light in vacuum, and n is the refractive index. This ensures that the instantaneous optical power can be calculated as $|A|^2$. The change in pulse envelope A as the pulse propagates along the fiber axis z is described by the generalized nonlinear Schrödinger equation.

$$\frac{\partial A}{\partial z} = -\frac{\alpha(w)}{2}A + i\sum_{m\geq 2}\frac{\beta_m}{m!}[w-w_0]^m A + i\gamma(w)\left[1+\frac{w-w_0}{w_0}\right]F\left\{A(z,T)\int_{-\infty}^{+\infty}R(T')|A(z,T-T')|^2 dT'\right\} \quad (2)$$

where F denotes the Fourier transform and A(z, ω) is the Fourier transform of A(z, t),

$$F\{A(z,t)\} = A(z,w) = \int_{-\infty}^{+\infty}A(z,t)exp[i(w-w_0)t]\,dt \quad (3)$$

and the pulse envelope A(z, T) is considered in a retarded time frame(T= t- β_1z) moving with the group velocity 1/ β_1 at the carrier frequency. The dispersion coefficients ß2,ß3 , . . . , are defined from the Taylor expansion of the mode propagation constant ß(ω)[1]:

$$\beta(w) = \beta_0 + \beta_1[w-w_0] + \frac{1}{2}\beta_2[w-w_0]^2 + \frac{1}{6}\beta_3[w-w_0]^3 + \quad .... \quad (4)$$

Where

$$\beta_m = \beta_m(w_0) = \left(\frac{d^m\beta}{dw^m}\right)_{w=w_0} \quad ,(m=1,2,3,...) \quad (5)$$

$\alpha(w)$ is the power attenuation coefficient. $\gamma(w) = n_2 w_0/[cA_{eff}(w)]$ is the nonlinear parameter, where $n_2 = 2.6 \times 10^{-20}$ m^2/W is the nonlinear-index coefficient for silica ,and Aeff is the effective core area, It is usually defined as: [1]

$$A_{eff}(w) = \frac{\left[\iint_{-\infty}^{+\infty}|F(x,y,w)|^2 dxdy\right]^2}{\iint_{-\infty}^{+\infty}|F(x,y,w)|^4 dxdy} \quad (6)$$

the more general definition is best suited for the present work. R(t) is the Raman response function [1,2]

$$R(t) = (1 - f_R)\delta(t) + f_R\, h_R \quad (7)$$

$$h_R(t) = \frac{\tau_1^2+\tau_2^2}{\tau_{1\tau_2^2}}\theta(T)exp(-t/\tau_2)sin(t/\tau_1) \quad (8)$$

where f_R=0.18 is the fractional contribution of the delayed Raman response, τ_1=12.2fs,and τ_2=32fs. θ(t) is the Heaviside step function and δ(t) is the Dirac delta function. There exists both a parallel and an orthogonally polarised delayed Raman response [3], but the orthogonal component is generally negligible [4, 5] and therefore usually not considered, which is also the The factor [1+(ω-ω0)/ω] in Eq. (2) is responsible for self- approach taken here. steepening and is due to the intensity dependence of the group velocity [1]. The propagation in Eq. (2) is often written in the time domain by neglecting the frequency dependence of γ, γ = γ(ω0), and $\alpha, \alpha = \alpha(w_0)$, and then Fourier transforming of Eq. (2) using the Fourier transformation replacement property ∂/∂t ↔ -i[ω - ω0][1,2]:

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A + i\sum_{m\geq 2}\frac{i^m\beta_m}{m!}\frac{\partial^m A}{\partial T^m} + i\gamma(w)\left[1 + \frac{i}{w_0}\frac{\partial}{\partial T}\right]\left[A(z,T)\int_{-\infty}^{+\infty}R(T')|A(z,T-T')|^2 dT'\right] \quad (9)$$

$$\text{Where} \quad \frac{\partial A}{\partial z} = \left[D_{(w)} + N_{(z,w)}\right]A \quad (10)$$

Where D(ω) is the dispersion operator given by:

$$D(w) = i\sum_{m=1}^{\infty}\frac{\beta_m}{m!}[w-w_0]^m \quad (11)$$

And N is the nonlinear operator and is given by:

$$N(z,\omega)A = i\gamma(\omega)F\{A(z,T)|A(z,T)|^2\} \quad (12)$$

The Pulse parameters

The Gaussian pulse can be written as:

$$A(T) = \sqrt{p_0}\,exp\left(-\frac{T^2}{2T_0^2}\right) \quad (13)$$

with pulse energy E given by

$$E = \int_{-\infty}^{+\infty}|A(T)|^2dT = \sqrt{\pi}\,P_0T_O \approx 1.06P_0T_{FWHM} \quad (14)$$

T_0 is the half-width at 1/e-power, related to the power FWHM by

$$T_{FWHM} = 2\sqrt{ln2T_0} = 1.665T_0 \quad (15)$$

An especially MATLAB package is designed to evaluate these parameters through the simulation of equations (2 to 15).

RESULTS AND DISCUSSION

The split-step (Fourier) method is a pseudo-spectral numerical method used to solve nonlinear partial differential equations like the nonlinear Schrödinger equation, and the numerical results of the second order dispersion was shown in table (1)&(2), It shown that the 2nd order dispersion inversely proportional with wavelength. The same optical property of the input pulse laser source for silica and Ba-fluoride photonic crystal fiber, that have laser full width at half maximum (FWHM) pulse time is 10 fs, and peak power is 90 km/nJ, the spectrum will be 10 dB-width=11.4nm was shown in figure (1) and (4). In figure (2)&(5) the pulse property in the observer, the normalized power in the silica fiber have FWHM is 2.65*10^4fs & the FWHM in Ba-fluoride photonic crystal fiber is 2.74*10^4, the dispersion in silica increases with increases wavelength while the dispersion in Ba-fluoride photonic crystal fiber decreases with increases the wavelength, The 2nd order dispersion(GDD) of the silica is negative dispersion while in the Ba-fluoride photonic crystal fiber is positive GDD, the spectrum in the silica have 10B-width 11.4nm while in the Ba-fluoride photonic crystal fiber have 10dB-width is 2.65*10^4nm. In figure (3)&(6) that shown output pulse property (the

relation of normalized power with time(femtosecond) in silica photonic crystal fiber the FWHM is 2.65*10^4fs while the FWHM in the Ba-fluoride photonic crystal fiber is 2.74*10^4fs. the relation between the dispersion and wavelength, in silica the dispersion increases with increases wavelength while the dispersion in Ba-fluoride photonic crystal fiber decreases with increases the wavelength, The 2nd order dispersion GDD of the silica is negative dispersion while in the Ba-fluoride photonic crystal fiber is positive GDD, the spectrum in the silica have 10B-width -2.65nm while in the Ba-fluoride photonic crystal fiber have 10dB-width is 10nm.

CONCLUSIONS

In this study we have applied Numerical modeling of the split step Adaptive Fourier method to solve a form of nonlinear Schrödinger equation, this method is easy to implement on a computer and one can easily introduce higher-order splitting formulae to increase greatly the accuracy of split-step method. The dispersion in the BaF2 fiber is less than the dispersion in silica fiber because the dispersion in BaF2 is decreases with increases wavelength while the dispersion in silica increases with wavelength. The second order dispersion GDD in silica is negative while in BaF2 is positive.

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Table (1) the numerical result of wavelength and 2nd order dispersion GDD in silica

Wavelength range in (nm)	GDD(ps/km.nm)
1300	-1.2313*10^7
1350	-3.1661*10^7
1400	-5.9804*10^7
1450	-8.267*10^7
1500	-1.1081*10^8
1550	-1.372*10^8
1600	-1.7414*10^8
1650	-2.7967*10^8
1700	-2.4098*10^8
1750	-2.7967*10^8
1800	-3.1661*10^8
1850	-3.5531*10^8
1900	-4.028*10^8
1950	-4.4853*10^8
2000	-5.01308*10^8

Table (2) the numerical result of wavelength and 2nd order dispersion GDD in Bafluoride BaF2

Wavelength range in (nm)	GDD(ps/km.nm)
1300	9.3159*10^7
1350	8.6168*10^7
1400	7.8442*10^7
1450	7.1452*10^7
1500	6.483*10^7
1550	5.7103*10^7
1600	4.9009*10^7
1650	4.2019*10^7
1700	3.6132*10^7
1750	2.951*10^7
1800	2.2887*10^7
1850	1.2278*10^7
1900	5.2276*10^6
1950	-3.604*10^6
2000	-1.2064*10^7

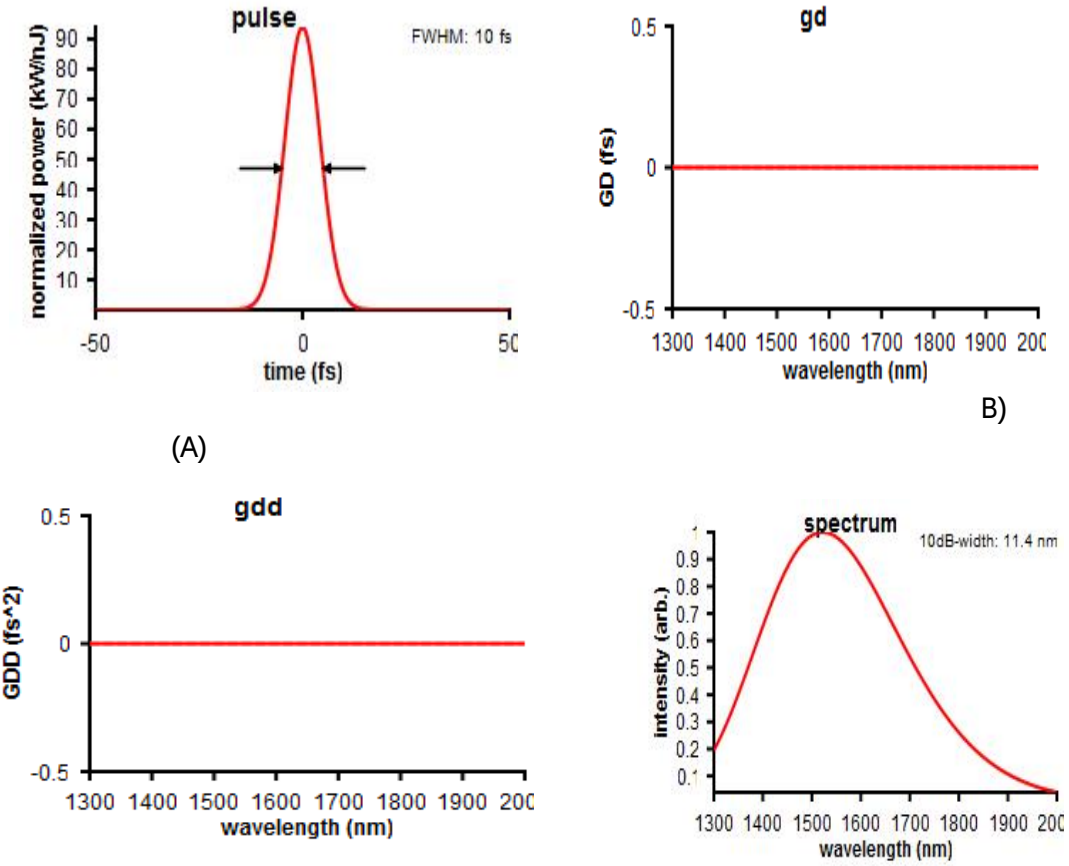
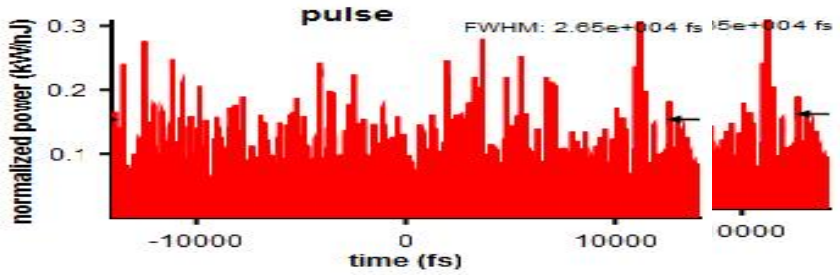


Figure (1) (A,B,C,D) input pulse property for silica photonic crystal fiber input pulse property for silica photonic crystal fiber

(A)



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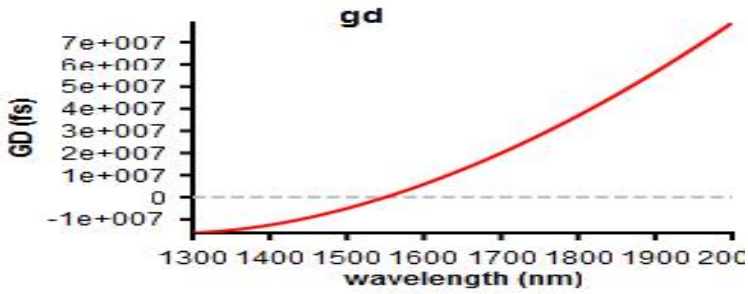

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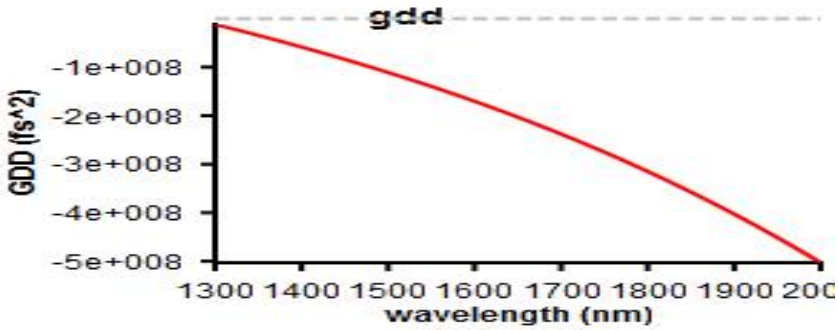


(D)

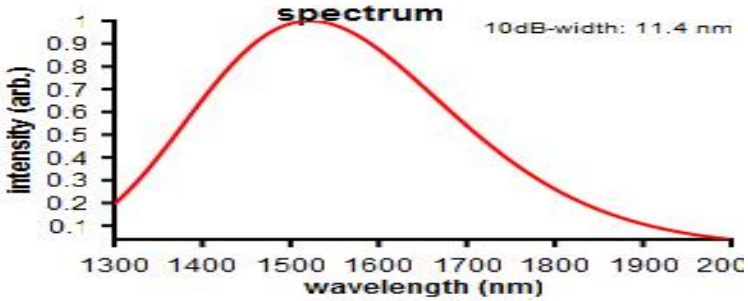
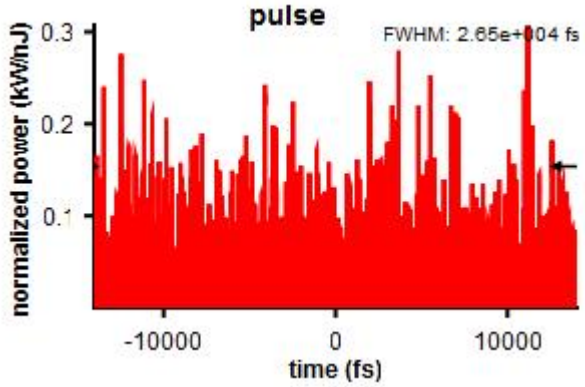


Figure (2) (A,B,C,D) observer pulse property for silica photonic crystal fiber

(A)

(A)



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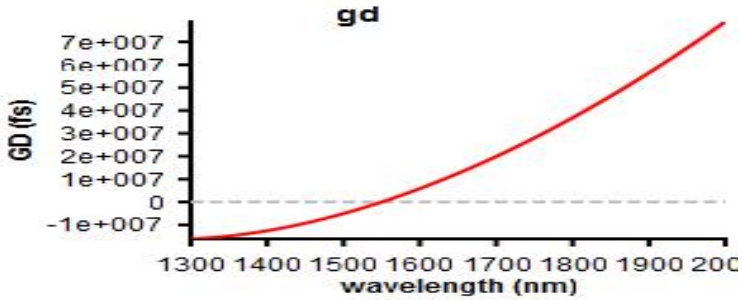

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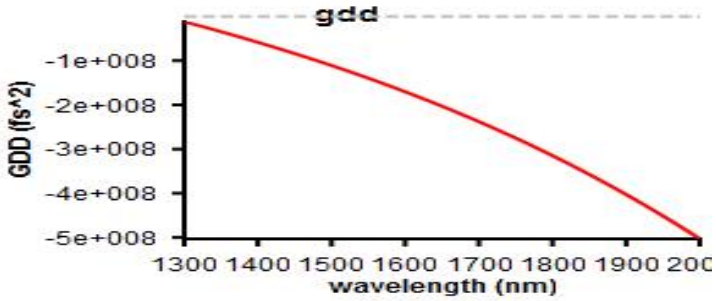

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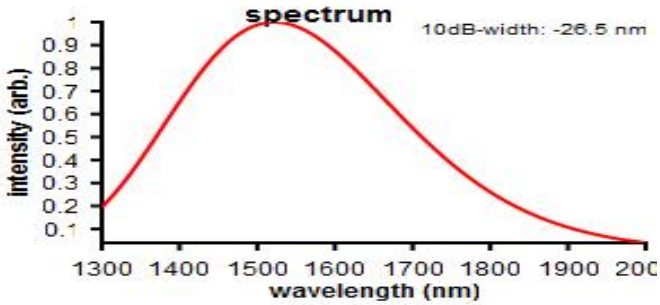
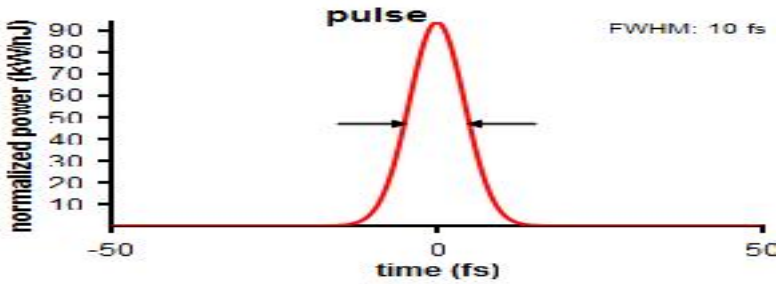


Figure(3) (A,B,C,D) output pulse property for silica photonic crystal fiber

(A)



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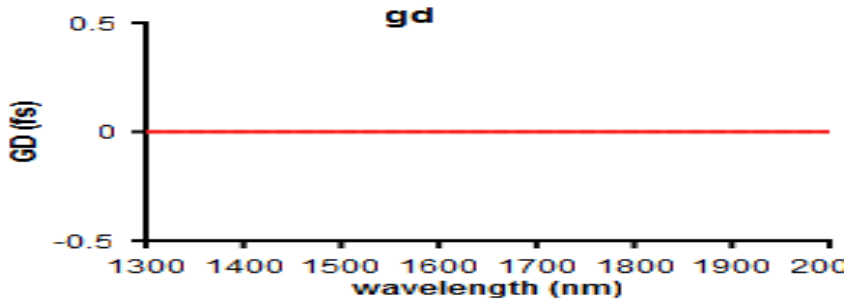

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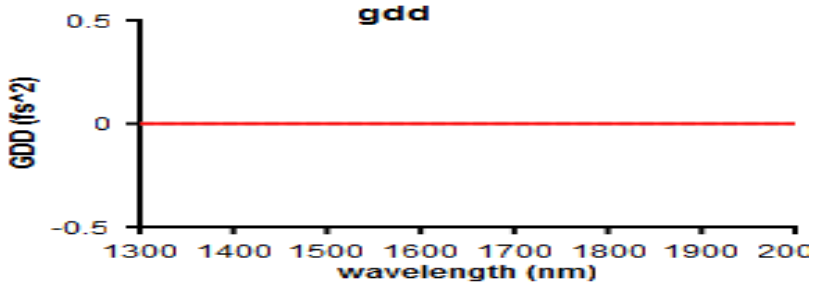

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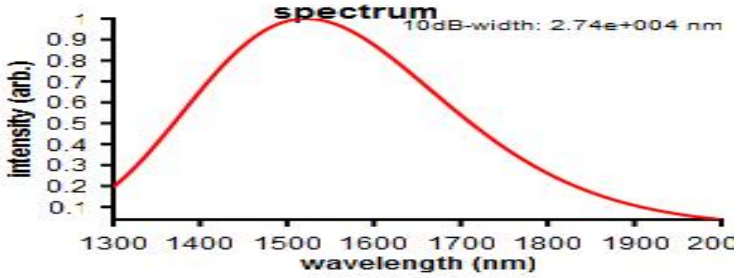
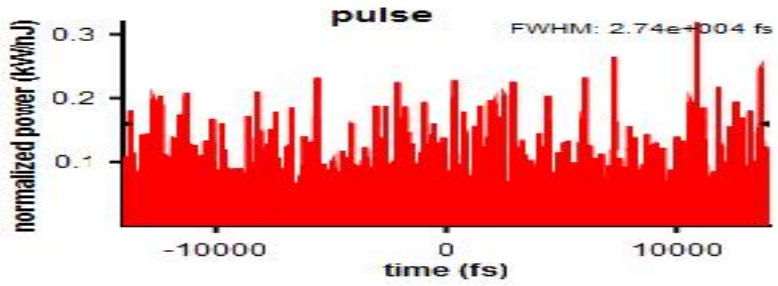


Figure (4)(A,B,C,D) input pulse property for Bafloride BaF2 photonic crystal fiber

(A)



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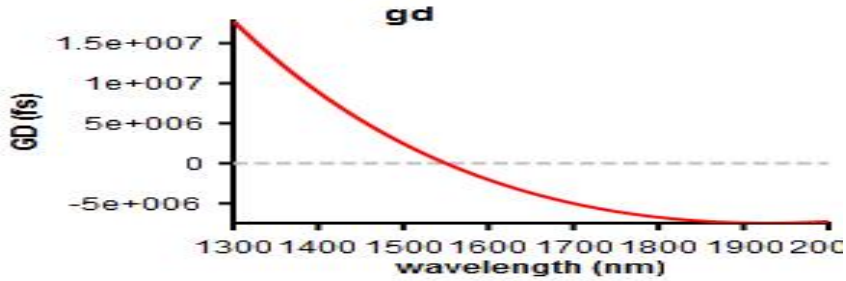

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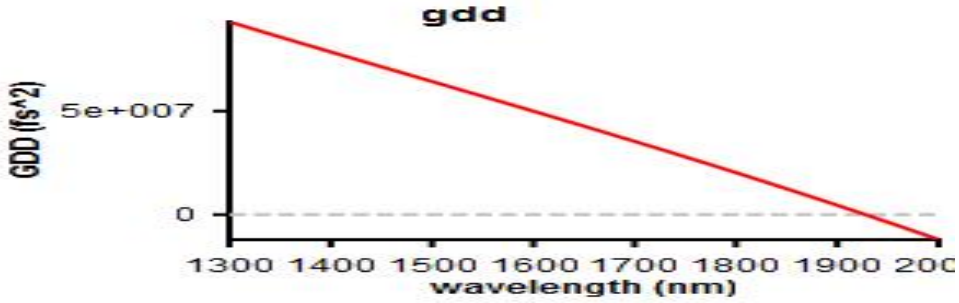

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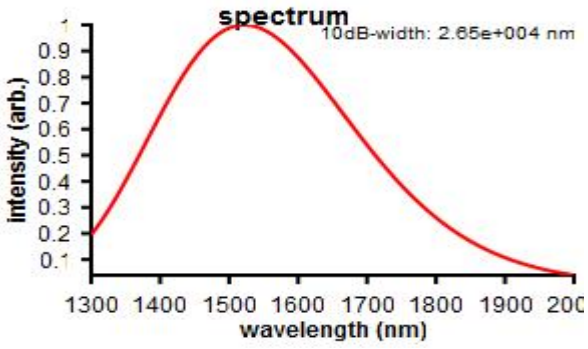
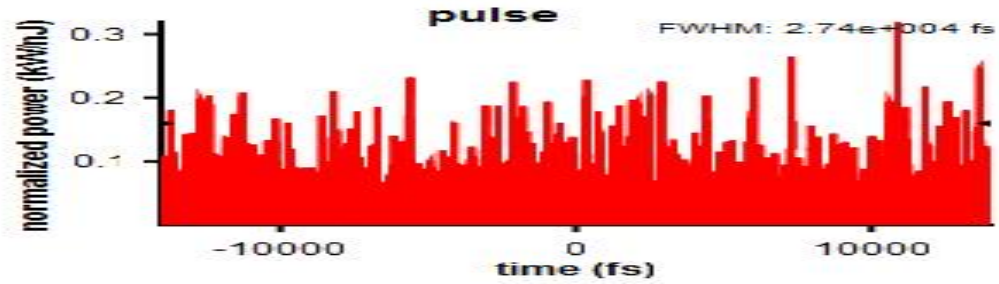


Figure (5)(A,B,C,D) observer pulse property for Bafloride BaF2s photonic crystal fiber

(A)



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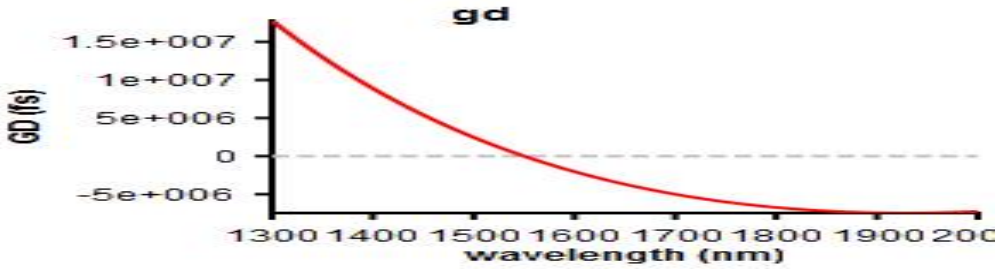

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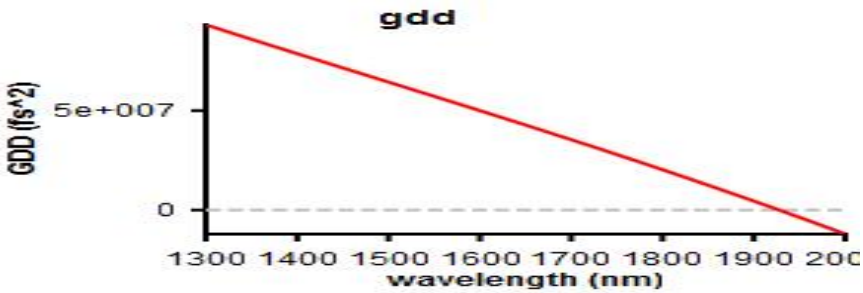

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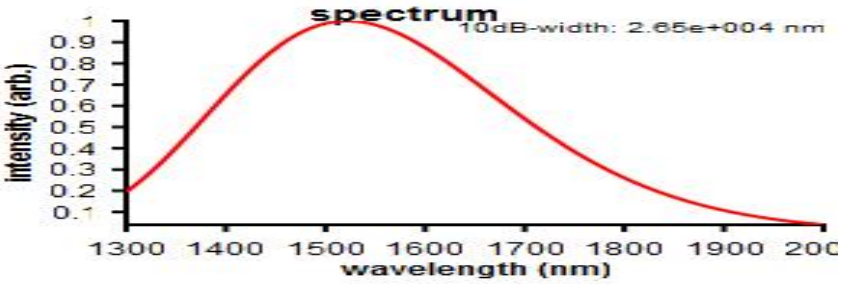

Figure(6)(A,B,C,D) output pulse property for Bafloride BaF2 photonic crystal fiber