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Overview of temporal soliton transmission on photonic crystal fiber and nanowires

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ABSTRACT

Solitons are nonlinear waves that exhibit persistent propagation in the anomalous dispersion regime. In this article, we demonstrate the generation of soliton pulse in photonic crystal waveguide and nanowire at nonlinear length 6 mm in several photonic crystal waveguides and nanowire including fiberglass, silicon, silica, hollow photonic crystal, and tellurite glass. Optical soliton pulse compression 0.5 ps with increasing order observed in this model. This study reveals the propagation of soliton is feasible at high order mode in silicon nanowire and tellurite glass as compared with normal fiber and photonic crystals.

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1. INTRODUCTION

Dispersion management in the optical-fiber network created the great potential to be optimized for long-haul transmission. Optical soliton is pulse propagating in a negative velocity dispersion region which is a table for long-distance with high-bit-rate optical transmission systems in the time domain [1-3].

Soliton propagation has become quite intertest in the nonlinear wave where it demonstrated soliton wave transmitted spectrally in a photonic waveguide such as silicon waveguide in femtosecond input pulse [4-6]. The quest to demonstrate soliton dynamics is challenging due to nonlinear interaction and compatibility of the light source [7-9], pulse duration [10], and energy limited [11]. Here, we demonstrate a soliton pulse model generated in different mediums including photonic crystal, hollow photonic crystal, silica nanowire, silicon nanowire, and tellurite crystal glass fiber.

2. RESEARCH METHODS

In this section, a self-consistent formulation for the temporal soliton model is briefly discussed. Transmission of soliton in optical fiber is described in dimensionless form according to perturbed nonlinear Schrodinger equation:

$$i\frac{\partial u}{\partial z}\frac{1}{L_D} = \frac{\beta_2}{2T_0^2}\frac{\partial^2 u}{\partial \tau^2} - \gamma|u|^2 uP_0 \quad (1)$$

where given dispersion length $L_D = \frac{T_0^2}{|\beta_2|}$ and nonlinear length $L_{NL} = \frac{1}{\gamma P_0}$, therefore:

$$i\frac{\partial u}{\partial z} = \frac{\beta_2}{2}\frac{\partial^2 u}{\partial \tau^2} - N|u|^2 u \quad (2)$$

the order of soliton, N is determined by $N^2 = \frac{\gamma P_0 T_0^2}{|\beta_2|}$,

$$u(z,\tau) = \text{sech}(\tau) e^{-\frac{i}{z}C\tau^2} \quad (3)$$

thus, the solution of soliton profiles, $u(z,\tau)$ describes the pulse envelope in time τ at the spatial position z, in which β_2 refers to group velocity dispersion coefficient in ps^2/m, C refer to chirping parameter, and γ refer to nonlinear Kerr parameter.

The evolution of a field in nonlinear for soliton propagation is solved by using a numerical spit-step algorithm where the interval is created in the midpoint between two neighboring basic cells. The split-step method has been selected since it is one of a reliable algorithm for an ultra-fast pulse in communication for up to a rate of Tb/s [12]. In this model, a half segment of the linear portion is created and the other half created for the nonlinear portion. Thus, as a pulse wave generated between cells, it superimposed between half segments of the cell's edge.

3. RESULTS AND DISCUSSIONS

The large magnitude of Kerr coefficient in photonic crystals [13] and as compared with fused silica has enabled transmission in normal and anomalous dispersion regime, pulse reshaping [14] phase modification [15], and compression phenomena [16]. This led to novel soliton interaction given in different media applied. Photonics crystal such as hollow crystal fiber also allowing low-loss transmission and effective guiding promote nonlinear medium for wave propagation [17, 18]. Table 1 shows several types of fiber, nanowire, and photonic crystals and their related dispersion coefficient properties used for this model.

Table 1. several types of fibers, nanowires, and photonic crystals and material properties.

Type of optical fiber/NW	Material's properties		References
	β_2 (ps^2/m)	γ_{eff} (W/m)	
Fused silica	0.022	0.0011	[19]
Hollow photonic crystal fiber	0.0183	0.000002	[20]
Tellurite crystal fiber	0.185	5.70	[21]
Silica nanowire	0.009	0.22	[22]
Silicon nanowire	2.26	300	[23]

Figure 1 shows the result of soliton generated in the different medium at different soliton order. As depicted in Figure 1 (a), soliton generated in fused-silica fiber experienced increased two-fold of power with increasing soliton order from N = 1 to N = 3. Pulse compression behavior is seen as soliton order increased. Also, the chirping effect becoming prominent with increasing soliton's order [24].

The result shows the single pulse soliton's profile is easily generated by applying for the first soliton's order, N = 1 in photonics hollow crystal fiber, tellurite, and silica nanowire as depicted In Figure 1 (b), (c), and (d). Meanwhile, a single pulse profile is generated within second-order soliton, N = 2 for tellurite crystal fiber, and silicon nanowire. Both mediums also showing the behavior of pulse compression with increasing soliton order until N = 3. However, silicon nanowire in Figure 1 (e) showing stable pulse generation without chirping effect as soliton's order get higher which showing increasing of self-phase modulation effect [25].

Ideal soliton propagation is observed for generation at first order in silica nanowire as depicted in Figure 1 (d). Increasing the soliton's order led to larger attenuation and carrier dispersion. As result, the pulse power getting lowered with further increasing soliton's order.

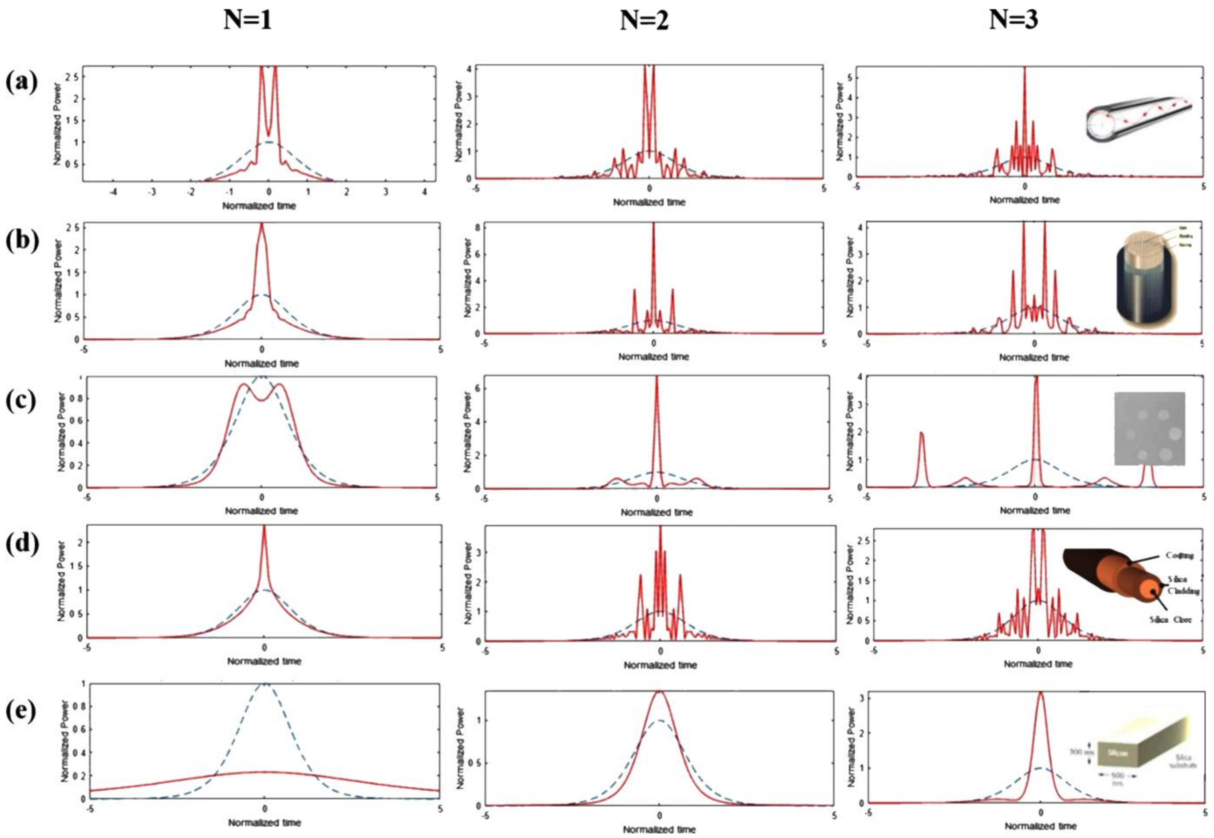

Figure 1. Temporal soliton generated in different optical medium with variant soliton order,N = 1 – 3 (dashed line represent input and red line represent output spectrum): (a) fused silica; (b) hollow-core photonic crystal; (c) tellurite crystal fiber; (d) silica nanowire; and (e) silicon nanowire. Insert showing typical fiber/NW.

4. CONCLUSION

This study reports the realization of soliton generation within different media of optical fiber including capillary-type, hollow-type, and nanowire. Soliton pulse is exhibited by generation in the anomalous dispersion regime. Silica nanowire easily generates soliton at first order, meanwhile, tellurite glass and silicon nanowire form soliton pulse within second order of generation. Pulse compression phenomena are observed with increasing soliton's order where stable pulse generation of soliton is supported by the self-phase modulation effect. The numerical result showing the stability of pulse compression within higher soliton's order for generation in tellurite crystal fiber and silicon nanowire. The soliton pulse dynamics in temporal evolution could potentially be implemented in future picosecond integrated photonics and chips applications.

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