Shaping Single Photons By Fiber Bragg Gratings

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Abstract

Fiber Bragg gratings (FBGs) are distributed reflectors realized by periodic or aperiodic variation of refractive in optical fibers. In this work, we explore the waveform shaping of a phase-modulated optical pulse at the single photon level in a FBG [1][2]. We describe the theory, simulation, techniques and provide a novel approach to control waveform.

Introduction

We use transfer matrix to express the effect of FBG. Transfer matrix method is a way to solve multilayer problems in optics. For a single domain (Fig. 1a), the four interfaces can be presented with equations (1)~(4) as following. Waveform shaping has lots of benefits. For instance, appropriate waveforms of single photons can improve communication performance, which increases transmission distance and rate. Moreover, in atomic ensembles, it can optimize or suppress the absorption or storage of single photons. Our input pulse has a waveform of the first-order Hermite Gaussian as shown in Fig. 1b.

$$M_1 = \begin{bmatrix} \frac{1}{t} & -\left(\frac{t-1}{t}\right) \\ -\left(\frac{t-1}{t}\right) & \frac{1}{t} \end{bmatrix} \text{— (1)} \qquad M_2 = \begin{bmatrix} e^{i\varphi} & 0 \\ 0 & e^{-i\varphi} \end{bmatrix} \text{— (2)}$$

$$M_3 = \begin{bmatrix} \frac{1}{t'} & \frac{t'-1}{t'} \\ \frac{t'-1}{t'} & \frac{1}{t'} \end{bmatrix} \text{— (3)} \qquad M_4 = \begin{bmatrix} e^{i\varphi} & 0 \\ 0 & e^{-i\varphi} \end{bmatrix} \text{— (4)}$$

where $t = \frac{2n_1}{n1+n2}$, $t' = \frac{2n_2}{n1+n2}$, φ is $\frac{distance}{\lambda}$

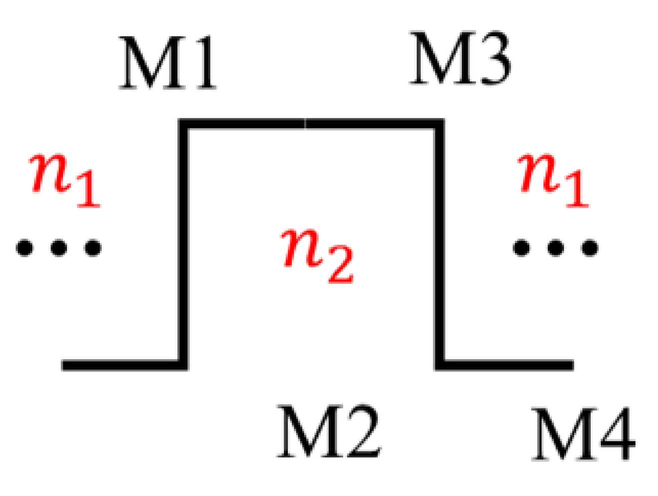

Fig. 1a

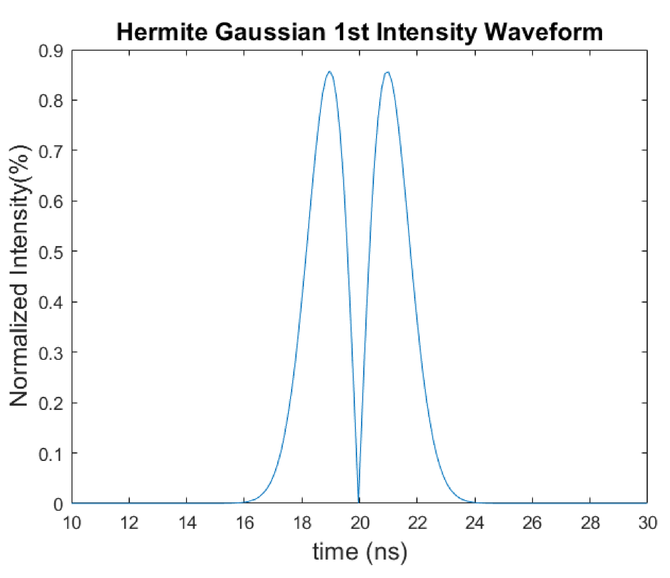

Fig. 1b

Experimental Setup

The experimental setup is illustrated in Fig. 2, where the DFB laser's central wavelength is 1550 nm. Arbitrary waveform generator is used to implement the electro-optic amplitude modulation and two electro-optic phase modulations. The first EOM[P] randomly generates four sets of sixteen points in time for the phase modulation of HG1. The second EOM[P] generates π phase modulation to HG1 in the first half time domain. However, FBGs possess polarization selectivity, therefore the polarization beam splitter and the polarization controller are arranged for adjusting polarization. Circulator is set to avoid the reflection light interfering in FBGs.

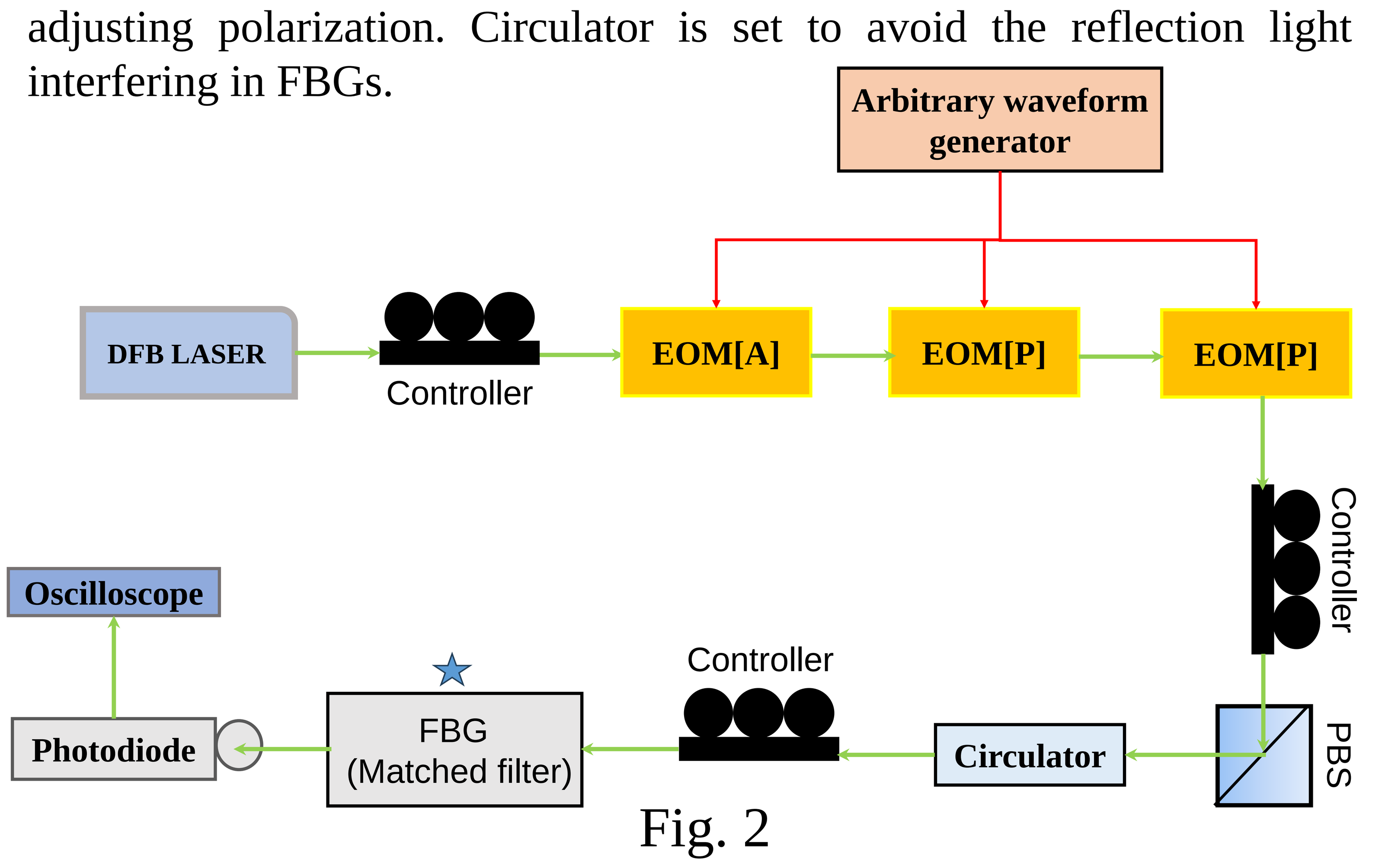

Fig. 2

Results

The phase modulation is implemented by imposing a set of discrete phases on the input waveform. Four examples of the simulated waveforms after the FBG are shown in Fig. 3. We apply the same phase modulations to our experimental waveform and obtain similar waveform shaping as shown in Fig. 4. We also conduct waveform shaping for weak coherent state as shown in Fig. 5. Due to the electrical signal's distortion and the defects in FBGs, the experimental results do not fully match the theoretical simulations. However, we discover that a set of phase modulations can still correspond to a set of waveform shaping. This provides a novel method for the waveform control.

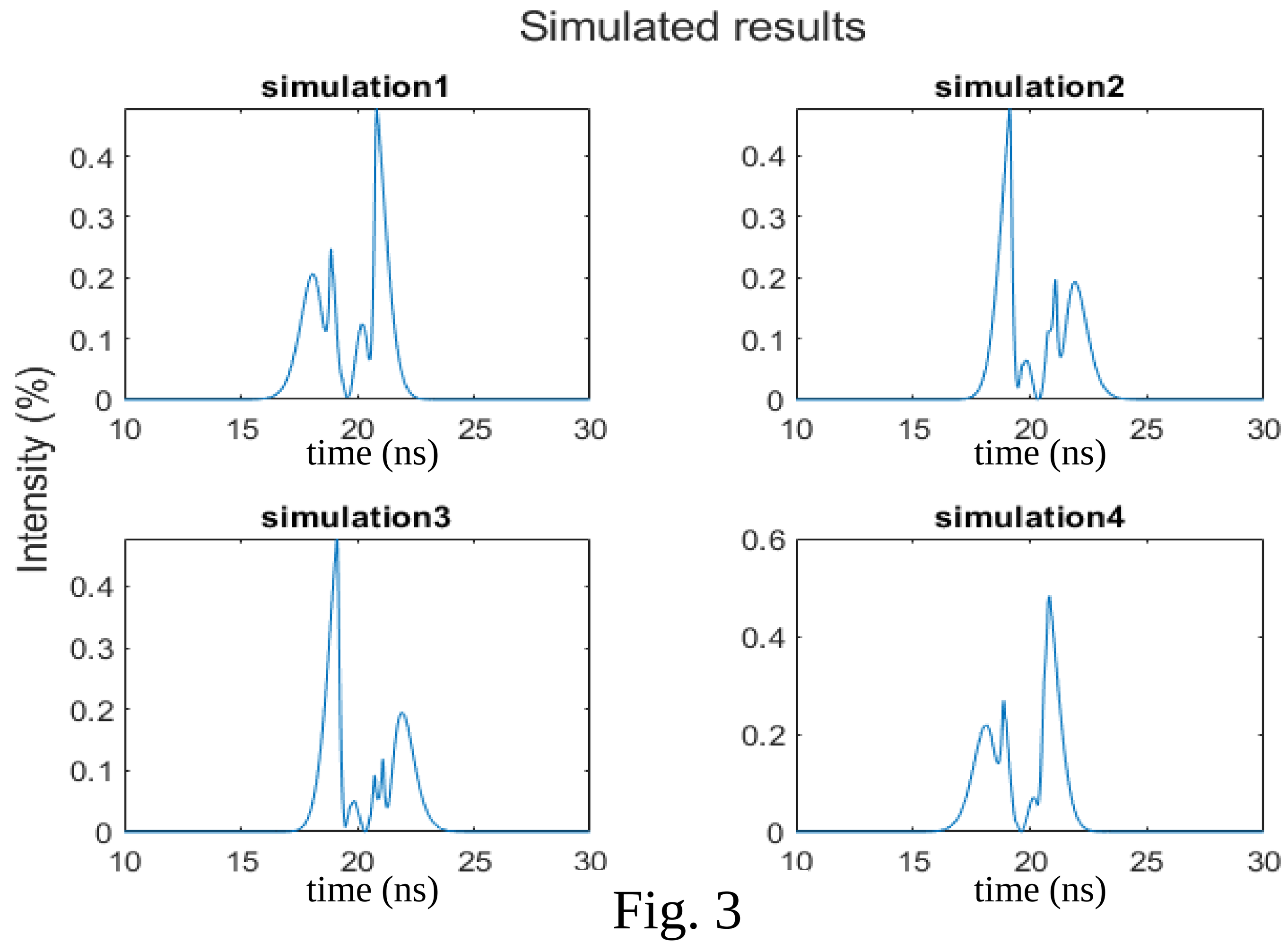

Fig. 3

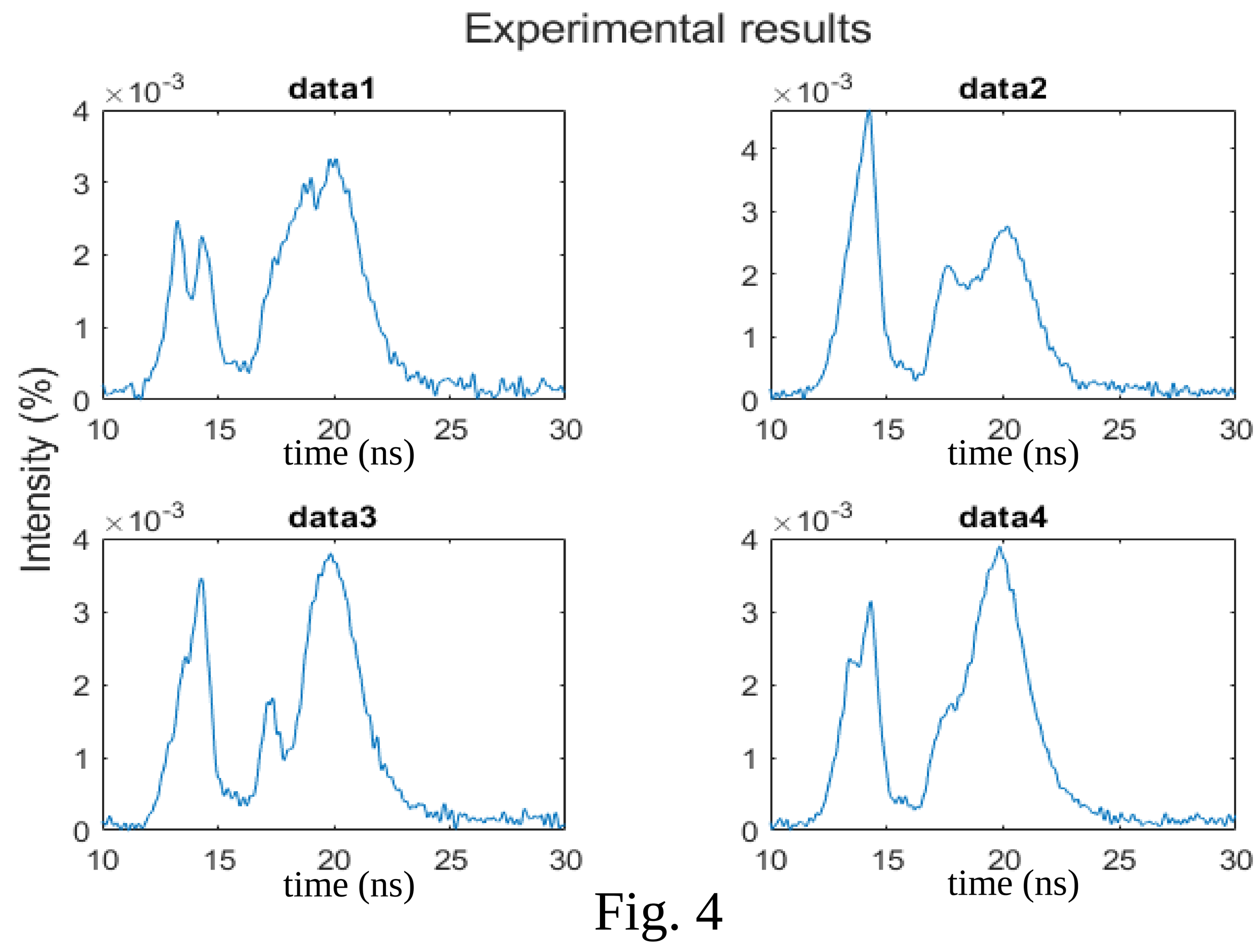

Fig. 4

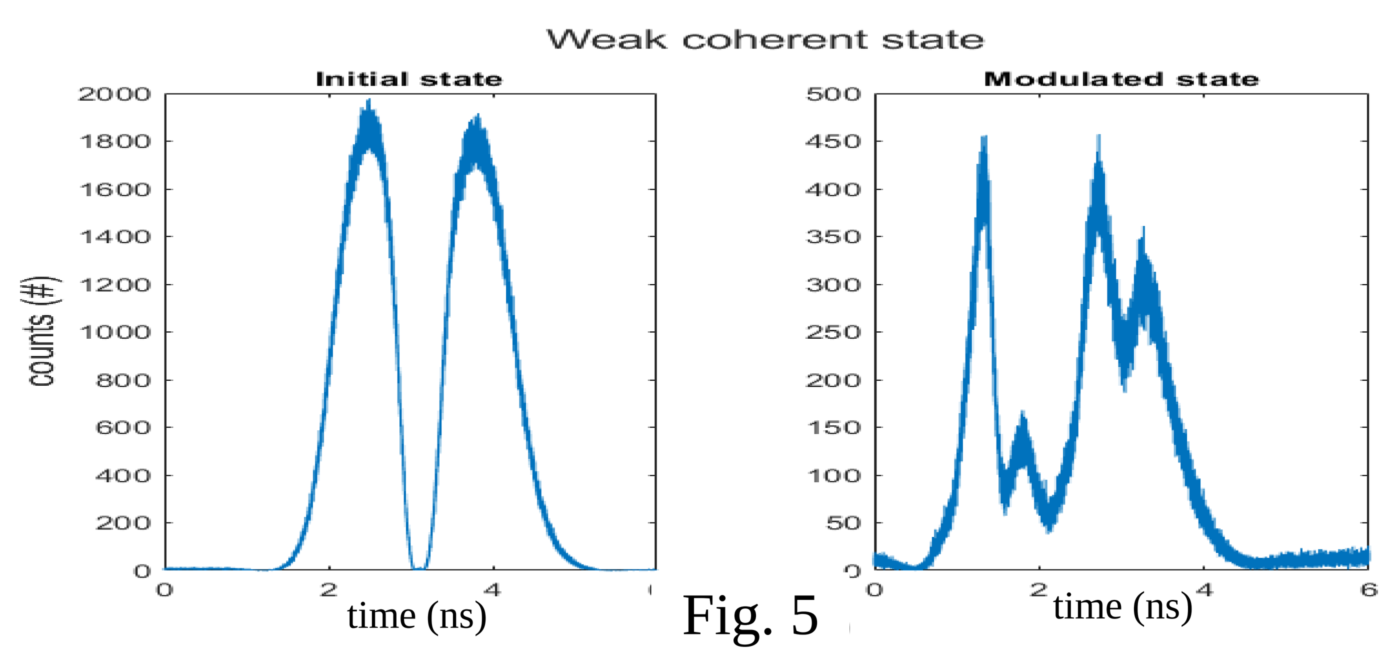

Fig. 5

Conclusions

We demonstrate a novel method to control the optical waveform at the single photon level by fiber Bragg gratings. Waveform shaping results from both simulation and experimentation show waveforms with similar shapes by corresponding phase modulations.

Reference

[1] Ryan P. Scott, Nicolas K. Fontaine, Jonathan P. Heritage, and S. J. B. Yoo, *Optics Express Vol. 18, Issue 18, pp. 18655-18670 (2010)*
[2] Abijith S. Kowligy, Paritosh Manurkar, Neil V. Corzo, Vesselin G. Velev, Michael Silver, Ryan P. Scott, S. J. B. Yoo, Prem Kumar, Gregory S. Kanter, and Yu-Ping Huang, *Optics Express Vol. 22, Issue 23, pp. 27942-27957 (2014)*