Experimental Study of Results of Fiber Bragg Grating Solitons

PHYSICS

Dr.Brijesh.N.chawda

Professor , Department of Humanities and sciences, Jayaprakash Narayan college of Engg, Mahaboobnagar, Telangana, India.

ABSTRACT

One important nonlinear application of fiber Bragg grating is grating solitons, including gap soliton and Bragg soliton. This paper summarily introduces the numerous experimental results on this field each indicating the potential these solitons have in all-optical switching, pulse compression, limiting, logic operations and especially important for the optical communication systems.

1.1.1 Introduction

The concept of "photonic band structure" is introduced by Yablonovitch in the late 1980's [6]. A notable feature of this linear periodic structure is the presence of stop gap in the dispersion curve popularly known as photonic band gap (PBG) [7]. This PBG exists at frequencies for which the medium turns highly reflective and hence the light pulse will not be able to propagate through the periodic structure. Light interaction with nonlinear periodic media yields a diversity of fascinating phenomena, among which two solitonic phenomena have been studied most intensively, namely, discrete (or lattice) solitons [9] and gap (or Bragg) solitons [7]. While discrete solitons are spatial phenomena in two-dimensional or three-dimensional arrays of coupled waveguides, gap solitons are usually considered as a temporal phenomenon in one-dimensional (1D) periodic media [8]. Perhaps the most fascinating feature of solitons is their particle like behavior. Survival of two such colliding solitons is even more remarkable if one notes that solitons interact strongly with each other during the collision. But for co-propagating solitons, the interaction is either attractive or repulsive, depending on the relative phase between two solitons. In both cases the evolution of the soliton pair is well understood [4].

As first pointed out by Winful [5], because the dispersion is many orders of magnitude larger than the total dispersion due to the combined effects of material and waveguide dispersions that arise in the conventional fibers, the interactions lengths are reduced accordingly. Hence, the grating induced dispersion dominates over the total dispersion in the conventional fibers. When the en- tire spectral components of the input pulse lie within the PBG structure, the grating induced dispersion counter- balanced by the Kerr nonlinearity through the self-phase modulation (SPM) and cross-phase modulation (XPM) effects, forming solitons are referred to as gap solitons since their spectral components are within the PBG structure. Many research groups [3] theoretically predicted the existence of gap solitons and Bragg grating solitons in FBG and the investigations on these exciting entities are going on. However, it can be noticed that, in literatures, nowadays the distinction between gap solitons and Bragg solitons is hardly maintained and, in general, they are simply called grating solitons [2]. Ul [5], because the dispersion is many orders of magnitude larger than the total dispersion due to the combined ef fects of material and waveguide dispersions that arise in the conventional fibers, the interactions lengths are reduced accordingly. Hence, the grating induced dispersion dominates over the total dispersion in the conventional

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1.1.2 Experimentation and Applications

Recently conducted experiments have provided strong evidence for the existence of the grating solitons in FBGs[2]. To our knowledge, it was Larochelle, Hihino, Mizrahi and Stegeman [7] who were the first to report (in 1990) an experimental investigation of the optical response of nonlinear periodic structures. They employed an optical Kerr-effect cross-phase modulation in fiber gratings to achieve switching of a probe beam by a control beam.The first detailed experimental observation ofall-optical switching dynamics in a nonlinear periodic structure was reported by Sankey, Prelewitz and Brown in 1992 [6]. Experimental observations of nonlinear grating behaviour are limited, principally by the difficulty in getting sufficiently high power densities within the core of a FBG in a suitable spectral and temporal range. In order to reduce the nonlinear threshold for gap soliton formation one can use the somewhat weaker dispersive properties of FBGs outside of the band gap. An investigation of nonlinear pulse propagation in uniform fiber gratings was published by Eggleton *et al.* in 1996 [1].In this report, the Bragg solitons are most easily generated in the laboratory travel at 60–80% of veocity of light in fiber absence of grating [4]. This was followed by further reports from the same group, which both refined the experimental technique and broadened the experimental understanding of the dynamics of pulse

propagation in periodic structures [5]. In their initial experimental observations of Bragg solitons [3], the agreement between the experiments and the numerical calculations was qualitative. However, stationary (or nearly stationary) gap solitons have not been observed yet. Subsequently, the South hampton group [9] first demonstrated switching at the important optical communication wavelength of 1550 nm, and in doing so have confirmed certain key aspects of the physics of pulse propagation in nonlinear periodic structures. We now understand that a Bragg soliton need not be centered near the Bragg resonance indeed, some very interesting propagation effects occur rather far from the band edge. Experimental studies of BG solitons were further developed including, in particular, formation of multiple BG solitons in Refs [2]. Broderick et al. also report the first experimental demonstration of a novel type of all optical pulse compression [1]. It is significant experimentation that Taverner *et al.* [7] reported the first observation of gap soliton generation in a Bragg grating at frequencies within the photonic bandgap. Furthermore the sets of experiments were performed in relatively short gratings. Thus, in these experiments, pure soliton propagation effects are difficult to distinguish from effects due to soli ton formation. The occurrence of modulational instability (MI) in fibers had been first suggested by Hasegawa and Brickman [2] and experimentally verified by Tai *et al.* [3]. The effects of MI which occurs when a perturbed continuous wave experi-

ences an instability that leads to an exponential growth of its amplitude or phase during the course of propagation in optical fibers due to an interplay between the nonlinearity and group velocity dispersion (GVD) act in opposition. THE studies on modu lational instability (MI) have some impacts on solitons.

The researchers recently have realized the potential applications of these solitons in fiber Bragg grating forall-optical switching [3], pulse compression [6], limiting [8], and logic operations [2], also promising for the fiber-sensing technology [7], especially important for the optical communication sys- tems [5]. One would hope to achieve zero velocity by a clever tailoring of the Bragg grating. This research goes beyond its intellectual value; all optical buffers and storing devices can be based on such fibers. About logic operations, for the first time to our knowledge, an all- optical 'AND' gate based on a configuration proposed by S. Lee and S.T. Ho [4]. The operation of the gate relies on the formation and propagation of coupled gap solitons by two orthogonally polarised high intensity input beams incident within the bandgap of a FBG [1]. Recently Nuran Dogru was pursueing for the hybrid soliton pulse source (HSPS) developed as a pulse source for the soli- ton transmission system [8]. In a Bragg grating SPM results in the transmission being bistable with one

state (high power) having a transmission of unity while in the other (low power) the transmission is vanishingly small [2]. For strong optical pulses this behavior can result in all-optical switching. The all- optical switching of a fiber Bragg grating (FBG) was first seen by La- Rochelle et al. in 1990 [6] using a self-written grating centered at 514 nm. In their experiment the probe beam was centered on the grating, while the pump beam had a wavelength of 1064 nm. It was in this vein that Radic, George and Agrawal suggested the use of l/4 phase- shifted gratings for use in optical switching [7]. Ju Han Lee [2]demonstrate the use of a superstructured fiber Bragg grating obtain more optimal operation of nonlinearall-optical switches [5], all-optical modula- tion and demultiplexing systems [86], tunable optical pulse source [7]. In long distance communications, that a third-ordernonlinear effect is together with anomalous dispersion, can result in the formation of bright temporal optical solitons. Beacause of the shape-preserving prop- erty of the bright and dark solitons, they have received considerable attention from optical communication in- dustries. Solitons are particularly desirable for dtra-longdistance communication system and high-bit-rate fiber communications. A challenging possibility is to use fiber gratings for the creation of pulses of slow light, which is a topic of great current interest. A possible way to trap azero-velocity soliton is to use an attractive finite-size or local defect [8] in BG. The interaction of the soliton with an attractive defect in the form of a local suppres- sion of BG was studied recently in Refs [9].

1.2.1 Conclusions
Clearly grating solitons have played an important role in past and ongoing nonlinear optical research in fiber Bragg grating, and I believe fiber Bragg grating solions to have their greatest impact in the years to come.

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