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Fiber Bragg Grating for Producing Ultra Short Femtosecond Pulses for Data Transmission

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Keywords

Phase Grating, Notch Filters, Soliton, SPM-Self Phase Modulation, SRS-Stimulated Raman Scattering, Optical Amplifier

In order to perform high- speed digital communications we have to necessarily reduce of the pulse width and thereby increase the information rate that can be transmitted and this technique offers the potential for faster computational devices. It is expected that when the pulse width becomes shorter, our ability to accurately model the propagation of the pulse will become more complicated. With a proper design of the FBG, one can ensure that most of the power is reflected effectively and other signals are transmitted. Thus, the main use of such a FBG is that they are fiber compatible and the loss generated due to interconnection between fibers is very low. In this work, I have used an Erbium doped fiber as an optical amplifier and have studied the nonlinear behavior of electromagnetic fields in optical fiber. The main contribution to the non-linear effect is the Self-Phase Modulation (SPM) and Stimulated Raman Scattering (SRS).Non-linear effects are really required for a transmission due to which both the amplitude and the width of the propagated pulse remain nearly unchanged. This means that the pulse is not dispersive as it progresses along the optical fiber. The resulting anti dispersion tends to cancel out the dispersion caused by the linear effects and the combination of the two effects, namely SPM and SRS result in a soliton-like pulse.

Introduction

The primary application of fiber Bragg gratings is in optical communications systems. They are specifically used as notch filters. The fiber Bragg grating is used for an all fiber wavelength demultiplexer. A Germanium doped silica glass is photosensitive and when light of a short wavelength is passed through the fiber; the refractive index of the doped silica glass is slightly changed. It is thus possible to create a periodic variation in the refractive index of the core itself, thereby creating a 'phase grating'. A Fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length. It is formed by the exposure of the core to an intense optical interference pattern. Permanent gratings in an optical fiber were first demonstrated by Hill et al.in 1978 at the Canadian Communications Research Centre (CRC), Ottawa, Ontario, Canada. The propagation of pulses with widths of the order of several femtoseconds, that is, with short widths has significant results. When the width of the pulse becomes shorter, its bandwidth becomes larger. The dispersion property of the material of the fiber will thus become effective if non-linear effects are taken into account. It is this non-linear effect that contributes to the better wave propagation in the material. Nonlinearity effect reduces the overall dispersion along the optical fiber. The nonlinear behavior of electromagnetic fields in optical fiber is due to the nonlinear relation between the electric field and the induced electric The main contribution to the non-linear effect is the Self-Phase Modulation (SPM) and Stimulated Raman Scattering (SRS).

Self-phase modulation (SPM) is a nonlinear optical effect of light-matter interaction. An ultra short pulse of light, when travelling in a medium, will induce a varying refractive index of the medium due to the Optical Kerr Effect. This variation in refractive index will produce a phase shift in the pulse, leading to a change of the pulse's frequency spectrum [Fig. 1].

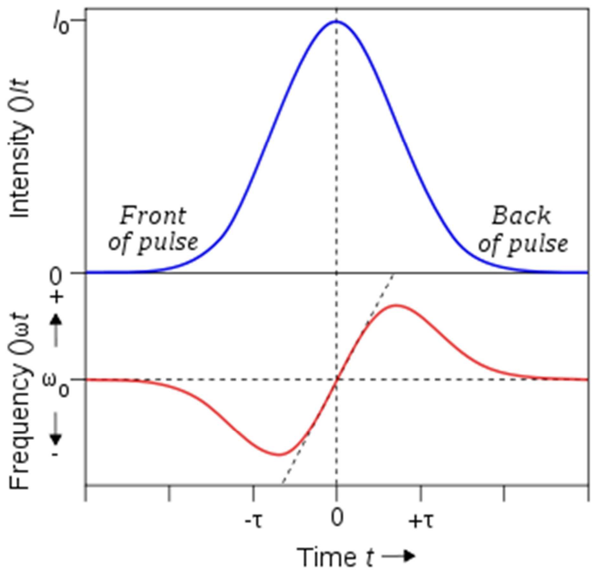

Figure 1. *Self Phase modulation of an input pulse (Courtesy: Wikipedia).*

Methodology

Self Phase Modulation (SPM) is one of the most important reach-limiting nonlinear effects. It can be reduced by lowering the optical power at the expense of increased noise and Dispersion management, because dispersion can partly mitigate the SPM effect [1].Stimulated Raman Scattering(SRS) can take place when deliberately injecting Stokes photons ("signal light") together with the original light ("pump light").

In this case, the total Raman-scattering rate is increased beyond that of spontaneous Raman scattering: pump photons are converted more rapidly into additional Stokes photons [2]. The more Stokes photons are already present, the faster that more of them are added. Effectively, this amplifies the Stokes light in the presence of the pump light. Stimulated Raman scattering is a nonlinear-optical effect. It can be described using a third-order nonlinear susceptibility $X^{(3)}$ [Fig.2]. [3]

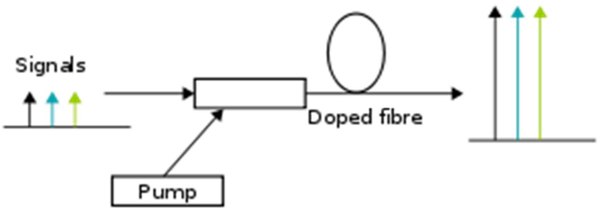

Figure 2. *A simple diagram of a fiber amplifier (Courtesy: Wikipedia).*

Femtosecond pulse propagation through single mode optical waveguide is well known and governed by a generalized nonlinear Schrodinger equation accounting for chromatic dispersion and nonlinear effects. In this paper, multicore fiber is used as waveguides which is useful for communication. In fiber optic long haul communications, normally one is interested in wavelengths between λ = 1540 to 1550 nm region and erbium doped silica multicore fibers are suitable for this purpose. The same fibers when pumped with λ = 0.98μm or λ=1.48μm are used as optical amplifiers in optical communication systems. In order to convert its application from an amplifier to an oscillator, erbium doped with silica multicore fiber is placed in an 'optical resonator', by using Fiber Bragg gratings (FBG) [4]. The spatially dispersed spectrum is imaged on the fiber input face so that different frequency bands are then coupled to different channels of the multicore fiber.

Erbium can be employed as dopants in crystals or in glass. When external sources are used, these active elements can be pumped to reach the desired level of 'population inversion'. Both the amplitude and the width of the propagated pulse remain nearly unchanged. [5-8]. This means that the pulse is not dispersive as it progresses along the optical fiber. The resulting anti dispersion tends to cancel out the dispersion caused by the linear effects and the combination of the two effects results in a soliton-like pulse. The major advantage of these all fiber systems, where the free space mirrors are replaced with a pair of fiber Bragg gratings (FBG's), is the elimination of realignment during the life of the system, since the FBG is spliced directly to the doped fiber and never needs adjusting. The challenge is to operate these monolithic cavities at the kW CW power level in large mode area (LMA) fibers such as 20/400 (20 um diameter core and 400 um diameter inner cladding) without premature failures at the intra-cavity splice points and the gratings. Fiber Bragg grating (FBG) has many important practical applications. The most promising applications are in the fields of light wave communications and optical fiber sensors which are based on the existence of photosensitivity in silica optical fibers and optical waveguides. However, this technology could be extended to other types of applications with the discovery of large photosensitivity in different material systems. The new manufacturing techniques of fabrication of optical fiber have minimized its loss. However, long haul transmission requires high power optical amplifiers to compensate for the fiber loss. Here, the pulse distortion due to the fiber nonlinearity should also be considered [9]. An alternative method to study such type of complex problems due to the rapid increase in computational capabilities is the finite-difference time-domain (FDTD) Technique [10]. Optical signals can be amplified by putting pieces of erbium doped fiber at proper locations in the network. Optical fibers and FBG optical sensors are nonconductive, electrically passive, and immune to EMI-induced noise [11-18].

Conclusion

The main challenges for achieving such high data rate systems lie in pulse generation, dispersion and loss compensation, and nonlinearity management. The development of high power fiber lasers has generated a new set of applications for fiber Bragg gratings (FBG's), operating at power levels that were previously thought impossible. The approach investigated for pulse transmission is also well suited to femtosecond amplification in fibers. In that case the multicore fiber must be doped with rare earth ion like erbium and fiber laser pumped. In the case of a simple fiber laser, the FBG's can be used as the high reflector (HR) and output coupler (OC) to form the laser cavity. The gain for the laser is provided by a length of rare earth erbium doped optical fiber. The main innovation of an Er^{3+} doped with silica fiber laser is in long distance communication over networks in fiber optics known as "Wavelength Division Multiplexing" (WDM). It is specially applied to 'under water' communication links. Thus a FBG can be used to produce femtosecond pulses for data transmission effectively.

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