Fiber Bragg gratings for dispersion compensation in optical communication systems

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Abstract. This paper presents an overview of fiber Bragg gratings (FBGs) fabrication principles and applications with emphasis on the chirped FBG used for dispersion compensation in high-speed optical communication systems. We discuss the range of FBG parameters enabled by current fabrication methods, as well as the relation between the accuracy of FBG parameters and the performance of FBG-based dispersion compensators. We describe the theory of the group delay ripple (GDR) generated by apodized chirped fiber gratings using the analogy between noisy gratings and superstructure Bragg gratings. This analysis predicts the fundamental cutoff of the high frequency spatial noise of grating parameters in excellent agreement with the experimental data. We review the iterative GDR correction technique, which further improves the FBG quality and potentially enables consistent fabrication of FBG-based dispersion compensators and tunable dispersion compensators with unprecedented performance.

1. Introduction

Conventionally, compensation of the fiber dispersion is accomplished using dispersion compensation fiber (DCF), which is the main component of dispersion compensation modules (DCMs) employed in WDM and OTDM systems. Alternative solutions for dispersion compensation, other than DCF, have been suggested in order to reduce the insertion loss, spatial dimensions, nonlinearities, and costs. While transmission fibers and DCF has evolved to satisfy almost all of these demands [1], the new technologies have allowed important functions, such as dispersion tunability, as well as small size, cost, and loss for single channel applications. Currently, several types of
dispersion compensation schemes are known and the fiber Bragg grating (FBG) dispersion compensator (DC) originally suggested in [2], is one of the most versatile and well developed techniques [3]. Generally, chirped FBG (CFBG) can serve as a single and a multi-channel DCM as well as provide additional feature of dynamic dispersion compensation [4], which are not possible with DCF and become critical for high-speed WDM and OTDM systems. In this paper we mostly concentrate on the fabrication principles, properties and applications of the single-channel CFBG, which find applications in both high-speed WDM and OTDM systems.

A schematic of CFBG based dispersion compensation is shown in Fig. 1. Depending on the wavelength of the light component, it is reflected from different locations within the FBG (Fig. 1) and therefore experiences different group delay, $\tau$. The group delay is approximately proportional to the distance to the turning point, $z_t$, $\tau(\lambda) = z_t(\lambda)/c$, where $c$ is the speed of light in the fiber and $\lambda$ is the radiation wavelength. The distance $z_t$ is determined by the local Bragg condition $\lambda = 2n_0\Lambda(z_t)$ where $n_0$ is the effective refractive index and $\Lambda(z)$ is the local FBG period. The device shown in Fig. 1 has negative dispersion enabling compensation of positive dispersion introduced by optical fiber. For WDM systems, in order to perform DC within a single channel, the fiber grating should be linearly chirped, i.e., the change in FBG period $\Lambda$ should be linear with the distance along the mask $z$, $\Lambda(z) = \Lambda_0 + Cz$, where the coefficient $C$ determines the chirp of FBG. In the case of OTDM systems, the dependence $\Lambda(z)$ includes non-linear terms (see, e.g., [6]).

In practice, the requested dependence $\Lambda(z)$ cannot be achieved exactly because of systematic and random errors, which are introduced during the CFBGs fabrication. As the result, the spatial dependencies of realistic CFBG parameters are noisy. The latter introduces reflection amplitude ripple and group delay ripple (GDR) resulting in imperfect dispersion compensation and hence, optical signal-to-noise ratio (OSNR).