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The ABCs Of Fiber Bragg Gratings

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As the demand for bandwidth and high-speed transport grows, so does the use of fiber-optic based transport. One of the enabling technologies associated with optical transport are Fiber Bragg gratings (FBGs). This tutorial will introduce the concept of FBGs and describe the advantages provided by use of FBGs for chromatic dispersion compensation.

What Are Fiber-Bragg Gratings?
An FBG is basically a periodic perturbation or change of the refractive index along the fiber length that's formed by exposing the core of the optical fiber to an intense optical interference pattern. When the grating period equals half the input light wavelength, the first wavelength signal will be reflected coherently to make a large reflection. The reflected wavelength (λ_B) is called the Bragg wavelength, and defined by the relationship:

$\lambda_B = 2 n \Lambda$ or Bragg wavelength equals twice the refractive index multiplied by the grating period

where n is the effective refractive index of the grating in the fiber core and Λ is the grating period. Figure 1 demonstrates a uniform FBG structure. For general fiber, with a fringes distance of 500 nm, the reflected wavelength is about 1500 nm.

There are basically three quantities that control the properties of the FBG. These are refractive index profile, grating length, and grating strength. In addition, three properties need to be controlled in an FBG: reflectivity, bandwidth, and side-lobe strength.

The refractive index profile can be uniform, apodized, or chirped by the specific variation of the induced index change along the fiber axis. The uniform grating bandwidth and reflectivity depend on grating strength and grating length. The term apodization refers to the grating of the refractive index approaching zero at the end of the grating. Compared to uniform gratings, apodized gratings offer significant improvement in side-mode suppression, while maintaining reflectivity and bandwidth.

Chirped grating has a linear variation in the grating period, which broadens the reflected spectrum. The variations in the grating period force different wavelengths to reflect at different positions along the grating, and be subject to different delays. This property has been successfully used in fiber chromatic dispersion compensation.

How Are FBGs Manufactured?
Fiber Bragg gratings are created by using an intense ultraviolet (UV) light-fringe pattern to inscribe the periodic variation of refractive index into the core of a photosensitive optical fiber. The amount of index changing depends on the exposure intensity and duration of UV light. The two primary methods for creating FBGs are interference scanning and phase mask.

Both methods have been successfully developed for commercial volume FBG manufacturing. With the phase-mask method, however, the length of the FBG is limited by the length of the phase mask. The interference scanning method doesn't have this limitation and is much more flexible.

Interference-scanning technology utilizes a two-beam interferometer (Fig. 2) to create a fringe pattern of UV light used for inducing the change of refractive index to the core of the fiber. A highly accurate motion controller can sequentially add up these fringe patterns with nanometer precision over long distances. Chirped FBGs as long as 10 meters have been written for fiber chromatic dispersion compensation. By actively controlling the period of the fringe pattern, basically any type of FBG, including uniform, chirped, and apodization FBGs, can be generated. Even blazed gratings can be written with the same machine.

Where Are FBGs Used?

FBGs are widely used in fiber-optic communication and fiber-optic sensor systems. FBG sensors use wavelength-encoded characters. Any change in fiber properties, such as temperature or strain, which varies the grating pitch, will change the Bragg wavelength. The FBG can be used for sensing and monitoring applications, such as detecting changes in structural factors in buildings and bridges; depth measurement of rivers for flood control; and in remote areas like oil fields.

FBG sensors are passive, require no electrical power, and can be used for many years without requiring recalibration. That makes them useful in remote, hazardous deployments.

FBGs filter light directly between one fiber and another via splicing, which minimizes loss and reduces costs by eliminating the need for additional optics to link fibers and bulk components. FBGs also protect against spectral hopping due to changes in temperature, drive current, and optical feedback. This particularly suits FBGs for harsh environments such as undersea settings.

FBGs are used in laser systems for dense wavelength-division demultiplexing, dispersion compensation, and erbium-doped fiber-amplifier (EDFA) gain flattening. A tunable laser is a laser whose wavelength of operation can be controlled. Furthermore, FBGs can be used in tunable filters, multiplexers, spectrum analyzers, and amplifiers.

Why Is FBG Needed In Optical Communication?

Despite the benefits of high capacity, one of the drawbacks of using fiber optics to carry voice and data traffic is the resulting chromatic dispersion or spreading of the signal as it travels down the length of the fiber. Dispersion will, if not properly compensated, result in data loss, distortion, and traffic disruption.

To overcome these issues, carriers have traditionally used dispersion compensating fiber (DCF) throughout the optical network. A DCF is basically a fiber that has a dispersion coefficient of the opposite sign to that of the transport fiber, hence counteracting the dispersion by recompressing the optical pulse.

One drawback of this technology is that the DCF by design have a quite high attenuation, i.e. insertion loss (IL). This, combined with the fact that the length of the DCF is proportional to the length of the transport fiber, inevitably leads to high insertion loss and quite bulky terminal components, both of which negatively affect the cost efficiency.

There is, however, a better alternative for managing dispersion, namely FBG-based dispersion compensation. By utilizing the unique properties of the FBG, both insertion loss and form-factor issues can effectively be addressed. Hence, it provides a really cost-effective alternative to the incumbent DCF technology.

Two main types of FBG-based dispersion compensation modules (FBG-DCMs) are commercially available today: channelized and continuous band. Channelized devices provide channel spacing specific, i.e. ITU grid specific, compensation. The continuous devices provide, in much the same manner as the DCF, full un-disrupted compensation throughout the C or L band. This, as a result, creates total channel plan independence.

Figure 3 demonstrates the principle of the FBG-DCM. By combining a reflective chirped FBG with a circulator, wavelength-specific time delays, i.e. dispersion, can be achieved.

A chirped FBG has a spatial variation in the grating period. These chirped gratings provide frequency-dependent delay for recompression of dispersed pulses. Due to the specific periodicity of the grating, different components of the light spectrum are reflected at different locations along the grating.

The ability to tailor the chirp of these FBGs makes it possible to mimic the dispersion characteristics of common fibers used in optical networks. Hence, this provides an excellent technology to counteract the negative effects of dispersion.

Benefits Of FBGs As Chromatic Dispersion Compensator

The most obvious and commonly known advantage related to FBG-DCMs is low insertion loss (IL). Typically, a 120-km FBG-DCM has an insertion loss in the range of 3 to 4 dB, depending on type. Furthermore, the FBG-DCM holds an advantage in that it has virtually constant IL versus span length, whereas the IL of the DCF-DCM grows linearly with span length.

A few meters long, the FBG has a small footprint and very low latency compared to a 10- or 20-km long DCF. The diagram in Figure 4 shows the comparison of insertion loss between FBG-DCM and DCF-DCM.

Residual dispersion is another key parameter for compensators. Due to the very flexible grating process developed by Proximion, the chirp characteristics can readily be chosen according to fiber specifications, i.e. dispersion level and dispersion slope can be tailored to fit any fiber type. The maximum residual dispersion of DCM is then controlled by less than &plusmin;2% over the entire operating bandwidth (Fig. 5).

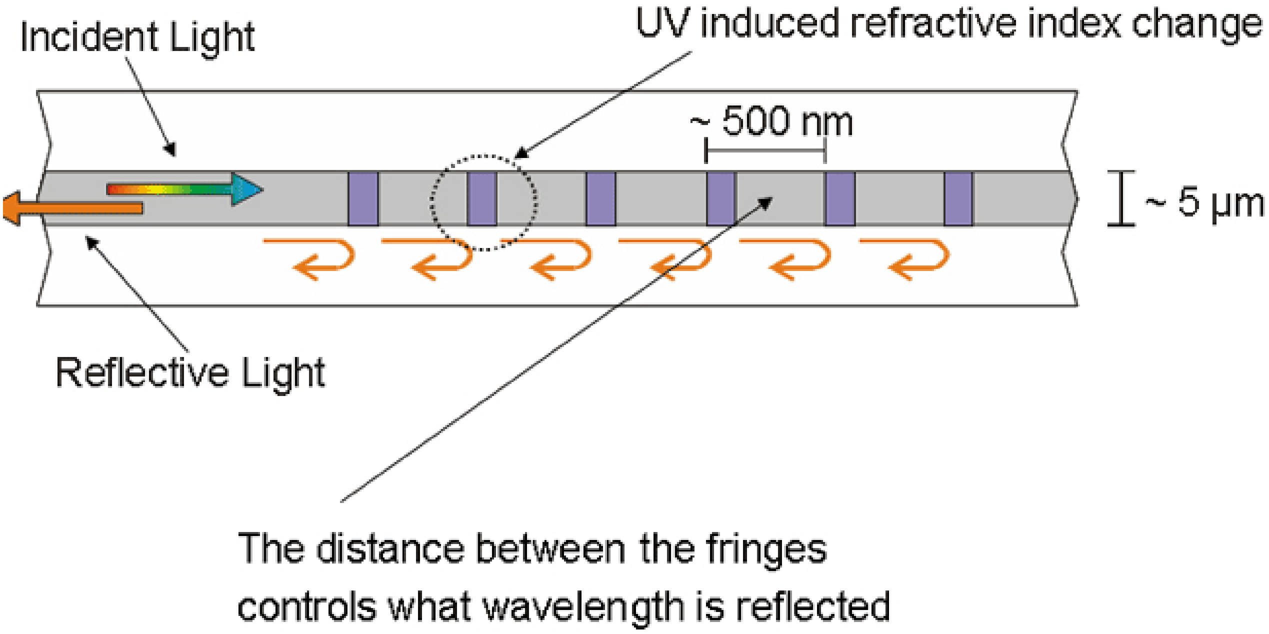
The ability to tolerate high optical powers without suffering from penalties caused by nonlinear effects is also one prominent characteristic separating the FBG-DCM from the DCF-DCM. Although a DCF will display nonlinearity effects at rather low optical powers, typically limiting the power to –2 dBm per channel, the FBG-DCM won't introduce such effects even at the highest power levels present throughout any traditional optical network.

Dispersion requirements increase with higher bandwidth, and as networks trend toward 40, or even 100 Gbits, the focus on dispersion compensation is high. There's also increased use of longer fibers, which means higher expense associated with the placement of amplifiers along the fiber routes. FBG-based DCMs may be concentrated in a single location. That equates to fewer compensation points and fewer amplifiers to upgrade with the DCMs, which leads to cost savings.

Conclusion

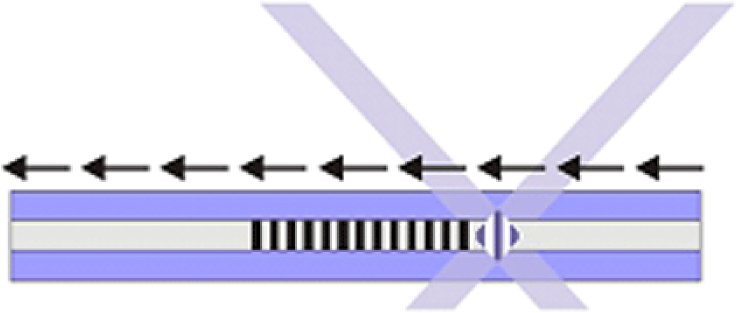
Fiber Bragg gratings have contributed to the great growth in optical components and DWDM. As the market moves toward higher bandwidth to meet the demand for traffic, the needs continue to grow and evolve for FBGs. This trend is likely to continue with further innovations ahead.

Fig1 WEB



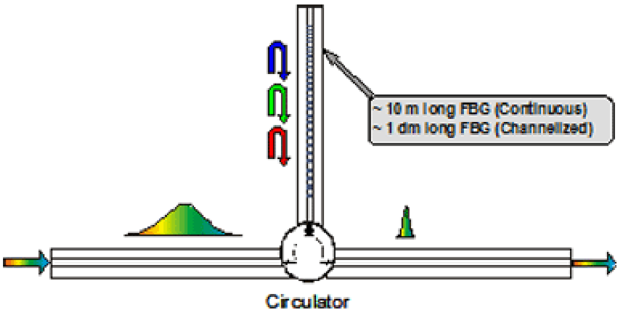
1. This is an example of a uniform FBG in a fiber.

Fig2 WEB



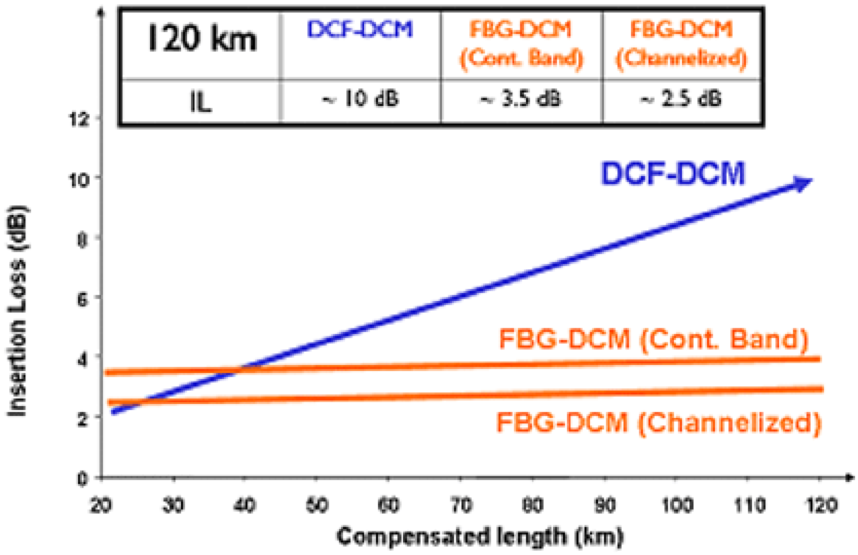
2. When two ultraviolet laser beams interfere, it results in a fringe pattern. By accurately controlling the motion of the fiber, many successive fringe patterns can be added into very long gratings.

Fig3 WEB



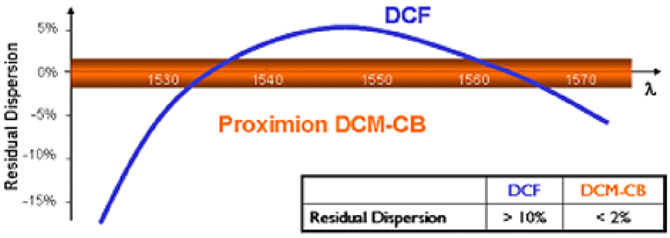
3. A dispersion compensation module uses a circulator in combination with a chirped FBG to provide the compensation required for greater bandwidth.

Fig4 WEB



4. Here, insertion loss is compared between FBG-DCM and DCF-DCM.

Fig5 WEB



5. This graph shows residual dispersion versus wavelength for a DCF.