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Fiber Bragg Gratings
FREQUENTLY ASKED QUESTIONS
(FAQ)

What is a Fiber Bragg Grating (FBG), and how it is different from a regular optical fiber?

A Fiber Bragg Grating, or FBG, is a formed by inscribing periodic refractive index modulation in the fiber core. Highly transitive fiber becomes reflective for some wavelength. Key parameter determining the grating performance are (refer to fig. 1):

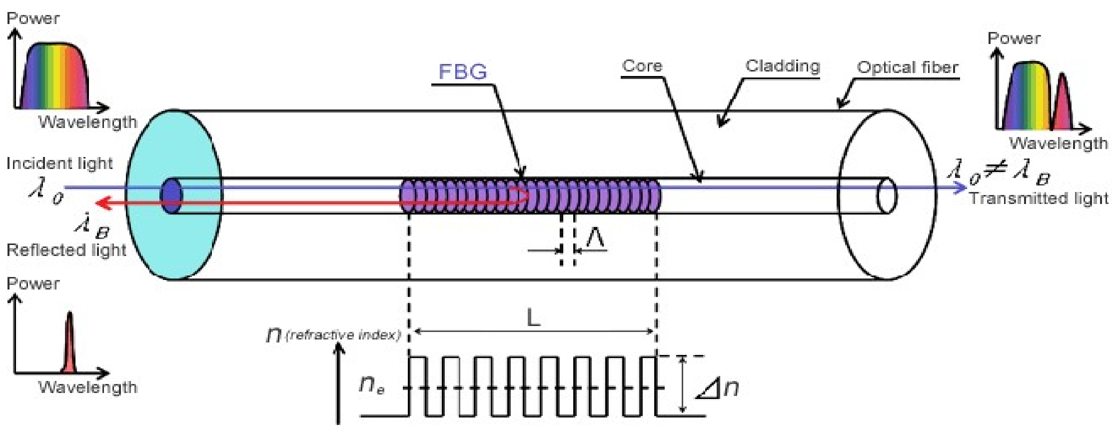

Figure 1: FBG structure

a) Grating period **Λ**

b) Length of the grating **L**

c) Effective index of the fiber core $\mathbf{n_e}$ (~1.45 for standard single mode fiber)

d) Index modulation **Δn** (higher the value of **Δn** stronger the FBG will be)

What is a single-mode fiber? What is a single-mode FBG?

Single-mode fiber (SMF) is an optical fiber, which allows propagation of fundamental 'mode' only. For standard single mode fiber core diameter is <12 µm. FBG inscribed on single-mode fiber is also called single-mode FBG.

What is a multi-mode fiber? What is a multi-mode FBG?

A multimode fiber (MMF) allows propagation of large number of modes. Multimode fibers have larger core size, typically >50 µm. FBG inscribed on multi-mode fiber is called multi-mode FBG.

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What are the main characteristics of an FBG?

FBGs works as a reflection band filter, it reflects a narrow bandwidth spectrum (<2 nm for uniform FBGs and even more than 100 nm for Chirped FBGs) and transmits all other wavelengths. FBG characterized by central wavelength (λ_0), maximum reflectivity (R_{max}), bandwidth (FWHM) and side lobe suppression ration, as shown in fig. 2.

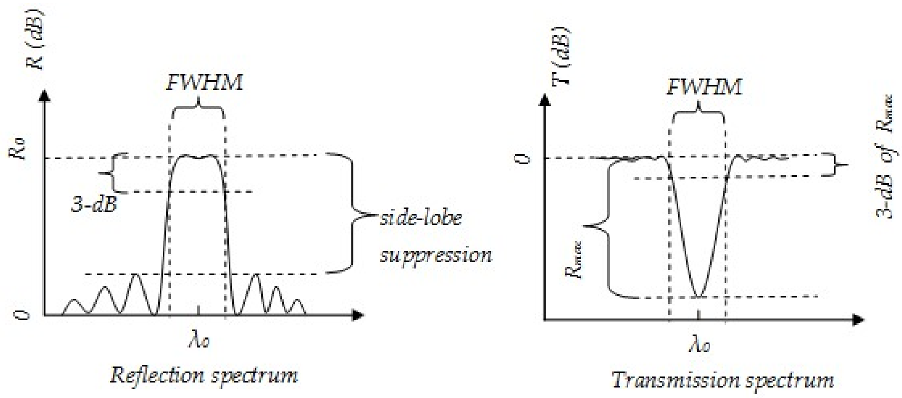

Figure 2: FBG spectrum showing maximum reflectivity (R_{max}) and 3-dB bandwidth (FWHM-full-width half-maximum)

What are the main applications of FBGs?

FBGs are mainly used for spectral filtering or sensing purposes.

What are the fundamental FBG equations?

The following are the main equations for an FBG:

$$\text{Bragg wavelength } \lambda_B = 2n_e\Lambda \qquad (1)$$

where **n_e** is the 'effective index' of the fiber where grating is written (~1.45 for standard single mode fiber) **Λ** is the period of the grating.

Bragg wavelength is also known as design wavelength. Central wavelength of the grating is slightly different from this, for basic understanding we can assume they are equal.

$$\text{Reflectivity } R_{max} = \tanh^2\left(\frac{\pi\Delta n L}{\lambda_0}\right) \qquad (2)$$

$$\text{Bandwidth } \Delta\lambda \sim \frac{\lambda_B \Delta n}{n_e}\sqrt{1+\left(\frac{\lambda_B}{\Delta n L}\right)^2} \qquad (3)$$

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What are the major types of FBGs?

FBG mentioned above is called **Uniform FBG**, where grating period is constant throughout. There is another type of FBGs, known as **Chirped FBG**, grating period is linearly increased/decreased over the grating length.

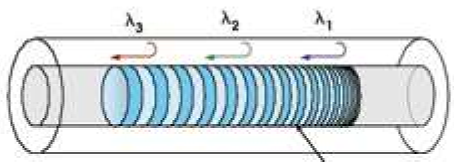

Figure 3: Chirped FBG

In standard FBGs, the refractive index variation is perpendicular the propagation axis or fiber axis. When there is a non-zero angle between the propagation axis and the grating, it is called **Tilted-FBG**, fig. 4. In addition to the single reflection band like uniform FBG, some part of the spectrum is lost into the cladding.

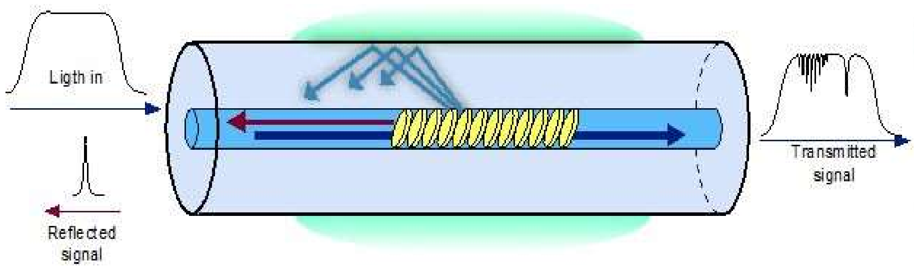

Figure 4: Tilted FBG

How the output characteristics of an FBG are controlled?

Central Wavelength (CWL), Reflectivity and Bandwidth are the major specifications of a grating. As shown in the grating equations, these are controlled by tuning the grating period, index modulation or grating length. It is obvious from the equations that reflectivity and bandwidth are interrelated.

Required Central Wavelength is obtained by using right period of phase-mask (as calculated by the grating equation).

Reflectivity is increased by increasing the grating strength or $\Delta \mathbf{n}$, see eq. 1.

Bandwidth is controlled mainly by grating length and by index modulation to some extent.

For weak gratings: eq. 2 reduces to

$$\Delta\lambda \sim \frac{\lambda_B^2}{n_e L}$$

means, longer grating length will give narrower bandwidth.

For strong gratings:

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$$\Delta\lambda \sim \frac{\lambda_B \Delta n}{n_e}$$

Bandwidth increases as the index modulation increases. Grating length has no effect in this case, this due to the fact that grating is so strong, and light penetrates only to a portion of the total grating length.

How the FBGs are inscribed?

Major writing techniques are based irradiation with ultra-violet (UV) laser. Doped core of standard fiber is photo sensitive to UV. In other words, refractive index profile of such fiber is permanently altered by UV irradiation. This feature can be used for inscribing a refractive modulation into the fiber core. If the UV light falling on the fiber has a periodic intensity variation, that will result in a periodic refractive modulation into the fiber core. This periodic intensity pattern is generated by a UV laser beam interference, see figure 5. Generating a precise stable interference patter is not an easy task.

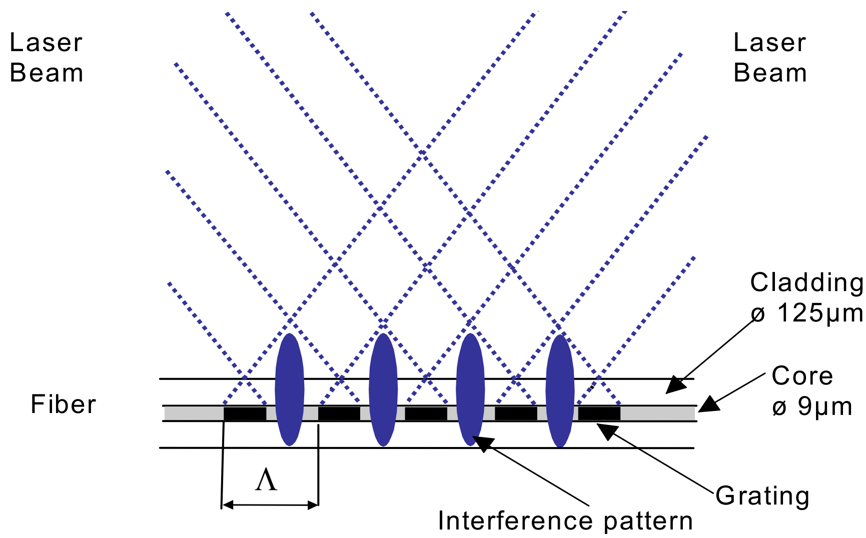

Figure 5: FBG writing – UV laser interference

More stable technique is to use a phase mask, as shown in figure 6. Phase mask has periodic line inscribed on it and a normal beam incident on it is spitted into two identical beams (+1 and -1 order) they interfere pattern in close to the phase mask. Period of the interference pattern is half that of the phase-mask. Then eq. 1 reduces to

$$\lambda_B = n_e \Lambda_{PM} \qquad (4)$$

where Λ_{PM} is the period of the phase mask. Effective index n_e depends on (i) fiber type, (ii) wavelength, (iii) writing process and (iv) annealing process. Precise value of n_e need to be estimated for each fiber/job types.

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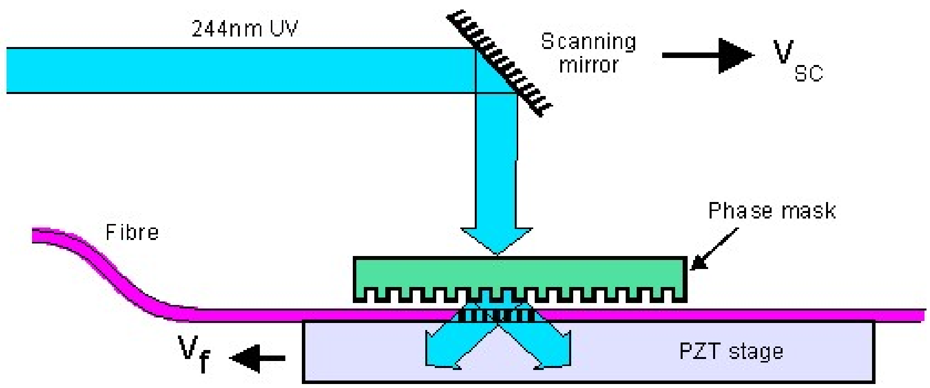

Figure 6: FBG writing using phase-mask technique

Chirped FBGs are inscribed using phase-mask with similar chirp. Tilted FBGs are inscribed using uniform phase-mask and fiber is kept such that there is non-zero angle (which is the tilt angle) between it and the phase-mask line.

How the output characteristics of an FBG are controlled during the inscription process?

As shown in the grating equations, grating specs (central wavelength, bandwidth, reflectivity, dispersion) are determined by grating period, grating length and index modulation strength.

Grating period and dispersion is directly chosen by phase-mask period and chirp rate. Grating length is controlled by scanning range (fig. 6). Index modulation strength can be increased by increasing the laser power or keep writing for long time.

Why we use apodization?

Apodization required because of “Gibbs phenomenon”. Sharp changes in index profile results in ripples in spectral domain or larger ‘side-lobes’ in reflection spectrum. Apodization means grating is weaker in both ends, see fig. 7 and fig. 8. Apodization is practically achieved by shaping the laser beam, such that transverse intensity profile of the laser beam is slowly varying.

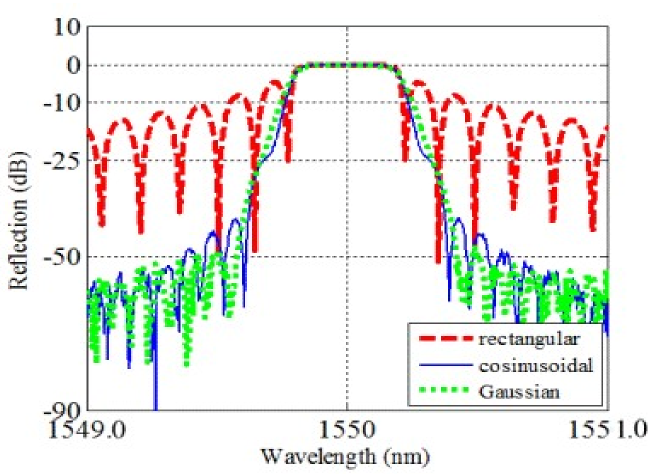

Figure 7: FBG reflection spectrum for different types of apodization

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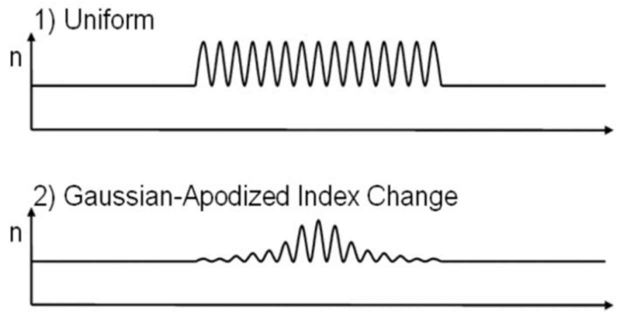

Figure 8: Refractive index profile with and without apodization

How to choose a phase mask for a particular job?

Uniform and chirped phase makes are listed separately in the database. Uniform grating is characterised by period and length. The period is a single constant number along the grating length. Use eq. (4) to calculate the phase-mask period required for a particular job. Typical value $\mathbf{n_e}$ is ~1.447 for standard single mode fibers. For different fiber types or job types, more precise value of $\mathbf{n_e}$ need to be taken from previous test results.

Chirped phase mask is characterized by start period, end period, chirp rate or the corresponding start wavelength, end wavelength and dispersion. In a chirped phase-mask, period varies linearly from one end to other. In addition to this, length is another key parameter. Checklist for choosing the chirped phase-mask:

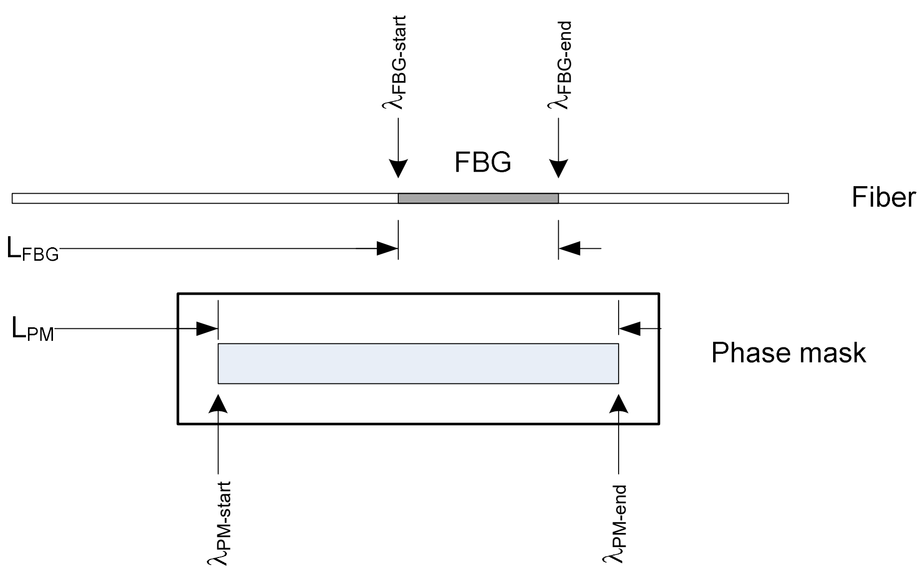

Figure 9: Phase-mask and FBG

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i. Required spectral band of chirped FBG need to be within the spectral band of phase-mask, see fig. 7. In other words:

$\lambda_{FBG\_start} \geq \lambda_{PM\_start}$ and $\lambda_{FBG\_end} \leq \lambda_{PM\_end}$

ii. Length of FBG calculated as $L_{FBG} = L_{PM} \frac{\lambda_{FBG\_end} - \lambda_{FBG\_start}}{\lambda_{PM\_end} - \lambda_{PM\_start}}$, this need to be a practical value, a few nm or more.

iii. If the dispersion value is a required specification, a phase mask with matching dispersion/chirp value must be chosen.

What is the definition of uniform FBG?

A uniform FBG is the one inscribed using a uniform phase-mask.

What is the definition of chirped FBG?

FBGs inscribed using chirped phase masks are called chirped FBGs, whose reflection wavelength linearly varies from one end to other.

How the FBGs are measured?

The following are the two main setup for FBG measurement, in transmission and reflection configuration.

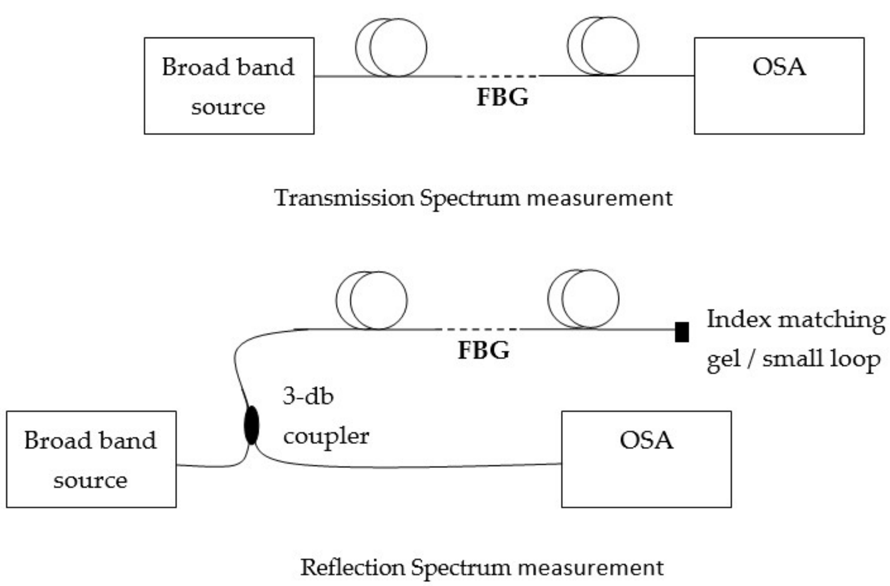

Figure 10: FBG measurement setup

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The necessary equipment needed for the measurement:

- Broadband light source, covering the center wavelength of the FBG.
- Optical Spectrum Analyzer (OSA) to visualize the FBG spectra, and to take the measurements.
- Optical coupler in case of measurement of the FBG reflection, and some index-matching compound.

To make proper measurement:

i. Need to launch enough power to the fiber. Noise level of OSA is -65 -50 dBm (this can be found out by scanning the OSA without any input source), transmission/reflection minimum need to be above this level.
ii. To ensure enough power launching, we need light source with good power level and low-loss fiber connection. Good cleaving, cleaning and use of matching adapters will ensure negligible connector loss.
iii. While measuring the reflection spectrum it is important to apply index matching gel to the free end of the fiber. There will be broadband reflection (up to 4%) from the cleaved fiber end that can result in poor isolation (or poor side-lobe suppression) in reflection spectrum. Applying index matching gel or bending the tip to small radius will almost eliminate this back reflection.