VOLUME BRAGG GRATINGS™
A NEW PLATFORM TECHNOLOGY FOR WDM APPLICATIONS

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Introduction

The development of WDM [wave division multiplexing] technology has had a profound effect on increasing the bandwidth of fiber optic networks over the last decade.

Practically all WDM devices/subsystems incorporate wavelength selective filters employing various physical phenomena to achieve the required wavelength selectivity. The main purpose of this article is to describe an entirely new and exclusive WDM filter technology recently developed by PD-LD Inc.

One could perhaps summarize this new technology with the following expression:

VBG>TFF+FBG

In other words, the VBG [Volume Bragg Gratings] technology combines and perhaps exceeds the best characteristics of the TFF [Thin Film Filters] and FBG [Fiber Bragg Gratings] filters. Add to this efficient manufacturing techniques and robust material properties and this new entrant into an already crowded field of WDM filters starts to make sense: hence this article.

Volume Bragg Gratings

In this section we shall describe principles of operation, the manufacturing and applications of VBG filters and WDM devices/subsystems.

Volume Bragg grating technology developed at PD-LD is based on a proprietary photorefractive glass that changes index of refraction in areas exposed to UV light. This characteristic can be utilized for direct writing of periodic structures such as gratings, to create filters with desirable properties. Filter shape, center wavelength, pass bandwidth, side band suppression and other characteristics are determined by the combination of recording and processing procedures and the composition of glass. Physically, VBG elements are small glass cubes or parallelepipeds, 2 to 5 mm on a side, robust and easy to handle, well suited for high temperature processing [soldering, brazing, glass fritting, etc] and automated manufacturing. Since the glass is silica based, the produced filters are physically and chemically very stable, in difference from filters recorded in photorefractive plastics or crystals, which usually encounter problems with dimensional stability and permanence of recording, when subjected to typical telecom operating and storage temperatures.

Figure 1 depicts VBG filters operating either in transmission or in reflection mode. In reflection mode, the selected wavelength is reflected as by FBG filters, while express channels go through with only a minimal loss. A receiving collimator-fiber assembly, just like in TFF based devices, easily picks up the reflected beam. Hence FBG-like performance combined with TFF-like packaging, avoiding the need for circulators to extract the selected wavelength. Reflection type VBGs are suitable for DWDM applications, with channel spacing of 25 to 200 GHz.

In a transmission type VBG all channels go through the filter, but the selected wavelength is deflected from the beam, to be picked up by the properly placed collimator-fiber assembly. Transmission type VBG are suitable for CWDM applications, where pass bands are several nanometers wide.

Another interesting and unique characteristic of VBG elements is that a single element can contain multiple filters in the same volume. Thus one element can manage several, e.g. 4 selected wavelengths. This is a distinct advantage over conventional TFF or FBG based approaches that would require 4 distinct and separate filters to accommodate 4 distinct wavelengths. This reduction in number of filters employed translates into huge cost and space savings.

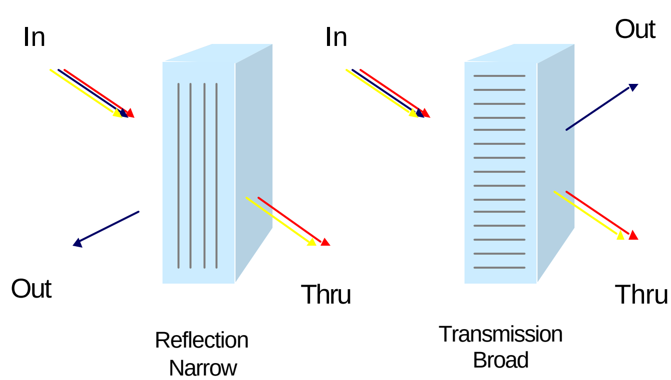

Figure 1A. Principles of operation of VBG filters – thin lines denote planes with changed index of refraction. In a reflection type, all wavelengths except the selected one pass through the filter with a minimal loss. The reflected wavelength is picked-up by a fiber-collimator assembly positioned at the proper angle. In a transmission type VBG, all wavelengths pass through the filter with a minimal loss, and only the selected wavelength is deflected to be picked-up by a fiber-collimator assembly positioned at the proper angle. Note that a VBG element can contain more than one grating in the same volume to select more than one wavelength from the multi-wavelength stream. Note also that a different wavelength[s] can be selected by angular tuning of the VBG element.

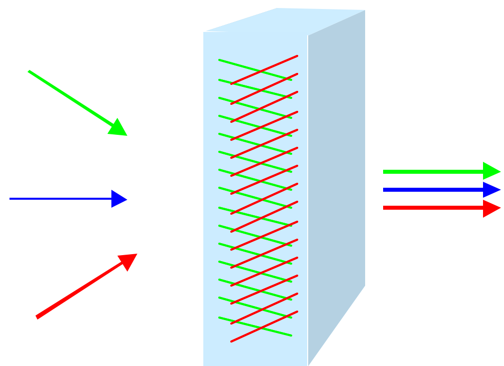

Fig. 1B. Several VBG filters can be overlapped, or multiplexed in the same volume. This allows fabrication of multi-port, multi-functional elements in a very compact volume.

Manufacturing of the VBG filters and devices is a complex, multi-step process that requires vertical integration of the company. Several steps of the manufacturing sequence are proprietary and unique to PD-LD [e.g. glass composition, glass processing, holographic recording, filter shape modeling, VBG characterization, etc].

Photorefractive glasses developed and used at PD-LD are oxide glasses, based on SiO_2 and containing numerous other additives. It is believed the photorefractive action is based on a redox reaction of silver initiated by the UV exposure. The elemental silver particles serve as nucleation centers for the growth of a second phase during the thermal development process, at ~ 500 C for several hours. This second phase is thought to be Na and K halogenide rich, thus resulting in a material with somewhat lower index of refraction than in the unexposed areas.

The produced glass must be of optical quality, with excellent compositional uniformity and absence of bubbles, striations and other imperfections. It also must be free of chemical impurities that might strongly influence the extent and nature of photo-induced reactions.

Subsequent to melting and annealing, the glass boule is cut into wafers, which are then polished. These wafers are then subjected to holographic recording and development.

In the recording of the VBG filter(s), a wafer of the photorefractive glass is illuminated by two mutually coherent laser beams. These beams create a standing wave pattern with sinusoidal variation of the light intensity. This pattern is imprinted in the bulk of the material, penetrating its entire thickness. At this stage, the photochemical changes induced by light are not complete (i.e. they are latent) and the index of refraction is unchanged. Only bringing the material to the elevated temperature sufficient for the rapid growth of the second phase as mentioned above completes the process. During this step the latent grating is transformed into the grating of the refractive index, or the true VBG. These gratings are completely stable at temperatures as high as 150 to 200 C. The recording of the VBG wafer can be done by using truly “holographic” techniques, or alternatively, by using a phase mask, much like the ones used for the recording of the fiber Bragg gratings. In either method, the spectral shape of the filter is controlled by proper manipulation of the amplitude and the phase of the recording beams. In doing so, a filter with any shape can be constructed, such as, for example, the flat-top, steep roll-off filters required for the fiber-optic communication networks.

After development, wafers are diced into individual VBG filter elements, which might be AR coated. The finished filter elements undergo QC and characterization and are ready for application. Figure 2 shows a diced wafer and a single VBG element.

Characteristics of VBG filters

VBG filter can reflect (or deflect) the selected wavelength of light at a convenient angle to be picked up by a receiving collimator or sent to some other suitable target (e.g. photodiode). As mentioned earlier, the very important implication of this is that, unlike with a fiber Bragg grating, VBG requires no circulators to operate. All other wavelengths of light that are outside of the pass-band are transmitted through the VBG unaffected.

The amplitude and phase envelopes of the VBG determine the spectral shape of the filter. With proper design, steep filters are obtained having, for example, 0.5 dB width of 0.2 nm and 25 dB width of < 0.7 nm. For comparison of filter shapes Figure 3 shows spectral curves for VBG filters: a. 50 GHz DWDM filters, operating in reflection b. unapodized 12nm bandpass CWDM filter, operating in transmission.
In the case of the narrow filter, the light at the peak wavelength is reflected by the grating practically completely, with 55+ dB attenuation, making it also an excellent notch filter.

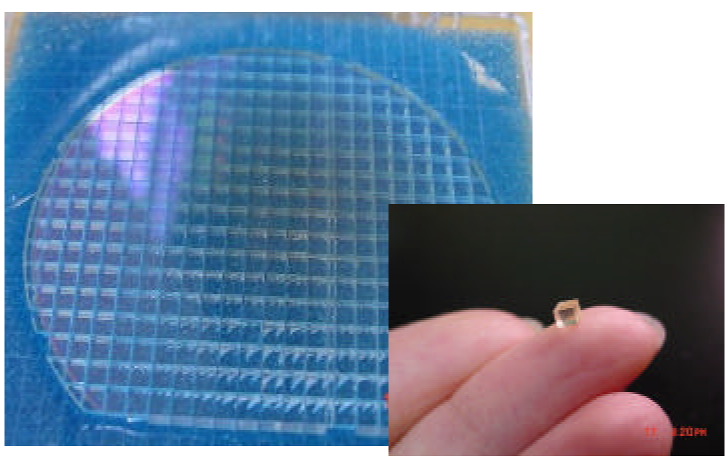

Figure 2. Photo of a diced wafer and a single VBG element. Manufacturing VBG elements is an efficient process, since the whole wafer is recorded in one-step, to produce many VBG elements at a time.

As mentioned previously, multiple VBG filters can be recorded in the same volume, thus reducing the number of filter elements in a given device. This means that very compact, integrated multi-functional subsystems can be constructed using this technology. Moreover, since the peak wavelength of the VBG depends somewhat on the angle of incidence, VBG filters can be tuned by rotation if tunability is required for a particular application.

Current applications of VBG technology

As the above description has shown, VBG filters have a significant potential for application in numerous WDM devices and subsystems due to their excellent performance characteristics, combined with small size, robustness, ease of application and efficient manufacturing techniques.

At this point PD-LD is concentrating on products based on the transmission type VBGs suitable for applications with wide wavelength separation. Applications based on narrow DWDM filters will be addressed in another article.

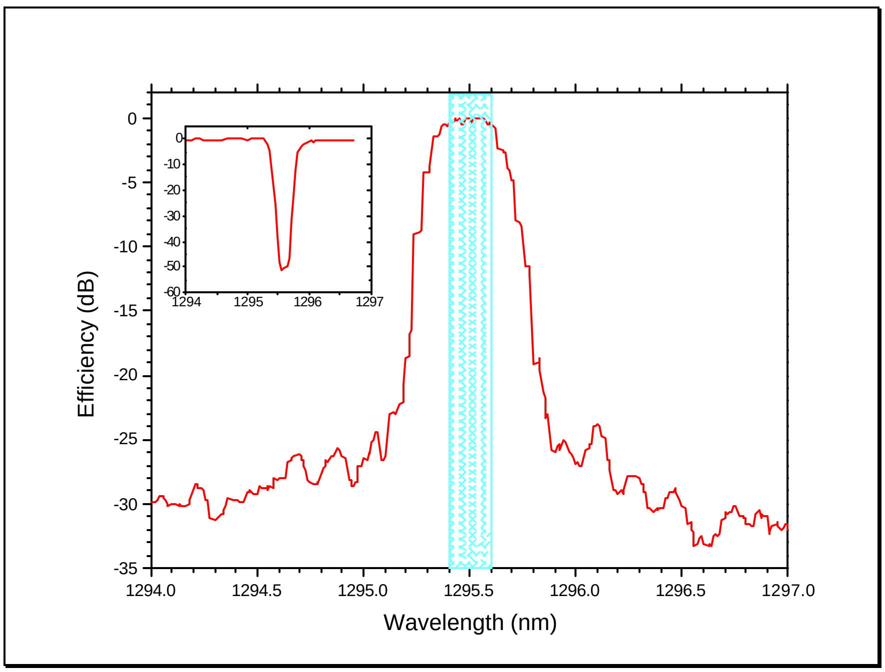

Figure3a. Spectral response of a 50 GHz VBG filter for DWDM applications [reflection type].

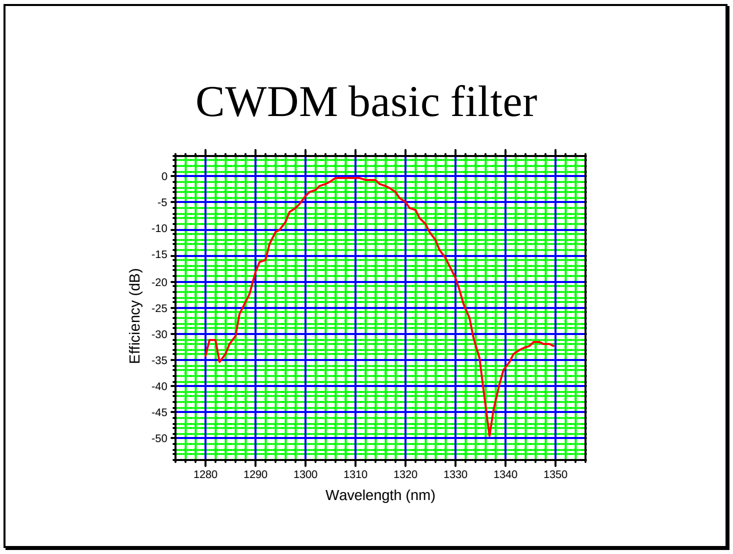

Figure 3b. Spectral response of a 12 nm wide CWDM VBG filter [transmission type].

We offer discreet VBG elements themselves as well as the universal broad band WDM combiners described below. PD-LD has also demonstrated capability to build hybrid modules, in which active devices [lasers and detectors] are combined with VBG filters to produce unique components and subsystems.

i. VBG discrete filter elements

The essential characteristics of VBG filters and methods for manufacturing them have been discussed previously.

The main advantages of VBG filters are:

- FBG performance combined with TFF simplicity
- More than one filter in the same volume
- Small size, robustness, durability
- Filter shape control, excellent performance characteristics
- Amenable to automated packaging
- Low cost

ii. Universal WDM combiners/ splitters

WDM combiners/splitters for combining 2 wavelengths such as 1310 nm and 1550 nm are well known devices. They are based on fused fiber [low isolation units] or TFF technology [high isolation units]. WDM combiners/splitters based on VBG technology can combine up to 4 wavelengths with excellent isolation and low losses.

Our initial product combines 3 wavelength bands, 850 – 1100 nm, 1300 nm and 1550 nm bands, respectively. Other combinations are possible, e.g.:

1310 nm, 1490 nm, 1550 nm – for CATV applications

1275 nm, 1350 nm, 1490 nm, 1550 nm – for low cost CWDM applications

440nm, 534nm, 630 nm –applications in displays, laser shows, pointers, etc.

Figure 4 depicts a universal 4-channel WDM combiner. In comparison with other 4 - channel multiplexers, this design offers a large advantage in price per channel and is only a fraction in size in comparison with competing devices.

Figure 4. Low cost package for a 4-channel WDM combiner. In this package one uses very wide VBG filters for combining four lasers from the near IR bands.

ii. Integrated Combiner modules

PD-LD has demonstrated a 4-channel, 1300 nm band CWDM transmitter module integrating DFB lasers with a compact VBG based multiplexer in a unit designed to perform to the LX 4 standard, specified for use in 10 Gbit Ethernet transmission [see Figure 5]. Figure 6 shows the output of this unit. Note high coupled power of 1 mw [0 dBm] for all channels in contrast with – 7.5 dBm, or less, when a standard 4 x 1 fused coupler is used. Thus VBG technology enables compact component integration into various multi-source4d transceiver footprints. The advantages of the integrated approach are:

- Compact size
- High coupled power [> 0 dBm/channel, making reaches of over 50km feasible]
- Utilizes standard hermetically packaged coaxial uncooled lasers
- Flexible, other wavelengths available on a custom basis

e. Other VBG based devices and subsystems

In addition to devices described in the previous section, VBG elements can be used in most devices where either TFF or FBG elements are used. The following list describes some but not all of the devices which might benefit from the VBG technology.

- Low cost pump comb iner
- OADMs for DWDM networks
- Wavelength sensitive tap for monitoring
- Wavelength locker

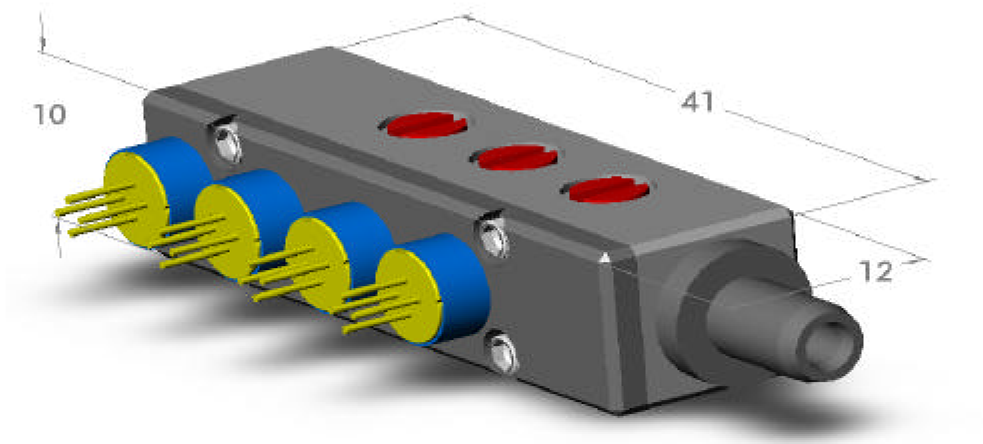

Figure 5. An integrated module based on VBG technology. This module contains 4 CWDM DFB lasers and VBG elements for multiplexing these lasers into single mode fiber.
Note that this unit couples over 1 mw per channel, thus avoiding the 7.5 dB loss associated with commonly used 4 x1 fused fiber couplers. The unit is sufficiently small to fit into a Xenpak package specified for 10 Gbit Ethernet networks.

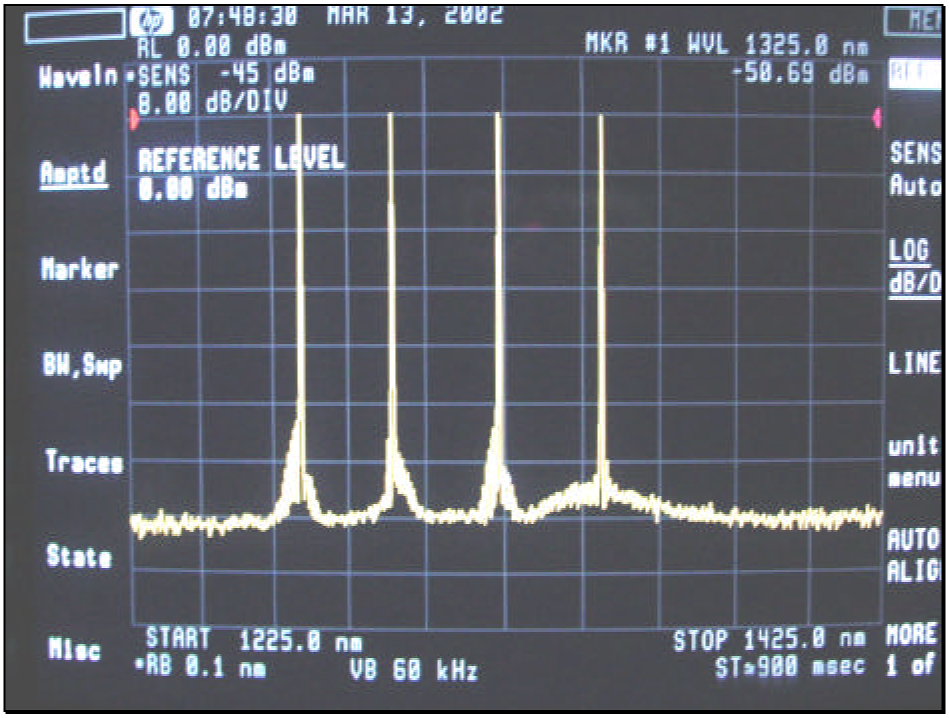

Figure 6. Spectral output of a 4-channel CWDM transmitter based on VBG elements. Note the high coupling efficiency [0 dBm], for the long range reach.

- Tunable devices – slight angular motion of a VBG element provides wavelength tuning

Summary and conclusions

In this article we have described a new technology of Volume Bragg Gratings developed by PD-LD Inc.

Characteristics such as compact size, physical toughness and durability, high volume manufacturability, combined with superior optical characteristics such as low insertion loss, high wavelength selectivity and free space operation, promise to make VBG elements essential parts of many future components used in communication networks.

We thus believe that VBG elements represent a technological and commercial breakthrough development for numerous applications in photonic industry.

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