High Reliability FBG Interrogation Analyzers

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ABSTRACT

The invention of optical fiber and semiconductor lasers in the 1960s opened up a cornucopia of applications, notably as a medium of carrying light signals for communications and sensing applications. Optical fibers provide a fundamental improvement over traditional methods offering lower loss, higher bandwidth, immunity to electromagnetic interference (EMI), lighter weight, lower cost, and lower maintenance. By applying a UV laser to "burn" or write a diffraction grating (A Fiber Bragg Grating-FBG) in the fiber it became possible to reflect certain wavelengths of light, which used together with an interrogation analyzer (spectral analyzer) precise sensing measurements could be taken. The recent developments of optoelectronics components in the optical telecommunications field have dramatically enhanced the capabilities of many components, such as: light sources, fibers, detectors, optical amplifiers, mux/demuxes, switches, etc. As a result, numerous applications are now available for monitoring strain, stress and pressure in harsh environments. Examples of current and planned deployments will be presented.

Keywords: Fiber bragg grating, interrogation analyzer, FBG monitor, fiber sensing, smart structure

1. INTRODUCTION

Structurally, an FBGA consists of a spectral analyzer element, a detection unit, and an electronic processing unit. The spectral element separates the wavelength components of the multiplexed signal containing a plurality of wavelengths. The detection unit is a single element or arrayed detector, which is used to convert the optical signal to electric signal for further processing by the electronics circuit. Functionally, an FBGA should be capable of providing fast measurements of the wavelength and power levels. From these measurements, the following information is collected: 1) peak central wavelengths, 2) central wavelength shifts with respect to reference wavelengths, 3) peak powers, 4) peak power distribution, and 5) presence of peaks.

1.1. FBG Interrogation Analyzer Types

The following information is helpful in selecting an optimal FBGA. The critical optical performance of an FBGA depends on its spectral element and detection unit. Let us look at what types of spectral elements and detection units can be used.

The spectral elements can be classified into three categories:

1) Scanning filters, such as tunable Fabry-Perot filters
2) Continuous dispersion spectral elements, such as volume holographic phase gratings.

The combination of one specific spectral element with one of the two detection manners determines the operating fashion of an FBGA. Table I summarizes the possible combinations.

Table I. Comparison of spectral elements and detection units

	Single Detector	Detector Array
Scanning Filters	✓	✓
Continuous Dispersion Elements	×	✓

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It is well known that the FBGA using scanning filters, whether combined with single or arrayed detectors, operates in a *serial* manner. This approach does not provide fast measurements due to its serial wavelength scanning and processing. Furthermore, such devices may contain moving mechanical parts compromising reliability and accuracy.

It is highly desirable to have a spectral element that can avoid moving parts and provide continuous spectrum measurement in order to overcome discrete wavelength measurements. Free-space diffraction gratings would do the job. In considering efficiency, reliability, and other related issues, transmission volume phase gratings (VPG) emerge to be the best spectral elements for FBGAs. FBGAs based on high-efficient VPG as its spectral element in combination with high-sensitive detector array provide the best solution and ideal choice. These spectral engines feature high speed parallel processing, continuous spectrum monitoring, superior performance, and the smallest dimension of this kind in the world.

1.2. How does a VPG-based FBGA work?

The basic operating block diagram of an FBGA is schematically shown in Figure 1. A fractional portion (e.g., <10%) of light power is tapped from the mainstream optical signal for the monitoring purpose while keeping the properties of the main traffic unchanged (in this situation the traffic is the light from the interrogation light source, it can be a broadband ASE source or some type of super luminescent LED sources). Since the tapped signal will not be added back to the mainstream data, there are no effects on the properties of the transmitted data and FBGA provides a non-invasive measurement. The weak signal tapped from the networks is then directed to the spectral element, from which the wavelength components are separated in space. These spatially dispersed signals are detected by a series of detectors, and from this, the light signals are converted into electric ones. The electric outputs are transmitted to the electronics circuitry for processing and output, from which power and wavelength are obtained.

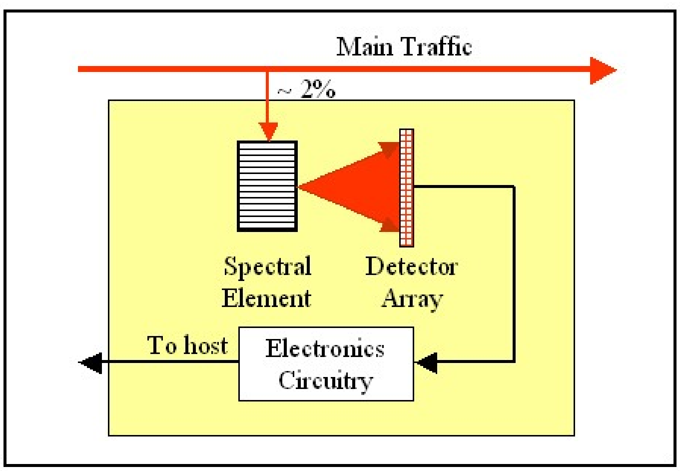


Figure 1. Schematic operating block diagram of an VPG-based FBGA.

1.3. FBG Interrogation Analyzer Configuration

BaySpec's WaveCapture™ FBG Interrogation Analyzer utilizes a proprietary high-resolution volume phase gratings (VPG®) spectral dispersion element and high-sensitive InGaAs array detector as detection unit so as to provide both high-speed parallel processing and continuous spectrum measurements. The WaveCapture™ configuration is schematically illustrated in Figure 2. From the main data transmission link, a small fraction of signal is taken with a tap coupler. The tapped signal is quite weak, typically ~10% in magnitude, depending on the applications. The weak light is inputted to the one-port FBGA through a single-mode fiber and is collimated by a micro lenses. The signal is spectrally dispersed by a high-efficient VPG and the diffracted field is focused onto a multi-element InGaAs array detector. The control electronics reads out the signal that is then processed by a DSP to extract the information. Both the raw data and the processed data are available in memory for the host through either serial communications or parallel port.

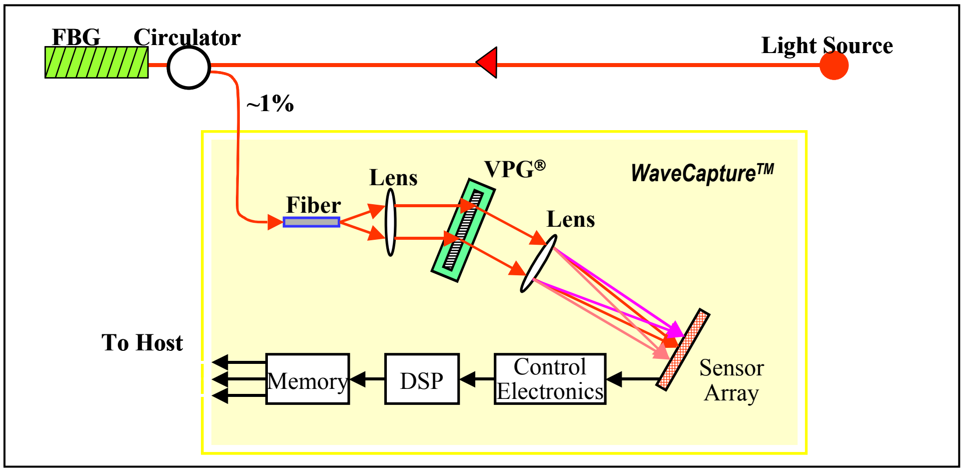


Figure 2. Schematic diagram of a WaveCapture™ FBG Interrogation Analyzer.

BaySpec's patented (issued) VPG® technology and patent (pending) FBGA design, have been developed and extensively tested for high-volume DWDM telecom monitoring. Figure 3 displays a photograph of the WaveCapture™ FBG Interrogation Analyzer spectral engine. The miniature optical unit measures 60 mm × 68 mm × 15 mm, which fits on an electronics board as small as a credit card. OEM designs are available for custom mounting with existing electronics boards.

Figure 3. WaveCapture™ Interrogation Analyzer

1.4. Features

FBGA spectral engines feature high-speed parallel processing, continuous spectrum monitoring, superior performance, and the smallest dimension of this kind in the world. In particular they feature:

- High-resolution VPG® spectral element
- Battery operational
- *Athermal* design and packaging
- High-efficient 256- or 512-element InGaAs array detector
- No moving parts
- High wavelength counts, covering S, C- and/or L-bands
- High sensitivity
- High dynamic range
- Fast milli-second response time
- Compact, robust, and lightweight package

It is worth emphasizing that the WaveCapture™ FBGA response is to a continuous spectral band, rather than to a series of discrete wavelengths. This is a differential advantage over tunable filter approaches. More importantly, as the ambient temperature changes, the center wavelengths of the carrier signal in a DWDM network will offset from the wavelength references. Thus, with the use of WaveCapture™ FBGAs, the whole spectral regime is measured independent of the absolute locations of wavelengths providing robust and unbiased measurements.

2. DATA

The ability to detect wavelength power and wavelength presence is demonstrated in Figure 4. As seen, both the present and absent wavelengths can be correctly detected. The yellow dots are the raw sampled data and the green lines are the processed results.

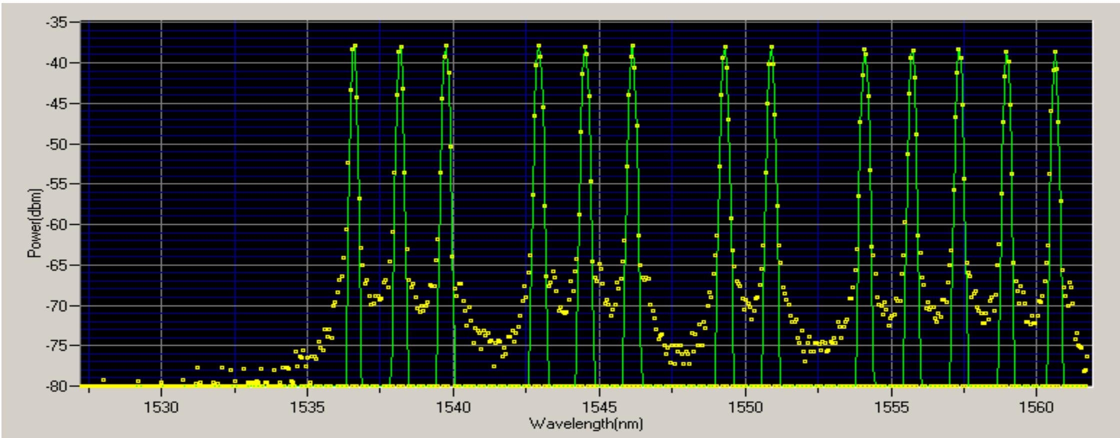
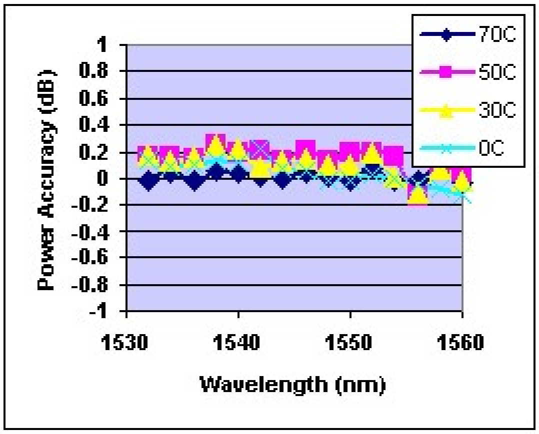


Figure 4. Raw and processed power spectrum detected by WaveCapture™ FBG Interrogation Analyzer

2.1 Power Accuracy and Stability

The power accuracy is power difference between the measured value and its true value for different wavelengths, and the power stability specifies the power variation with temperature. Figure 5(a) shows power accuracy of the WaveCapture™ FBGA against wavelength over the C-band at four different temperatures. Fluctuations are well within ±0.2 dB. Figure 6(b) depicts the power accuracy versus the operating temperature for four different wavelengths. The maximum deviation is less than 0.4 dB.



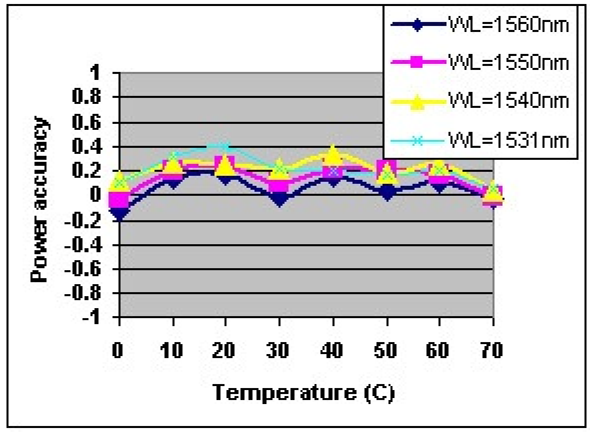


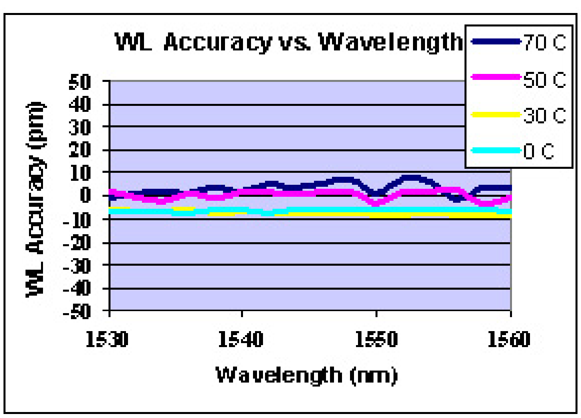
Figure 5. Power accuracy versus wavelength (a) and temperature (b).

2.2 Peak Power Repeatability

Peak power repeatability specifies the power variation over a given time period. BaySpec's WaveCapture™ FBGAs are tested over 24 hours. The fluctuated values measured are exceptionally within ±0.2 dB.

2.3 Wavelength Accuracy and Stability

The wavelength accuracy is the wavelength offset with respect to its true value and the wavelength stability specifies the wavelength variation with temperature. Figure 6(a) plots the measured central wavelength of each channel as a function of the true one at four different temperatures. Figure 6(b) shows the dependence of the central wavelength variation on the operating temperature for four wavelengths. In both diagrams, a wavelength accuracy of ±15 pm is guaranteed.



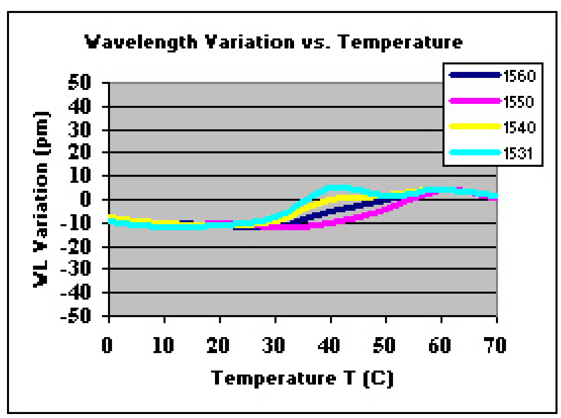


Figure 6. Wavelength accuracy versus wavelength (a) and temperature (b).

3. CONCLUSIONS

BaySpec's FBG Interrogation Analyzer spectral engines are now shipping in volume. Wavelength resolution is specified for the customer's applications, not for the FBGA since the device utilizes a continuous spectral band, usually specified by the response bands, S, C- and/or L-band. For example, in a single C- or L-band, the device can handle up to 40 detection peaks to if a 256 detector array is used; up to 60 peaks when a 512 detector array is used. Table 2 gives a typical specification for a single-band WaveCapture™ FBGA based on a 256 array detector. The peak power repeatability is measured over 24 hours.

Parameter	Data	Unit
Wavelength Range	1525 – 1565 or specify	nm
Wavelength Accuracy	± 30	pm
Display Spectral Resolution	± 1	pm
Frequency	~5	kHz
Channel Input Power Range	-60 to –20 or specify	dBm
Channel Power Accuracy	± 0.5	dB
Power Resolution	0.1	dB
PDL	<0.3	dB
Response Time	<0.6	ms
Size	68 x 96 x 15.8	mm^3
Interface	USB, RS-232 or Dual-port RAM	
Software	included	

Table 2. BaySpec WaveCapture™ FBG Interrogation Analyzer specifications

At present, FBG Interrogation Analyzers based on VPGs and detector arrays technology have the largest installed base in high-performance DWDM, such as ROADM networks. Both the DWDM networking and FBGA technologies are evolving. High-degree performance measurements are required and small-size monitoring deviceS are desired. In addition, key performance for selecting an FBGA is identified according to wide dynamic range, high power and wavelength accuracy, and excellent thermal stability. In view of these considerations along with low-cost requirements, BaySpec's WaveCapture™ Interrogation Analyzer provides the industry's best price-performance solution for FBG sensing applications.

REFERENCES

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