

Visible wavelength fiber Bragg grating arrays for high speed biomedical spectral sensing

G. E. Carver¹, D. L. Farkas², J. Porque³, K. S. Feder³, and P. S. Westbrook³

¹Omega Optical Brattleboro, Vermont 05301, Phone: 802 251 7346, gcarver@omegafilters.com

²Cedars-Sinai Medical Center Los Angeles, California 90048, Phone: 310 423 7746, daniel.farkas@cshs.org

³OFS Laboratories, Somerset, New Jersey 08873, Phone: 732 748 7495, westbrook@ofsoptics.com

Abstract

Spectral data for each pixel in a confocal spatial scan are acquired by mapping spectral slices into the time domain with an array of visible fiber Bragg gratings. Multispectral images of biomedical tissue can be generated in real time.

©2010 Optical Society of America.

OCIS codes: (050.2770) Gratings, (170.6280) Spectroscopy, fluorescence and luminescence

1. Introduction

Fast multispectral confocal mapping has great promise for imaging cancer at the cellular level [1]. Biomedical researchers have shown that laser induced autofluorescence at 500 to 800 nm can detect cancer in unstained tissue [2]. Existing technologies have not combined sufficient spatial, spectral, and temporal resolution in one instrument. Spectrometer acquisition speeds are not fast enough to generate multispectral data at rates that avoid spatial impairments due to the movements of living biological samples.

In this paper we show that spectra can be acquired for each pixel in a confocal spatial scan by using a fast spectrometer based on an array of strong, broadband visible fiber Bragg gratings. As an added benefit, the fiber entrance face can act as the pinhole in our confocal microscope. This allows fast spectroscopy to be combined with fast microscopy, enabling real-time diagnostics in both R&D centers and clinical settings.

2. Experiment

As depicted in Fig. 1, a serial array of strong ($R > 90\%$), broadband (bandwidth $> 10\text{nm}$) visible fiber Bragg gratings is used to map wavelength bins into time slots [3]. This design can resolve wavelengths to within 1-10 nanometers over a wide configurable spectral bandwidth. When a broadband pulse of light propagates into the array, light of wavelength λ_1 reflects from the first grating, and light of wavelength λ_N reflects from the N^{th} grating. All wavelengths are detected within about $2.5\mu\text{sec}$ – matching the dwell time of the confocal scan. Over ten datacubes (x mm, y mm, λ nm) can be generated per second - compatible with surgical applications. These speeds are made possible by avoiding the long integration times required by detector arrays (see left side of Fig. 1). Beyond speed, this new design has several other advantages. Spectral bin centers and widths can be arranged in an arbitrary manner without the constraints of the diffraction equation. The bin centers are set via the pitch of the gratings, and the bin widths can be adjusted by changing the bandwidth of the gratings in the array. A map of a given color will spatially register with a map of another color. Further, each polarization state is treated in a similar way by the gratings.

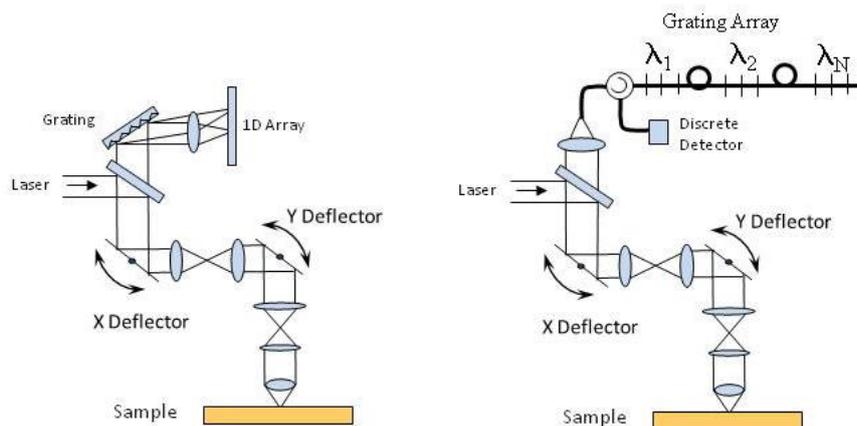


Fig. 1. Multispectral imaging with 1 bulk grating and N pixels (left), versus N fiber gratings and 1 high gain bandwidth detector (right)

Acceptable signal to noise required strong ($R > 90\%$) and large bandwidth ($> 10\text{nm}$) visible Bragg gratings to define the spectral bins. These were created by writing a step chirped grating in deuterium loaded single mode fiber (450 nm cutoff, Fibercore Limited). Spectral bin centers were set at 550, 600, and 700 nm. See Fig. 2. Each step chirped grating was comprised of several individual gratings (each with a 1 mm length and a 1 nm

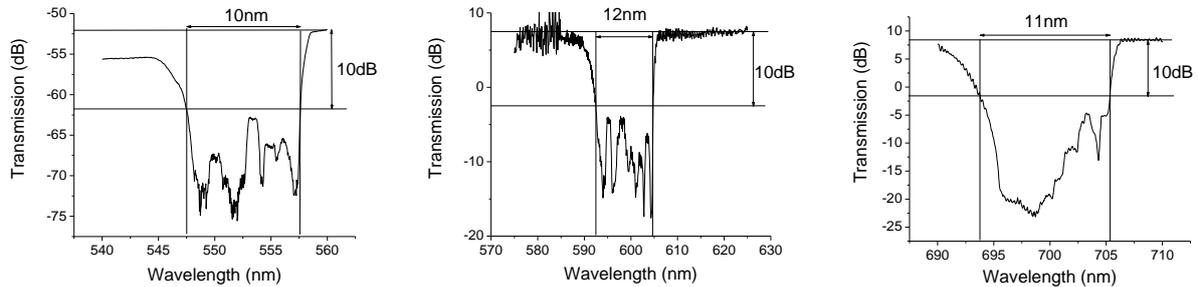


Fig. 2. First order visible step chirped fiber Bragg gratings centered at 550 nm (left), 600 nm (middle), and 700 nm (right). Horizontal and vertical lines indicate desired spectral bin for spectrometer grating array.

bandwidth) written along 3.5 cm of fiber to create one spectral bin. Inscription was accomplished by spot exposure in a CW UV interferometer operating at 244nm. The pitch varied from about 370 nm to 470 nm, making all Bragg resonances first order. The transmission curves in Fig. 2 were measured with a supercontinuum source (Koheras) and an Ando spectrometer.

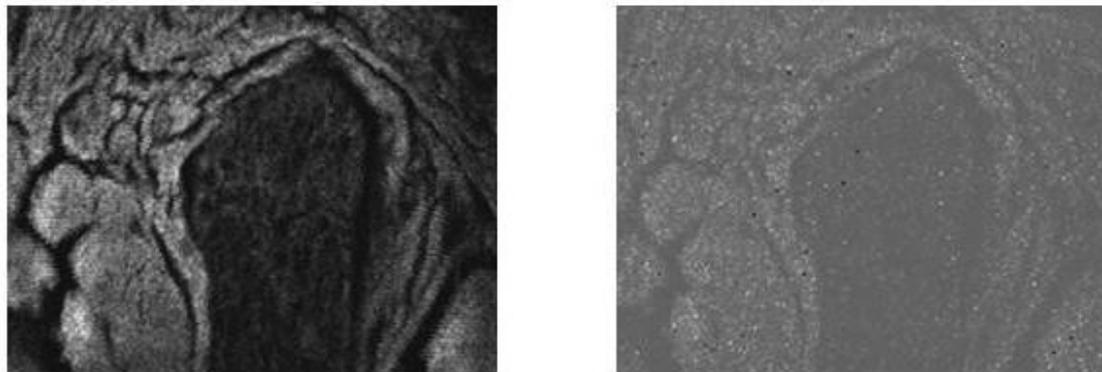


Fig. 3. Near simultaneous images (200 μm horizontal field of view) acquired on diseased rat breast at 600 nm (left) and 700 nm (right).

3. Results and conclusion

Fig. 3 shows images generated with the system and gratings described above. Brightness variations from spot to spot and from wavelength to wavelength can be used to isolate disease. Clinicians will ultimately use this technology to take optical biopsies, perform treatments, and monitor long-term results. Going forward, grating arrays can be extended to more wavelengths over a larger wavelength range to increase the sensitivity and specificity of the technique for minimizing false positives and false negatives.

4. Acknowledgements

GEC and DLF were partially supported by Award Number R44CA124036 from the National Cancer Institute. The above content is solely the responsibility of the authors and does not necessarily represent the official views of the National Cancer Institute or the National Institutes of Health

5. References

- [1] Farkas, DL. "Spectral Microscopy For Quantitative Cell And Tissue Imaging" in *Methods In Cellular Imaging*. A. Periasamy (Editor). Oxford University Press, Pp. 345-361 (2001)
- [2] Zellweger M, Goujon D, Conde R, Forrer M, van den Bergh H, Wagnieres G, "Absolute autofluorescence spectra of human healthy, metaplastic, and early cancerous bronchial tissue in vivo," *Applied Optics*, 40: 3784-3791 (2001),
- [3] Carver, G.E., W.R. Holland, "Optical Spectrum Analyzer," US Patent #6,452,681, 2002.