



HAL
open science

Optic fiber temperature sensor based on cascading fiber Bragg gratings

Jin Xu, Rongping Wang, Adnane Cabani

► **To cite this version:**

Jin Xu, Rongping Wang, Adnane Cabani. Optic fiber temperature sensor based on cascading fiber Bragg gratings. AIP Advances, 2019, 9 (1), pp.015206. 10.1063/1.5057357 . hal-02302071

HAL Id: hal-02302071

<https://normandie-univ.hal.science/hal-02302071>

Submitted on 28 May 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

RESEARCH ARTICLE | JANUARY 09 2019

Optic fiber temperature sensor based on cascading fiber Bragg gratings

Jin Xu; Rongping Wang; Adnane Cabani



AIP Advances 9, 015206 (2019)
<https://doi.org/10.1063/1.5057357>



28 May 2024 14:29:33

Biomicrofluidics
Special Topic:
Microfluidic Biosensors
Submit Today

Optic fiber temperature sensor based on cascading fiber Bragg gratings

Cite as: AIP Advances 9, 015206 (2019); doi: 10.1063/1.5057357

Submitted: 13 September 2018 • Accepted: 1 January 2019 •

Published Online: 9 January 2019



View Online



Export Citation



CrossMark

Jin Xu,^{1,a)} Rongping Wang,² and Adnane Cabani³

AFFILIATIONS

¹École de Technologie Supérieure, University of Quebec, Montreal, QC H3C 1K3, Canada

²Advanced Technology Research Institute, Ningbo University, Ningbo 315211, China

³Normandie Univ, UNIROUEN, ESIGELEC, IRSEEM, 76000 Rouen, France

^{a)}Electronic mail: xujin18@msn.com

ABSTRACT

In this paper, we demonstrate a novel method of distributed temperature sensing in optical fibers. The method is based on cascading fiber Bragg gratings (FBGs) single-ended Brillouin optical time-domain analyzer (BOTDA). This proposal applies the cascading FBGs both as a reflector and an optical filter to improve the measurement. Experimental results show that a 75-km sensing range with 3°C temperature resolution and 5 m spatial resolution are achieved.

© 2019 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>). <https://doi.org/10.1063/1.5057357>

Distributed optical fiber sensors (DOFS) have advantages of electromagnetic immunity, chemical stability and radiation interference resistance ability, which make it gain increasing popularity in many engineering applications, such as distributed strain and temperature measurement. The research of the long distance distributed optical fiber sensors is mainly focusing on the optical scattering in the optical fiber, including Rayleigh, Raman and Brillouin scattering. The Rayleigh scattering is not sensitive to temperature or strain.¹⁻⁶ It is usually used to measure the fiber loss and identify the position of the fault. The Raman scattering is only sensitive to temperature and the sensing length. It is limited by the weak scattering signal. The Brillouin scattering is sensitive to both temperature and strain,⁷ and it is stronger in signal than the Raman scattering around 10dB. Therefore, the DOFS based on Brillouin scattering is much more suitable than those based on Rayleigh and Raman scattering for realizing long distance distributed measurement of temperature or strain. According to the different working methods, the DOFS based on Brillouin scattering have four main structures. They are Brillouin optical time domain analyzer (BOTDA),⁸⁻¹¹ Brillouin optical time domain reflector (BOTDR),^{12,13} Brillouin optical frequency domain analyzer

(BOFDA)^{14,15} and Brillouin optical correlation domain analyzer (BOCDA).^{16,17}

In this paper, we propose a novel approach for distributed temperature sensing in optical fibers, which is based on cascading FBGs single-ended BOTDA. Experimental results demonstrate that our structure achieves high performance at temperature resolution and spatial resolution.

The experimental setup of the proposed cascading FBGs based on single-ended BOTDA sensor is shown in Fig. 1. In this scheme, a tunable narrow linewidth (~100 kHz) laser source (Agilent HP 81682A) is used as the light source (LS) with maximum output power of 18 dBm centered at 1549.5 nm. The pump pulse duration is 50 ns, which corresponds to a 5 m spatial resolution. The output of the light source is split into two branches using a 50:50 beam splitter (BS). One of the branches is modulated by a pulse modulator to generate pump pulses. The pulse modulator is controlled by an acousto-optic modulator (AOM) and an electrical-optic modulator (EOM) with a high extinction ratio of 50 dB. An Erbium-Doped fiber amplifier (EDFA) is used to amplify the pump pulses peak power to 20 dBm. Then, a fiber Bragg grating (FBG1) filter

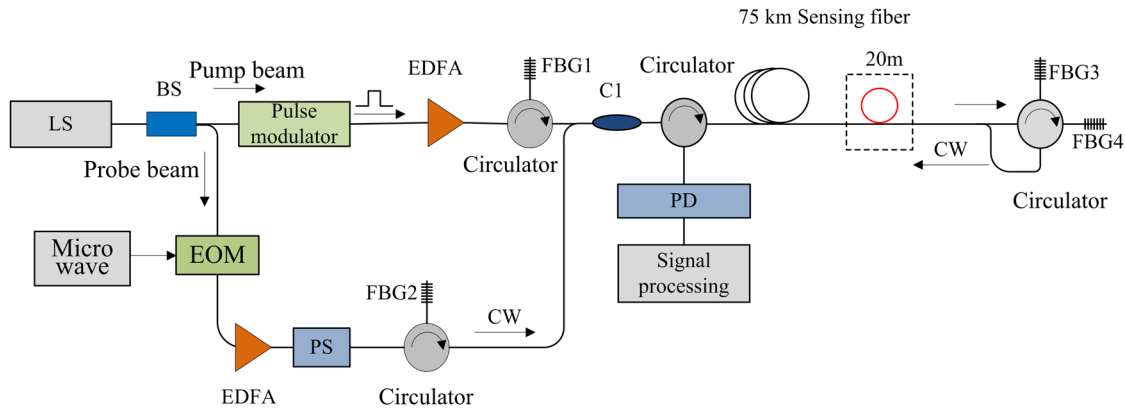


FIG. 1. Experimental setup of a 75 km DOFS based on single-ended BOTDA.

is employed to filter out the amplified spontaneous emission (ASE) noise emitted from EDFA. In the other branch, the continuous counter-propagating Stokes wave (CW) is generated by EOM, which is driven by a microwave generator to generate a two probe sidebands signal (suppressed carrier) with 11 GHz frequency shift around the center wavelength. Through the EDFA, two probe sidebands are fixed to the same power level as -20.3 dBm to refrain from nonlocal effects. The probe signal is depolarized by a polarization scrambler (PS), which is also used to avoid polarization-induced fluctuations in the Brillouin gain. The FBG2 is used to select the low-frequency probe sideband (Stokes frequency). The two optical beams are together launched into the beginning-end of the fiber via a polarization-maintaining coupler (C1) and transmitted to the 75 km sensing fiber through a circulator. The far end 20 m of sensing fiber is heated by a water bath.

In the receiver block, the signals pass through the circulator into cascading tunable narrowband FBGs filters, which are combined with the FBG3 filter (centered at 1549.555 nm, 3 dB bandwidth of ~ 0.229 nm) and the FBG4 filter (centered at 1549.500 nm, 3 dB bandwidth of ~ 0.191 nm). The measured spectra of FBG3 and FBG4 are shown in Fig. 2. We adjust light source center wavelength (1549.500nm) to make sure that the pump light's wavelength is in the FBG3's 3dB bandwidth, and the probe light's wavelength is in the FBG4's 3dB bandwidth. Therefore, the cascading tunable narrowband FBGs filter the reflection of the pump light and reflect the probe light. These two cascading FBGs have a narrow bandwidth to filter the reflection of the pump light efficiently, and thus improve the accuracy of measurement. Finally, the probe light after the SBS along the sensing fiber is received by the photoelectric detector (PD) with 2 GHz sampling and processed by a fast signal processing system to obtain the distribution of Brillouin frequency shift (BFS) with the temperature information along the fiber.

Since there is a linear relationship between the BFS and temperature or strain, the temperature and strain information along the optical fiber can be achieved to realize the

long range and distributed measurement.¹⁸ The interaction between Stokes light and pump light follows the two steady-state coupled intensity SBS equations:

$$\frac{dI_s}{dz} = -g_B I_p I_s + \alpha I_s \tag{1}$$

$$\frac{dI_p}{dz} = -g_B I_p I_s - \alpha I_p \tag{2}$$

Where I_s is the Stokes light intensity, I_p is the pump light intensity, α is the fiber loss coefficient, g_B is the Brillouin gain coefficient which is related to the optical fiber material and the BFS:

$$g_B(f_m, z) = \frac{\gamma(z)g_{Bp}}{1 + \left[\frac{f_m - \nu_B(z)}{\Delta\nu_B/2} \right]^2} \tag{3}$$

Where g_{Bp} is the peak value, $\nu_B(z)$ is the local BFS, f_m is the frequency offset, $\Delta\nu_B$ is the full-width at half-maximum of

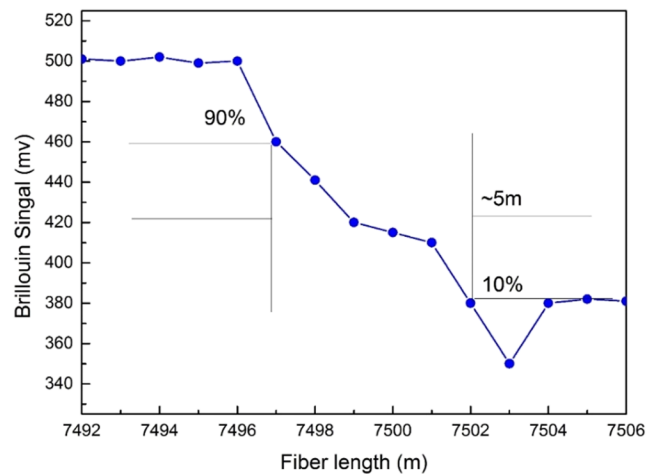


FIG. 2. The BFS versus distance near the end of the sensing fiber.

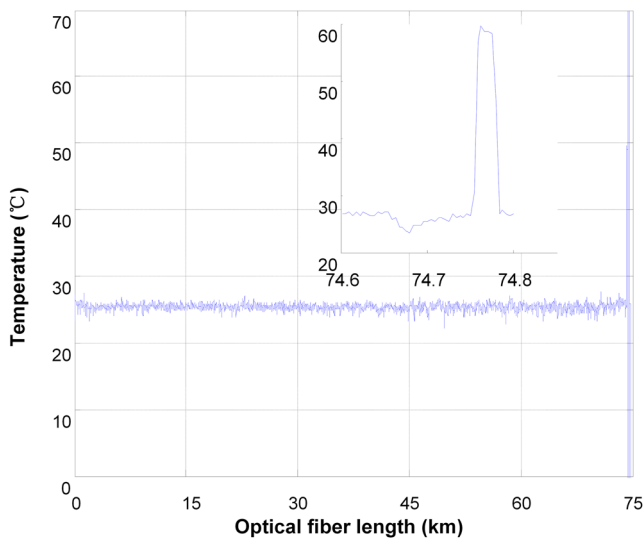


FIG. 3. Temperature curve of the 75 km sensing fiber.

the BGS, $\gamma(z)$ is the polarization factor which depends on the polarization state of two beams.¹⁹

Spatial resolution is defined as the 10%-90% of rise/fall transition region edge on the Brillouin photon counts. As shown in the Fig. 2, the experimental spatial resolution is 5 m under 75 km sensing length, which is in consonance with the 50 ns pulse width that we used.

The temperature dependence of fiber length is shown in Fig. 3. The curve is resulted from three time the standard deviation of the signal fluctuations processing. In the calculation of temperature fluctuations, we use temperature sensor DS18B20 to measure at room temperature of 24°C as the reference. The temperature fluctuations do not exceed 3°C (24°C \pm 3°C). The results show that the proposed cascading FBGs single-ended BOTDA sensor can be applied to temperature-distributed measurements well.

In conclusion, we have proposed and experimentally demonstrated a new method of distributed temperature sensing based on cascading FBGs single-ended BOTDA. Compared with the traditional BOTDA, the fabrication of fiber sensor is significantly simplified. Furthermore, the experimental results of this investigation demonstrate that the proposed scheme achieves 5m spatial resolution and 3°C temperature resolution over 75 km sensing fiber. The results prove that the proposed configuration is promising for a wide range of temperature sensing with excellent accuracy. The sensing length can be further extended if the probe pulse power increase to the allowable power without arousing nonlinear effects in fiber and the spatial resolution can be further improved by using narrower probe pulse.

This work was supported by National Natural Science Foundation of China (NSFC) (61775109).

REFERENCES

- 1T. Horiguchi and M. Tateda, "BOTDA-nondestructive measurement of single-mode optical fiber attenuation characteristics using Brillouin interaction: Theory," *Journal of Lightwave Technology* **7**(8), 1170–1176 (1989).
- 2D. Garus, K. Krebber, F. Schliep, and T. Gogolla, "Distributed sensing technique based on Brillouin optical-fiber frequency-domain analysis," *Opt. Lett.* **21**, 1402–1404 (1996).
- 3K. Hotate and T. Hasegawa, "Measurement of Brillouin gain spectrum distribution along an optical fiber using a correlation-based technique—Proposal, experiment and simulation," *IEICE Trans. Electron.* **E83-C**, 405–412 (2000).
- 4T. Kurashima, T. Horiguchi, H. Izumita, S. Furukawa, and Y. Koyama, "Brillouin optical-fiber time domain reflectometry," *IEICE Trans. Commun.* **E76-B**, 382–390 (1993).
- 5Y. Mizuno, W. Zou, Z. He, and K. Hotate, "Proposal of Brillouin optical correlation-domain reflectometry (BOCDR)," *Opt. Express* **16**, 12148–12153 (2008).
- 6Y. Mizuno, N. Hayashi, H. Fukuda, K. Y. Song, and K. Nakamura, "Ultrahigh-speed distributed Brillouin reflectometry," *Light Sci. Appl.* **5**, e16184 (2016).
- 7A. Denisov, M. A. Soto, and L. Thevenaz, "Going beyond 1000000 resolved points in a Brillouin distributed fiber sensor: Theoretical analysis and experimental demonstration," *Light Sci. Appl.* **5**(5), e16074 (2016).
- 8K. Y. Song and H. J. Yoon, "Observation of narrowband intrinsic spectra of Brillouin dynamic gratings," *Opt. Lett.* **35**, 2958–2960 (2010).
- 9T. Sperber, A. Eyal, M. Tur, and L. Thevenaz, "High spatial resolution distributed sensing in optical fibers by Brillouin gain-profile tracing," *Opt. Express* **18**, 8671–8679 (2010).
- 10Y. Dong, H. Zhang, L. Chen, and X. Bao, "2 cm spatial-resolution and 2 km range Brillouin optical fiber sensor using a transient differential pulse pair," *Appl. Opt.* **51**, 1229–1235 (2012).
- 11Y. Mao, N. Guo, K. L. Yu, H. Y. Tam, and C. Lu, "1-cm-spatial-resolution Brillouin optical time-domain analysis based on bright pulse Brillouin gain and complementary code," *IEEE Photonics J.* **4**, 2243–2248 (2012).
- 12M. A. Soto, G. Bolognini, and F. D. Pasquale, "Enhanced simultaneous distributed strain and temperature fiber sensor employing spontaneous Brillouin scattering and optical pulse coding," *IEEE Photonics Technol. Lett.* **21**, 450–452 (2009).
- 13F. Wang, W. Zhan, X. Zhang, and Y. Lu, "Improvement of spatial resolution for BOTDR by iterative subdivision method," *J. Lightwave Technol.* **31**, 3663–3667 (2013).
- 14A. Minardo, R. Bernini, and L. Zeni, "Distributed temperature sensing in polymer optical fiber by BOFDA," *IEEE Photonics Technol. Lett.* **26**, 387–390 (2014).
- 15A. Wosniok, Y. Mizuno, K. Krebber, and K. Nakamura, "L-BOFDA: A new sensor technique for distributed Brillouin sensing," *Proc. SPIE* **8794**, 879431 (2013).
- 16J. H. Jeong, K. H. Chung, S. B. Lee, K. Y. Song, J.-M. Jeong, and K. Lee, "Linearly configured BOFDA system using a differential measurement scheme," *Opt. Express* **22**, 1467–1473 (2014).
- 17R. K. Yamashita, M. Kishi, and K. Hotate, "Theoretical evaluation of Brillouin dynamic grating length localized by optical correlation domain technique through reflection spectrum simulation," *Appl. Phys. Express* **10**, 042501 (2017).
- 18M. Alem, M. A. Soto, M. Tur, and J. Thévenaz, "Analytical expression and experimental validation of the Brillouin gain spectral broadening at any sensing spatial resolution," *Proc. SPIE* **10323**, 103239J (2017).
- 19D. Zhou, Y. Dong, B. Wang, T. Jiang, D. Ba, P. Xu, H. Zhang, Z. Lu, and H. Li, "Slope-assisted BOTDA based on vector SBS and frequency-agile technique for wide-strain-range dynamic measurements," *Opt. Express* **25**, 1889–1902 (2017).