

Tilted Fiber Bragg Gratings: Principle and Sensing Applications

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Abstract: Tilted Fiber Bragg Gratings (TFBGs) are a type of fiber grating structure that has been widely studied and applied in the field of photonic sensors. This review article aims to provide a comprehensive overview of the principle and sensing applications of TFBGs. The article starts with a brief introduction to the basic principle of TFBGs, followed by a detailed discussion of their sensing mechanisms and applications in various fields, including temperature, strain, and refractive index sensing. The article also discusses the advantages and disadvantages of TFBGs compared to other types of fiber gratings. Finally, the article concludes with a summary of the current research status and future prospects of TFBGs.

Keywords: Tilted Fiber Bragg Gratings (TFBGs); Fiber Gratings; Photonic Sensors; Temperature Sensing; Strain Sensing; Refractive Index Sensing

1. Introduction

Fiber Bragg Gratings (FBGs) are a type of fiber grating structure that has been widely studied and applied in the field of photonic sensors. FBGs are formed by a periodic modulation of the refractive index in the core of an optical fiber. This periodic structure causes light to be reflected back and forth within the fiber, creating a Bragg resonance. The Bragg resonance wavelength of an FBG is determined by the grating period and the refractive index of the core. FBGs have been widely used in various sensing applications, including temperature, strain, and refractive index sensing. In this review article, we focus on the principle and sensing applications of Tilted Fiber Bragg Gratings (TFBGs). TFBGs are a type of fiber grating structure that is formed by tilting the grating planes relative to the fiber axis. This tilting causes the Bragg resonance wavelength to shift in response to changes in the refractive index of the core. TFBGs have been widely studied and applied in various sensing applications, including temperature, strain, and refractive index sensing. In this review article, we provide a comprehensive overview of the principle and sensing applications of TFBGs.

TFBGs are a type of fiber grating structure that is formed by tilting the grating planes relative to the fiber axis. This tilting causes the Bragg resonance wavelength to shift in response to changes in the refractive index of the core. TFBGs have been widely studied and applied in various sensing applications, including temperature, strain, and refractive index sensing. In this review article, we provide a comprehensive overview of the principle and sensing applications of TFBGs. The article starts with a brief introduction to the basic principle of TFBGs, followed by a detailed discussion of their sensing mechanisms and applications in various fields, including temperature, strain, and refractive index sensing. The article also discusses the advantages and disadvantages of TFBGs compared to other types of fiber gratings. Finally, the article concludes with a summary of the current research status and future prospects of TFBGs.

Diagram illustrating the sequence of boxes (1 to 16) used in the experiment. The boxes are arranged in two rows of eight, connected by lines, representing the sequence of stimuli presented to the subjects.

1. 在 2018 年 12 月 31 日，公司应收账款账面余额为 1,000 万元，坏账准备余额为 100 万元。2019 年 1 月 1 日，公司应收账款账面余额为 1,200 万元，坏账准备余额为 120 万元。2019 年 2 月 1 日，公司应收账款账面余额为 1,100 万元，坏账准备余额为 110 万元。2019 年 3 月 1 日，公司应收账款账面余额为 1,300 万元，坏账准备余额为 130 万元。2019 年 4 月 1 日，公司应收账款账面余额为 1,400 万元，坏账准备余额为 140 万元。2019 年 5 月 1 日，公司应收账款账面余额为 1,500 万元，坏账准备余额为 150 万元。2019 年 6 月 1 日，公司应收账款账面余额为 1,600 万元，坏账准备余额为 160 万元。2019 年 7 月 1 日，公司应收账款账面余额为 1,700 万元，坏账准备余额为 170 万元。2019 年 8 月 1 日，公司应收账款账面余额为 1,800 万元，坏账准备余额为 180 万元。2019 年 9 月 1 日，公司应收账款账面余额为 1,900 万元，坏账准备余额为 190 万元。2019 年 10 月 1 日，公司应收账款账面余额为 2,000 万元，坏账准备余额为 200 万元。2019 年 11 月 1 日，公司应收账款账面余额为 2,100 万元，坏账准备余额为 210 万元。2019 年 12 月 1 日，公司应收账款账面余额为 2,200 万元，坏账准备余额为 220 万元。2019 年 12 月 31 日，公司应收账款账面余额为 2,300 万元，坏账准备余额为 230 万元。

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本文主要研究了基于深度学习的图像识别方法，并探讨了其在实际应用中的性能表现。参考文献 *et al.* 的研究成果，本文在以下几个方面进行了详细分析：

4. Theoretical progress of TFBG research

在理论层面，TFBG 的研究取得了显著进展。首先，在模型结构方面，研究者提出了多种新的网络架构，如残差网络（ResNet）、卷积神经网络（CNN）等，这些模型在图像识别任务中表现出色。其次，在训练方法方面，研究者探索了不同的优化算法，如 Adam、RMSProp 等，以提高模型的收敛速度和性能。

此外，研究者还关注了模型的鲁棒性和泛化能力。通过引入数据增强、正则化等技术，模型在应对复杂场景和噪声数据时表现出更强的稳定性。在应用层面，TFBG 被广泛应用于人脸识别、物体检测、图像分类等领域。随着硬件设备的不断进步和算法的持续优化，TFBG 在实际应用中的性能得到了显著提升。未来，研究者将继续探索更高效的模型结构和训练方法，以进一步提升 TFBG 的性能和应用范围。

综上所述，TFBG 的研究在理论和应用两个方面都取得了重要进展。未来，随着技术的不断进步，TFBG 将在更多领域发挥重要作用，为人工智能的发展做出更大贡献。

在应用层面，TFBG 的研究取得了显著进展。首先，在模型结构方面，研究者提出了多种新的网络架构，如残差网络（ResNet）、卷积神经网络（CNN）等，这些模型在图像识别任务中表现出色。其次，在训练方法方面，研究者探索了不同的优化算法，如 Adam、RMSProp 等，以提高模型的收敛速度和性能。

5. Sensing applications of TFBG research

在传感应用方面，TFBG 的研究取得了重要突破。研究者利用 TFBG 的高精度测量能力，开发了一系列新型传感器，用于环境监测、工业检测等领域。这些传感器具有体积小、精度高、响应快等优点，为各种应用场景提供了可靠的解决方案。

此外，研究者还探索了 TFBG 在通信领域的应用。通过利用 TFBG 的光学特性，研究者设计了一系列新型光通信器件，如光滤波器、光调制器等，这些器件在高速光通信系统中具有重要作用。未来，随着 TFBG 技术的不断进步，其在传感和通信领域的应用将更加广泛。

综上所述，TFBG 的研究在传感应用方面取得了重要进展。未来，随着技术的不断进步，TFBG 将在更多领域发挥重要作用，为人工智能的发展做出更大贡献。

1. 在 1990 年，中国开始实施改革开放政策，这一政策极大地促进了中国的经济发展和国际交流。

2. 随着改革开放的深入，中国在国际舞台上的影响力日益增强，成为全球瞩目的焦点。

3. 在这一过程中，中国不仅实现了经济的快速增长，还显著提高了人民的生活水平。

4. 然而，在取得巨大成就的同时，中国也面临着一些挑战，如环境污染和区域发展不平衡等问题。

5. 为了应对这些挑战，中国政府采取了一系列措施，包括加强环境保护和推动区域协调发展。

6. 此外，中国还积极参与国际事务，推动构建人类命运共同体，为世界和平与发展作出了重要贡献。

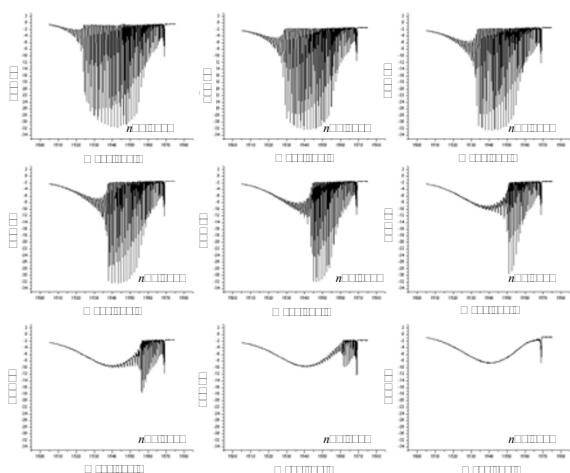
7. 总的来说，中国的改革开放政策取得了举世瞩目的成就，为中国的现代化进程奠定了坚实基础。

8. 未来，中国将继续深化改革，扩大开放，为实现中华民族伟大复兴的中国梦而努力奋斗。

9. 这一过程不仅是中国自身发展的需要，也是世界和平与发展的必然要求。

10. 通过持续的努力，中国必将迎来更加美好的明天，为世界带来更大的贡献。

[illegible]

[illegible][illegible]

1. 在 2019 年 12 月 31 日，公司 2019 年度财务报告已经编制完成，并经公司负责人签字确认后，按照《企业会计准则》的规定，编制了 2019 年度财务报告。

Ambient refractive index	Transmission power (dBm)
1.370	0.610
1.380	0.605
1.390	0.585
1.400	0.565
1.410	0.535
1.420	0.510
1.430	0.490
1.440	0.480
1.450	0.470

[illegible]

$$P = \boxed{}\boxed{}\boxed{}\boxed{}\boxed{}n^{\boxed{}} - \boxed{}\boxed{}\boxed{}\boxed{}\boxed{}\boxed{}\boxed{}n^{\boxed{}} + \boxed{}\boxed{}\boxed{}\boxed{}\boxed{}n - \boxed{}\boxed{}\boxed{}\boxed{}\boxed{}\boxed{}\quad (\square)$$

[illegible]

6.1.2 HF-etched TFBG refractometer with enhanced sensitivity [59]

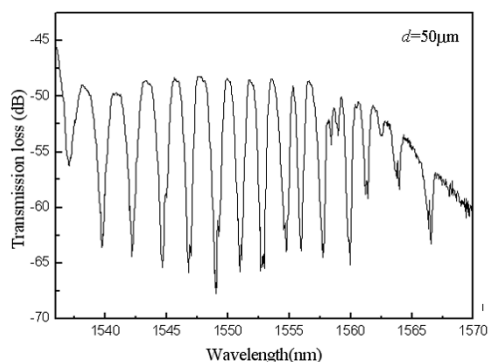
[illegible]

Figure 10 is a line graph with two y-axes. The x-axis represents Temperature (°C) from 30 to 80. The left y-axis represents Wavelength (nm) from 1558 to 1568. The right y-axis represents Difference between core and cladding mode (nm) from 8.0 to 10.0. Three data series are plotted: Core mode (top line, ~1566.5 nm), Unetched BFBG (middle line, ~1561.5 nm), and Cladding mode (bottom line, ~1557.5 nm). All three series show a slight increase with temperature. Arrows indicate the mapping of the lines to the respective y-axes.

Temperature (°C)	Core mode Wavelength (nm)	Unetched BFBG Wavelength (nm)	Cladding mode Wavelength (nm)
30	1566.5	1561.5	1557.5
40	1566.5	1561.5	1557.5
50	1566.5	1561.5	1557.5
60	1566.5	1561.5	1557.5
70	1566.5	1561.5	1557.5
80	1566.5	1561.5	1557.5

Figure 10 is a line graph showing the temperature dependence of the Bragg wavelength and the difference between the core and cladding modes for an etched BFBG. The x-axis represents Temperature in degrees Celsius, ranging from 30 to 80. The left y-axis represents Wavelength in nanometers (nm), ranging from 1558 to 1568. The right y-axis represents the Difference between core and cladding mode in nanometers (nm), ranging from 8.0 to 10.0. Three data series are plotted: Core mode (top line, black squares), Etched BFBG (middle line, black squares), and Cladding mode (bottom line, black squares). All three series show a slight increase with temperature. The Core mode and Cladding mode lines are nearly horizontal, while the Etched BFBG line shows a more pronounced upward slope.

Temperature (°C)	Core mode (nm)	Etched BFBG (nm)	Cladding mode (nm)
30	1566.5	1558.5	1557.5
40	1566.6	1558.8	1557.6
50	1566.7	1559.1	1557.7
60	1566.8	1559.4	1557.8
70	1566.9	1559.7	1557.9
80	1567.0	1560.0	1558.0

 $(\square)$ [illegible]

Figure 10 shows the relative wavelength shift of the 3rd, 6th and 10th order cladding mode resonance peaks as a function of the ambient refractive index. The relative wavelength shift is defined as $\Delta\lambda/\lambda$, where λ is the wavelength of the resonance peak. The relative wavelength shift increases with the ambient refractive index, and the 10th order cladding mode resonance peak shows the highest sensitivity.

Figure 11 shows the relative wavelength shift of the 3rd, 6th and 10th order cladding mode resonance peaks as a function of the ambient refractive index. The relative wavelength shift is defined as $\Delta\lambda/\lambda$, where λ is the wavelength of the resonance peak. The relative wavelength shift increases with the ambient refractive index, and the 10th order cladding mode resonance peak shows the highest sensitivity.

Figure 12 shows the relative wavelength shift of the 3rd, 6th and 10th order cladding mode resonance peaks as a function of the ambient refractive index. The relative wavelength shift is defined as $\Delta\lambda/\lambda$, where λ is the wavelength of the resonance peak. The relative wavelength shift increases with the ambient refractive index, and the 10th order cladding mode resonance peak shows the highest sensitivity.

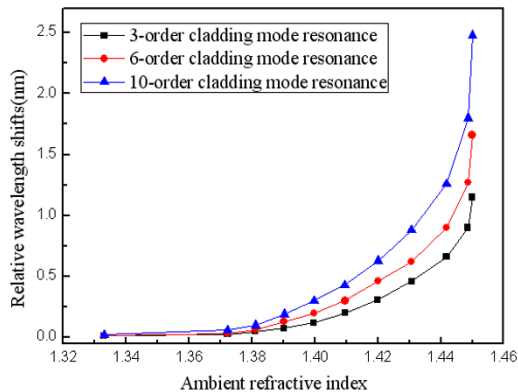


Figure 13 shows the relative wavelength shift of the 3rd, 6th and 10th order cladding mode resonance peaks as a function of the ambient refractive index. The relative wavelength shift is defined as $\Delta\lambda/\lambda$, where λ is the wavelength of the resonance peak. The relative wavelength shift increases with the ambient refractive index, and the 10th order cladding mode resonance peak shows the highest sensitivity.

Figure 14 shows the relative wavelength shift of the 3rd, 6th and 10th order cladding mode resonance peaks as a function of the ambient refractive index. The relative wavelength shift is defined as $\Delta\lambda/\lambda$, where λ is the wavelength of the resonance peak. The relative wavelength shift increases with the ambient refractive index, and the 10th order cladding mode resonance peak shows the highest sensitivity.

6.1.3 TFBG sensor for relative humidity measurement [60]

The TFBG sensor for relative humidity measurement is based on the principle of the TFBG. The TFBG is a periodic structure of refractive index modulation in a fiber. The refractive index modulation is caused by the interference of two counter-propagating light beams. The refractive index modulation is periodic along the length of the fiber. The refractive index modulation is caused by the interference of two counter-propagating light beams. The refractive index modulation is periodic along the length of the fiber.

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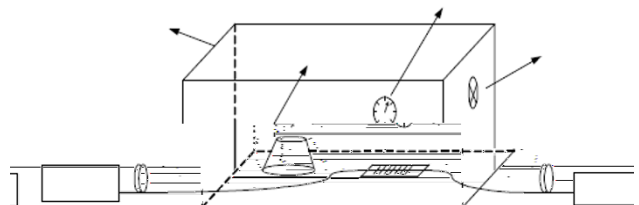


Figure 15. Schematic diagram of the TFBG sensor for relative humidity measurement.

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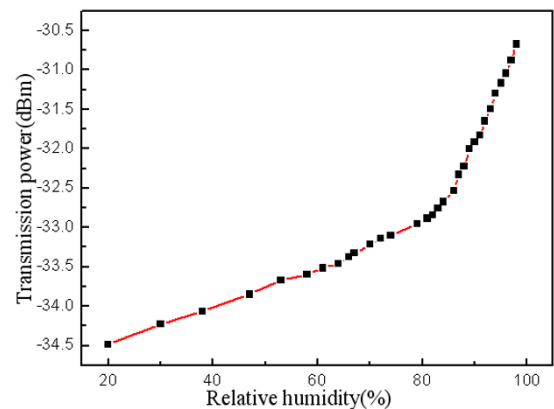


Figure 6.1.3

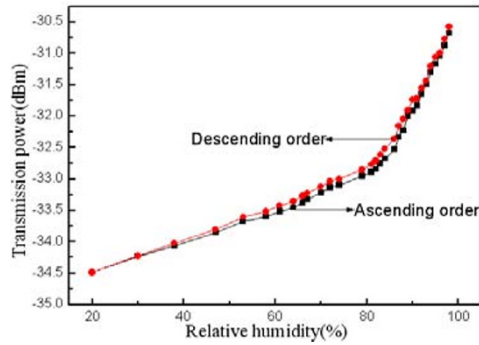


Figure 6.1.3 shows the transmission power of the TFBG sensor as a function of relative humidity.

The transmission power of the TFBG sensor is measured in dBm, and the relative humidity is measured in %.

6.1.4 Bending and directional characteristics of TFBG [61]

The TFBG sensor is a type of fiber optic sensor that is used to measure bending and directional characteristics. The sensor is made of a fiber optic cable that has a Bragg grating structure. The Bragg grating structure is a series of periodic refractive index variations that are formed in the core of the fiber. When the fiber is bent, the Bragg grating structure is deformed, which causes a change in the transmission power of the sensor. This change in transmission power can be used to measure the bending of the fiber. The directional characteristics of the TFBG sensor are determined by the orientation of the Bragg grating structure. The sensor is designed to be sensitive to bending in a specific direction, which allows it to be used to measure the direction of bending.

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$$N_{\text{eff}}(x) = n_{\text{eff}}(x) + \frac{1}{k_{\text{eff}} R} + \frac{1}{R} \left(n_{\text{eff}} - \frac{1}{k_{\text{eff}} R} \right) x \quad (6.1.4)$$

where $k_{\text{eff}} = \pi/\lambda$ is the effective wave number, R is the radius of curvature, and $n_{\text{eff}}(x)$ is the effective refractive index of the fiber. The effective refractive index of the fiber is a function of the position x along the fiber. The effective refractive index of the fiber is determined by the refractive index of the core and the cladding of the fiber. The effective refractive index of the fiber is also affected by the bending of the fiber. The effective refractive index of the fiber is a function of the position x along the fiber. The effective refractive index of the fiber is determined by the refractive index of the core and the cladding of the fiber. The effective refractive index of the fiber is also affected by the bending of the fiber.

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$$C = \frac{d}{d^2 + L^2} \quad (6.1.5)$$

where d is the distance between the two ends of the fiber, and L is the length of the fiber. The distance d is a function of the bending of the fiber. The length L is a function of the directional characteristics of the fiber. The distance d is a function of the bending of the fiber. The length L is a function of the directional characteristics of the fiber.

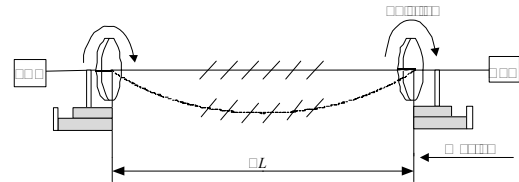


Figure 6.1.4 shows the bending and directional characteristics of the TFBG sensor. The diagram illustrates the bending of the fiber and the deformation of the Bragg grating structure.

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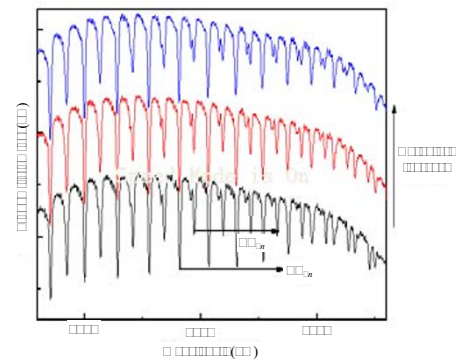


Figure 6.1.5 shows the transmission power of the TFBG sensor as a function of the bending angle. The graph illustrates the bending of the fiber and the deformation of the Bragg grating structure.

[illegible]

Figure 6.1.4 shows the transmission loss of the LP modes in the TFBG sensor. The transmission loss is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

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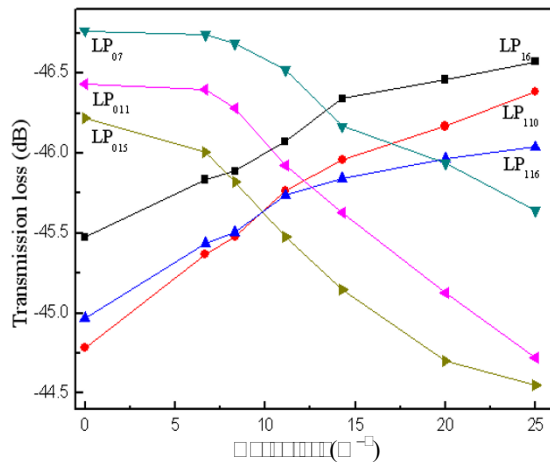


Figure 6.1.4 Transmission loss of the LP modes in the TFBG sensor.

Figure 6.1.5 shows the transmission loss of the LP modes in the TFBG sensor. The transmission loss is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

Figure 6.1.6 shows the transmission loss of the LP modes in the TFBG sensor. The transmission loss is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

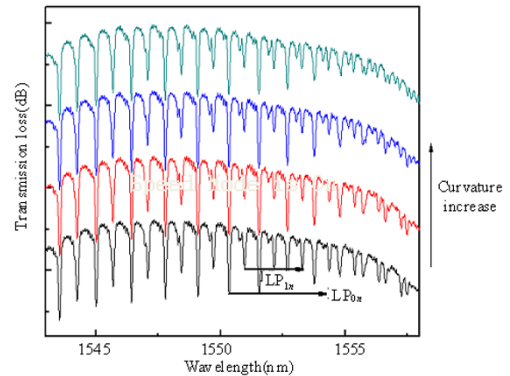


Figure 6.1.5 Transmission loss of the LP modes in the TFBG sensor.

Figure 6.1.7 shows the transmission loss of the LP modes in the TFBG sensor. The transmission loss is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

6.1.5 TFBG sensor for liquid-level measurement [66]

The TFBG sensor is used for liquid-level measurement. The sensor is made of a TFBG structure. The transmission loss of the LP modes is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

The TFBG sensor is used for liquid-level measurement. The sensor is made of a TFBG structure. The transmission loss of the LP modes is measured in dB and the wavelength is in nm. The LP modes are labeled as LP₀₇, LP₀₁₁, LP₀₁₅, LP₁₆, LP₁₁₀, and LP₁₁₆. The transmission loss increases with the wavelength for all modes. The LP₀₇ mode has the highest transmission loss, while the LP₁₁₆ mode has the lowest transmission loss.

The experimental setup for liquid level measurement is shown in Figure 1. A BBS (Beam Splitter) is used to split the light signal into two paths. One path is connected to the OSA (Optical Spectrum Analyzer) and the other path is connected to the PD (Photodetector). The BBS is connected to the OSA and PD via optical fibers.

The experimental setup for liquid level measurement is shown in Figure 1. A BBS (Beam Splitter) is used to split the light signal into two paths. One path is connected to the OSA (Optical Spectrum Analyzer) and the other path is connected to the PD (Photodetector). The BBS is connected to the OSA and PD via optical fibers. The liquid level is measured by the change in the transmission power of the BFBG (Bragg Fiber Bragg Grating) when it is immersed in the liquid. The transmission power is measured by the OSA and PD.

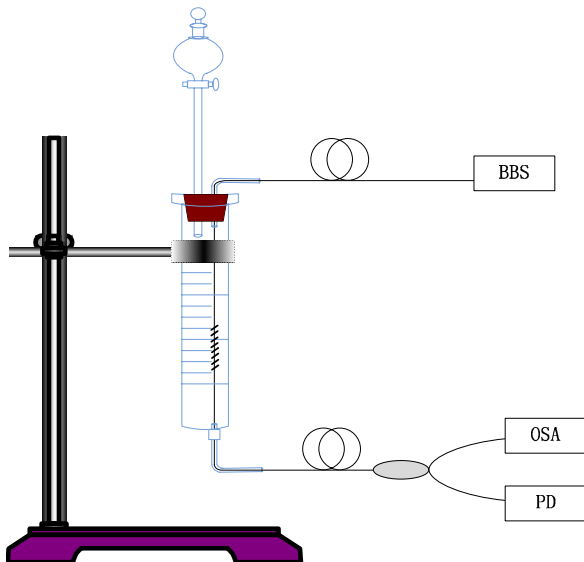


Figure 1. Schematic diagram of the experimental setup for liquid level measurement.

The experimental setup for liquid level measurement is shown in Figure 1. A BBS (Beam Splitter) is used to split the light signal into two paths. One path is connected to the OSA (Optical Spectrum Analyzer) and the other path is connected to the PD (Photodetector). The BBS is connected to the OSA and PD via optical fibers. The liquid level is measured by the change in the transmission power of the BFBG (Bragg Fiber Bragg Grating) when it is immersed in the liquid. The transmission power is measured by the OSA and PD. The liquid level is measured by the change in the transmission power of the BFBG when it is immersed in the liquid. The transmission power is measured by the OSA and PD.

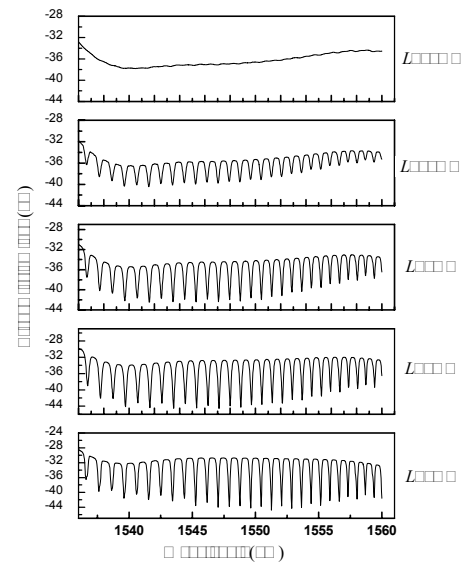


Figure 2. Transmission power (dBm) versus the length of the BFBG immersed in the liquid (cm) for different liquid levels.

The experimental setup for liquid level measurement is shown in Figure 1. A BBS (Beam Splitter) is used to split the light signal into two paths. One path is connected to the OSA (Optical Spectrum Analyzer) and the other path is connected to the PD (Photodetector). The BBS is connected to the OSA and PD via optical fibers. The liquid level is measured by the change in the transmission power of the BFBG (Bragg Fiber Bragg Grating) when it is immersed in the liquid. The transmission power is measured by the OSA and PD. The liquid level is measured by the change in the transmission power of the BFBG when it is immersed in the liquid. The transmission power is measured by the OSA and PD.

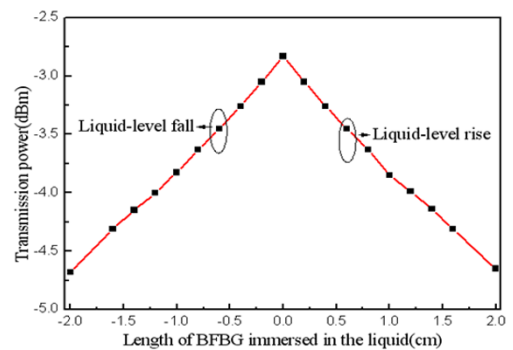


Figure 3. Transmission power (dBm) versus the length of the BFBG immersed in the liquid (cm) for different liquid levels.

The experimental setup for liquid level measurement is shown in Figure 1. A BBS (Beam Splitter) is used to split the light signal into two paths. One path is connected to the OSA (Optical Spectrum Analyzer) and the other path is connected to the PD (Photodetector). The BBS is connected to the OSA and PD via optical fibers. The liquid level is measured by the change in the transmission power of the BFBG (Bragg Fiber Bragg Grating) when it is immersed in the liquid. The transmission power is measured by the OSA and PD. The liquid level is measured by the change in the transmission power of the BFBG when it is immersed in the liquid. The transmission power is measured by the OSA and PD.

$$y = -\text{Transmission power} - \text{Length of BFBG immersed in the liquid} \quad (1)$$

$$y = -\text{Transmission power} + \text{Length of BFBG immersed in the liquid} \quad (2)$$

温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

因此，在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

6.2 Temperature cross sensitivity of TFBG sensors

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

6.2.1 TFBG sensor for simultaneous measurement of strain and temperature [67]

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

$$\begin{aligned} \frac{\Delta\lambda_B}{\lambda_B} &= \left(\frac{\partial n_{\text{eff}}}{\partial T} + \frac{\partial \Lambda_g}{\partial T} \right) \Delta T + \left(\frac{\partial \Lambda_g}{\partial \varepsilon} + \frac{\partial n_{\text{eff}}}{\partial \varepsilon} \right) \Delta \varepsilon \quad (6.1) \\ &= K_{\text{TFBG},T} \Delta T + K_{\text{TFBG},\varepsilon} \Delta \varepsilon \\ \frac{\Delta\lambda^i}{\lambda^i} &= \left\{ \frac{\partial \alpha(n_{\text{eff}}^i + n_{\text{eff}}^i)}{\partial T} + \frac{\partial \Lambda_g}{\partial T} \right\} \Delta T \\ &\quad + \left\{ \frac{\partial \Lambda_g}{\partial \varepsilon} + \frac{\partial \alpha(n_{\text{eff}}^i + n_{\text{eff}}^i)}{\partial \varepsilon} \right\} \Delta \varepsilon \quad (6.2) \\ &= K_{\text{TFBG},T} \Delta T + K_{\text{TFBG},\varepsilon} \Delta \varepsilon \end{aligned}$$

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

$$\begin{pmatrix} \Delta\lambda_{\text{TFBG}} \\ \Delta\lambda_{\text{TFBG}} \end{pmatrix} = \begin{pmatrix} K_{\text{TFBG},T} & K_{\text{TFBG},\varepsilon} \\ K_{\text{TFBG},T} & K_{\text{TFBG},\varepsilon} \end{pmatrix} \begin{pmatrix} \Delta T \\ \Delta \varepsilon \end{pmatrix} \quad (6.3)$$

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

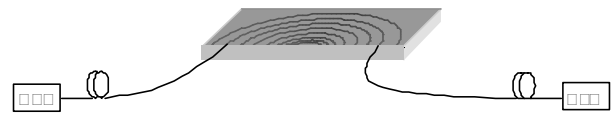
$$\begin{pmatrix} \Delta T \\ \Delta \varepsilon \end{pmatrix} = \begin{pmatrix} K_{\text{TFBG},T} & K_{\text{TFBG},\varepsilon} \\ K_{\text{TFBG},T} & K_{\text{TFBG},\varepsilon} \end{pmatrix}^{-1} \begin{pmatrix} \Delta\lambda_{\text{TFBG}} \\ \Delta\lambda_{\text{TFBG}} \end{pmatrix} \quad (6.4)$$

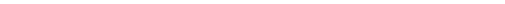
在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

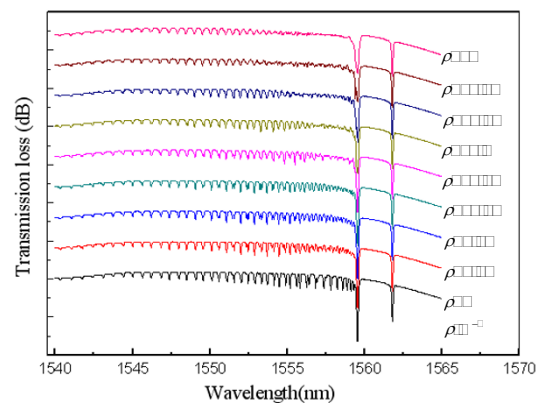
在本文中，我们假设温度变化引起的折射率变化与应变变化引起的折射率变化相比，可以忽略不计。

1. 在 2019 年 12 月 31 日，本公司应收账款的账龄主要集中在 1 年以内，占比为 98.53%，账龄结构较为合理，不存在重大信用风险。







[illegible]

The diagram illustrates the decomposition of a 2D grid of 16 squares into two rows of eight squares each. The top row is labeled '16 squares' and the bottom row is labeled '8 squares'.

[illegible][illegible]

[illegible]

[illegible]

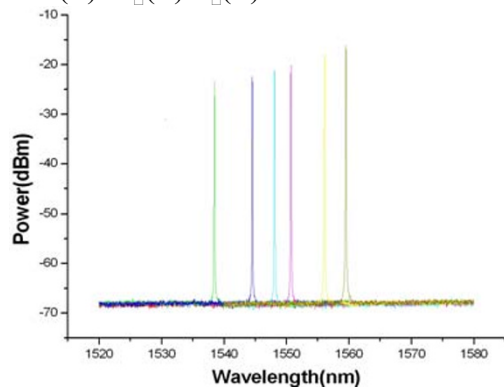


the following equation:

where I_{ref} is the reference intensity, I_{FBG} is the intensity of the FBG signal, $H(\lambda)$ is the transfer function of the FBG, and λ is the wavelength. The transfer function $H(\lambda)$ is defined as the ratio of the output intensity to the input intensity, and it is a function of the wavelength λ .

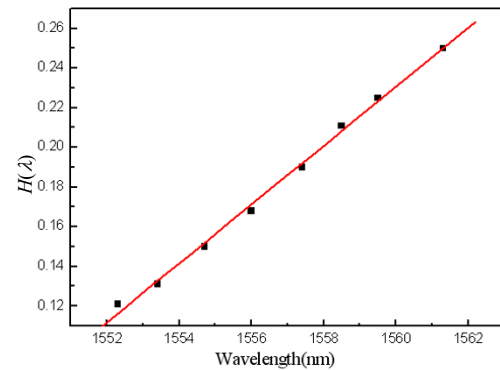
The transfer function $H(\lambda)$ is a function of the wavelength λ , and it is defined as the ratio of the output intensity to the input intensity. The transfer function $H(\lambda)$ is a function of the wavelength λ , and it is defined as the ratio of the output intensity to the input intensity.

$$H(\lambda) = \frac{I_{\text{FBG}}(\lambda)}{I_{\text{ref}}(\lambda)} = \frac{I_{\text{FBG}}(\lambda)}{I_{\text{ref}}(\lambda)}$$



The graph shows the power spectrum of the FBG signal, with the power (dBm) plotted against the wavelength (nm). The peaks represent the different wavelengths of the FBG signal.

The following equation:



The graph shows the transfer function $H(\lambda)$ as a function of the wavelength λ . The data points show a linear relationship between $H(\lambda)$ and λ .

The following equation:

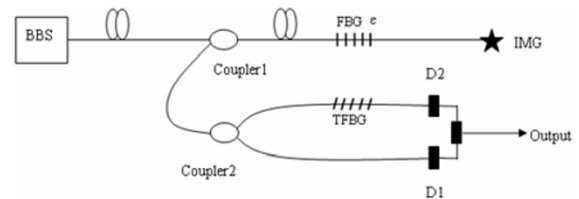
The transfer function $H(\lambda)$ is a function of the wavelength λ , and it is defined as the ratio of the output intensity to the input intensity. The transfer function $H(\lambda)$ is a function of the wavelength λ , and it is defined as the ratio of the output intensity to the input intensity.

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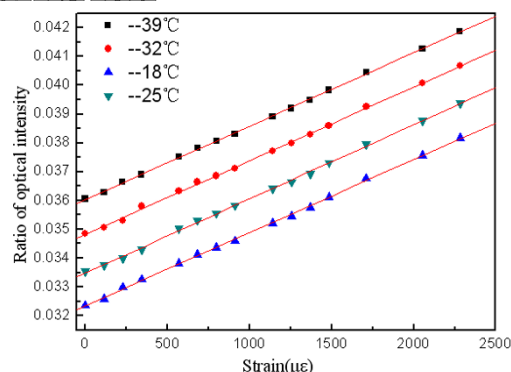
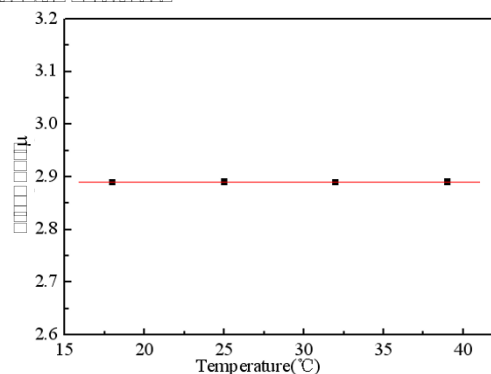
6.3.2 TFBG-based dynamic temperature compensation interrogation technique for strain sensors [70]

The TFBG-based dynamic temperature compensation interrogation technique for strain sensors is a method for measuring strain and temperature simultaneously. It uses a TFBG (Tilted Fiber Bragg Grating) sensor that is sensitive to both strain and temperature. The technique involves measuring the shift in the Bragg wavelength of the TFBG sensor, which is caused by changes in strain and temperature. By using a dynamic temperature compensation technique, the strain measurement can be made independent of temperature changes.

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The diagram illustrates the setup for the TFBG-based dynamic temperature compensation interrogation technique. The BBS (Beam Splitter) is used to split the light into two paths. One path goes through Coupler1 to the FBG sensor, and the other path goes through Coupler2 to the TFBG sensor. The FBG sensor is connected to the TFBG sensor, and both are connected to the detectors D1 and D2. The output of the detectors is used to measure the strain and temperature.

[illegible][illegible]

7. Brief summary on the key techniques of TFBG sensors

[illegible]

1. 在 2019 年 12 月 31 日，公司应收账款账面余额为 1,000 万元，坏账准备余额为 100 万元。2020 年 1 月 1 日，公司应收账款账面余额为 1,200 万元，坏账准备余额为 120 万元。2020 年 2 月 1 日，公司应收账款账面余额为 1,500 万元，坏账准备余额为 150 万元。2020 年 3 月 1 日，公司应收账款账面余额为 1,800 万元，坏账准备余额为 180 万元。2020 年 4 月 1 日，公司应收账款账面余额为 2,000 万元，坏账准备余额为 200 万元。2020 年 5 月 1 日，公司应收账款账面余额为 2,200 万元，坏账准备余额为 220 万元。2020 年 6 月 1 日，公司应收账款账面余额为 2,500 万元，坏账准备余额为 250 万元。2020 年 7 月 1 日，公司应收账款账面余额为 2,800 万元，坏账准备余额为 280 万元。2020 年 8 月 1 日，公司应收账款账面余额为 3,000 万元，坏账准备余额为 300 万元。2020 年 9 月 1 日，公司应收账款账面余额为 3,200 万元，坏账准备余额为 320 万元。2020 年 10 月 1 日，公司应收账款账面余额为 3,500 万元，坏账准备余额为 350 万元。2020 年 11 月 1 日，公司应收账款账面余额为 3,800 万元，坏账准备余额为 380 万元。2020 年 12 月 1 日，公司应收账款账面余额为 4,000 万元，坏账准备余额为 400 万元。2020 年 12 月 31 日，公司应收账款账面余额为 4,200 万元，坏账准备余额为 420 万元。

9. Conclusions

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Acknowledgment

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References

Abstract. We study the asymptotic behavior of the ground state energy of a system of two particles interacting via a Coulomb potential and confined by a harmonic trap. The ground state energy is shown to converge to the minimum value of the sum of the kinetic energy and the interaction energy as the mass of the particles tends to infinity. This result is proved by using the variational method and the properties of the ground state wave function.

[illegible]

Opt. Fiber Technol.

The proposed system is designed to be a modular, open-source platform for research and development in the field of autonomous systems. It is built upon a robust hardware foundation, featuring a high-performance processor and a rich set of sensors and actuators. The system's architecture is designed to be flexible, allowing for the integration of various software modules and the adaptation to different environments and tasks.

The system is composed of several key components, including a central processing unit, a power management system, and a communication interface. The central processing unit is responsible for coordinating the system's operations and processing data from the sensors and actuators. The power management system ensures that the system has a reliable and efficient power supply. The communication interface allows the system to interact with external devices and networks.

The system is designed to be easy to use and maintain. It includes a comprehensive set of documentation and tools that make it simple to configure and operate the system. The system is also designed to be scalable, allowing it to be adapted to a wide range of applications and environments.

The system is a valuable tool for researchers and developers in the field of autonomous systems. It provides a platform for testing and validating new algorithms and techniques, and it can be used to develop a wide range of autonomous systems, from small-scale robots to large-scale autonomous vehicles.

The system is a testament to the power of open-source development and the collaborative efforts of the research community. We hope that this system will inspire others to develop their own autonomous systems and contribute to the advancement of the field.

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Optical fiber
Communication Conference, OFC'90

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Electron.

IEEE Photon. Technol. Lett.










Figure 1 illustrates the structure of a 128-bit input vector x . The vector is partitioned into three primary segments: a 64-bit segment on the left, a 32-bit segment in the center, and a 32-bit segment on the right. The 64-bit segment is subdivided into four 16-bit blocks. The 32-bit central segment is subdivided into four 8-bit blocks. The 32-bit right segment is also subdivided into four 8-bit blocks. The text "Appl. Opt." is positioned within the central 32-bit segment.

IEEE
Photon. Technol. Lett.

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17th
International Conference on Optical Fibre Sensors

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IEEE J. Lightwave Technol., Vol. 23, No. 1, January 2005.

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Abstract—We present a novel approach to the problem of detecting and localizing multiple targets in a cluttered environment. The method is based on a combination of a particle filter and a genetic algorithm. The particle filter is used to represent the posterior distribution of the target positions, while the genetic algorithm is used to optimize the search process. The results show that the proposed method is able to detect and localize multiple targets in a cluttered environment with high accuracy and low computational complexity.

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Y. Wang is now with the School of Information Science and Technology, Beijing University of Aeronautics and Astronautics, Beijing 100084, China.

IEEE Photon. Technol. Lett.

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A number line consisting of two segments of 10 units each, separated by a minus sign. The first segment has 10 empty boxes, and the second segment has 10 empty boxes.

[illegible]

Optical Fiber Sensors

[illegible]

1. The first part of the paper is devoted to the study of the asymptotic behavior of the solutions of the system of equations (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

2. In the second part of the paper, the asymptotic expansion of the solutions of the system (1) is constructed. It is shown that the asymptotic expansion of the solutions of the system (1) has the form

$$u = u_0 + \epsilon u_1 + \epsilon^2 u_2 + \dots,$$

where $u_0, u_1, u_2, \dots$ are the solutions of the system of equations (2).

3. In the third part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

4. In the fourth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

5. In the fifth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

6. In the sixth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

7. In the seventh part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

8. In the eighth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

9. In the ninth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

10. In the tenth part of the paper, the asymptotic expansion of the solutions of the system (1) is used to study the asymptotic behavior of the solutions of the system (1) as $\epsilon \rightarrow 0$. It is shown that the solutions of the system (1) converge to the solutions of the system of equations (2) in the sense of the weak convergence in the space $L^2(\Omega; \mathbb{R}^n)$.

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20th International Conference on Optical Fibre Sensors
 2019, 10-14 November, Beijing, China

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