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# Impact of gamma irradiation on the properties of fiber Bragg grating: A review

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**ABSTRACT**

Fiber Bragg grating (FBG) is an optical sensor used to detect environmental changes, such as temperature, pressure, and radiation. This study analyzes the impact of gamma-ray irradiation on the shift of Bragg reflection wavelength in FBG optical fibers at various temperatures. The results show that increasing temperature from 18°C to 40°C before gamma irradiation causes a Bragg wavelength shift of about 5.48 pm/°C. Gamma-ray irradiation with a cumulative dose of 22.85 kGy for 124 min at 35°C resulted in a radiation dose-dependent Bragg wavelength shift, with a value of about 5.25 × 10-3 pm/Gy. After the irradiation was stopped, the Bragg reflection wavelengths on the FBG fibers showed a recovery of up to 84.4% for the buffer fiber and 36.2% for the reference fiber. These findings provide important insights into the behavior of FBG sensors in an environment of gamma radiation and temperature fluctuations, making them potential for applications in extreme condition monitoring.

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## 1. INTRODUCTION

The swift advancement of contemporary times undoubtedly propels the evolution of sensor technology, driven by the growing demand for accurate and dependable monitoring systems. One sensor that garners attention is the fibre optic sensor. This sensor has garnered significant interest from researchers because to the capability of optical fibres to detect and quantify physical properties [1]. Fiber Bragg grating (FBG) represents a significant advancement in photonics, functioning as a fibre optic sensor that use light reflection principles to monitor variations in environmental parameters such as temperature, pressure, and voltage [2, 3].

FBG offers numerous advantages, including immunity to electromagnetic wave interference, the possibility for wavelength division multiplexing, and rapid response. The benefits of optical fibre with FBG render it a viable alternative for applications in demanding situations [4]. The numerous advantages of optical fibre with FBG do not imply the absence of weaknesses. An illustration of its vulnerability is its inability to withstand excessive radiation exposure. Gamma-ray irradiation of optical fibres with FBG can lead to an increase in transmission loss and a subsequent shift in the peak Bragg wavelength [5]. This presents a significant issue, particularly when the FBG is situated in a high-radiation environment, such as a Nuclear Power Plant. FBGs may endure high radiation settings by the utilisation of germano-silicate glass optical fibres, which feature a pure silica glass buffer and Boron-doped inner cladding, fabricated via OVD and MCVD techniques [4]. This study will examine the impact of gamma irradiation on the shift of Bragg reflection wavelength in optical fibres using FBGs at different temperatures.

## 2. THEORITICAL REVIEW

### 2.1. FBG

FBG is an optical fibre characterised by multiple fluctuations in refractive index. The periodic configuration of the FBG is created by exposing the fibre core, which is responsive to electromagnetic radiation [6]. FBG is a form of FBG, functioning as a transmission wave at a specific wavelength, while other wavelengths are reflected. One of the operational principles of FBG is Fresnel reflection, defined as the phenomenon where light propagating at an interface between media with differing refractive indices results in one beam being reflected and another transmitted [7]. FBG is a filter characterised by a regularly varying refractive index, enabling it to operate as both a reflector and a transmitter. FBG optical systems has the capability to reflect wavelengths with certain features, contingent upon the grating period at the fibre core [8]. The configuration of the FBG on optical fibre is seen in Figure 1.

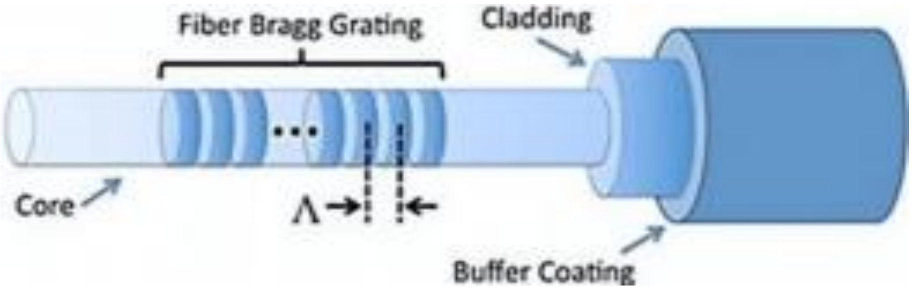


Figure 1. FBG applied to optical fibre.

FBG sensors are fibre optic sensors characterised by a uniform grating dispersion. Optical fibres with a spatially varying refractive index, particularly in FBGs, can reflect a restricted spectrum of received light while simultaneously transmitting the remainder. FBG fundamentally pertains to the notion of Bragg reflection. The incident light traversing regions of varying refractive indices will result in partial reflection at each interface within those regions. The fibre core, when exposed to FBG, can function as an optical filtering element along the optical fibre core at designated wavelengths. FBGs are often categorised as apodizing and homogenous. Uniform FBGs exhibit inherent sensitivity to variations in external strain and temperature. The Bragg wavelength is the central wavelength in the reflection spectrum of FBGs. Temperature and tension can influence the refractive index and period of the Bragg grating, resulting in a wavelength shift [5].

The nuclear industry has shown considerable interest in fibre optic sensing technology due to the remarkable durability of optical fibres in radiation environments; however, fibre optic sensors utilising FBG are not deemed suitable for high radiation exposure environments. The method for producing optical fibres with FBGs that can endure high radiation environments involves creating radiation-resistant germano-silicate glass fibres, utilising a pure silica glass buffer and boron-doped silica glass inner cladding.

### 2.2. Gamma Rays

Gamma rays are a type of electromagnetic radiation generated when an atom experiences an energy transition, during which the nucleus emits energy as gamma rays while moving from an excited state to a ground state. This radiation possesses considerable energy, typically exceeding 10 keV, and can be produced through multiple means, including radioactive decay, annihilation interactions between electrons and positrons, or energy transitions in atomic nuclei. Gamma rays, released by excited atomic nuclei, constitute a form of high-energy electromagnetic radiation.

## 3. MATERIALS AND METHOD

Changes in FBG features due to variations in radiation, without temperature fluctuations, can be measured by selecting a temperature of 35°C, as at this temperature, the rise in radiation dose will not elicit a response. Consequently, it will be feasible to assess the alteration in FBG features. The relative intensity attenuation (RIA) and relative induced Bragg reflection wavelength shift (RIBRW) shifts of the FBG were recorded during a duration of 124 minutes at 3-minute intervals, during which γ-ray radiation was administered for 100 minutes at 3 – 5 minute intervals. The impact of γ-rays can be examined for 124 minutes utilising the electric temperature chamber, as it mitigates the reduction in radiation caused by the chamber's radiation shielding. Consequently, it is feasible to assess variations in radiation independent of temperature fluctuations.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Gamma-Ray Exposure During Assessment

The outcomes of γ-ray irradiation during the measurement with the temperature profile are illustrated in Figure 2.

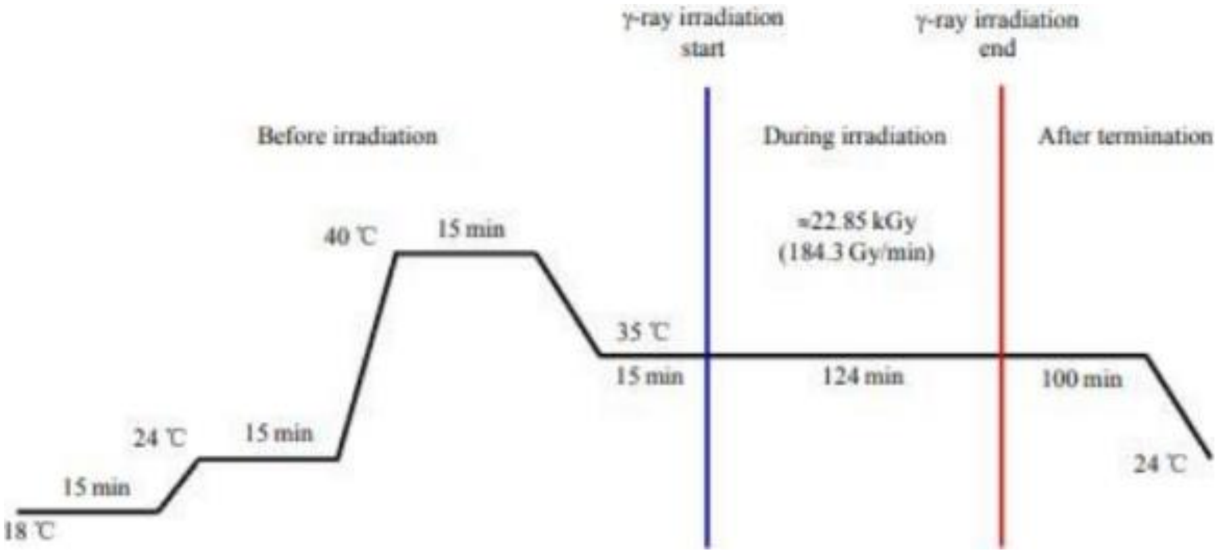


Figure 2. Temperature profile under incident γ-ray irradiation during measurement.

### 4.2. Bragg Reflection Wavelength of FBGs

The temperature rises from 18°C to 40°C prior to γ-ray irradiation, resulting in an increase in optical attenuation and a shift of the Bragg wavelength of the FBG towards longer wavelengths. An elevation in temperature can accelerate the movement of ions compared to a reduction in temperature. The alteration in wavelength direction and the shift in the centre wavelength of the FBG are caused by thermal expansion, which modifies the grating period and refractive index. Nevertheless, the rise in attenuation due to temperature variation is significantly less than that caused by γ-ray irradiation. The wavelength shift due to Bragg's law from a temperature change of 18°C to 40°C prior to γ-ray irradiation yields approximately 4.57 dB and 5.48 pm/°C, with error margins of 4.9% and 0.9%, respectively. In the FBG reference fibre, the errors recorded are 12.2% and 1.2%, corresponding to approximately 27.50 dB and 5.06 pm/°C. The outcomes are illustrated in Figure 3.

The Bragg wavelength increases with escalating γ-ray irradiation from 0 to 22.85 kGy at 35°C, as illustrated in Figure 4. The Bragg wavelength of the FBG during and subsequent to γ-ray irradiation at a cumulative dosage of 22.85 kGy distinctly demonstrates γ-ray dependence. As γ-ray irradiation escalated from 0 to 22.65 kGy, the Bragg reflectance rose from 17.69 dB to 17.92 dB for the FBG buffer fibre and reached 17.48 dB for the FBG reference fibre. The Bragg reflectance wavelength shifted to longer wavelengths, from 1549.55 nm to 1549.67 nm for the FBG buffer fibre, and from 1550.09 nm to 1550.20 nm for the FBG reference fibre, under γ-ray irradiation without any temperature variation. Augmenting the dosage of γ-ray. The irradiation at 1550.5 nm saturated the outcomes of the Bragg reflection wavelength. The γ-ray irradiation was halted at 22.85 kGy, and the Bragg reflectance wavelength results were restored.

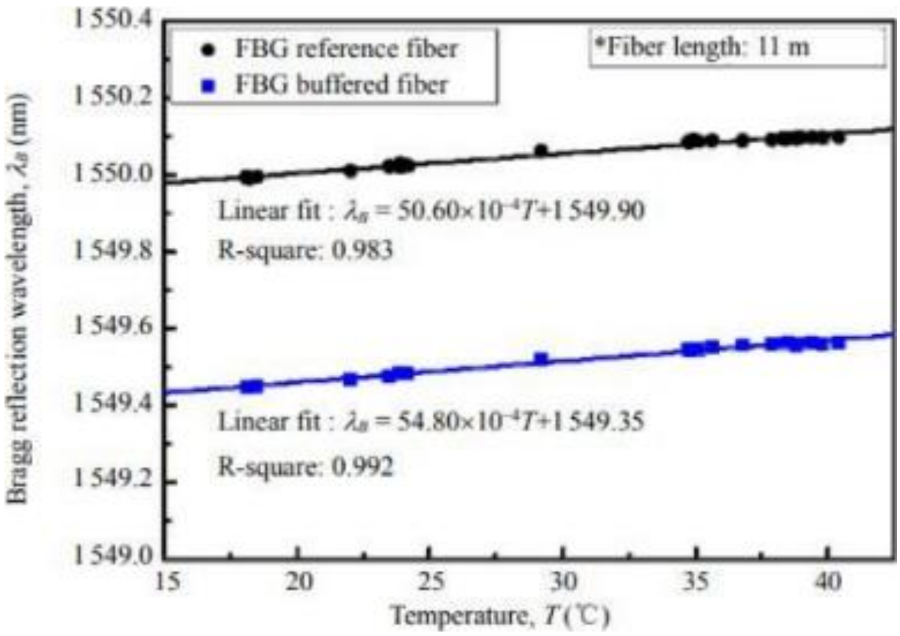


Figure 3. Wavelength shift of Bragg reflection in FBG fibre from 18°C to 40°C prior to γ-ray irradiation.

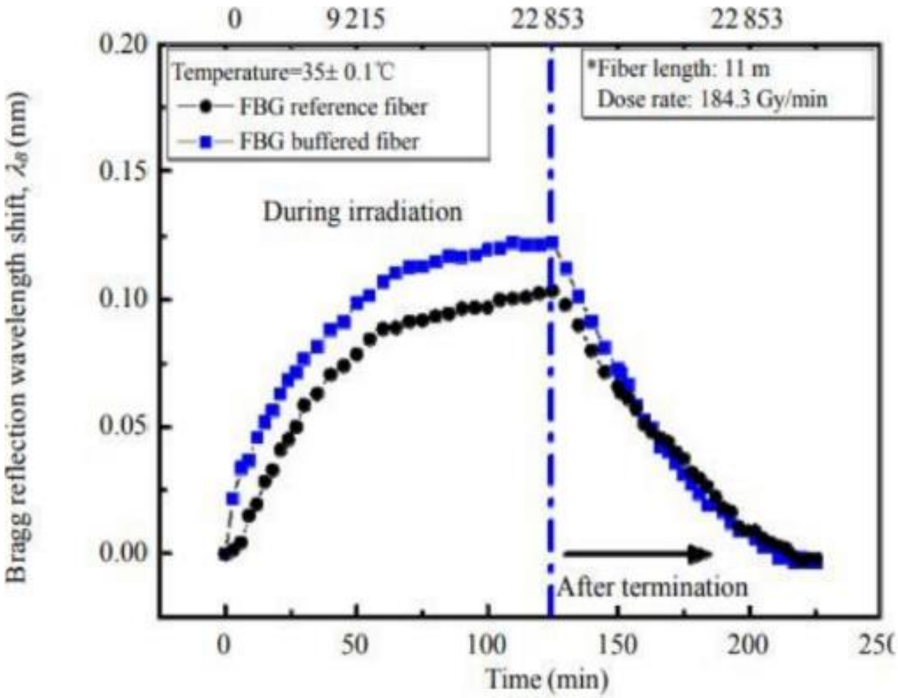


Figure 4. Bragg reflection wavelength of FBG fibre during and subsequent to γ-ray irradiation with a cumulative dose of 22.85 kGy at 35°C.

The Bragg wavelength data indicate a complete recovery to 1549.54 nm for the FBG buffer fibre and 1550.09 nm for the FBG reference fibre following the cessation of γ-ray irradiation. The reflectance at the Bragg wavelength was 17.99 dB for the FBG buffer fibre and 17.52 dB for the FBG reference fibre. The comprehensive data of the acquired results are presented in Table 1.

Table 1. Residual stresses of the propped and reference prior to and subsequent to γ-ray irradiation of 22.85.

| Type | Specification | Temperature (°C) | Wavelength and Bragg reflection |
|---|---|---|---|
| Reinforced fiber | Prior to irradiation (0 Gy) | 35.0 ± 0.1 | 1549.55 nm |
| | Subsequent to irradiation (22.85 kGy) | | 1549.67 nm |
| | 100 minutes post-termination | | 1549.54 nm |
| Reference fiber | Prior to irradiation (0 Gy) | 35.0 ± 0.1 | 0.152 |
| | Subsequent to irradiation (22.85 kGy) | | 0.151 |
| | 100 minutes post-termination | | 0.152 |

The Bragg reflection wavelength shift in both fibres has a similar trend with temperature variations, demonstrating a linear relationship as temperature increases. The impact of temperature elevation on the Bragg reflection wavelength is approximately 1000 times more significant than that of γ-ray irradiation, thereby demonstrating its potential as a temperature sensor in a gamma-ray irradiation setting.

The alteration in the Bragg reflection wavelength of the FBG fibre exposed to γ-rays is attributable to radiation effects, the formation of colour centres, and an increase in the refractive index. After 100 minutes of cessation of γ-ray irradiation, the buffer fibre and reference fibre FBG exhibited recoveries of approximately 84.4% and 36.2%, respectively. Consequently, the Bragg reflection wavelengths of both FBG fibres can be entirely restored due to the relaxation of physical parameters induced by temperature fluctuations.

The Bragg reflection wavelength shift during RIBRW irradiation exhibits a nearly linear increase up to 11.1 kGy; however, the Bragg wavelength shift of the FBG buffer fibre and reference fibre appears to saturate at this dose. The dependence of γ-ray on the Bragg wavelength of the FBG buffer fibre and the reference fibre, subjected to 11.1 kGy at a dose rate of 184.3 Gy/min for 60 minutes, was about $8.41 \times 10^{-3}$ pm/Gy and $8.52 \times 10^{-3}$ pm/Gy, with error margins of 2.4% and 0.9%, respectively. The γ-ray irradiation at 22.85 kGy for 100 minutes completely restored the reflected Bragg wavelength of the FBG. The data obtained confirm that there is no alteration in the refractive index following γ-ray irradiation.

## 4. CONCLUSION

Analysis of the variation in Bragg reflection wavelength of optical fibres with FBG before and after γ-ray irradiation at different temperatures indicates that, prior to gamma irradiation, the Bragg reflection wavelength shifts of the FBG buffer fibres at temperatures between 18°C and 40°C are approximately $4.57 \times 10^{-4}$ dB/°C and 5.48 pm/°C, respectively. Following γ-ray irradiation at doses between 0 and 22.85 kGy for 124 minutes at 35°C, the RIA and RIBRW for the 11-meter-long FBG buffer fibre are approximately 0.32 dB (0.03 dB/m) and 0.12 nm, respectively. The dependence of γ-ray irradiation on the Bragg wavelength shift of the FBG buffer fibre is approximately $5.25 \times 10^{-3}$ pm/Gy. These findings offer significant insights into the behaviour of FBG sensors under γ-ray irradiation and fluctuating temperatures.

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