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High sensitivity sapphire FBG temperature sensors for the signal processing of data communications technology

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ABSTRACT

This study has outlined the fiber bragg grating (FBG) temperature sensors signal processing for data communications by using OptiGrating simulation software. The reflectivity of the silica and sapphire fiber grating spectrum is reported against the grating wavelength for internal and external temperature variations. As well as apodized Gaussian reflectivity of the silica and Sapphire fiber grating spectrum is simulated and clarified against the grating wavelength for high temperature variations. The temperature sensitivity of sapphire FBG nearly 0.11 pm/^{0}C, where its value is three times higher than silica FBG. It is observed that silica and Sapphire FBG sensors were tested up to 1000 ^{0}C by using Gaussian apodization type, side lobes in reflectivity spectrum are totally suppressed.

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1. INTRODUCTION

For a uniform FBG, the spectral response is affected by the length of grating which is changed by external perturbation such as strain, temperature and pressure [1-9]. Reflectivity based on designed model for a uniform FBG using OptiSystem simulator was analyzed at different values of grating length. Their results show the reflectivity of the uniform FBG increased as the grating length increased but reflectivity of side lobes also increased [7-12], and the bandwidth of a FBG reduced as increasing in grating length. Their results for the reflectivity of FBG, it was provide highly better performance as increasing in grating length and given 99.99 % power reflection at 20 mm of grating length [4-7, 10-12, 13-15].

2. MODEL DESCRIPTION

FBG based sensor device used for the temperature, strain, pressure and flow measurement has been studied over the past several years [13-15]. Sapphire optical fiber provides a highly resistant against radiation and has a melting point up to 2000 ^{0}C [16-20]. It provides excellent temperature profile also at low temperatures given radiation resistant [16]. Sapphire FBG is used as a temperature sensors up to 1600 ^{0}C [18-29]. The Bragg wavelength with the grating period and effective fiber index is [7, 30-49]:

$$\lambda_B = 2n_{eff}\Lambda \tag{1}$$

Temperature and strain induced Bragg wavelength shifted shown as [15, 34-38]:

$$\Delta\lambda_B = \lambda_B\left[\Delta T\left(\alpha + \frac{1}{n}\frac{dn}{dT}\right) + \varepsilon\left(1 - \frac{n^2}{2}[p_{12} - \nu(p_{12} + p_{11})]\right)\right] \tag{2}$$

$$\Delta\lambda_B = \lambda_B\left[\Delta T\left(\alpha + \frac{1}{n_{eff}}\frac{dn}{dT}\right)\right] \tag{3}$$

$$K_T = \lambda_B\left(\alpha + \frac{1}{n_{eff}}\frac{dn}{dT}\right) \tag{4}$$

With ΔT is the temperature variation, α is the temperature optic factor, ε is the applied strain, ν is the poisons ratio and p_{11}, p_{12} are the strain optic coefficients and K_T is the coefficient for temperature sensitivity. Shift in Bragg wavelength $\lambda_{B|T}$ induced by temperature changes is described by [20-24]:

$$\Delta\lambda_{B|T} = \lambda_B(\alpha + \xi)\Delta T \tag{5}$$

$$\alpha = \frac{1}{\Lambda}\left(\frac{\partial\Lambda}{\partial T}\right) \tag{6}$$

$$\xi = \frac{1}{n_{eff}}\left(\frac{\partial n_{eff}}{\partial T}\right) \tag{7}$$

With Λ is the period of the grating, α is the fiber thermal expansion, and ξ is the thermo-optic factor [21].

3. PERFORMANCE ANALYSIS WITH DISCUSSIONS

As shown in Figure 1 and Figure 2 at the internal temperature of 37.1 ^{0}C, the Bragg wavelengths were 1.55018 µm for FBG $_{written}$ in silica optical fiber and 1.55038 µm for a Sapphire Bragg grating respectively. Also in Figure 3, Figure 4 at the outlet temperature from the reactor core 44 ^{0}C the Bragg wavelengths were 1.55025 µm for FBG in silica optical fiber and 1.55059 µm for a Sapphire fiber Bragg grating respectively.

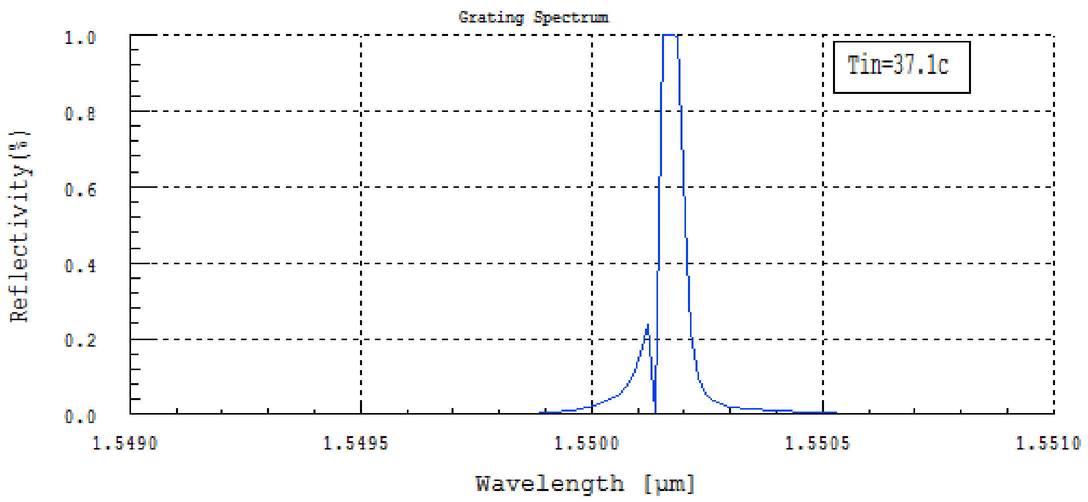

Figure 1. Reflectivity of the silica fiber grating spectrum versus the grating wavelength for internal temperature of 37.1 °C.

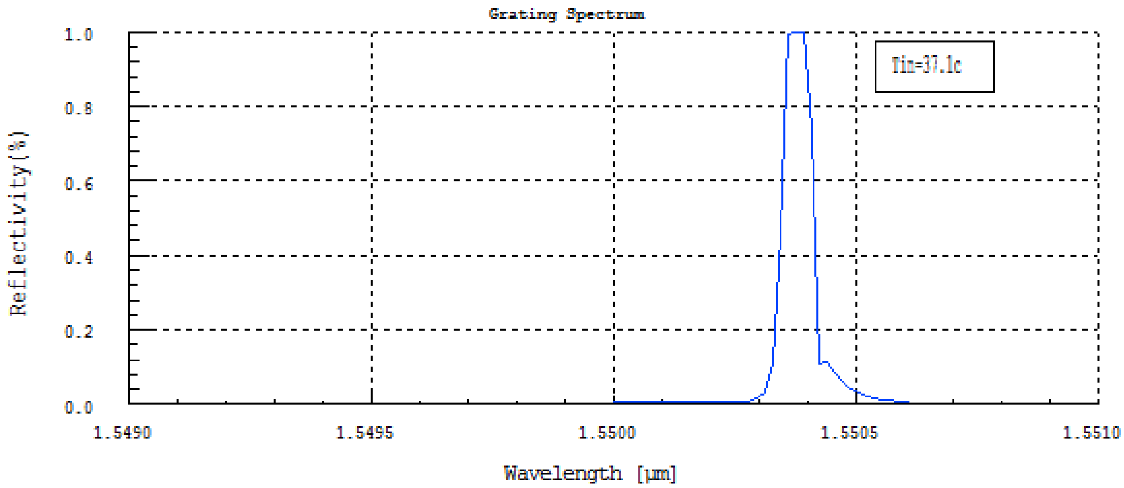

Figure 2. Reflectivity of the Sapphire fiber grating spectrum with grating wavelength for internal temperature of 37.1 °C.

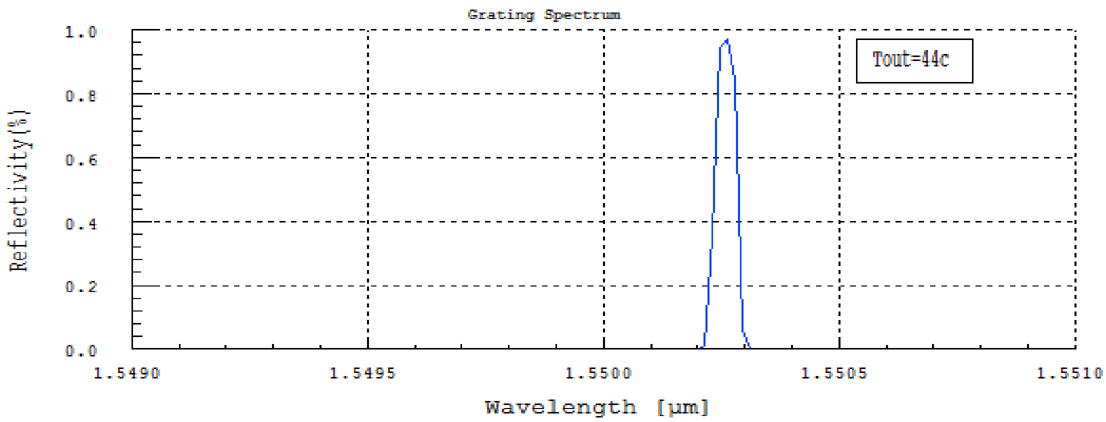

Figure 3. Reflectivity of the silica fiber grating spectrum versus the grating wavelength for external temperature of 44 °C.

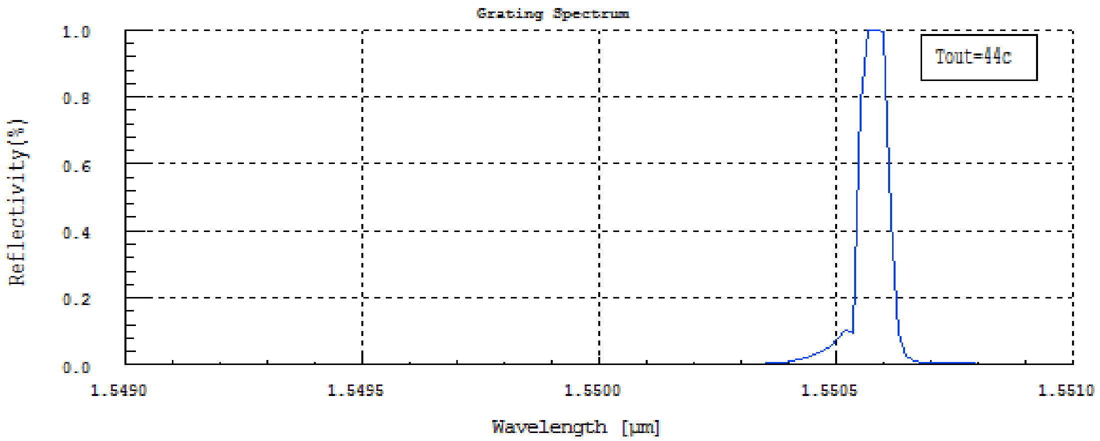

Figure 4. Reflectivity of the Sapphire fiber grating spectrum with grating wavelength for external temperature of 44 °C.

From Figure 5- 6 and from Figure 7-8, the Bragg wavelength shift as a result of temperature changes for the inlet and outlet temperature for both FBG written in silica optical fiber and Sapphire Bragg grating respectively, all of side lobes have been completely eliminated whicfh provide an accurate temperature measurements that must be achieved in nuclear applications.

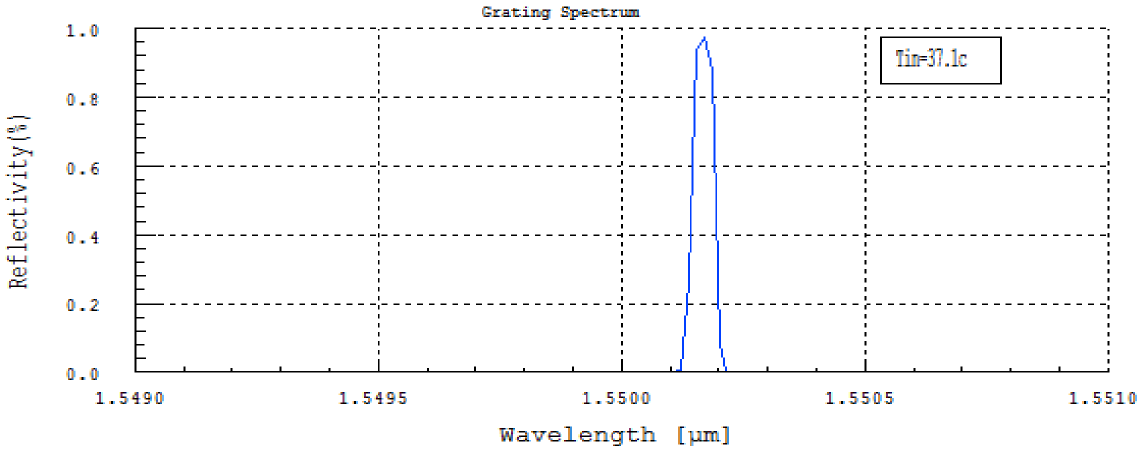

Figure 5. Apodized reflectivity of the silica fiber grating spectrum versus the grating wavelength for internal temperature of 37.1 °C

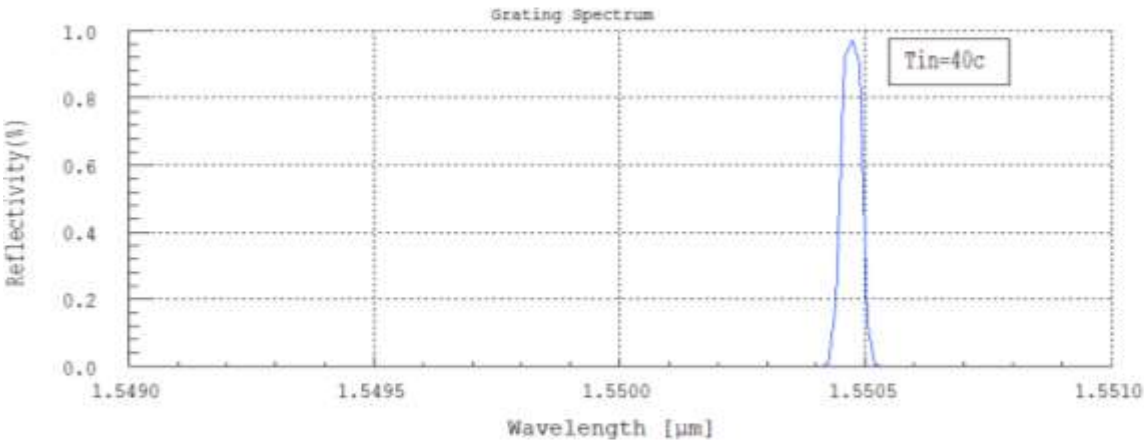

Figure 6. Apodized reflectivity of the Sapphire fiber grating spectrum versus the grating wavelength for internal temperature of 40 °C

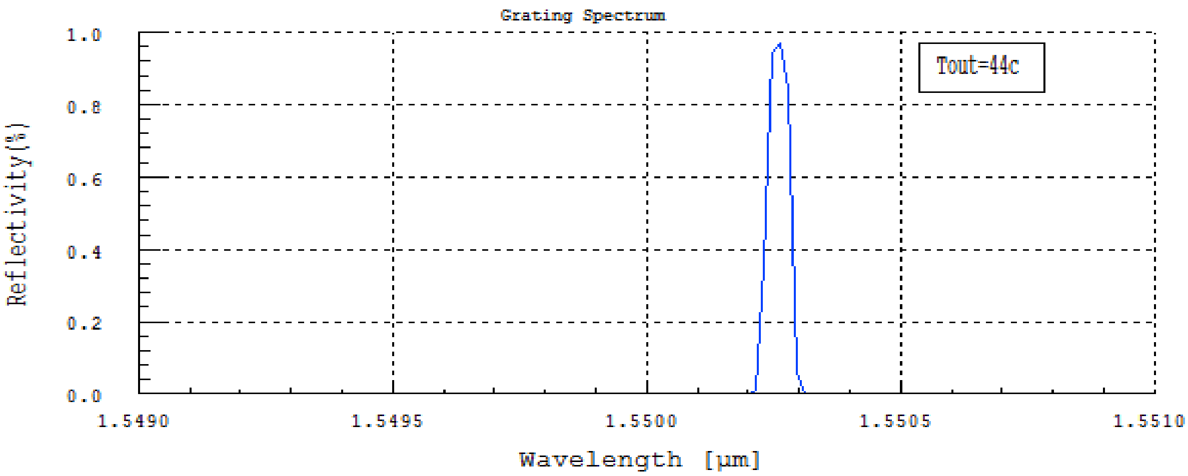

Figure 7. Apodized reflectivity of the silica fiber grating spectrum versus the grating wavelength for external temperature of 44 °C

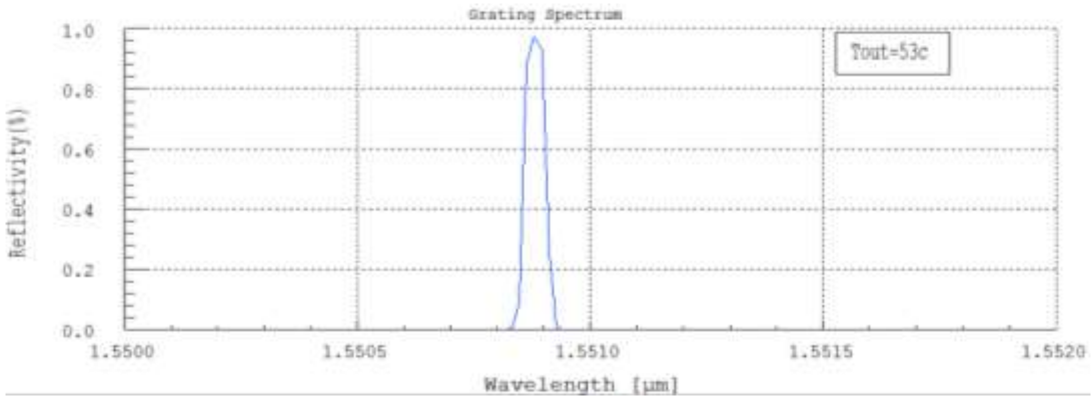

Figure 8. Apodized reflectivity of the Sapphire fiber grating spectrum versus the grating wavelength for external temperature of 53 °C

In case of high temperature variations, we have demonstrated the Bragg wavelength shift induced by higher temperature change for both silica and sapphire fiber Bragg grating as outlined and reported in Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13.

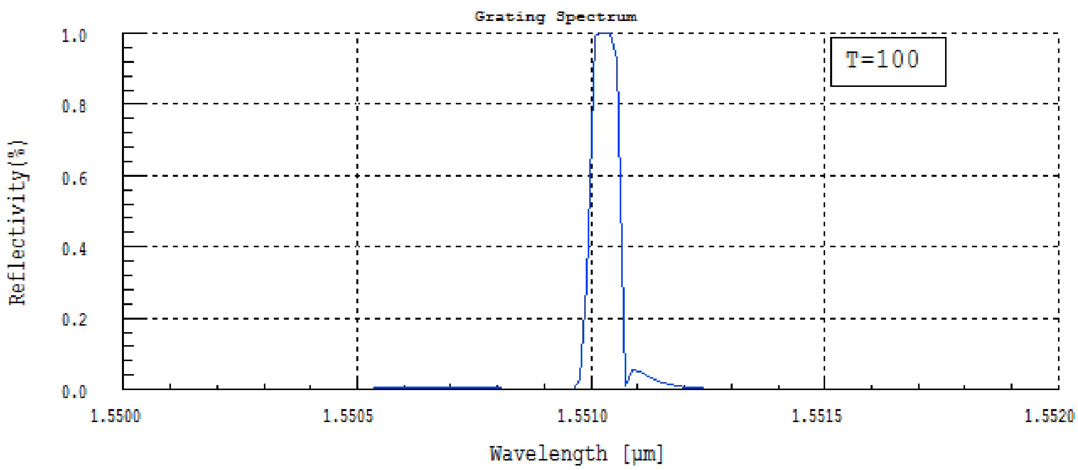

Figure 9. Reflectivity of the silica fiber grating spectrum versus the grating wavelength for high temperature value of 100 °C

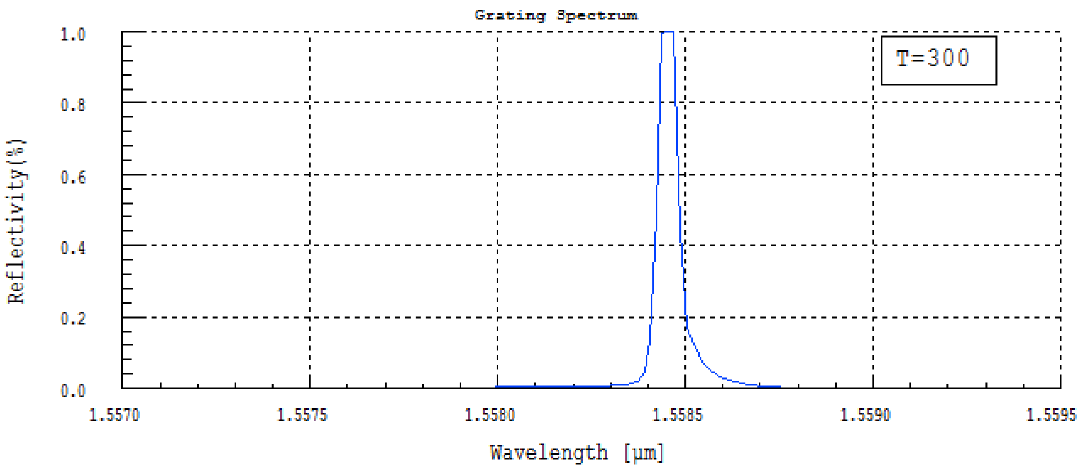

Figure 10. Reflectivity of the Sapphire fiber grating spectrum versus the grating wavelength for high temperature value of 300 °C

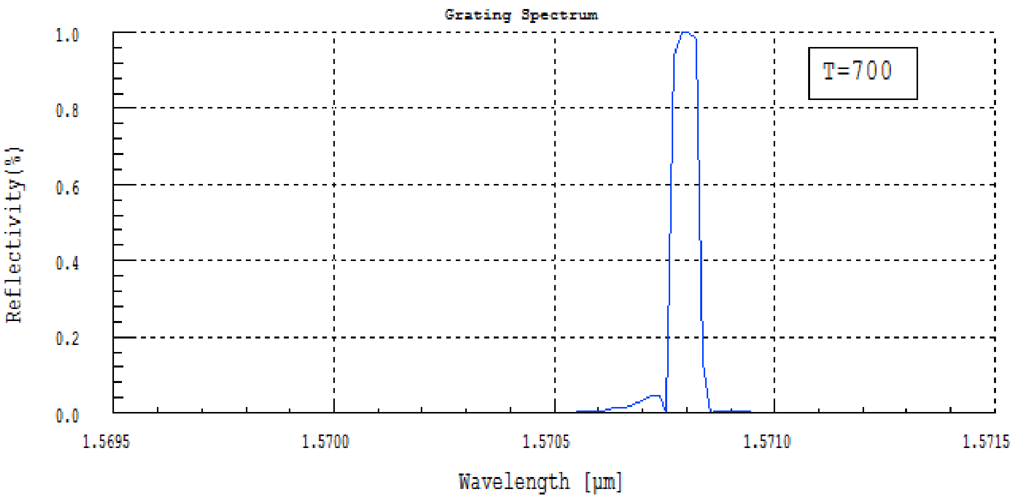

Figure 11. Reflectivity of the Sapphire fiber grating spectrum versus the grating wavelength for high temperature value of 700 °C

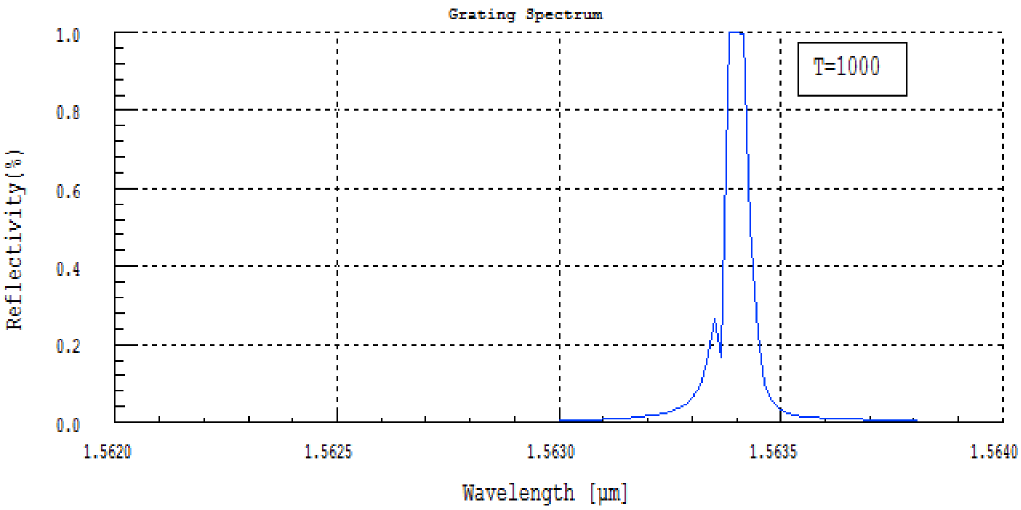

Figure 12. Reflectivity of the silica fiber grating spectrum versus the grating wavelength for high temperature value of 1000 °C

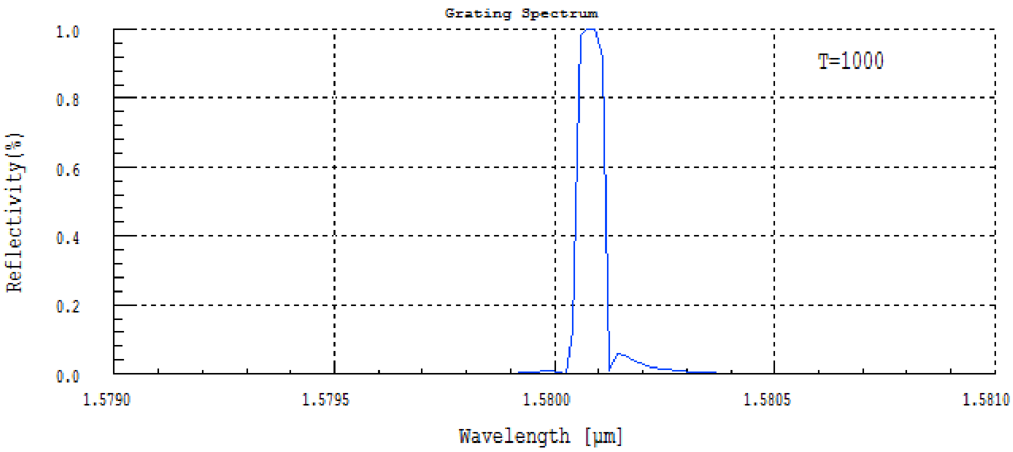

Figure 13. Reflectivity of the Sapphire fiber grating spectrum versus the grating wavelength for high temperature value of 1000 °C

4. CONCLUSION

We have simulated the high sensitivity sapphire FBG temperature sensors for the signal processing of the data communications technology. It is reported that temperature sensitivity of sapphire FBG nearly 0.11 pm/^{0}C, where its value is three times higher than silica FBG due to high sapphire index factor. Two FBG sensors were tested up to 1000 ^{0}C by using a Gaussian apodization type, side lobes in reflectivity spectrum are totally suppressed.

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