Sensitivity alteration of fiber Bragg grating sensors with additive micro-scale bi-material coatings

This article has been downloaded from IOPscience. Please scroll down to see the full text article.
(http://iopscience.iop.org/0957-0233/24/2/025106)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 174.94.53.216
The article was downloaded on 16/01/2013 at 02:38

Please note that terms and conditions apply.
Sensitivity alteration of fiber Bragg grating sensors with additive micro-scale bi-material coatings

Xixi Zhang, Hamidreza Alemohammad and Ehsan Toyserkani

Department of Mechanical and Mechatronics Engineering, University of Waterloo, 200 University Ave. West, Waterloo, ON N2L 3G1, Canada
E-mail: ehsan.toyserkani@uwaterloo.ca

Received 25 September 2012, in final form 15 December 2012
Published 15 January 2013
Online at stacks.iop.org/MST/24/025106

Abstract
This paper describes a combined fabrication method for creating a bi-material micro-scale coating on fiber Bragg grating (FBG) optical sensors using laser-assisted maskless microdeposition (LAMM) and electroless nickel plating. This bi-material coating alters the sensitivity of the sensor where it also acts as a protective layer. LAMM is used to coat bare FBGs with a 1–2 μm thick conductive silver layer followed by the electroless nickel plating process to increase layer thickness to a desired level ranging from 1 to 80 μm. To identify an optimum coating thickness and predict its effect on the sensor’s sensitivity to force and temperature, an optomechanical model is developed in this study. According to the model if the thickness of the Ni layer is 30–50 μm, maximum temperature sensitivity is achieved. Our analytical and experimental results suggest that the temperature sensitivity of the coated FBG with 1 μm Ag and 33 μm Ni is almost doubled compared to a bare FBG with sensitivity of 0.011 ± 0.001 nm °C⁻¹. In contrast, the force sensitivity is decreased; however, this sensitivity reduction is less than the values reported in the literature.

Keywords: fiber Bragg grating, electroless plating, thin film deposition, laser-assisted maskless microdeposition

(Some figures may appear in colour only in the online journal)

1. Introduction
Optical sensors are among the important mainstream sensing technologies on the market today, prompting researchers to enhance performance of optical fiber sensors and develop new generations of optical fiber-based sensing devices. Optical sensors are used in a variety of applications such as structural health monitoring, biomedical sensing, vibration measurement and many more.

Fiber grating is a type of optical fiber sensor with periodic modulations of the index of refraction. Fiber gratings with a short period of ~500 nm are called fiber Bragg gratings (FBG). In FBGs, the gratings are inscribed in the core of single-mode optical fibers using a UV laser [1]. For sensing applications, FBGs can either be surface mounted or embedded in-structure to monitor physical parameters, such as temperature and force.

There are a few laser-based methods that make the embedding of optical sensors within metallic structures possible [2–5]. In the laser-based embedding process, a protective layer must be created around the FBGs using cold processes [6, 7]. Then, in a layer-by-layer manufacturing approach, the rest of the part can be manufactured [8, 9]. The embedding processes alter the sensitivity of FBGs positively and negatively, thus calling for a diligent design of geometrical features and physical properties of metallic coatings. To address this concern, this study was undertaken to determine the effects of coating material and thickness on the FBGs’ sensitivity.

Sensitivity of FBGs plays an important role in the performance and industrial acceptance of such sensors. The sensitivity required for FBGs is highly dependent on applications, environment of use and the magnitude of physical parameters measured by the sensors. In addition,
such sensitivity dependence is more complicated if FBGs are embedded in metallic structures using laser-assisted additive coating processes as mentioned above. The coating process should not induce high temperature on the sensors as UV-written gratings in optical fibers start to degrade at around 200 °C and are removed permanently at higher temperatures [1]. Low temperature processes such as electroplating, vacuum brazing, metal evaporation and ultrasonic consolidation have been utilized to deposit metallic coatings on bare FBG sensors [9–12].

Sandlin et al [9] developed a coating method with electroplating. They used Tollen’s silver mirror test to coat optical fibers with silver. The coating material was made by the reduction of silver ammonium complex with glucose. With the conductive Ag layer, they applied the electroplating method to deposit a Ni layer for further embedding process. Sandlin et al [10] also reported on placing the metal-coated FBGs sensor in a groove of Inconel and covering the groove and FBG using a vacuum brazing method at 1050 °C. Iadicicco et al [11] coated optical fiber sensors with a gold layer at nano-scale by using an evaporation technique. In none of these studies is the sensitivity of the embedded sensor reported.

Li et al [12] used a low temperature process of magnetron sputtering to coat FBGs with a titanium film ~1 μm thick followed by an ~2 μm thick Ni film over the titanium film. They then used electroplating to plate a protective Ni layer with a thickness of 0.5–1 mm. With the protection layer, their FBG sensors could be embedded into metals with a high temperature process such as laser fusion or a casting process. Feng et al [13] studied the temperature sensitivity of FBGs coated with copper and nickel. The method of coating process is a combination of electroless and electroplating processes. They found out that FBGs coated with Cu–Ni, Cu, Ni–Cu and Ni showed different thermal sensitivities, where the Cu–Ni coating is the optimum. However, they reported on the oxidization of the copper in the air that changes the sensor performance. They suggested that the optimum coating material in their application was Ni–Cu.

Lupi et al [14] reported on the enhancement of the sensitivity of FBG sensors at cryogenic temperature by coating the FBGs with thin films of various metals such as tin, lead, zinc and aluminum, by the method of cast and electrocoating processes. The sensitivity of FBG was measured at cryogenic temperature, and lead-coated FBG showed the highest sensitivity, Feng et al [15] described a duplex metal coating to enhance the FBG's temperature sensitivity, and found that a Ni–Cu-coated FBG sensor has both higher temperature repeatability and higher temperature sensitivity. The sensitivity of the FBG coated with a Ni–Cu layer was reported to be 0.018 86 nm °C−1.

Song et al [16] improved the FBG’s pressure sensitivity by putting the FBG sensor into a metal package, which is made of Ti–5Al–2.5Sn alloy, and bonded the package’s ends with aluminum cylinders.

The methods reported in the literature for metal coating of FBGs such as magnetron sputtering, electro-winning (also called electroextraction) and evaporation process are not flexible for patterning the fibers. Additionally, most of them require pressure and temperature controlled chambers.

We propose a new method called laser-assisted maskless microdeposition (LAMM) that is classified under ‘direct-write technologies’, and then combine it with the electroless-plating process to deposit Ag and Ni layers on the FBGs. Optimum process parameters are discussed in this paper. This bi-material coating changes the sensor’s sensitivity. The results of experimental sensitivity analysis are presented where they exhibit a better sensitivity than that reported in the literature. In addition, an analytical opto-mechanical model is developed to predict the thermal and structural sensitivity of FBG coated with metal films. The outcomes of the model are compared with experimental results.

2. Materials and manufacturing procedure

2.1. Preparation of fiber Bragg gratings (FBG)

The FBG sensors (written in SMF28, QPS Photronics, Pointe-Claire, QC, Canada) and regular bare fibers were used for trials and experimental studies. For the coating fabrication, a portion of the acrylic coating of FBGs was removed using fiber stripper. The stripped fibers were cleaned by acetone followed by gentle cleaning using isopropanol.

2.2. Ag thin-film fabrication with laser-assisted maskless microdeposition (LAMM)

The LAMM system was used for the direct printing of Ag nanoparticles on optical fibers. For thin film deposition, Ag nanoparticles (CSD-32, Cabot Corp, Boston, MA, USA) suspended in ethylene glycol with a weight percentage of 45–55 wt% and an average particle size of less than 60 nm were used. Thin layers (1–2 μm) of Ag were deposited on the bare fiber. The details of the LAMM process are available in our previous papers [5]. For this study, we developed a synchronized rotational stage to the LAMM workstation to hold the fiber and spin it at controlled angular velocities. This setup enhances the manufacturability of the Ag coating, promoting repeatability and reliability of the sensors while being used under different forces/temperatures. Figure 1 shows the LAMM workstation and the rotational stage installed in the LAMM system. We characterized the LAMM process to deposit and cure Ag nanoparticles and create thicknesses in the range of 500 nm to tens of micrometers using the layer-by-layer deposition method. The process can be performed at atmospheric pressure and does not need clean-room facilities. An erbium continuous wave (CW) fiber laser with a wavelength of 1550 nm (ELR-20, IPG Photonics, Oxford, MA, USA) was used to sinter Ag nanoparticles.

The laser sintering step was followed by hot plating sintering for 1 h at 230 °C to enhance agglomeration of nanoparticles.

The optimum parameters of LAMM for the deposition of Ag films on fiber and laser sintering are listed in table 1.

2.3. Electroless plating process

After the deposition of a thin layer of Ag on the optical fiber, electroless plating was used to build another metallic
layer around the pre-coated fiber. We chose Ni for the second metallic layer.

Before the Ni plating process, the fiber coated with Ag was immersed in a solution of 10% H₂SO₄ at 65 °C for 5 min for acid cleaning. Then, the fiber was immersed in deionized water for rinsing. Prior to the Ni plating, to decrease the potential barrier for Ni deposition, one additional step was required. To do that, the FBG sensor was immersed in 5% PdCl₂ solution for 5 min at 50 °C and a thin Pd activation layer was deposited on the Ag surface [17, 18].

For the plating, the fiber was placed on a piece of steel and taped at both sides to ensure that the contact points are established. The steel was also used as a material to activate the electroless plating process. The Ni electroless plating solution (CASWELL Inc., Lyons, NY, USA) was heated to 90 °C by a water bath and the steel with the mounted fiber was immersed in the bath for half an hour. In the electroless plating process, Ni was deposited all over the fiber. After half an hour, the steel with the FBG sensor taped on it was taken out of the Ni bath. In order to make the deposition with a better quality and uniform thickness, the FBG sensor was mounted on a piece of glass for an extra hour and a half Ni plating. Figure 2 shows the procedural steps of the Ni electroless plating process.

2.4. Characterization methods

Characterizations of the Ni and Ag layers were performed by a scanning electron microscope (SEM; JEOL JSM-6460 SEM, USA) and energy-dispersive x-ray spectroscopy (EDAX; INCA EnergySEM 350, Energy Microanalysis System, England).

2.5. Sensor calibration and packaging

A calibration setup, as shown in figure 3, has been developed in our research group to obtain the characteristic curves of the sensors [19]. The calibration setup applies axial force
on optical fibers by a linear micro-stage with a positional resolution of 0.005 μm and a minimum incremental motion of 0.1 μm. The axial force is recorded by a load/displacement sensor with the resolution of 0.03 N [19]. To calibrate the sensor without damaging, FBG is placed on a special package, which is made of Invar-36 (FeNi36) [19]. Invar-36 was chosen due to its low thermal expansion coefficient. A virtual control panel designed in LabVIEW controls the components of calibration setup.

3. Opto-mechanical modeling

To study the effects of the coating on the sensitivity of FBGs and find the optimum thickness, an opto-mechanical model was developed which includes the photo-elastic and thermo-optic properties of optical fibers.

3.1. FBG opto-mechanical model

The opto-mechanical model predicts the Bragg wavelength shift as a function of temperature and axial force at different thicknesses. The components of axial strain εzz and radial strain εrr in an FBG, as shown in figure 4, exposed to temperature and axial force are obtained by using an analytical model developed in Maple software [20]. These parameters are then fed into the opto-mechanical Maple model to find the relation between the Bragg wavelength changes (∆λB), and temperature variations (∆T) and the strain components. The shift of Bragg wavelength (∆λB) in the FBG sensor exposed to loading strain and thermal strain variation is obtained from [20]

\[ \Delta \lambda_B = 2n_{\text{eff}} \Lambda \cdot \varepsilon_{zz} - \frac{n_{\text{eff}}^2}{2}(p_{11} + p_{12}) \varepsilon_{rr} \\
+ p_{12} \cdot \varepsilon_{zz} \cdot 2n_{\text{eff}} \Lambda + \frac{1}{n_{\text{eff}}} \cdot \left( \frac{\partial n}{\partial T} \right) \Delta T \cdot 2n_{\text{eff}} \Lambda \\
+ \frac{p_{12}^2}{2} \cdot (p_{11} + 2p_{12}) \cdot \alpha \Delta T \cdot 2n_{\text{eff}} \Lambda \]  

(1)

where \( n_{\text{eff}} \) is the effective refractive index, \( p_{ij} \) (i, j = 1, …, 6) are the Pockels constant for the photoelastic effect in optical fibers, also called strain optic tensor, \( \frac{\partial n}{\partial T} \) is a constant showing the temperature sensitivity of the refractive index, \( \alpha \) is the coefficient of thermal expansion and \( \Lambda \) is the grating pitch. The
Table 2. Values of constants for modeling.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{\text{eff}}$</td>
<td>1.44405</td>
</tr>
<tr>
<td>$\rho_{11}$</td>
<td>0.113</td>
</tr>
<tr>
<td>$\rho_{12}$</td>
<td>0.252</td>
</tr>
<tr>
<td>$\Lambda$ (nm)</td>
<td>537</td>
</tr>
<tr>
<td>$\frac{dn}{dT}$</td>
<td>$1.2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

term $2n_{\text{eff}}\Lambda$ in (1) can be replaced by the Bragg wavelength ($\lambda_B$) according to the FBG equation:

$$\lambda_B = 2n_{\text{eff}}\Lambda$$

(2)

where $\Lambda$ is the grating pitch length [21].

Further information about the modeling procedure can be found in [20] and [22]. In summary, the following parameters and assumptions are materialized in this modeling.

(1) The values of optical parameters used in the model are listed in table 2 [20].

(2) The thermo-mechanical properties of materials used in the modeling to express loading and thermal strain/stress terms are listed in table 3, where $E$ is the Young’s modulus, $\nu$ is the Poisson ratio and $\alpha$ is the coefficient of thermal expansion. It should be noted that we used bulk properties in this study as the elastic moduli of a thin film should not vary substantially from the bulk where dimensions are in micro-scale [23]. The reason is the fact that this property is related to atom-to-atom bonds. For dimensional features larger than a nanometer, where the effect of atomic surface contact is not dominant, it is reasonably correct to consider the bulk properties for thin films [23].

(3) By assuming that $\Delta T$ is zero, the function of sensitivity and the applied $F$ can be found. Similarly, by assuming that $F$ is zero, the relation between sensitivity and $\Delta T$ can also be obtained.

(4) The effect of Ag thin film is ignored; therefore, a single material system is considered as the coating in the modeling. As we will discuss later, the bi-material coating includes a thin film of Ag with thickness of 1 $\mu$m; however, the inclusion of this thin film along with the other material in the modeling domain imposes convergence problems mainly due to the finite precision of computations involving a floating point at interfaces in such a discrete and small size system. A study is underway to identify a solution for this numerical issue. If resolved, we will address our methodology in a future article.

3.2. Simulation comparison results

The model was run for seven single material coatings (i.e. silver, nickel, gold, magnesium, chromium, titanium and aluminum) with the thickness in the range of 1–100 $\mu$m. Figure 5 represents a relation between the temperature sensitivity and the coating thickness.

Figure 6 shows the axial force sensitivity versus the coating thickness. A glance at the figures reveals that the coating reduces force sensitivity whereas it increases the temperature sensitivity. The increase in the temperature sensitivity stems from the higher thermal expansion of metallic coating compared to the optical fibers.

As seen in figure 5, silver, magnesium, aluminum, gold and nickel exhibit higher sensitivity to temperature.

<table>
<thead>
<tr>
<th>Material</th>
<th>$E$ (GPa)</th>
<th>$\nu$</th>
<th>$\alpha$ ($\mu$m m$^{-1}$ K$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>75</td>
<td>0.17</td>
<td>0.55</td>
</tr>
<tr>
<td>Ag</td>
<td>83</td>
<td>0.37</td>
<td>18.9</td>
</tr>
<tr>
<td>Al</td>
<td>70</td>
<td>0.35</td>
<td>23.1</td>
</tr>
<tr>
<td>Au</td>
<td>79</td>
<td>0.44</td>
<td>14.2</td>
</tr>
<tr>
<td>Cr</td>
<td>279</td>
<td>0.21</td>
<td>4.9</td>
</tr>
<tr>
<td>Ni</td>
<td>200</td>
<td>0.31</td>
<td>13.4</td>
</tr>
<tr>
<td>Ti</td>
<td>116</td>
<td>0.32</td>
<td>8.6</td>
</tr>
<tr>
<td>Mg</td>
<td>45</td>
<td>0.29</td>
<td>24.8</td>
</tr>
</tbody>
</table>
Figure 7. Effect of plating time on the thickness of the deposited Ni.

Figure 6 suggests that the force sensitivity reduction is less for magnesium, aluminum, gold and silver. As seen in the figures, increasing the thickness of the coatings increases the thermal sensitivity but results in a reduction in sensitivity for force measurements. Although the coating reduces the force sensitivity for all elements, it is less reduced if magnesium or aluminum is used where coatings with a thickness less than 40 μm are produced on the fiber.

According to the analytical analysis, Ag and Ni exhibit superior effects on temperature sensitivity where Ag has less effect on the force sensitivity reduction. Although Mg and Al are well suited for sensitivity enhancement, they are not stable enough at room temperature as they are prone to oxidization easily. In addition, their manufacturability as coatings for optical fibers in micro-scale is a major problem.

Since Ag can be injected by LAMM and Ni can be electroless plated, we chose the bi-material of Ag–Ni for this study. In order to have the maximum temperature sensitivity and the minimum reduction in force sensitivity, 30–35 μm thickness of the Ni layer was considered as the optimum thickness for our experiments. In addition, the thin Ag seed layer will positively enhance temperature sensitivity.

The theoretical model for a 33 μm Ni coating predicts sensitivity of 0.0229 nm °C−1 for temperature and 0.308 nm N−1 for axial force.

4. Experimental and modeling results

As described before, LAMM was used to deposit the conductive Ag layer followed by Ni electroless plating to deposit a 33 μm Ni layer on the thin Ag film.

4.1. Optical microscopy images

Several experiments were done to test the thickness of Ni which is affected by the duration of electroless plating. The dependence of the thickness on the duration of Ni plating is shown in figure 7. The Ag and Ni coatings are shown in figures 8 and 9, respectively.
Figure 10. Fiber coated with 1 μm thin Ag sintered with (a) 2.5 W laser, (b) 3.5 W laser and (c) 4.5 W laser.

Figure 11. Fiber coated with a 33 μm Ni layer with (a) 2.5 W laser, (b) 3.5 W laser and (c) 4.5 W laser for Ag sintering.

4.2. SEM results

4.2.1. Fiber coated with Ag. Figure 10 shows the fibers coated with Ag before electroless plating when they have been sintered at different laser power (2.5, 3.5 and 4.5 W) and followed by a hot plate at 230 °C for 1 h.

As seen from the pictures, the 4.5 W and 3.5 W laser powers have created more cracks on the Ag surface compared to the low laser power (2.5 W). The crack formation may be a result of over-sintering and possible shrinkage and residual stress in the agglomerated Ag. It may be controllable by adjusting the sintering temperature and the thickness of the Ag coating. Although some cracks are distinguishable, the cracks did not exhibit any counterproductivity during the Ni plating.

4.2.2. Fiber coated with Ni. Figure 11 shows the SEM pictures of the FBG sensor after Ni electroless plating.

When compared with the high (4.5 W) power laser sintering fiber sample, which is shown in figure 11(c), the low and medium laser power sintering sample shows quite good quality, the surface of the Ni is smooth and even, and with less porosity and cracks.

4.3. EDAX results

Using EDAX, the chemical composition of the deposited layers can be detected.

Table 4 shows the chemical composition of the deposited layers.

<table>
<thead>
<tr>
<th>Laser power</th>
<th>Ni (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High power (4.5 W)</td>
<td>81.09</td>
</tr>
<tr>
<td>Medium power (3.5 W)</td>
<td>91.34</td>
</tr>
<tr>
<td>Low power (2.5 W)</td>
<td>85.56</td>
</tr>
</tbody>
</table>

Ni layer. The Ni content is also higher compared to the sample sintered at other laser powers. We have observed that if we have a post-annealing process for 1 h using a hot plate, the Ni content of the sample increases to 100% within the spectrum area of 125 × 125 μm² as shown in figure 12.

4.4. Temperature sensitivity results

Figure 13 shows the experimental temperature sensitivity of the Bragg wavelength and modeling results for both bare and coated FBG. The experiments were repeated multiple times to ensure repeatability and reliability of data. As seen in the figure, the peak wavelength increases linearly with a slope of 0.0207 nm °C⁻¹. Compared to the bare FBG sensor with sensitivity of 0.01 nm °C⁻¹, it has almost doubled. This value is in excellent agreement with the 0.023 nm °C⁻¹ obtained from modeling.

4.5. Force sensitivity results

The experimental results from the force measurement are presented in figure 14. The experiments were repeated multiple
times to assess the repeatability and reliability of procedures. As seen in the figure, the Bragg wavelength has a sensitivity of 0.4155 nm N\(^{-1}\). The modeling results for bare and coated sensor have also been presented in the figure. The 2D error bar represents deviation in the force and the Bragg wavelength. Due to the sensitivity of our nano-stage to temperature, we could not apply a constant force to the sensor and thus present the force deviation using horizontal error bars.

Compared to the original bare sensor, which is 1.351 nm N\(^{-1}\), the coated FBG sensitivity with 1 \(\mu\)m Ag and 33 \(\mu\)m Ni coating has been decreased by 82%. Although they are close, this value is higher than the modeling value (i.e. 0.3078 nm °C\(^{-1}\)). The reason that the force sensitivity did not fall as low as the theoretical value could be the effect of the thin Ag layer, which was not considered in the modeling. This will be discussed in the next section.

5. Discussion

A combined LAMM and electroless plating process was developed to coat FBGs to not only produce a protective layer around the sensor but also to control the sensitivity of FBGs. Through many experimental trials conducted in this study, the combined coating process with the reported parameters has shown repeatable outcomes in terms of geometrical and physical properties of the coatings and the sensor performance as seen in figures 7, 13 and 14. Although the laser sintering
process caused some cracks and pores on Ag, the Ni layer is still even and smooth with high content of Ni. This will remain an open topic to achieve crack-free coatings while anticipating improved durability that in turn results in a longer life span.

The electroless plating process was observed to be extremely sensitive to the process parameters; however, the parameters and the procedures reported in this paper may confidently be used for the fiber coating. By adjusting the ratio of the solution and adding the activation processes, the Ni layer was successfully deposited on the conductive Ag layer.

In our study, different kinds of coating materials were analyzed and the optimum thickness and material, which are manufacturable, were selected based on the results of an opto-mechanical model. A thickness of 33 μm was an optimum value for Ni on a 1 μm thick Ag seed layer.

The Ni–Ag layer doubles the thermal sensitivity of the bare FBG and provides protection to the sensor at transient high temperature conditions. This rise in sensitivity will promote the precision of the sensor to measure temperature variations in a variety of environments. Figure 13 contains the original bare FBG sensitivity and modeling results from room temperature to 105 °C. As seen, the improved FBG sensor’s thermal sensitivity is 2.07 times higher than the bare FBG sensor. There is a slight difference of 10% between the modeling and experimental data which may result from the absence of the Ag layer in the model and also experimental errors in temperature measurements.

According to figure 14, the force sensitivity has been decreased to 0.4155 nm N⁻¹, which is a third of that of the uncoated bare FBGs.

The modeling results show a lower sensitivity than the experimental ones. This can be related to the fact that in the opto-mechanical modeling, the Ag layer was not considered due to its small thickness. The reason may also be attributed to the test setup and uncertainties arising from the friction in the moving parts. In addition, we considered the bulk physical properties in the modeling that may vary from the thin film properties. This may impose some numerical errors on the modeling results.

When compared with other results reported in the literature, the method in this study provides better and comparable temperature sensitivity which is adjustable by controlling the geometry of the coatings. Our methodology resulted in lower force sensitivity; however, the thickness parameters were selected in such a way as to result in a minimum reduction in the force sensitivity.

Feng et al [13] have reported that the Cu–Ni coating showed a temperature sensitivity approximately twice that of the bare FBG. Zhu et al [24] reported on Ni-coated FBGs, with the thickness of 2.8 μm, with a temperature sensitivity of 1.3 times higher than the bare FBGs. They also showed that using electroplating process, the thickness of Ni was increased to 60.85 μm and the temperature sensitivity was almost 1.6 times higher than bare FBGs. Li et al [25] used electroplating to partially plate Ni on FBGs. The part of FBG with metallic coating showed high thermal sensitivity (0.02605 nm °C⁻¹) and the non-metallized FBG kept the original sensitivity (0.01045 nm °C⁻¹). However, the force sensitivity has remained at 0.082 nm N⁻¹. As observed, the sensitivities reported in this paper are better than or comparable to the counterpart studies.

6. Conclusion

A novel combined LAMM and electroless plating manufacturing technique was developed to effectively and
selectively coat FBGs for the purpose of controlling the sensitivity of FBGs. Additionally, the coating can act as a protective layer on the fiber when it is embedded in larger metal components. A model to predict the sensitivity of the coated FBGs at different thicknesses for different materials was developed. Using this model, the optimal material and proper thickness were determined. It was shown that the bi-material Ni–Ag layer with 1 μm of Ag and 33 μm of Ni improves the sensor’s thermal sensitivity by a factor of 2 compared with a bare FBG sensor. The force sensitivity has been reduced by a factor of 3; however, this reduction is smaller than the amounts reported in the literature. The advantage of the proposed methodology is the enhancement of selectivity for FBG sensitivities using additive manufacturing of engineered coatings.

Acknowledgment

The authors gratefully acknowledge funding support from the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

[19] Foroozmehr E, Alemohammad H and Toyserkani E 2011 Dual-parameter optical fiber sensors for structural health monitoring Int. Workshop on Fibre and Optical Passive Components, WFOPC (Montreal, Canada) pp 1–4