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Temperature and strain sensing properties of the zinc coated FBG

Yulong Li*, Yubo Wang, Changjin Wen

Key Lab for Robot & Welding Automation of Jiangxi Province, Mechanical & Electrical Engineering School, Nanchang University, Nanchang 330031, China

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ABSTRACT

Fiber Bragg grating (FBG) was metal coated and the associated sensing properties were tested. In the metal coating, FBG was firstly coated with a thinner nickel conductive layer by chemical plating, and then electroplated with a thicker zinc coating. Surfaces of the metal coated FBGs are smooth, uniform and compact, without any obvious defects. Temperature and strain sensing results show that temperature sensitivity of the zinc coated FBG can be enhanced about 5 times than the bare FBG, and the wavelength shift under the applied load shows a linear trend as well. In order to further study the thermal sensing properties, three zinc coated FBGs and a bare FBG were compared in subjecting to the transiently changed temperature. Results indicate that the response tendency of the zinc coated FBG to a transient temperature change is similar to that of bare FBG, which could be attributed to the small thermal capacity and thickness of the metal coating. In addition, the central wavelength stability of the metal coated FBG is lower than that of the bare FBG due to the high temperature sensitivity.

1. Introduction

FBG sensors have undergone a rapid development in civil engineering, chemical industries, aerospace engineering, petroleum chemical industry and so on, because of the advantages over traditional sensors such as immunity to electromagnetic interference, remote sensing, easy in handing, low cost, small size and light weight [1–4]. Nevertheless, FBG (mainly composed of SiO_2) is so fragile that may be damaged by the nonuniform stress, strain, and thermal loads during the application. Hence, protective coatings are necessary for FBG sensors applied in the harsh environment.

In the present studies, methods of vacuum evaporation [5], sputtering [6–9], dipping [10,11], chemical plating and electroplating [12–17] were proposed for metal coating of FBGs. Typically, Sekar et al. [5] coated FBGs with Al/Pb by using flash evaporation technology, and they studied the thermal response of the metal coated FBG and compared the differences of temperature sensing between the Al and Pb coated FBGs. Dai et al. [6] sputtered Pd/Ag and Pd/Ni [7] on the etched FBGs, respectively, forming novel optical fiber hydrogen sensors. Results showed that the hydrogen sensors had great potential in the measurement of hydrogen. The vacuum evaporation and sputtering are, however, too expensive due to the equipment expense and time-consuming. Kim et al. [10] applied molten tin on FBG by dipping method. In his work, capability of producing residual strain and the tensile failure strength of tin-coated FBG sensors were experimentally investigated by cyclic

* Corresponding author.
E-mail addresses: liyulong1112ster@gmail.com, liyulong@ncu.edu.cn (Y. Li).

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Table 1
Chemical plating solution and the optimum conditions.

$NiSO_4 \cdot 7H_2O$	20–30 g/L
$NaH_2PO_2 \cdot 2H_2O$	15–25 g/L
$C_3H_6O_2$	15–25 ml/L
H_3BO_3	15–25 g/L
pH	4–5
Temperature	80–85 °C
Time	1–3 h

loading tests. However, for the hot-dipping method, melting point of the molten metal must be lower than that of substrate to be coated, which restricts other metals with high melting point to be coated on FBGs. Sandlin et al. [12] presented a method including chemical plating silver and electroplating nickel to FBG. Methods mentioned above have feasibilities for coating FBGs, while among the various coating methods, the method presented by Sandlin is economic and simple though some expensive silver was applied.

The accuracy and stability of the central wavelength of FBG is affected by the ambient conditions, which limits the engineering applications. Several studies concern on the stability of central wavelength of FBG to a limit extent: Zhao et al. [18] proposed a novel athermalisation of FBGs to reduce the fluctuations of central wavelength; Zhang et al. [19] pointed out that the stability of the central wavelength can be greatly improved by using a slow water-cooling for FBGs. However, central wavelength stability of FBGs after metallization is ignored by most of the researchers. According to the previous study, residual stress could be produced during the processes of plating [20], which could cause the fluctuation of centre wavelength [21]. Accordingly, the centre wavelength stability of FBGs after metallization should be systematically studied.

FBG sensors, which could be used to investigate transient behavior of the structures attract many researchers. Ma and Chuang [22] used FBG sensor to study the transient vertical displacement response of the cantilever subjected to the impact of a steel ball. Thomas and Okelman [23] used FBG sensors to monitor transient temperature and heat flux behavior of casting molds. However, transient response behavior of FBGs, especially response behavior of the metal coated FBG to the transient temperature change, has been rarely systematically studied. Hence, differences of the sensing behavior between bare FBG and metal-coated FBG to the transient temperature change should be investigated.

In this paper, FBG was firstly coated with a thin conductive nickel layer by chemical plating and then electroplated with a thick zinc coating. Efforts were made to develop a highly sensitive metal coated FBG as well as determine the sensing characteristics in terms of temperature/strain sensitivity, measurement stability and transient sensing behavior.

2. The metal coating process

2.1. Reaction theories of chemical plating

FBG can be coated with a nickel layer by the reduction of nickel sulfate complex with sodium phosphate, propionic acid, and boric acid in an acid condition within the temperature range of 80 °C–90 °C.

$$Ni^{2+} + 6H_2PO_2^- \rightarrow Ni \downarrow + 2P \downarrow + 4HPO_3^{2-} + 2H_2 \uparrow + 4H^+ \quad (1)$$

This reaction is known as hydrogenization chemical plating with sodium hypophosphite as the reducing agent, which is well accepted by most of the researchers.

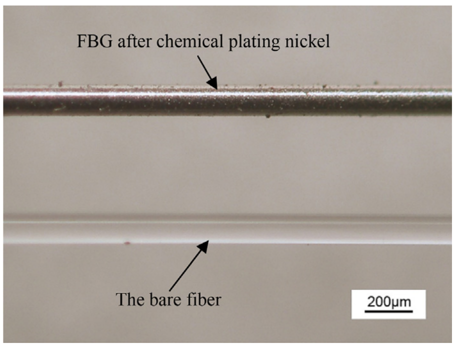

Fig. 1. Chemical plating results under optimum conditions.