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The use of thin diamond films in fiber-optic low-coherence interferometers

D. Milewska, K. Karpienko

Department of Metrology and Optoelectronics, Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology, Narutowicza Street 11/12, 80-233 Gdańsk, Poland

E-mail: k.karpienko@pro.wp.pl

Abstract. In this paper we present the use of thin diamond films in fiber-optic low-coherence interferometers. Two kinds of diamond surfaces were used: undoped diamond film and boron-doped diamond film. They were deposited on glass plates as well as silicon layers. A conventionally used mirror was used as a reference layer. Diamond films were deposited using Microwave Plasma Enhanced Chemical Vapour Deposition (μPE CVD) system. Measurements were performed using two superluminescent diodes (SLD) with wavelengths of 1300 mm and 1550 mm. The optimal conditions for each layers were examined: the required wavelength of the light source and the length of Fabry-Perot interferometer cavity. Metrological parameters of Fabry-Perot interferometer with different mirrors were compared. The presented thin diamond films may be an interesting alternative to the commonly used reflective surfaces.

1. Introduction

Fiber optic low-coherence interferometers are widely used as sensors of many physical [1,2] and biological quantities [3-5]. Information about the measured physical quantity is encoded in the full spectrum of light reflected from the sensing interferometer. A very important part of the sensing interferometer is a reflective layer and it has an impact on the quality of the obtained spectra. Application of diamond films in fiber-optic interferometers as a reflecting layer has the potential to improve the visibility of spectrum fringes. Moreover, they are biocompatible and provide great chemical stability. A Fabry-Perot interferometer has been successfully used as the sensing interferometer in many measurement systems [6,7]. One of the possible configurations is a fiber-optic Fabry-Perot interferometer operating in reflective mode. In this mode, the interference occurs due to multiple reflections of the light beam from two parallel surfaces: fiber tip and mirror, which is shown in Figure 1.

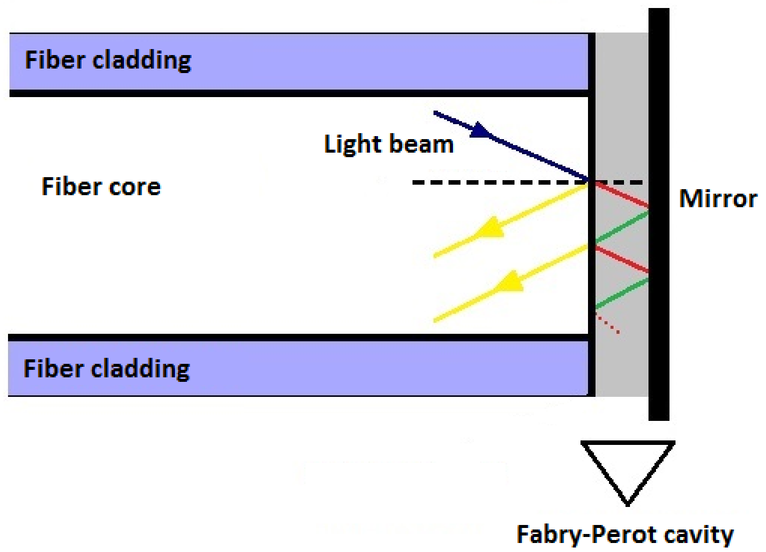

Figure 1. Fiber optic configuration of Fabry-Perot interferometer working at reflectance mode.

For the reflection mode, the optical intensity at the output of interferometer is given by [8]:

$$I_R = I_0[R + R(1-R)^2 + 2R(1-R)cos\varphi] \tag{1}$$

where: I_0 - intensity of light incident on the first boundary surface of the interferometer, R – reflectance of the reflecting surface, φ – phase shift.

The use of a broadband, low coherence light source in Fabry-Perot interferometer allows achieving high sensitivity, high resolution and dynamic measurement. However, in order to obtain the best possible metrological parameters of fiber-optic low-coherence Fabry-Perot interferometric sensors, the most important task is to maximize the visibility of the measured signal. This can be achieved by the use of the most suitable reflecting surface as a mirror in the Fabry-Perot cavity. Most commonly used as a reflective surface in the Fabry-Perot interferometers are silver mirrors. This material is cheap and sufficiently well reflecting for a light beam, however, it is sensitive to mechanical damage. Therefore, there is a need to implement other materials as the reflective surfaces so as to achieve greater resistance to harmful mechanical and chemical conditions. In addition, with a view to using a fiber-optic low-coherence Fabry-Perot interferometer as a biosensor, the reflective surface should be biocompatible with the measured sample (e.g. bodily fluids) and provide great chemical stability. Diamond thin films meet all these conditions. Moreover, application of diamond films as a reflecting layer has the potential to improve the visibility of measured signal. In the presented experiment, we investigate the possibility of using diamond thin films as reflective surfaces in Fabry-Perot interferometer.

2. Materials

Diamonds are characterized by high thermal conductivity [9] mechanical hardness, optical transparency in broad wavelength [10,11] and biocompatibility [12,13]. In addition, diamond doped with boron is a promising material to build various biocompatible and chemically stable optical biosensors.

In the experiment two kinds of diamond thin films as a reflective surfaces were investigated: undoped diamond and boron-doped diamond. Both materials were deposited on glass plates as well as silicon substrates. A silver mirror was used as a reference reflective surface.

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Diamond thin films were deposited using the microwave plasma assisted chemical vapor deposition (μPE CVD). The undoped and boron-doped diamond films were synthetized with the use of MW PA CVD system (SEKI Technotron AX6200S, Japan). Substrate temperature was approximately at 500 ^{o}C and plasma excitation was achieved by the microwave radiation (2.45GHz). Base pressure inside the chamber was 10−4 Torr and process pressure 50 Torr. Mixture of hydrogen, methane (1%) and diboran (boron-doped – 5%, undoped – 0%) filled the chamber. The doping level of boron in the gas phase was 10 000 ppm. The growth time were: 60 min for silicon substrates and 270 min for glass plates. Preparation of diamond film on glass plates have been described by Sobaszek et al. [14]. Produced diamonds films have thickness of ~ 200-300 nm.

3. Experimental

The experimental setup consists of two interchangeable, broadband light sources (superluminescent diodes) produced by Superlum Ltd., Ireland. Parameters of these light sources were as follows:

- S1300-G-I-20: λ = 1290 nm, $\Delta\lambda_{FWHM}$ = 50 nm,
- S-1550-G-I-20: λ = 1550 nm, $\Delta\lambda_{FWHM}$ = 45 nm.

Detection of the measured signal was performed using an Ando AQ6319 optical spectrum analyzer with resolution bandwidth set to 1 nm. All devices were connected with a single-mode commercially available, telecommunications coupler (fibre SMF-28). The Fabry-Perot interferometer was formed by the fibre tip and the examined reflective surface.

4. Results

The identification of the optimal length of Fabry-Perot cavity for the reference surface – silver mirror (Figure 1a) was the first step of the experiment. Then, measurements of undoped and boron-doped diamond thin films on silicon substrates and glass plates were performed. For each reflective surface, the influence of the length of the Fabry-Perot cavity on the visibility of the measured signal was investigated. At each measurement, the cavity length was varied from 0 μm to 600 μm in increments of 50 μm. Representative measured spectra obtained with a cavity length of 200 μm are presented in Figure 2.

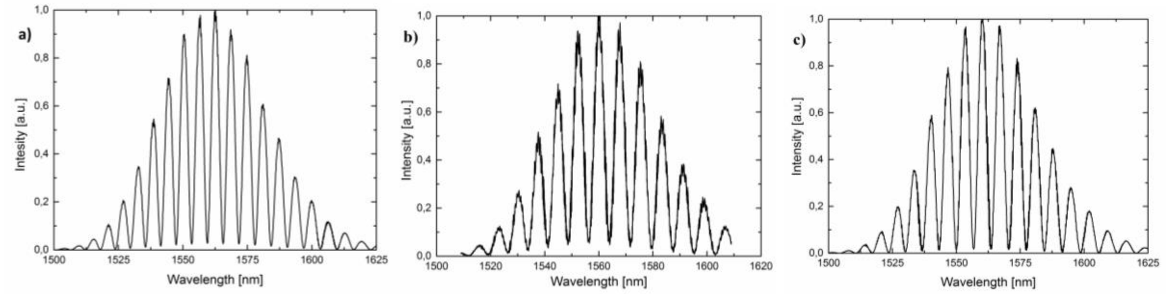

Figure 2. Representative registered spectra from the low-coherence fiber-optic Fabry-Perot interferometer, light source 1500 nm: (a) silver mirror;(b) undoped diamond on glass plate; (c) boron-doped diamond on glass plates.

It can be noted that the use of the investigated reflective surfaces did not worsen the signal visibility. However, the spectral separation was changed. This was due to the change in refractive index and does not affect the proper operation of the measurement system. Comparison of the obtained visibility for all of reflecting surfacea at a length of Fabry-Perot cavity equal to 200 μm, is shown in Table 1.

Table 1. The visibility value for different reflective surfaces of Fabry-Perot cavity and different light sources. The length of the Fabry-Perot cavity was constant – 200 µm.

Reflective surface	Light source [nm]	Signal visibility [%]
silver mirror	1300	97,2
undoped diamond on silicon substrate	1300	97
boron-doped diamond on silicon substrate	1300	51
undoped diamond on glass plates	1300	62,2
boron-doped diamond on glass plates	1300	91,1
silver layer	1500	97,3
undoped diamond on silicon substrate	1500	80,3
boron-doped diamond on silicon substrate	1500	63,4
undoped diamond on glass plates	1500	94,9
boron-doped diamond on glass plates	1500	98.1

As it can be noted from Table 1. The use of boron-doped thin films deposited on glass plates as reflective surfaces allows us to achieve a high visibility value, almost as high as when the silver mirror is used. The value of measured signal visibility when undoped diamond films deposited on silicon substrate are used is smaller, yet still acceptable and interesting for sensing applications.
The use of different mirrors influences the optimal geometrical parameters of Fabry-Perot cavity. For the use of silver mirror and silicon substrates as interferometer mirror the optimal length of cavity is 200 µm, when for thin films deposited on glass plates is 100 µm and 150 µm for undoped and boron-doped diamond on glass plates respectively.

Table 2. The value of visibility of the measured signal for thin films deposited on glass plates for different lengths of the Fabry-Perot cavity and different light sources.

Reflective surface	Light source [nm]	Length of the Fabry-Perot cavity [µm]	Signal visibility [%]
undoped diamond on glass plates,	1300	100	82,5
boron-doped diamond on glass plates	1300	150	97
undoped diamond on glass plates	1500	150	99,4
boron-doped diamond on glass plates	1500	150	99,7

The obtained results indicate that undoped and boron-doped diamond films deposited on glass plates have shorter optimal Fabry-Perot cavity length, so they can be successfully implemented in measurements of thin samples.

5. Conclusion

An investigation of the possibility of using diamond thin films as a reflective surfaces in Fabry-Perot interferometer has been presented. Measurements with undoped and boron-doped diamond thin films as reflective surfaces in fiber optic low-coherence Fabry-Perot interferometer have been performed. Analysis of results indicates that the use of diamond thin films as the reflective surface in Fabry-Perot interferometer allows achieving very good visibility of the signal for the other lengths of the Fabry-Perot cavity, than those achievable using a conventional silver mirror. This property can be successfully used to change the size of Fabry-Perot cavity, so as to adapt its size to the sample. Moreover, Fabry-Perot interferometer with diamond thin film would be more immune to mechanical damage and chemical conditions. This kind of thin films may be used in biocompatible biosensors.

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