Innovative UV sensor based on highly birefringent fiber covered by graphene oxide

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Abstract— The innovative idea of this paper implies the possibility to exploit the properties of graphene oxide (GO) to UV radiation sensor design. The idea assumes that a temperature change around the fiber can be induced by UV radiation. In the case of UV radiation detection, particular attention should be focused on GO, which has a high UV absorption. Only UV lighting will increase the internal energy of GO and consequently locally raise the temperature on the surface of the optical fiber. The temperature changes the stress distribution in the fiber.

The measurement of UV radiation becomes very significant because of its numerous negative effects on human health. Ultraviolet radiation has genotoxic, mutagenic, cancerogenic and imunotoxic properties, which make ultraviolet radiation a serious threat to human health. In order to prevent dangerous influence of UV radiation, different methods for UV detection are developed. One example is UV detection with nanowires based on monitoring the current–voltage or electrical conductance variation when exposed to UV radiation [1]. An ultraviolet sensor based on ferroelectric-semiconductor thin film structures is proposed in [2]. A wireless UV sensor based on the photocapacitive effect in GaN (upon illumination of oscillator with ultraviolet light the oscillator frequency decreases due to the photocapacitive effect) is reported in [3]. These are relatively complex methods of measuring ultraviolet radiation. The need for simpler solutions has led to fiber optic sensors.

Fiber-optic sensors have many advantages over conventional optical sensors [4]. Fiber-optic sensors are small in size, light, electrically safe and immune to electromagnetic interference. The immunity to electromagnetic interference is especially important during measurements near an UV lamp due to intense electromagnetic fields encountered in its vicinity [5]. Also, fiber-optic sensors offer the possibility of distributed and localized measurements along the whole sensor length, ensuring power measurements over an interval and in a point.

In the case of UV radiation detection, particular attention should be focused on graphene oxide (GO), which has a high UV absorption [6]. A typical absorbance spectrum of aqueous solution of graphene oxide (Fig. 1) shows the absorption maximum at 230nm [7]. Other wavelengths (visible and infrared) are not absorbed to a significant extent. UV lighting will increase the internal energy of GO and, consequently, locally raise the temperature on the surface of the optical fiber. The temperature change can affect light propagation in the fiber in many ways [8].

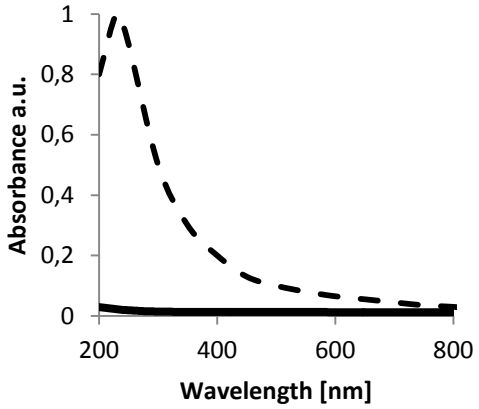

Fig. 1. Typical UV-vis absorbance spectrum of synthesized graphene oxide in solution [7] (dashed line) and fused silica (line).

In this paper we investigate the possible use of graphene oxide to measure UV radiation by using a highly birefringent (HB) fiber. This approach has a number of advantages over the arrangements currently used. The main advantage is the ability to easily use different types of optical sensors recording temperature changes. The measuring system has all advantages of fiber optic sensors and can also be optimized in terms of selection of light sources and detectors so that the cost of its implementation would be modest.

Polarimetric optical fiber sensors based on highly birefringent polarization-maintaining fibers have focused great interest for the last decades [9-10]. In HB fibers, the difference between the phase velocities for two orthogonally polarized modes is high enough to avoid coupling between these two modes. Fibers of this class have a built-in, well-defined, high internal birefringence obtained by designing a core and/or cladding with noncircular (mostly elliptical) geometry, or by using

anisotropic stress applying parts built into the cross-section of the fiber.

The modal behavior of the lowest-order mode HB fibers under various external deformations is of special interest for sensors and device applications. A number of physical quantities can be measured on the basis of HB fibers: hydrostatic pressure, strain, vibration, temperature, acoustic wave, etc.

A symmetric deformation effect induced by temperature, influences both propagation constants β of the polarization modes. In a single-mode regime, this leads to changes in the phase difference between both polarizations of the fundamental LP_{01} mode along the fiber [1]:

$$\frac{\delta(\Delta\Phi)}{\delta T} = \Delta\beta\frac{\partial L}{\partial T} + L\frac{\partial(\Delta\beta)}{\partial T}. \quad (1)$$

The effect of temperature on mode coupling is to modulate the relative phase retardation between the two orthogonal polarizations in the LP_{01} mode. The general formula describing the birefringence sensitivity to temperature can be expressed in terms of an experimental parameter T_T describing the amount of temperature T required to induce a 2π phase shift of a polarized light observed at the output as [3]:

$$\Delta\beta(T) = \Delta\beta^0 + T\frac{2\pi}{T_T L}, \quad (2)$$

where $\Delta\beta^0$ signifies the unperturbated polarization birefringence of the fiber.

Graphene oxide films were produced via a standard vacuum filtration method [11] and deposited onto an optical fiber. As a starting material we used a water solution of the graphene oxide (concentration - 4mg/ml) purchased from Graphenea. Before a vacuum process the solution was diluted by pure water (18MΩ) to obtain a concentration of 0.1mg/ml. In order to achieve 100nm thickness of the GO film, an appropriate amount of the solution was vacuum filtered onto a mixed cellulose ester membrane (MCE, 0.45μm pore-size, 25mm diameter). The thickness was calibrated by the AFM measurements by using flat substrates. After the vacuum process, the membrane was dried. Next, the GO film coated MCE membrane was cut to obtain 2mm×3mm small pieces, which were immediately immersed into liquid acetone to dissolve the membrane. When the GO films were cleaned from the residual filter, the acetone was replaced by the ethanol/water solution with the ratio of 1:1. Then a small piece of pure GO thin film was transferred onto each optical fiber and gently dried by the nitrogen stream (Fig. 2).

A typical Raman spectrum of a graphene oxide film covering the optical fiber is shown in Fig. 3. Two main bands can be seen: D-band (1357.55cm^{-1}) and G-band (1588.84cm^{-1}), which are typical of graphene oxide material. The relative intensity ratio of these peaks (ID/IG=1.32) confirms the presence of GO on the fiber [12-13]. Raman measurements have been performed by using a Renishaw inVia spectrometer equipped with a laser operating at the 514-nm wavelength. Measurements were done at room temperature in air and with a low power (1mW) laser. The spectra are reproducible all over the sample.

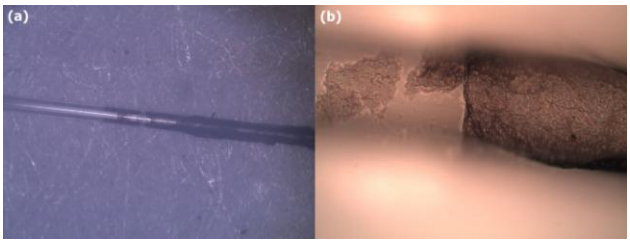

Fig. 2. Image from an optical microscope of optical fiber partially covered by a film of graphene oxide: (a) objective 5×, (b) objective 50×.

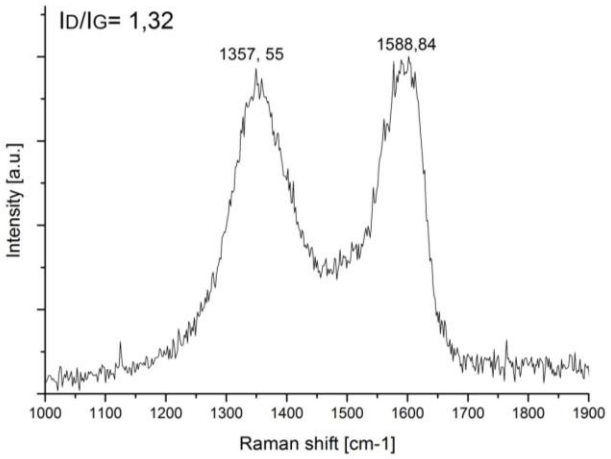

Fig. 3. A typical Raman spectrum of a GO thin film deposited on optical fiber. Peak position obtained from lorentzian fit.

In the experiment, a 405-nm laser beam was focused (Fig. 4) on the covered and uncovered parts of the fiber separately. The measurement system included also a 633-nm laser source and the HB fiber. The output fiber signal was monitored with a Soleil-Babinet compensator and an analyzer. A half wave plate was used to excite both polarization modes in HB fiber. The UV light focused on the HB fiber covered by GO is absorbed and heats the fiber. An increase of temperature around the HB fiber is registered as a change in the output polarization of the 633-nm light propagated in the fiber. On the other hand, the focused UV light on the HB fiber uncovered by GO is not absorbed by the fiber.

The bow tie HB fiber is known for high temperature sensitivity (7.4rad/m·K) [14]. The heated length of the

HB fiber was 4 mm long. The results presented in Fig. 5 show that the UV light absorbed by GO warms up the HB fiber. The measurement data were collected repeatedly in order to become independent from ambient temperature changes. The average temperature change on the surface of the fiber calculated from the experimental results was about 20K for maximum laser power. Therefore temperature changes of the GO layer were not significant. The reduction of the GO layers appears when temperature changes are higher than 300K [15]. Any polarization change was registered when the uncovered part of the fiber was exposed to UV light.

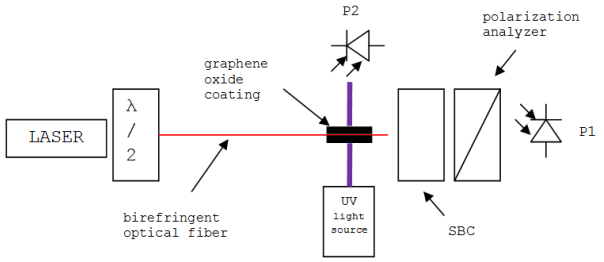

Fig. 4. Measurement setup, where P1 and P2 are detectors.

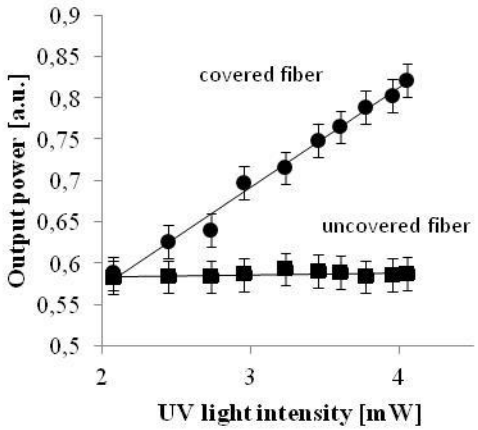

Fig. 5. Output light intensity of the 633nm beam as a function of UV light intensity focused on covered (dots) and uncovered (squares) parts of the HB fiber.

In conclusion, in this paper the authors have investigated a possible use of the graphene oxide to measure UV radiation by using a highly birefringent fiber. The results obtained show that UV light focused on the HB fiber covered by GO induces changes in the output polarization of the 633nm light propagated in the HB fiber. These polarization changes can be easily converted to light intensity changes by the analyzer. An effective way to improve the measurement sensitivity of UV light is to increase the illuminated area.

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