Influence of Gold Nanoparticles Film on the Sensitivity of Long Period Fiber Grating

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Abstract: The responses of three coated and uncoated long period gratings to the refractive index of the surroundings are compared. Gratings operate at the visible spectral range close to the plasmon resonance band of gold nanoparticles. Sensitivity increase up to 85.2% was achieved after coating the grating.

1. Introduction

Optical fiber sensors based on long period gratings (LPG) have been widely employed to detect chemical and biological agents. The key characteristic that enables the detection is the interaction between the light transmitted by the fiber and the surrounding medium. Such interaction relies on the coupling between the fundamental core mode and the *m-th* co-propagating cladding modes [1] provided by the grating. Such coupling results in attenuation bands centered at wavelengths λ_m given by $\lambda_m = (n^{eff,}_{core} - n^{eff,}_{clad(m)})\Lambda$, where $n^{eff,}_{core}$ and $n^{eff,}_{clad(m)}$ are the effective refractive indexes of fundamental core mode and the *m-th* cladding mode, respectively, and Λ is the grating pitch. As the $n^{eff,}_{clad(m)}$ depends on the refractive index of the medium surrounding the fiber, LPG is a very attractive refractive index sensor, however presenting low sensitivities in water environments. An effective method to increase the LPG sensitivity in such media is promoting the coupling between the evanescent fields of the cladding modes with localized surface plasmon resonances (LSPR) that can be produced on the fiber. In this sense, gold nanoparticles (AuNP) deposited on the fiber surface have been employed for this purpose [2,3].

A chemical route is normally employed to reduce Au^{3+} to Au^0 in order to grow the AuNP in a reaction between tetrachloauric acid ($HAuCl_4$) and sodium borohydride ($NaBH_4$), resulting in a film which characteristics are critically dependent on the relative concentrations of the reagents. An alternative and promising method that discards the use of the reducing agent and results in a more homogeneous films with smaller AuNPs and increased crystallinity is the thermal route for the tetrachloauric reduction [4].

In this work, the synthesis of AuNPs via thermal route was adapted in order to produce an AuNP film on the surface of an optical fiber with a previously inscribed LPG. The AuNPs films were produced on the surface of three LPGs using solutions with different concentrations of $HAuCl_4$. The effect of matching the resonances of several LPG modes and the localized surface plasmon band was analyzed as a function of the refractive index of the medium surrounding the device.

2. Methodology

The LPGs used in this work were produced in hydrogen-loaded optical fiber (Thorlabs SM-450, n_{clad} =1.4616 at 514 nm, cut-off @ 350-470 nm) at the Photorefractive Devices Unit of the Federal University of Technology – PR. The fiber was exposed to the light emitted by a UV laser (Coherent, Xantos XS, ArF at 193 nm, frequency of 300 Hz and energy per pulse of 5 mJ) producing gratings with periods of modulation (pitch) of 60 µm (LPG1 and LPG2) and of 90 µm (LPG3). The writing parameters were chosen in order to obtain LPGs with attenuation bands at the visible spectral range near the turning point and resonant with the gold nanoparticles LSPR band. LPGs responses to changes in the external medium refractive index were measured before and after the deposition of the gold nanoparticles film over the fiber surface.

LPGs sensitivities were determined from their transmission spectra acquired using the light of a broadband source (FOSTEC, EKE 8375) and a UV-Vis spectrometer (Ocean Optics, HR4000 with resolution of 3.3 nm). Transmission was measured with the LPG kept under constant longitudinal strain on the surface of a glass slide. Liquid samples containing different proportions of water and glycerin were carefully poured over the LPG. During the experiments, realized to measure the samples refractive index and to acquire the LPG transmission spectra, a thermostatic bath (Lauda Staredition RE212) connected to an Abbe refractometer (Atago, DR-A1, 0.0001 resolution, 1.3000 – 1.7100 nD) was used to keep the temperature of the samples and the LPG at (20.0 ±