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Matching long-period grating modes and localized plasmon resonances: effect on the sensitivity of the grating to the surrounding refractive index

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The sensitivity and dynamical range of an optical-fiber transducer consisting of a long-period grating coated with gold nanoparticles is investigated. For a grating with an 80 μm spatial periodicity, the resonances close to the turning point lie within the 450–900 nm spectral range. Employing a bottom-up production route, the localized surface plasmon resonance of gold nanoparticles is matched to the grating resonances; it is shown that this results in an increase in the refractive index sensitivity of the device. The device also shows increased dynamic range and enhanced refractive index sensitivity in water.

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1. INTRODUCTION

The ability of surface coatings to improve the performance of optical sensors has been widely explored in the past few years [1–3]. New sensors based on optical fibers coated with films of metallic nanoparticles have been proposed, and it has been demonstrated that sensor characteristics, such as sensitivity and dynamical range, can be improved by coating the fiber [3]. These devices combine the unique properties of nanoparticles with the well-known advantages of fiber-optic sensors: small dimensions, real-time monitoring, multiplexing, and remote-sensing capabilities.

Different optical-fiber sensor concepts have been proposed to excite the surface plasmons in metallic nanostructured films [4–7]. These sensors take advantage of the light propagation through optical fibers to promote efficient coupling to the surface plasmon resonance (SPR) of the nanostructures. An important drawback that must be considered in the design of optical-fiber plasmonic sensors arises due to the need for a specific polarization state of the light used to excite the resonance of a surface plasmon polariton (SPP). For such cases, when the boundary between the fiber cladding and the external medium is a continuous metallic film of adequate thickness, the excitation of an SPP requires light polarized perpendicularly to the metal surface (i.e., TM polarization). However, for cylindrical optical fibers with hybrid modes, only a portion of the guided light fulfills this requirement, decreasing the amount of light that can be used to excite the plasmons. This is not the case when metallic nanoparticles are used, mainly owing to the three-dimensional characteristics of the particle surface. The increased surface provides a greater contact area with the analyte, improving the overall detection efficiency of the sensor [3].

Refractometric sensors based on long-period fiber gratings coated with metallic films have also been reported [6,8]. For these fiber sensors, the evanescent modal field of the guided cladding modes is used to excite the SPR or the localized surface plasmon resonance (LSPR). Among fiber-optic structures, long period gratings (LPGs) are considered to be one of the most sensitive to external parameters, particularly the surrounding refractive index, which justifies the interest in this device. Uncoated LPGs have been proposed as refractometric sensors for different applications [9].

LPG results from a periodic modulation produced in the refractive index of the optical-fiber core along its length. Light launched in the fiber core is coupled from the fundamental core mode to the cladding modes after interaction with the grating, when the phase-matching condition is satisfied, and thereafter is coupled from the cladding modes to the radiation modes. Attenuation bands appear in the fiber-transmission spectrum at wavelengths specified by the phase-matching condition. The spectral position of these bands depends on the modal field interaction with the surrounding medium and, therefore, on the order of the cladding mode. This interaction