Interaction of LSP resonances and Fabry-Perot cavity modes

M. Bahramipanah¹, S. Dutta-Gupta¹, B. Abasahl, and O. J. F. Martin¹*  
¹ Nanophotonic and Metrology Laboratory, Swiss Federal Institute of Technology, Lausanne, Switzerland  
*corresponding author: olivier.martin@epfl.ch

Abstract- We experimentally and numerically demonstrate the coupling between Fabry–Perot modes of the microcavities and the localized surface plasmon resonance of metallic nanostructures. Coupling the plasmonic nanostructures to a Fabry–Perot microcavity creates compound modes, which have the characteristics of both Fabry–Perot and the LSPR modes. The special features of the proposed structure and the device concept introduced in this work are applicable in the realization of ultra-high sensitive plasmonic devices for biosensing, optoelectronics, and related technologies.

Recent developments in nanotechnology have led to the fabrication of new optical sensors that can measure a broad range of analytes in liquid and gaseous forms [1–2]. The overall figure-of-merit of the sensing response of LSP-based sensors harshly suffers from the wide plasmon resonance linewidth associated with the large intrinsic absorption of metals at optical wavelengths [3]. In this paper, we demonstrate that coupling the dipolar plasmon resonance of a two-dimensional nanodisks array to the narrow bandwidth resonances of an optical microcavity creates compound modes, which effectively combine the advantages of Fabry–Perot microrcavities with those of plasmonic nanostructures, providing exceptional features such as ultra-high sensitivity and FoM, large spatial sensing depth and strongly improved detection resolution.

Figure 1. Light paths through the cavity-coupled plasmonic structure.

The cavity-coupled plasmonic structure studied here is shown in Fig. 1. When the structure is illuminated from the glass side, some of the light is reflected back from the nanodisks array, with a phase change of $\Delta \phi_1$, and some of the light is transmitted into the microcavity. During one round-trip inside the Fabry-Perot cavity, the light is partly reflected back from the nanodisks array into the cavity and partly transmitted out of the cavity with a $\Delta \phi_2$ phase change. When the geometrical parameters of the nanodisks array and Fabry-Perot cavity are properly chosen, the transmitted light from inside the cavity will have an odd multiple of $\pi$ phase difference with the light reflected back from the nanodisks array, i.e., $\Delta \phi_2 - \Delta \phi_1 = (2k-1)\pi$, and destructive interference for the total reflection from the structure will be achieved. In this case, a net absorption at the corresponding wavelengths can be observed (perfect absorption). However, when the Fabry-Perot resonances coincide with the LSPR mode of the nanodisks array, the transmitted light from the cavity will have an even multiple of $\pi$ phase difference with the light reflected back from the nanodisks array, i.e., $\Delta \phi_2 - \Delta \phi_1 = (2k)\pi$, and constructive
interference for the total reflection will be achieved, which leads to a near unity reflection. We study the effect of the cavity length on the optical response of the system. The material inside the cavity is assumed to be air. The normalized reflectance and the phase difference between the transmitted light from the cavity and the reflected light from the nanodisks array are shown as a function of the wavelength and of the cavity length in Figs 2(a) and 2(b). This figure clearly shows the Fabry-Perot modes and their number N. In the vicinity of these Fabry-Perot resonances, phase differences between the transmitted light from the cavity and the reflected light from the nanodisks array exhibit strong variations with a $2\pi$ shift. In this case, destructive interference for the reflection is achieved. As can be seen in Fig. 2(a) and 2(b), for a fixed wavelength, the higher order modes of the cavity-coupled plasmonic structure exhibit the Fabry-Perot resonance condition with increasing microcavity length. Moreover, there is one region in Figs. 2(a) and 2(b) where the Fabry-Perot dips vanish, such that near unity reflection is achieved. This region, highlighted by a horizontal white dashed line, corresponds to the LSPR mode. We observe that when the Fabry-Perot resonances coincide with the LSPR mode of the nanodisks array, the transmitted light from the cavity is in phase with the reflected light from the nanodisks array interface and constructive interference of the reflected planewaves leads to near unity reflection. When the cavity length is varied, this interaction with the plasmon mode occurs whenever the cavity resonance is equal to the LSPR resonance. Vertical black arrows in Figs. 2(a) and (b) indicate these resonant modes. This very significant narrowing in the linewidth of the cavity-coupled plasmonic structure arise from the high quality factor of the microcavity and has a positive influence on the sensing capabilities of the structure.

Figure 2. Colormap maps of (a) normalized reflectance and (b) phase difference of the transmitted light outside the cavity as a function of the wavelength and cavity length for cavity-coupled plasmonic structures.

REFERENCES