Intersubband Surface Plasmon Polariton Modes and Exceptional Points in Lossy Planar Plasmonic Resonators

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The strong coupling between a collective intersubband excitation in a multiple quantum well (MQW) structure and the ground photonic mode of the semiconductor microcavity (MC) leads to the formation of coherent mixed modes termed intersubband-cavity-polaritons (ICPs). The ICPs have attracted great attention of the research community. It is mainly due to the fact that the intersubband optoelectronic devices operating in a strong coupling regime have potential for applications [1].

The majority of work on the intersubband-polaritons has explored all dielectric, hybrid metal-dielectric or double metal MCs. The dispersion characteristics of the intersubband-surface-plasmon-polaritons (ISPPs) supported by (lossless) all-semiconductor three- and four-layer planar plasmonic resonators (with identical semi-infinite plasmonic mirrors) have been investigated theoretically in our recent paper [2]. A semiclassical approach based on the transfer matrix formalism and the effective medium approximation has been employed. The results obtained indicate, for example, that in the case of four-layer (asymmetric) structures, the ISPP branches have a multimode character. Moreover, their dispersion characteristics, can be engineered in the context of the slow/stopped light phenomena [3], i.e., the formation of zero group velocity points at finite values of $k_{\parallel}$.

In this work we discusse the influence of losses on the dispersion characteristics of the ISPPs branches supported by the above mentioned plasmonic resonators. We focus on the temporal-damped excitations which can be described by a real in-plane wave vector $k_{\parallel}$ and complex mode frequency ω. The complex-ω picture is relevant for applications that utilize, like in [3], an optical pulse (not a continuous pump source) to excite the modes of the system. In particular, we will show that in the case of the ISPP branches originating from the antisymmetric surface-plasmon-polariton mode the transition through (or more realistically in the vicinity) of the exceptional points (EPs) is potentially possible by changing continuously only one parameter $k_{\parallel}$. In other words, the situation is similar to the case studied experimentaly in [4] where the continuous transition between weak and ultrastrong coupling through EP in a carbon nanotube-microcavity system has been realized. It is worth to stress that at EP not only the real and imaginary pars of two eigenvalues are identical but also the eigenvectors. It implies a whole host of interesting phenomena which have recently attracted enormous interest [5]. For example, very counterintuitive influence of an EP on the operation characteristics a coupled microcavity QCL has been demonstrated [6].

[1] R. Colombelli and J.-M. Manceau, *Phys. Rev. X* **5**, 011031 (2015).
[2] M. Załużny, *Phys. Rev. B* **97**, 035308 (2018).
[3] T. Pickering, J. M. Hamm, A. Freddie, S. Wustner, and O. Hess, *Nat. Commun*. **5**, 4972 (2014).
[4] W. Gao, X. Li, M. Bamba, and J. Kono, *Nature Photonics* **12**, 362 (2018).
[5] M.-A. Miri and A. Alu, *Science* **363**, 1 (2019).
[6] M. Brandstetter, M. Lietzer, C. Deutsch, P. Klang, J. Schorbel, H.E. Tureci, G. Strasser, K. Unterrainer, and S. Rotter, *Nat. Commun*. **5**, 4034 (2014).