Enhanced Spontaneous Emission by Coupling of Radiation to Microcavity, Surface and Internal Guided Modes of One-Dimensional Photonic Crystals

ABSTRACT

The artificially manufactured photonic crystals which are composed of at least two different kinds of materials that differ in their dielectric constants and structured on an optical length scale are promising candidates for photonic device applications. In this thesis, enhancement of light-matter interaction with the help of one-dimensional (1D) microcavity mode, optical Tamm states (OTSs) at the 1D photonic crystal (1DPhC)-metal interface, the 1DPhC surface waves (PCSW) and the 1DPhC internal modes (PCIM) have been studied. The 1DPhC samples under study were fabricated by dip-coating dielectric thin films using economical sol-gel synthesis route. The experimental results have been supported by numerical calculations using transfer matrix method (TMM). To obtain enhancement of the spontaneous emission from emitters, materials having broad photoluminescence (PL) in the visible range of the electromagnetic spectrum are explored.

Graphene oxide (GO) sheets were incorporated in a 1D microcavity and the effect of the cavity resonance on the PL emission of GO has been studied. The field confinement in the optically active microcavity led to amplified spontaneous emission (ASE) at the microcavity resonance and at the low-frequency band-edge of the photonic stop band (PSB) of the structure. Also, the spectral position of the ASE peak is tuned as a function of the detection angle with respect to the sample surface normal. To study the optical Tamm states (OTSs) at room temperature, carbon quantum dots (CQDs) from organic precursors are embedded in the final few layers of the metal-1DPhC structure. The broad PL from the CQDs is amplified and controlled by the OTS coupled with the emitter at the metal-1DPhC interface. Consequently, ASE due to the presence of the OTS in the CQDs incorporated Tamm structure is demonstrated. These results are followed by studies on the coupling between the microcavity mode and the OTS in the 1DPhC framework to compare the enhancements in microcavity and OTS as a function of the spatial distance between the microcavity and the metal-1DPhC interface. It is observed that the microcavity mode and the OTS repel each other as the microcavity approaches the metal-1DPhC interface. The effect of coupling is experimentally demonstrated using reflectance and PL spectroscopies in CQDs incorporated coupled structures. Finally, the PCSW and the PCIMs of a 1DPhC have been explored to enhance directional fluorescence from emitting dipoles. The effect of the terminating dielectric layer on the PCSW and the PCIM has been studied numerically as well as experimentally. It is observed that the fluorescence enhancements corresponding to the PCSW and the PCIMs are comparable, showing equal significance of these modes for potential sensing device applications.

Keywords: One-dimensional photonic crystal, Microcavity, Optical Tamm states, Photonic crystal surface wave, Photonic crystal guided mode.