Spectroscopic Foundations of Lasers: Spontaneous Emission Into a Resonator Mode

Marc Eichhorn and Markus Pollnau

(Invited Paper)

***Abstract*—We review the physics underlying the process of spontaneous emission, with a special focus on spontaneous emission into a resonator mode. We define the mode volume, verify the fundamental modal dimensions, present the spectral mode profile, the coherence time, the Q-factor, the Füchtbauer–Ladenburg equation, and the Purcell factor, and discuss their influence on different types of lasers. We obtain the relation between peak emission cross section, radiative lifetime, and emission linewidth. By interpreting spontaneous emission as stimulated emission driven by vacuum fluctuations, we derive the spontaneous-emission rate into a resonator mode and establish physical expressions for the fractions of spontaneous emission and total decay from the upper laser level into this mode. Furthermore, we discuss coupling of the atomic system with the coherent field inside a lasing resonator mode, resulting in the formation of a Mollow triplet, and demonstrate that it leads to a reduction of the spontaneous-emission rate into a coherently occupied resonator mode by a factor of 2.**

***Index Terms*—Lasers, optical resonators, laser modes, luminescence, spontaneous emission.**

coherence of a laser, its Q-factor and linewidth, how the laser operation is initialized, how the laser threshold depends on decay channels from the upper laser level i) at other transitions, ii) non-radiatively, and iii) into other optical modes, nor how threshold-less lasing can occur in micro-resonators.

In this paper, we review the physics underlying the process of spontaneous emission, with a special focus on spontaneous emission into a resonator mode. In a straight-forward manner we demonstrate that spontaneous emission can be interpreted as stimulated emission driven by the one vacuum photon per optical mode and polarization. We define the mode volume and present the relationship between spectral mode profile, coherence time, and Q-factor. Of importance for understanding spontaneous emission into a resonator mode is the derivation of the fundamental modal dimensions. We then obtain the relation between the radiative lifetime and the emission cross section, called the Füchtbauer–Ladenburg equation, introduce the Purcell factor to this equation, and discuss its influence on different