

Three Thresholds of Non-Stationary Superradiant Lasing

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In the physics of conventional lasers, the transition from steady-state single-mode to steady-state non-stationary (self-modulation or multimode) lasing is well studied [1] and is known as the second laser threshold. It is observed, for example, with increasing continuous-wave (CW) incoherent pumping. In superradiant lasers with a dense extended ensemble of active centers (atoms) located inside a low-Q asymmetric, generally, Fabry-Perot (FP) cavity, where the photon lifetime is shorter than the phase (incoherent) relaxation time of the optical polarization of the active medium [1-3], this transition is more complex and remains poorly understood.

One principle point is that superradiant lasing in an active medium with weak inhomogeneous broadening of spectral line is driven by polariton modes, in which oscillations of the optical dipole moments of the active centers play a leading role compared to oscillations of the electromagnetic field [2, 3]. Another principle point is that the structure and dynamics of the fundamental lasing mode are largely determined by the half-wavelength population inversion grating of the active centers, which is created by self-consistent beats of counter-propagating polarization and field waves in the FP cavity and can stabilize or destabilize both the single-mode laser regime and the emission of a quasiperiodic train of superradiant pulses.

We find that due to the presence of this grating, with increasing pumping over a wide range of parameters of the FP cavity and the active medium, two zones of steady-state single-mode lasing take place, *i.e.*, four thresholds exist: (1) the emergence of steady-state single-mode lasing with a weak stable grating; (2) transition to a non-stationary regime with a self-modulated grating; (3) stabilization of one strongly nonlinear polariton mode defined by a stable highly inhomogeneous grating; (4) repeated transition to a non-stationary regime with a complicated dynamics of the half-wavelength population inversion grating of the active centers.

We indicate possible self-modulation and pulsed regimes near all three thresholds to non-stationary CW superradiant lasing, which depend on the properties of the active medium and the FP cavity. We describe typical examples including superradiant lasers on electrons and holes in magnetized quantum wells and on excitons and impurity centers in solid-state or semiconductor matrices [2]. The results are obtained by means of analytical estimates and numerical modeling of superradiant lasing based on the standard semiclassical Maxwell-Bloch equations [1-3] for an electromagnetic field and a two-level active medium in the FP cavity with due account for the self-generated population inversion grating.

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References

- [1] Ya I Khanin, Principles of Laser Dynamics (North Holland, 2012)
- [2] VL V Kocharovsky, V V Zheleznyakov, E R Kocharovskaya and V V Kocharovsky, Phys. Usp. **60**, 345 (2017)
- [3] E R Kocharovskaya and VL V Kocharovsky, Radiophys. Quantum Electron. **66**, 167 (2023)