

Lasers for a long time, were considered to be similar to the phenomenon of Bose-Einstein condensation, as both those events are characterized by incredibly large particle densities in the light emitting states and the same phase oscillations for all particles within the quantum state, so by the coherent emission. Because of those and many other similarities, there arose some important questions; namely, what is the difference between those two quantum phenomena, and how do distinguish one from another? This project aims to answer those questions by systematically studying particle number fluctuations and the dynamical response of the conventional semiconductor lasers and the Bose-Einstein condensates of photons trapped in semiconductor microcavities.

In this project, the intensity fluctuation will be studied by the measurement of the second-order quantum correlations of photons. Theoretical works concerning the statistical physics of many-body systems predict that the photon number fluctuations will strongly differ in those two quantum states. In the Bose-Einstein condensation of photon regime near the critical temperature of condensations, the fluctuations are predicted to be unusually large, while for conventional laser action related to the population inversion reached above the laser threshold current, the intensity fluctuations will be strongly suppressed and in an ideal case no fluctuations at all will be present, which is a long-known property of highly coherent light emission. Experimental observation of such large number fluctuations would prove that the Bose-Einstein condensate of a photon is a thermal source of coherent light where the macroscopically occupied light-emitting state is a result of statistical boson distribution, rather than the result of the stimulated light emission like in the conventional laser action. This will bring a powerful tool for distinguishing the conventional lasers from the Bose-Einstein condensates of photons, potentially revolutionizing our understanding of light emission and its applications.

The system in which the Bose-Einstein condensation of photons will be realized within the framework of this project is a widely used type of semiconductor laser called a vertical-cavity surface-emitting laser. It is the newest physical platform in which photon condensation is observed. Thus, its physics is still unexplored and new to the community. The second part of this project will focus on the fundamental characteristics of photon Bose-Einstein condensation in relation to the semiconductor medium. This will be realized by characterization of the dynamical frequency response of the photon condensate to carrier density perturbations induced by small signal modulation of the driving current. Through this dynamical response, the nonlinearities of the system can be investigated and their influence on the physics of Bose-Einstein condensation. Observations of measurable nonlinearities would make a huge impact on the understanding of this systems as to this day, most investigated Bose-Einstein condensate of photons was created in the rhodamine 6G filled optical microcavity where only thermo-optical nonlinearities are observed. Still, due to the slow nature of those nonlinearities, the response of photon condensation is unmeasurable, making this whole system effectively noninteracting condensate. In theory, the nonlinearities present in semiconductors are predicted to be significantly faster, which brings new possibilities for observing interactions of photons in the condensed state.