Abstract

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In recent years, research on the emission properties of perovskites at room temperature has been intensively pursued in the scientific community. Despite this, it is still a topic with many more unknowns compared to their counterparts, semiconductor materials, at cryogenic temperatures. Due to its amazing properties, including strong and effective emission at room temperature; a high absorption coefficient; the possibility of lasering on perovskite single crystals; high exciton binding energy (of the order of several hundred meV); and the possibility of tuning the emission in the visible light range by changing the cation or anion in the perovskite structure, they have become ideal candidates for applications in laser systems, studies of nonlinear phenomena, and observations of exciton-polaritons.

Exciton-polaritons are quasiparticles formed as a result of strong interactions of a photon with bound electron-hole pairs. They are most often observed in the structure of microcavity in which an optically active material is placed. The research carried out as part of this doctoral dissertation focuses on the observation of the regime of strong light-matter coupling and, consequently, the investigation of nonlinear phenomena, i.e. polariton condensation in perovskites at room temperature. The use of perovskites as efficient emitters opens a number of new possibilities for their use in electroluminescent and electro-optical devices operating at room temperature.

The main aim of this thesis was to produce, test, and describe perovskite materials integrated into the structure of an optical cavity. The goal was to observe exciton-polaritons and non-equilibrium polariton condensation at room temperature. As a consequence, the obtained structures were ultimately used to construct prototype devices emitting efficient light at room temperature.

This dissertation consists of eight main chapters:

Chapter I contains a general introduction to the research topic and a review of the literature on perovskites, optical microcavities and the regime of strong light-matter coupling and polariton condensation. It presents in detail the elements required to construct a perovskite microcavity, and in particular, presents the physical basis describing the behavior of excitons trapped in an optical microcavity. Experimental techniques enabling the observation and detection of exciton-polaritons and polariton condensation are discussed.

Chapter II is devoted to descriptions of the synthesis of the produced perovskite materials. Recipes for obtaining good quality polycrystals and single crystals of perovskites, both organic-inorganic and inorganic hybrids, are provided in detail. The following procedures are discussed: layer thinning (exfoliation) in hybrid perovskite single crystals and crystallization of perovskite single crystals in special PDMS templates with a given microwire geometry. The produced materials were subjected to detailed characterization to check the quality of the fabricated perovskites and qualified for further research in optical cavities.

Chapter III presents various ways of implementing the strong light-matter coupling regime at room temperature, in perovskite single crystals and in the structure of an optical microcavity with perovskite material (in polycrystalline and single-crystalline form). Moreover, polariton condensation on microwires of $CsPbBr_3$ single crystals is presented.

Chapter IV focuses on the use of polycrystalline PEPI perovskite in the creation of flexible, suspended perovskite polyimide films. As a result, a millimeter-sized device is presented that emits efficient light and operates in the strong coupling regime at room temperature.

Chapter V presents innovative research on polycrystalline perovskites doped with manganese ions. The observed effects depend on the content of manganese ions introduced into the perovskite structure. Temperature-dependent emission tests and magneto-optical measurements were performed showing Zeeman splitting for low Mn:PEPI concentration values.

Chapter VI contains studies of the strong light-matter coupling regime in liquid crystal cavities filled with a two-dimensional hybrid perovskite. The influence of perovskite on the properties of the liquid crystal cavity is presented, various methods of arranging the cavity are discussed, and the Berry curvature in the mentioned structure is described.

Chapter VII presents a tunable polariton laser emitting chiral light with two circularly polarized beams. The device was made on the basis of a liquid crystal microcavity with an inorganic perovskite $CsPbBr_3$ operating at room temperature.

Chapter VIII is a summary of the dissertation along with prospects for further research and development of the discussed topic.