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Review of the PhD thesis: "Study of nonlinear effects in exciton-polariton condensates"

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I have reviewed the PhD thesis entitled *"Study of nonlinear effects in exciton-polariton condensates"* by Magdalena Furman, which was prepared under the supervision of Prof. Barbara Piętka. The thesis presents an experimental study of nonlinear optical effects in exciton-polariton microcavities based mainly on CdTe semiconductor structures. The topic lies in the field of semiconductor optics and polariton physics and addresses questions that are relevant both from a fundamental and an applied perspective.

Summary of the dissertation

The dissertation consists of seven chapters, including an extended introduction and a final summary. The structure is clear, as it guides the reader from the basic concepts of polariton physics to advanced experimental results.

In the introductory chapters, Magdalena Furman reviews the essential theoretical background on excitons in semiconductor quantum wells, optical microcavities, and the formation of exciton-polaritons in the strong coupling regime. The discussion is clear, addresses all the main concepts, and demonstrates a good understanding of the relevant physical concepts. The introduction also motivates the study by placing exciton-polaritons in the context of nonlinear photonics, information processing, and quantum simulation.

The experimental part of the thesis focuses on CdTe-based microcavities grown by molecular beam epitaxy. The thesis describes the fabrication, characterization, and optical spectroscopy of these structures in detail. The experimental methods include reflectivity and photoluminescence measurements with both real-space and momentum-space resolution, performed at cryogenic temperatures.

A central part of the dissertation is devoted to optical bistability measured in transmission experiments. The author reports the observation of bistable behavior in the transmission of a resonantly tuned laser and identifies two distinct types of hysteresis loops, depending on laser detuning. One of these bistabilities shows an unconventional triangular shape and an opposite switching direction of the hysteresis loop compared to previously reported systems. The experimental observations are supported by a theoretical model that includes thermal effects and a transition between strong and weak coupling. In this context, the author also demonstrates access to natural exceptional points in the polariton spectrum and performs encircling experiments.

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Another important part of the thesis, Chapter 5, addresses polariton condensates in semimagnetic CdTe microcavities. By applying an external magnetic field, the author demonstrates control over the parity of ballistically coupled polariton condensates. The parity switching between in-phase and anti-phase condensate states is observed both in real space and in momentum space. The results are explained using analytical arguments and numerical simulations based on the spinor Gross–Pitaevskii equation.

In the last main chapter, the author presents the development of polymer microlenses fabricated directly on top of microcavities using two-photon polymerization. These microlenses are designed with the help of ray-tracing simulations. Experimentally, they are shown to extend the accessible momentum range, enable parallel momentum-space measurements from multiple locations, and significantly reduce the optical power required to reach the polariton condensation threshold. This part of the work clearly goes beyond pure physics results and demonstrates strong experimental creativity and technical skill.

The dissertation ends with a concise summary and appendices that provide additional technical details and extended analyses.

Scientific quality and originality

The dissertation presents several results that can be considered original contributions to the field of exciton-polariton physics. In particular, the identification of new bistability mechanisms in transmissive CdTe microcavities and their interpretation are novel. The experimental realization and exploration of exceptional points in a polaritonic system is also a significant and timely result.

The magnetic-field control of condensate supermode parity in semimagnetic microcavities represents a clear step forward in the control of polariton condensate networks. This work connects nonlinear optics, magneto-optical effects, and nonequilibrium condensates in a convincing way.

The development of polymer microlenses integrated with microcavities is another strong point of the thesis. This work provides practical tools that can be useful for a broad range of experiments beyond the specific systems studied here.

Overall, the scientific level of the dissertation is high, and the results are well supported by experimental data and appropriate modeling. The work has already been published in prestigious peer-reviewed journals.

Assessment of the candidate

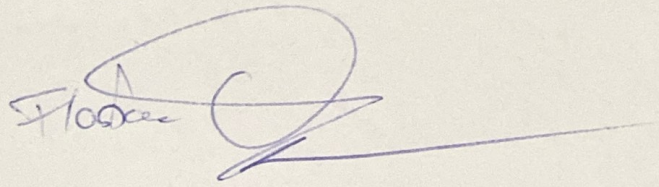
The dissertation demonstrates that Ms. Magdalena Furman has obtained a deep understanding of semiconductor optics and exciton-polariton physics. She shows strong experimental skills and a good knowledge of advanced optical techniques. The scope and coherence of the work further indicate a high degree of scientific independence. The candidate is clearly capable of identifying relevant problems, designing experiments, analyzing data, and placing the results in a broader scientific context.

Final conclusion

The thesis is well-written and easy to follow. Some sections, especially in the introductory parts, could be slightly more concise, and there is occasional repetition of background information. These points are minor and do not affect the overall quality or scientific value of the dissertation. Overall, I arrive at the conclusion that the PhD thesis of Magdalena Furman fulfills all formal and scientific requirements for awarding the degree of Doctor of Philosophy. It demonstrates a general theoretical knowledge and her ability to conduct independent scientific research.

In light of the above, I give a **positive evaluation** of the dissertation and recommend that it be accepted. In my opinion, the dissertation further deserves a **distinction**. This recommendation is based on the high scientific quality of the work, the breadth of original results achieved during her PhD, and the strong experimental competence demonstrated in this work. I am convinced that Magdalena Furman has a bright future in scientific research if she decides to pursue an academic career.

Kind regards,



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