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Report on the PhD thesis of Katarzyna Rechcińska

Title: The spin-orbit interaction of light in tunable liquid crystal microcavities

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Spin-orbit interaction originates from the relativistic motion of a particle's spin within a potential, and the effect was historically first discussed in the context of atomic physics to explain emission spectra. Subsequently, it had been recognized that it is important for the description of many solid state materials, very prominently also some in the technologically relevant class of semiconductors, such as GaAs. In her thesis, Katarzyna Rechcińska investigates a novel platform where spin-orbit physics can be studied. She introduces a combination of liquid-crystal material and optical microcavities where the photons with their polarization represent the spin-particles that propagate in the birefringent cavity. In her measurements, she demonstrates the unique in-situ tunability combined with extensive, direct measurement possibilities of energy, dispersion and polarization through spectroscopy and imaging, creating a new experimental model system to study synthetic Hamiltonians with artificial gauge fields. In the following, I will summarize briefly the thesis and discuss the novelty and significance of the work.

In chapter 1, the main theoretical background is introduced concisely, focusing on the relevant concepts and features that are essential for the thesis. This ranges from the polarization states of light, optical cavities to nematic liquid crystals. Moreover, the physics of spin-orbit coupling with the Rashba-Dresselhaus Hamiltonian from solid state physics is discussed and how this can be mapped to the light polarization.

The next chapter 2 describes the experimental optical setups and their layout for the measurements. The methodology of the real- and k-space imaging and dispersion measurements via an imaging spectrograph is presented. Then fabrication of the microcavity and the main properties of the materials that are embedded within, namely the liquid-crystal materials and various emitters (dichalcogenides and fluorescent proteins), are summarized.

The "workhorse" of the thesis, the tunable liquid-crystal microcavity, is thoroughly introduced in chapter 3. The properties of the dispersion curves and their tunability by

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changing the electrical driving voltage and frequency are explored. Furthermore, the connection between the cavity modes and the different regimes of spin-orbit interaction is established.

Chapter 4 describes in detail the theory (Prof. Bardyszewski is credited for the development) how the optical indicatrix of liquid crystal materials within the Maxwell equations effectively can be transformed to arrive at effective Hamiltonians of spin-orbit coupling. The mapping between the optical and the spin-orbit parameters is derived, and symmetry arguments are used to discern the different regimes (spin Hall effect, Rashba-Dresselhaus, ...) that originate from coupling different optical modes.

The presentation of the main scientific, experimental results starts in chapter 5. Careful dispersion measurements for each polarization state show that when inserting linearly polarized, the transmitted light acquires distinct polarization textures with left/right circular polarization. The theoretical modelling (by Mateusz Król using the Berreman method, as credited) very nicely rationalizes the obtained results in the context of the optical spin Hall effect.

Chapter 6 I consider the central highlight of the thesis with the realization of Rashba-Dresselhaus interaction in the liquid-crystal filled microcavity. By exploiting the tunability, Katarzyna Rechcińska was able to unambiguously show that the cavity could be brought into the regime where two different cavity modes and polarization states are interacting. Especially the tomographic characterization in reciprocal space is absolutely remarkable. This powerful demonstration of the versatility and wide-spread implications of this liquid-crystal cavity approach for creating synthetic Hamiltonians was rightfully published in the highest impact journal "Science", with Katarzyna Rechcińska as first author.

In chapter 7, it is impressively shown that the Rashba-Dresselhaus physics can lead to the creation of a persistent spin helix. The characteristic spatial spin pattern that is emerging was measured and showed convincing agreement with the modelling. Furthermore, the optical analog of the Stern Gerlach experiment was done where spin (here: polarization) states are separated by the cavity.

The last scientific chapter 8 deals with emitters that are combined with the tunable liquid-crystal cavity. Here, several different systems were explored ($MoSe_2$ monolayers, fluorescent proteins and a pyrromethene dye), showing tunability of the cavity resonance to the emitting wavelength as well as nonlinear effects that are interpreted as (polariton) lasing. It is clear, that the experiments mark the first initial steps with these systems, opening the door for weak and strong light matter interaction regime with tunable liquid-crystal cavities, that might well become subject to more thorough characterization and many more interesting results during future PhD projects in the group.

Overall, the thesis is well written, and structured clearly and didactically. The work and results are placed appropriately into context with theory and the state-of-the-art, and the relevant literature is cited, demonstrating comprehensive knowledge of the broader subject. Moreover, it is clearly described what Katarzyna Rechcińska's own, original contributions were, with a main focus on the optical measurements and the microcavity platform, and she properly credits her collaborators, e.g., with the theoretical modelling and for the materials and the fabrication.

In summary, the thesis is of very high scientific quality, and the investigation is very valuable for the field. Katarzyna Rechcińska's pioneering work with liquid-crystal filled microcavities shows impressive experimental skills and originality. Therefore, I recommend to accept her dissertation by the faculty. As I am wholeheartedly convinced by the excellence and significance of the work, I would like to explicitly propose her thesis for a distinction.

Sincerely,

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