Magneto-Optic Study of Novel HgTe-Based Thin Films

Name: Jan Gospodarič
Supervised by: Univ.Prof. Dr.rer.nat Andrei Pimenov

This thesis is mainly devoted to the magneto-optical spectroscopic study of HgTe/CdHgTe quantum wells in the sub-terahertz frequency range. HgTe quantum wells are unique examples of two-dimensional systems, in which many exotic thickness-dependent properties arise due to the inverted band structure of bulk HgTe.

A Mach-Zehnder interferometer implementing controlled polarization of the light was used as the primary experimental tool for transmission experiments. This approach allowed us to systematically observe the response of the two-dimensional electron gas in the studied samples to the applied electromagnetic fields, while the Fermi level in the system was shifted by top-gating. With the help of Drude theory and optical transfer-matrices, a model of the investigated samples was designed in order to analyze the cyclotron resonances in HgTe-based three-dimensional topological insulators and semi-metallic HgTe samples.

An investigation of the superradiance effects in a three-dimensional topological insulator has shown that the superradiance can be explained using the electrodynamic approach and is therefore a fully classical effect. This experimental procedure allows the separation of energy losses in the system into distinct intrinsic and radiation contributions.

Furthermore, this work demonstrates a procedure for experimental mapping of the band structure from the analysis of the cyclotron resonance. Within our approach, the acquired properties of the charge carriers in the system, such as cyclotron mass and carrier concentration, allowed the reconstruction of the electron- and hole-dispersion relations. In a three-dimensional topological insulator, top gating allowed the detection of separate resonance modes corresponding to the surface states at two opposite film interfaces, the bulk conduction band, and the valence band. Considering the effect of the asymmetric gating potential, the experimental band structure agrees reasonably well with the predictions of the $\mathbf{k} \cdot \mathbf{p}$ model.

A similar procedure was utilized for semi-metallic HgTe quantum wells. Detailed comparative analysis of experimental band structures with theoretical calculations demonstrates a very good agreement. In detail, the main findings are a direct proof of the electron- and hole-band overlap, the effective mass of holes, and the detection of the second conduction subband. The results are strongly supported by the analysis of Shubnikov-de Haas oscillations in capacitance, which confirm that an anomalous two-fold hole-valley degeneracy is observed due to bulk inversion and structure-inversion asymmetries.

In addition, the thesis also covers advances in 3D-printing as a way to design and prototype novel terahertz optical components. In particular, a new way of calculating, designing, and fabricating a waveplate that phase-modulates an incident beam to create a predefined intensity profile on a distant image plane is investigated. The results of this show good agreement with theoretical predictions.