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Abstract of the Ph. D. thesis

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Thesis title: **InAs/InP quantum dots for telecom quantum photonics**

Semiconductor nanotechnology is a rapidly growing branch of science and industry, benefiting from the unique properties of structures with reduced dimensionality, like quantum dots (QDs). These have a discrete energy spectrum and properties similar to atoms, which are essential for creating non-classical light sources, emitting nearly on-demand single photons or entangled photon pairs. Such light sources are crucial for photon-based quantum information processing (QIP), specifically for quantum communication protocols that rely on quantum mechanics principles, providing highly secure optical data transfer, meeting the demands of the modern information society.

In the telecom industry, silica fiber networks are crucial for providing a transfer medium for optical signals distributed between network nodes. To operate at a single photon level, it is necessary to overcome optical losses in fiber so that photon-encoded quantum information can be transmitted over long distances with minimal data transfer errors. Since silica fibers have the lowest transmission losses at 3^{rd} telecommunication window (~1.46-1.62 μm), it is beneficial to provide QD-based non-classical light sources operating at this spectral window.

Self-assembled InAs QDs epitaxially grown on InP substrates are among the most promising candidates for such quantum emitters. However, a significant drawback of the currently available nanostructures operating at 3^{rd} telecom window is the absence of high-performance photonic devices that could be fabricated deterministically. First, the low photon extraction efficiency, typically <1 %, limits the QD-based device performance. Secondly, the self-assembly process seriously deteriorates the device fabrication yield since the QD nucleation site is probabilistic. The thesis aims to address these problems and proposes solutions that pave the way for fabricating bright and scalable photonic devices with InAs/InP QDs that can potentially meet industry standards.

The thesis first elaborates on various fabricated and optically examined InAs/InP QD systems, focusing on their potential for QIP schemes. Second, novel hybrid heterostructures with InAs/InP QDs on the silicon platform are developed and presented. These structures are fabricated within the flip-chip technique and provide an enhanced photon extraction efficiency due to the presence of a metallic mirror. The QD brightness is sufficient for imaging their emission, thus providing information on their spatial position. The final part focuses on the establishment of a deterministic approach by employing photoluminescence imaging, exemplified by the fabrication of circular Bragg grating cavities at the QD nucleation sites. The state-of-the-art quantum emission properties in the 3^{rd} telecommunication window are reached, facilitating the light-matter interaction. The reported research has enabled:

1. obtaining InAs/InP QDs with good optical quality and low surface density,
2. maximizing the efficiency of emission extraction,
3. introducing determinism into the QD-based technologies at 3^{rd} telecom window.

The scientific findings were published in international peer-reviewed journals, with a focus on:

- Low-density QD ensembles as candidates for single-photon sources at 3rd telecom window: P. Holewa *et al.*, **Physical Review B**, 101, 19 (2020), P. Holewa *et al.*, **Physical Review Applied**, 14, 6 (2020), P. Holewa *et al.*, **Nanophotonics**, 11, 8 (2022),
- QD-based heterostructure with bright single-photon sources: P. Holewa *et al.*, **ACS Photonics**, 9, 7 (2022).

Additionally, one preprint complements the thesis:

- Optical localization of QDs, deterministic fabrication of nanocavities, and QD-cavity coupling: P. Holewa *et al.*, *Scalable quantum photonic devices emitting indistinguishable photons in the telecom C-band*, arXiv:2304.02515 (2023).

All articles are summarized in the introduction to the thesis, and full texts are included. Supplemental material is provided if relevant.