TU Darmstadt | Institute for Applied Physics | Schloßgartenstraße 7 | 64289 Darmstadt

Izabela Szabłowska-Petrycka
Biuro Rad Naukowych
Uniwersytet Warszawski
Wydział Geologii, pokój 3051
ul. Żwirki i Wigury 93
02-089 Warszawa
POLAND

TECHNISCHE UNIVERSITÄT DARMSTADT

Prof. Dr. Markus Gräfe

Institute for Applied Physics

Experimental Solid State Quantum Optics Group

Schloßgartenstraße. 7
64289 Darmstadt
Germany

Tel. +49 6151 16 - 20451
markus.graefe@tu-darmstadt.de
https://www.iap.tu-darmstadt.de/efq

Date: 28.08.2024

Review of the PhD Thesis "Ultrafast Quantum Optics with Spectral Resolution" by Michał Lipka

Michał Lipka's PhD thesis, "Ultrafast Quantum Optics with Spectral Resolution," represents a substantial and original contribution to the field of quantum optics. The thesis explores the spectral degree of freedom (DoF) of photons, focusing on the spectro-temporal DoF of single-photon and single-photon level broadband light. The research is primarily experimental and addresses key challenges in quantum and ultrafast optics through a series of well-designed studies.

The thesis is well-structured, with each chapter logically building on the previous one, ensuring a coherent narrative throughout. Chapter 1 provides a comprehensive introduction to the theoretical and experimental background necessary for understanding the subsequent work. It covers the basics of quantum optics, the significance of spectral resolution, and the relevance of ultrafast optics in quantum technologies. The introduction sets a solid foundation for the research questions explored in the thesis. Chapter 2 focuses on the characterization of hybrid entanglement between transverse and spectral DoF of photon pairs generated via non-collinear type-I SPDC. The experimental setup and methods are described in detail, and the results are thoroughly analyzed, providing new insights into the nature of hybrid entanglement. In chapter 3 the thesis investigates two-photon interference with spectrally resolved single-photon detection. The chapter excels in methodological rigor, presenting a novel approach to probing light-matter interactions dispersively. The results enhance the understanding of two-photon interference in quantum optics. Chapter 4 demonstrates a variation of electro-optic shearing interferometry at the single-photon level, suitable for ultrashort pulses in the near-infrared. The work presented is technically demanding, showcasing the author's expertise in experimental quantum optics. In chapter 5 the thesis introduces an electro-optic implementation of the Fractional Fourier Transform, a tool traditionally used in classical signal processing, adapted here for quantum applications. The chapter highlights the versatility of this technique and its potential applications in quantum information processing. The final study in chapter 6 presents a method for

achieving spectral super-resolution in frequency-domain quantum metrology. The innovative application of quantum-inspired imaging techniques to the frequency domain is particularly noteworthy, offering significant advancements in precision measurement.

The thesis is written in clear, precise, and technically sound language. Michał Lipka demonstrates a strong command of scientific writing, with complex concepts explained in an accessible manner without sacrificing depth or accuracy. The writing style is engaging, making the material approachable even when dealing with highly specialized topics. Each chapter flows naturally into the next, and the narrative is structured to maintain the reader's interest while thoroughly exploring the subject matter.

The thesis is well-referenced, drawing on a broad range of relevant literature to support the research. The references are current and include key papers in the field of quantum optics and ultrashort optics, ensuring that the work is grounded in the latest scientific developments. The author employs a sufficient number of figures and diagrams to illustrate the experimental setups and procedures, enhancing the clarity of the explanations. Each figure is well-captioned and integrated into the text, providing visual support to the complex concepts discussed. The detailed descriptions of the experimental setups are particularly commendable, as they allow the reader to understand the procedures and the significance of the results fully. In general, the amount of technical details in this thesis is very high and, so as not to disturb the reading flow, is concentrated in special sections in each chapter.

The main findings of Michał Lipka's thesis are both correct and original, making significant contributions to the field of quantum optics. Characterizing hybrid entanglement between transverse and spectral DoF is a novel achievement, providing new insights into manipulating and measuring quantum states. The work on two-photon interference with spectral resolution advances the understanding of quantum coherence and interference phenomena. The development of electro-optic shearing interferometry for single-photon levels is a technical milestone, offering a new tool for ultrafast optics. The adaptation of the Fractional Fourier Transform for quantum applications is particularly innovative, demonstrating the author's ability to translate classical techniques into the quantum domain. Finally, the method for spectral super-resolution in frequency-domain quantum metrology is groundbreaking, with potential applications in high-precision measurement and quantum information science.

The impact of Michał Lipka's work is substantial. The research presented in this thesis pushes the boundaries of what is currently possible in ultrafast quantum optics, particularly regarding spectral resolution. The techniques developed and the results obtained have broad implications for the future of quantum technologies, particularly in quantum communication, computing, and metrology. By addressing and overcoming key challenges in manipulating and measuring quantum states, this thesis sets the stage for future advancements in the field. The work is likely to inspire further

research and development, both in academic and industrial settings, as the methods and findings presented have the potential to be applied across a wide range of quantum technologies.

In conclusion, Michał Lipka's PhD thesis, "Ultrafast Quantum Optics with Spectral Resolution," demonstrates the candidate's general theoretical knowledge in a discipline or disciplines and the ability to conduct research work independently. It is an outstanding piece of work that makes significant contributions to the field of quantum optics and ultrashort optics at the single-photon level. The research is original, the methodologies are rigorous, and the results are of great importance. The quality of the writing and the clarity of the presentation further enhance the impact of the work. Besides the outstanding thesis, one must acknowledge the extraordinary publication work by Michał Lipka. He published 24 scientific papers in high-impact journals, with eleven of those as first author, and he holds three patents on his research topic. This is highly remarkable and speaks for the highest quality of the candidate. Therefore, I wholeheartedly recommend that this thesis be awarded the highest distinction, as it exemplifies the excellence that can be achieved in doctoral research. I evaluate this thesis with:

Excellent with distinction

I therefore recommend the acceptance of the dissertation and the continuation of the procedure.

With kind regards,

Markus Graefe
Digital unterschrieben von Markus Graefe
Datum: 2024.08.28 13:35:18 +02'00'

Prof. Dr. Markus Gräfe