OPINION

of dissertation work
for obtaining the educational and scientific degree "Doctor"
in professional field 4.1 Physical Sciences
under the defense procedure at the Faculty of Physics,
Sofia University "St. Kliment Ohridski"

The opinion was prepared by Prof. Dr. Germano Montemezzani from the University of Lorraine, Metz (France), **in his capacity of a member of the scientific jury according to the Order № РД38-321/06/07/2023 of the Rector of Sofia University.**

Title of dissertation: **Design of Composite Pulse Sequences for Quantum Technologies**
Author: **Hayk L. Gevorgyan**

Candidate details

The candidate Hayk L. Gevorgyan earned a bachelor degree in “Physics” from Yerevan State University, Yerevan (Armenia) in 2016 and a master degree in “Theoretical Physics” from the same University in 2018. This is combined with an International Master degree in “Physics, Photonics & Nanotechnology” from the University of Bourgogne-Franche-Comté in Dijon (F) in the same year. From 2018 to 2021 he won a Maria Sklodowska-Curie fellowship grant within the LIMQUET project of the Horizon 2020 research program, in the framework of which the present dissertation was prepared. Mr. Gevorgyan is presently a junior researcher at the Yerevan Physics Institute of the A. Alikhanian National Laboratory in Yerevan. His PhD dissertation is directly related to three scientific publications in excellent journals, one published in 2021 and two in press. A scrutiny of Web of Science reveal two additional publications not related to the present dissertation. Mr. Gevorgyan’s record also includes nearly 30 presentations at national or international conferences in oral or poster format, what confirms his indisputable qualification.

General characteristics of the candidate’s scientific achievements

In his dissertation manuscript, Hayk L. Gevorgyan presents a succinct and well-organized summary of his theoretical results in connection with the optimization of various types of composite pulse sequences relevant for quantum technologies and for polarization optics. The 128-pages-long manuscript contains an introduction, 6 major chapters, and a final short chapter with conclusions and perspectives. Former work is pertinently cited with a total of 181 bibliographic entries.
The introduction discusses briefly different quantum control techniques and introduces various rotation and phase gates acting on qubits. Some specific gates that will be discussed later in the thesis are first introduced here, such as the X and Hadamard rotation gates, or the Z, S and T phase gates. The concept underlying composite pulses is also discussed for the first time here with few examples from literature.
Chapter 2 is dedicated to the use of composite pulses for high-fidelity rotation gates. Before describing the optimization procedure Mr. Gevorgyan starts by discussing the SU(2) approach

being used and the fidelity measure (Frobenius distance fidelity) to be maximized. Various concrete examples of specific rotation gates optimized at different orders in the relative pulse area error (up to order 8) are given.

Chapter 3 presents similar results for the case of quantum phase gates, while Chapter 4 addresses methods to render the composite sequences for various types of gates either narrowband or passband, which can be of interest for quantum sensing.

Chapter 5 reflects in large extent a recently accepted article and presents new methods to obtain ultrasmall but precise excitation probabilities and ultrasmall qubit rotations. The presented composite pulse approach can be useful in applications such as single-photon generation by a cold atom ensemble of N atoms with transition probability of $1/N$.

Chapter 6 discusses an alternative derivation method leading to sequences suitable for broadband and narrowband wave retarders in polarization optics.

The case of polarization optics is further developed in Chapter 7 where a new method to realize nonreciprocal composite waveplates and optical isolators with broadband character is theoretically described. Here the non-reciprocity is provided by Faraday rotators included in each element (at least 3) of the composite sequence. This chapter precedes a short final conclusions and perspectives section.

Remarks, recommendations, and questions

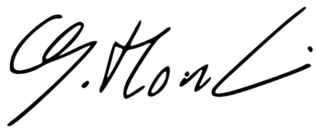
The PhD thesis is written in excellent English with a concise and professional style giving the clear indication that the candidate perfectly masters his research topic and the related literature. I have appreciated the introductions and conclusions given at the beginning and end of each chapter. I have no specific recommendations besides for the remark that in some cases the illustrating graphs have been relegated at the end of the chapter and could have been brought earlier to facilitate the reading. Two questions come to my mind:

- Throughout the manuscript it is assumed that the only source of error is in the pulse area (pulse amplitude and/or duration) and the relative error is assumed the same for all pulses, which appears reasonable. However, the calculated pulse phases required to compensate these errors are given with a large degree of precisions (generally four digits in units of π). The question is about the precision with which these phases can be established experimentally and what would be the effect of a small random error on these phases on the final performance.

- The second question concerns the nonreciprocal polarization optics elements in Chapter 7. Here the optimization is made in terms of the deviation ε of the retarder phase shift with respect to the nominal phase retardation, which is equivalent to the pulse area. However, the nonlinearity connected to the very strong dispersion of the material Verdet constant (Eq. (7.9)) has the effect that short wavelengths are overweighted with respect to longer wavelengths in the optimization procedure. This is because a same wavelength (or frequency) interval leads to a larger ε span at short wavelengths. Would there exist a method to treat the wavelength (or frequency) spectrum more equally in the optimization procedure? A related question concerns the choice of the ε interval $[-\pi,\pi]$ for the optimization of the broadband isolator which appears somehow arbitrary. Indeed, the deviation can easily exceed π by a lot on the positive side. For instance, if the nominal wavelength would be 850 nm the deviation would be $\approx 1.24\pi$ at 600 nm and $\approx 2.58\ \pi$ at 500 nm. Do you expect a significant improvement by adapting the optimization interval as a function of the targeted spectral range of achromaticity?

Conclusion

Mr. Gevorgyan has presented impressive theoretical results on the design of various composite pulse sequences for high fidelity and high precision quantum gates as well as highly achromatic polarization optics components. This is very good level research already published in major scientific journals (2 x Phys. Rev. A, 1 x Opt. Commun.). The dissertation and the scientific publications of Mr. Gevorgyan cover the minimum national scientific requirements of ZRAS and the Regulations to it, as well as the requirements of the Faculty of Physics of Sofia University St. Kliment Ohridski. I therefore strongly support the award of the educational and scientific degree "Doctor" in the professional field Physical Sciences.



Metz, 20.09.2023

Prof. Dr. Germano Montemezzani