REVIEW
of the PhD thesis
for obtaining the educational and scientific degree "Doctor" in Physical sciences,
at the Faculty of Physics of Sofia University St. Kliment Ohridski

The review is prepared by: Prof. Stéphane Guérin, University of Bourgogne, Dijon, France

Topic of the dissertation: "***Design of Composite Pulse Sequences for Quantum Technologies***"

Author of the dissertation: **Hayk L. Gevorgyan**

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Candidate details

Hayk Gevorgyan obtained his BSc degree Yerevan State University, Armenia in 2016 and a MSc degree (theoretical physics) in the same University in 2018. In parallel, he started two other master's degrees during the period 2016-2017: "Master of Cyber-security" at the Russian-Armenian University, and "Master of Agribusiness and Management" (joint programme with Texas A&M University) in Armenian National Agrarian University. During this period, he was awarded best student 2015 of the Republic of Armenia (first prize) and best student 2017 (winner) at the Yerevan State University. He next obtained an international master's degree in 2017-2018, "Physics, Photonics & Nanotechnology" at University of Bourgogne, Dijon (France). He was then enrolled in two PhD studies, in Yerevan Physics Institute (Experimental Physics Division) on the topics "Coherent Radiation of Density-Modulated Bunches of High-Energy Charged Particles in Micro- and Macro-Radiators" (supervisor: L.A. Gevorgian, 2018-2021, PhD incomplete) and at the Sofia University "St. Kliment Ohridski, as an early-stage researcher of the European Network (ITN) "Limquet" (2018-2021), supervised by Prof. Nikolay V. Vitanov during the period 2018-2023. The present review concerns the latter.
The candidate did a secondment in my Laboratory (ICB) at Dijon in January 2020 that was interrupted by the covid pandemic. During this period, Hayk Gevorgyan was very active. On the basis of recent works on shortcut to adiabaticity and optimal quantum control, he analyzed and proposed several options in order to optimize the existing composite pulse techniques.
We also notice that the other thesis work has led to two published peer-review papers.
The candidate has presented 28 oral or poster, national or international, communications since 2013.

General characteristics of the candidate's scientific achievements

The present thesis is about the general field of quantum control, featuring in particular the important property of robustness. This is of great importance since it constitutes the central tool for making quantum technologies operational.
The work focusses on the composite pulses (CP), a technique widely studied in N. Vitanov's group, with applications to quantum information processing requiring ultrahigh fidelity and to (classical) polarization optics. CPs have been developed for a long time (since the 1940s in

polarization optics, and in the 1980's in NMR), but its "optimal" production, e.g., in a time as short as possible, is lacking in literature. This is one of the main topics of the thesis, where systematic derivation of CPs by analytical and numerical methods is proposed.
The second main topics concerns the extension of CPs to the deterministic generation of arbitrary ultrasmall excitation, typically below 10^{-2}. Such ultrasmall excitation can be needed in some applications of quantum technologies, such as DLCZ protocol, for which a single excitation is shared among thousands of atoms, to produce a large Dicke state of many qubits sharing a single excitation. Standard protocols use very weak or far-detuned driving field which are sensitive to variations in the experimental parameters. No alternative reliable strategies exist in literature. The CP strategy uses non weak fields which allow high-fidelity and robustness, as it is convincingly demonstrated in the thesis.
The third part of the work is the extension of CPs towards applications in polarization optics. In particular, broadband nonreciprocal polarization waveplates are shown on the basis of the well-known analogy between polarization Jones vector and quantum state. The interest of producing nonreciprocal polarization waveplates (i.e. with functionality depending on the sense of propagation of light) is shown via the convincing example of optical isolator.

Chapter 1 of the thesis is devoted to a relatively brief introduction to the quantum control and more particularly to the CP techniques. Chapter 2 provides more details of the CP technique applied for (variable or constant) rotation operations and proposes ultra-robust CP solutions (with more than 5 pulses) featuring a shorter time than what is known in literature. This has been published in Phys. Rev. A [48]. Chapter 3 applies the technique for the design of ultrahigh-fidelity composite phase gate. A preprint has been published in arXiv [60]. These two chapters demonstrate the remarkable flexibility of CPs with an ultrahigh fidelity and a wide robustness to errors.
In Chapter 4, H. Gevorgyan implements CPs which produce narrowband and passband rotational gates. Three types of optimization are used: SU(2), modified-SU(2), and regularization. Figure 4.1 gathers the various families of CPs, but since it contains too many information, it is difficult to read. The title of Chapter 4 mentions application to quantum sensing, which is an interesting and vast question in quantum technologies. However, the implementation of this application is vague in the manuscript.
Chapter 5 is devoted to the deterministic generation of arbitrary broadband ultrasmall excitation with different strategies of symmetric and antisymmetric sequences of CP. This work has been accepted very recently in Phys. Rev. A.
Chapter 6 examines the capability of the technique for ultrarobust or ultrasensitive control at the expense of the precision. This finds applications in polarization optics as presented at Optica High-brightness Sources and Light-driven Interactions Congress (2022 - Ref. [61]).
Chapter 7 presents the extension of CPs for applications in polarization optics, more specifically broadband nonreciprocal polarization waveplates and optical isolator. This chapter has led to a publication in Optics Communications, very recently accepted [62].

Critical remarks and recommendations

The PhD thesis is written in a good English, it is well organized and presented. The CPs are exhaustively presented showing the solid knowledge of the candidate about this technique. However, it is regrettable that recent competitive studies of optimal control using shaped pulses are not mentioned.

The thesis has resulted so far in three published peer-reviewed papers of good quality (two in Physical Review A and one in Optics Communications), a conference report, another arXiv preprint, and a submitted paper. Hayk Gevorgyan is the first author of all these papers, which expresses the recognition of his significant contribution. These numerous (published, accepted, and potential) publications demonstrate the high quality of the thesis. In addition, the candidate has presented 7 communications in international conferences related to his PhD thesis.

I have the following questions to be addressed during the defense:

- Several solutions for the second error compensation of the X gate show a 5π area. How can one make sure that no other lower area CP solutions exist?
- Chapter 4 mentions application to quantum sensing but does not provide any information on how the resulting profiles can be exploited to quantum sensing. I suggest giving details of this application.

Conclusions

I am convinced that the theoretical results presented in the thesis will have a strong impact in the field of quantum technologies, as they have numerous potential significant applications. The dissertation, the abstract and the scientific publications of Mr. Gevorgyan largely cover the requirements of the Faculty of Physics of Sofia University St. Kliment Ohridski. I thus support the award of the educational and scientific degree "Doctor".

Prof. Stéphane Guérin