Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Nikita Stroev

PhD Program: Physics

Title of Thesis: Modelling of exciton-polariton condensates for unconventional computing

Supervisor: Professor Natalia Berloff

Name of the Reviewer: Sergei K. Turitsyn

I confirm the absence of any conflict of interest	**Date: 05-11-2021**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

The thesis “Modelling of exciton-polariton condensates for unconventional computing” by Nikita Stroev presents results of extensive research in the fast growing area of unconventional computing. The thesis deals with one of the major problems in the modern information and communication technology (ICT) – saturation of the “Moore’s low and demand for new data science concepts. An exploding generation of data requires a massive increase in processing power, memory and communication bandwidth. In the past, this ever-growing demand could be provided by the exponential increase in the performance of digital data storage and processing technologies (“Moore’s law”). However, technological progress rates of digital technologies are flattening out and inevitably will hit ultimate physical ceilings (“end of Moore’s law”). This growing gap between what is demanded and what can be delivered becomes exacerbated by the increasingly inacceptable energy consumption of our global ICT infrastructure. The thesis deals with the research on the so-called “unconventional”, nature-inspired approaches to computing which will address these global challenges. The topic of the thesis, indeed, is timeliness and relevant to high impact applications.

The thesis is appropriately structured in six chapters, that includes introduction part, physical preface, system design, algorithmic network, conclusion and additional resources with the supplementary information (the description of several hardware platforms and additional analysis on optimization). I would acknowledge as particularly clear and well-written the chapters related to XY model and its applications. In sections related to physics some definitions are missed and there are some minor non-accurate steps, see comments below.

The thesis clearly shows solid efforts delivered by the candidate, novel methodology and new innovative results obtained in this work. This work presents an original and substantial contribution to the knowledge in the field of unconventional computing. The work is professionally done, clearly written and results are certainly important for further progress in the field. Candidate has demonstrated high level of expertise in the field.

I have the following comments that might be addressed during the viva.

Section 3.2

1- In page 36 additive noise shown to be effective to avoid trapping in a local minimum, what are the requirements of this additive noise? Is there a minimum value or a specific random distribution? Can optimising the variance and properties of this additive noise give rise to a system with real coupling which can perform as good as TGD+CC?

Section 3.4 (and 3.5)

1- It’s possible to define any machine learning task (classification or regression) especially with supervised training as a minimisation problem. Having that in mind, why would

someone implement a ML solution using the XY Hamiltonian blocks instead of directly translating the ML problem into a Hamiltonian using the techniques explained in Chapter 4?

2- What is the speed of arriving at the ground state which directly impacts the data processing speed? What are the limitations? How does it change by increasing the number of spins?
3- This is a solution for implementing the inference stage of a ML technique, what does it take to include training (adaptive change of the system parameters via SLM for example)?

Section 3.5

1- How can one use this architecture to include the training stage as well? This entails performing backpropagation which includes calculating gradient. Does approximating these nonlinear activation functions in the way that is proposed here pose any issue in calculating the gradient? This is important because most often the gradient of the extremes of the nonlinear function (at small or large \theta_{in}) plays an important role and this is where the approximations shown in Figs. 3.5,3.6, and 3.7 deviate from the analytical values.

Section 4.1

1- What is the relation between the two representation of a Hopfield network in Eq. (4.34) and Eq. (4.35)? is it possible to derive (4.34) from (4.35)?
2- In a Hopfield system explained by Eq. (4.35) what is the input? Is it I_i or the initial state, $x_i(0)$?
3- In page 74 paragraph 6 it says: "The Hopfield NN can reduce more deep NN because every deep feedforward NN can be reduced to a shallow one with different parameters". Could you please explain how this reduction is done? Is there a general procedure to perform the reduction?

Few minor comments about definitions.

1) Equation 3.1. It would be helpful to explain physical meaning of \eta_d. Why \n_r is chosen in this form? Some discussion or references could be helpful.
2) Eqs. 3.4 и 3.5. Velocity u should be defined through derivative of S. It is easy and known, but nevertheless should be done, as not all readers are from the field.

To conclude, the presented results clearly demonstrate originality of the approaches used, innovative nature of the research and clear contribution to the knowledge in the field. This is a solid and good work that is, certainly, a fitting basis for awarding a degree of "Doctor of Philosophy".

Provisional Recommendation
☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*