Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Alexandra Tambova

PhD Program: Computational and Data Science and Engineering

Title of Thesis: The numerical modeling of nanophotonics by means of well-conditioned volume integral equation methods

Supervisor: Prof. Maxim Fedorov

Co-advisor: Prof. Athanasios Polimeridis

Chair of PhD defense Jury: Prof. Ivan Oseledets ***Email**: I.Oseledets@skoltech.ru*

Date of Thesis Defense: 28 November 2019

Name of the Reviewer: Francesca Vipiana

I confirm the absence of any conflict of interest	**Signature:** Francesca Vipiana **Date: 25-10-2019**

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

Brief evaluation of the thesis quality and overall structure of the dissertation.

The Thesis proposes the use of the Volume Integral Equation (VIE) method for the modelling and analysis of 3D nanophotonic devices, and it introduces two main novelties in the VIE implementation. First, adiabatic absorbing layers are added to the VIE formulation in order to efficiently analyze infinite or semi-infinite structures. Second, the original volume-volume integrals are reduced to surface-surface integrals over the faces of mesh elements, and evaluated with the state-of-the-art numerical techniques. Summarizing, the Thesis has a very high quality for the significant numerical improvements in the modelling and analysis of 3D nanophotonic devices. The Thesis is also well organized, clearly describing the introduced numerical novelties.

The relevance of the topic of dissertation work to its actual content

The numerical approach developed within the Thesis is devoted to the efficient and accurate analysis of silicon photonic devices that are a disruptive technology in several fields. Numerical methods are now playing a crucial role in designing the new generation of silicon photonic systems and devices, and a fast and reliable EM solver is essential to study the light behavior and light-matter interaction and to cheaply prototype new components. Hence, the Thesis topic is relevant in its actual content.

The relevance of the methods used in the dissertation

The method implemented in the Thesis is based on the volume integral equations (VIE) that seem to be a very promising approach for the analyses of silicon photonic devices since VIE are dispersion free by construction. Hence, volume integral equations can efficiently handle inhomogeneous materials, restrict the computational domain to the volume of the scatterer only, and boundary conditions are not needed in the case of finite scatterers. Moreover, in the Thesis, adiabatic absorbing layers are implemented and numerically tested in order to extend the VIE to infinite or semi-infinite devices' analyses, together with an efficient numerical evaluation of the integrals arising in the calculation of Galerkin inner products.

The scientific significance of the results obtained and their compliance with the international level and current state of the art

In this thesis, the first implementation of adiabatic absorbers in the volume integral equation (VIE) method has been introduced and deeply numerically tested. More in detail, a current-based VIE formulation has been proposed, allowing to introduce the adiabatic absorbers in a simple and straightforward manner, which does not affect the fast solution time of the proposed method. Moreover, the initial 6D volume-volume integrals are reduced to series of surface-surface integrals over the faces of support elements that, in most of the cases, can be accurately evaluated by readily available standard quadratures. To conclude, the proposed numerical method for the analysis of silicon photonic devices is a top-level research with respect to the current international state-of-the-art in numerical schemes.

The relevance of the obtained results to applications (if applicable)

I can conclude that the presented VIE method is an accurate and effective simulation tool for the modeling of nanophotonic devices. Integral equation methods have the distinct advantage to be dispersion free, key property in the nano-photonics setting where the structures of interest may span thousands of wavelengths over which dispersion could potentially lead to large phase errors.

The quality of publications

The quality of publication is good with three journal publications in peer-reviewed high level international journals and one conference publication.

Minor text corrections:

- page 39, line 6 correct “To avoid this compications, we use the dimensionality reduction method” with “To avoid this complications, we use the dimensionality reduction method”

- page 74, last line, in “Figs. 2.5–2.5 show different components of interior electric field along the x, y” figures’ numbers seem wrong.

-page 75, last line, in “Finally, the convergence rate of the interior fields calculated for the spheres of conductivities from 0 S to 104 S is examined in Fig. 2.5 by showing numerical errors” figure number seems wrong.

-page 92, line 5, in “From Figs. 4.1–4.1” figures’ labels seem wrong.

I would suggest to check in all the Thesis the figures’ citation numbers because most of them seem wrong or not updated.

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*