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Jury Member Report – Doctor of Philosophy thesis / Pre-examination statement for Aalto University

Name of Candidate: Alexey Tsapenko

PhD Program: Physics

Title of Thesis: Enhancing Optoelectronic Performance of Randomly Oriented Single-Walled Carbon Nanotube Films

Supervisors: **Prof. Albert Nasibulin, Skoltech, Russia**

Prof. Esko Kauppinen, Aalto, Finland

Chair of PhD defense Jury: Prof. Nikolay Gippius, Skoltech ***Email:***N.Gippius@skoltech.ru

Date of Thesis Defense: October 4, 2019

Name of the Reviewer: Prof. Alexander Okotrub, Nikolaev Institute of Inorganic Chemistry, Russia

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:** **Date: 11-08-2019**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury / Pre-examiner before the thesis defense. The members of PhD defense Jury / pre-examiner are asked to submit signed copy of the report at the latest on August 13th. 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

Please write your statement / summary of issues to be addressed before the thesis defense here. The guidelines were provided to you in the examination request:

This thesis presents diverse and actual study on the improvement of the optoelectronic characteristics of the highly promising material for numerous applications of transparent conductors – randomly oriented single-walled carbon nanotube single-walled carbon nanotube films. The candidate, Alexey P. Tsapenko, does not only introduces the approaches to radically simplify currently established techniques but also demonstrate the state-of-the-art values (equivalent sheet resistance of 40 Ω/□ at a wavelength of 550 nm) through careful investigation of pristine and treated film properties by a variety of characterization methods. Among the main findings are both charge carrier dynamics of the macro-scaled films and novel doping approaches based on the creation of hybrid material, optimization approaches, and improvement of uniformity. In the begging of his thesis, Alexey introduces the material (the way it is synthesized as well as its main distinctive and unique optical and electrical properties, doping concepts) and explains the feasibility of its use in the area of the upcoming flexible and stretchable transparent and conductive films (like, for instance – free-form displays, solar cells, etc.). In the next chapter, the key characterization techniques (aerosol, optical spectroscopies along with the electronic and electrical methods) are thoroughly discussed to justify their use in the nanotube quality and parameter assessment. As the next logical step, the chapter with author's main results starts. Firstly, the study of optical properties of pristine and treated/doped films presents their conductance behavior for different film thicknesses, at various ambient temperatures (from room temperature to 5 K), and by the influence of light. It should be noted here that most of the parameters (mobility, scattering rate, and mean-free path) are estimated as the effective ones that is of high importance for this material, which has no certain thickness. As a conclusion, 3 main contributions are proposed for the experimentally measured data: contributions from the free charge carriers (Drude model), plasmonic oscillations, and tunnel barriers. Along with it, the negative THz photoconductivity for both pristine and doped nanotube films is seen, which is related to the existence of bound states for charge carriers. The second part of this chapter is devoted to the doping of nanotubes. Mainly, several novel approaches are proposed and explained: hybrid structure of nanotubes and reduced graphene oxide, importance of the evaporation rate control during doping and aerosol-assisted doping for the fine-tuning of optoelectronic characteristics of the films. The achieved values and research outcomes are among the topmost of the currently published data and are summarized in 5 articles with high impact factor and already considerable amount of citations. In addition, a bunch of additional paper with Alexey's contribution is showing his attitude to the nanotube film properties related to particular applications (solar cells, supercapacitors, bolometers, etc.). Concerning the minor grammatical mistakes (chapters 2 and 4) and some missing abbreviations in the "List of abbreviations and symbols", I assess the quality of the work done by Alexey as a really high one.

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*