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

**Name of Candidate: Pramod Mulbagal Rajanna**

**PhD Program: Physics**

**Title of Thesis: Hybrid heterojunction solar cells using single-walled carbon nanotubes and amorphous silicon thin films**

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

**Prof. Peter Lund, Aalto University, Finland**

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

**Date of Thesis Defense: May 7, 2020**

**Name of the Reviewer: Prof. Dmitry Paraschuk**

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| I confirm the absence of any conflict of interest<br><br>(Alternatively, Reviewer can formulate a possible conflict) | **Signature:**<br>  <br>**Date: 31-03-2020** |

*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 April 21st . 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**

The most important results of the dissertation are the development of thin-film mechanically flexible transparent conductive electrodes of high performance (sheet resistance of 17 Ohm/sq. and 90% optical transmission) and successful application of these electrodes in a-Si:H solar cells. The most important merit is that these electrodes are ITO-free (based on SWCNT) and can be used in various flexible electronic devices, specifically, in thin-film solar cells.

The material in the dissertation looks scientifically correct, and the objectives of the research are clearly and well formulated. The input of the doctoral candidate in the publications on the dissertation is clearly stated and sufficient. The dissertation contributes significantly in the field of material science, specifically,

in development of new electrode materials for flexible electronics and solar cells. The scope of the dissertation is the novel electrode materials for hybrid solar cells, and the presented material is sufficient for the doctoral dissertation. The doctoral candidate shows high ability to formulate the key results from the material presented in the dissertation. The dissertation has a standard logic structure and includes the main necessary parts: Introduction, Methods, Results & Discussion, and Conclusions. The results are presented step-by-step with clear logic — from adhesion studies of SWCNT to various materials, to development of composite high-performance SWCNT-based electrodes and their application in solar cells. The last part of the dissertation includes the papers published in high-rank international journals on material science and solar cells. The doctoral candidate shows the solid knowledge and correct using of the literature. The language is good.

The following recommendations, questions, and comments should be taken account:

(1) General

A brief introduction and summary of all results of the thesis before section 4.1 would improve the presentation. Also, I would recommend giving a short conclusion with implications at the end of section 4.1.

Doping of SWCNT by PEDOT:PSS (p. 35, p.41). The statement that PEDOT:PSS dopes SWCNT does not seem conclusive from the thesis. Why should PEDOT:PSS dope SWCNT? The observation that the work function of the composite is between those of PEDOT:PSS and SWCNT seems to be not enough. Moreover, if the surface of the composite is PEDOT:PSS (Fig. 4-5), I would expect that KPFM probes PEDOT:PSS and not SWNT. The discussion on this should be extended.

Why may a strong blue shift arise from strong absorbance of SWCNT? (p. 38). On p. 40, the discussion on blue shift is not self-consistent. On the one hand, the doctoral candidate discusses a blue shift for CNT20; on the other hand, “the shape of the EQE spectra” does not change with SWCNT film thickness. This discussion should be revised.

PMMA as an AR layer (p. 43). The statement that PMMA works as an AR layer needs justification, or, otherwise, it should be presented as an explanation of the data. The statement should be supported by calculation (estimations) from the optical thickness (or/and experiments with various thickness) to understand which thickness would be optimal.

Which simulations of J-V curves and EQE were done? (section 4.3.3)

In section 4.3.3, the doctoral candidate compares the performance of HSC with the reference a-Si:H cell (PCE=7.5%). It would be nice to discuss why this PCE is below the best a-Si:H cells (PCE>10%).

It might be appropriate to discuss the potential for scaling of the proposed TCFs.

(2) Minor methodical issues

Section 3.7. Jsc calculation from EQE (without light bias) will be equal to Jsc from I/V curves, if Jsc depends linearly on the light intensity. This assumption should be mentioned.

p. 32, the method of thickness calculation of SWCNT films from thier optical transmittance should be mentioned. Also, it should be explained how the AFM thickness was measured on not continuous (mesh) films (SWNT).

p. 57, which equipment was used for bending experiments?

p.51, what was a reflective rear mirror?

(3) Other minor issues

Abstract: using optical and electrical instead of “opto-electrical” seems to be more relevant, NIP abbreviation should be defined.

p.5, abbreviation Al:ZnO does not fit AZO in the text.

p. 13, I am not sure that the candidate should self-evaluate his work (“impressive results”).

p. 15, unclear statement: “a-Si:H has a higher absorption edge…than c-Si”; it is better to use the term charge-carrier mobility or charge mobility, but not just mobility; inaccurate statement: “light above the absorption edge”.

p.20, the work function of MoO3 should be given with appropriate literature references. Deposition methods of MoO3 worth to be mentioned.

p.26, the last but one line, what is the dark current at the short-circuit conditions?

p.36, the 3rd paragraph from the bottom, the last sentence. I suppose that the author means not “PEDOT:PSS HSC”.

p.38, the text in the first line should be edited.

p. 39, what was the thickness of CNT10-CNT100?

p. 40, not a good style “during the analysis..”; the 2nd paragraph, what does the author imply in “This might be” (strong blue response or decreased EQE with thickness)?; the equation does add nothing (it can be removed) as it was mentioned in Methods; why was Isc(EQE) calculated only for CNT20?

p.42 and other places, drop-cast (not casted); italic “and” seems to be a format issue, and the statement is not clear: all the three parameters showed a 10% increase or only PCE?

p.43, it would be much better to formulate explicitly the idea of doping SWNT by MoO3 with appropriate references (if relevant).

p.45, the title of section 4.3.2 is not accurate, it seems to be “Optical, electrical, and …”

p. 51, in the sentence “The J-V …” “under AM1.5 conditions” should be deleted (as the figure shows also the dark curves), or one can remove the panel with the dark curves.

It would be nice to update Ref.8.

**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*