Skoltech
Skolkovo Institute of Science and Technology

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

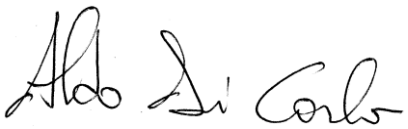
Supervisors: **Prof. Albert Nasibulin, Skoltech, Russia**

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. Aldo Di Carlo

I confirm the absence of any conflict of interest	**Signature:**  **Date: 06-04-2020**

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

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:

The PhD thesis of Pramod Mulbagal Rajanna concerns the development of new science and technology related to innovative architecture for photovoltaic energy generation. In particular, the work focusses on the development of new nanostructured contacts based on single wall carbon nanotubes (SWCNT) and their use in amorphous silicon (a-Si) solar cells.

The presented investigation is performed in a very systematic way. The candidate, as first step, presents a study of mechanical properties of the SWCNT contact, and in particular its adhesion property on a-Si, Silicon, glass and other substrates. Mechanical properties of layers, beside their fundamental importance in reliability of the system, are very rarely discussed in the field of nanostructured photovoltaics. Here, a specific method based on AFM measurement of the adhesion force is used and the relation with humidity and adhesion force is outline. Supported by theoretical calculations, the work presented in the first publication shows the superior adhesion properties of SWCNTs on substrates when the contact is made in inert atmosphere and how proper functionalization of the substrate could impact positively on the adhesion force. The study presented is very complete and combining theory and experiments will impact not only the CNT community but also in the large field of 2D materials such as graphene and related materials.

The candidate exploits these results to the fabrication of a SWCNT/a-Si soar cell also considering possible blend with PEDOT:PSS. Here a thorough investigation is made by using XPS for surface chemical characterization and Kelvin probe to measure work function. This is an important point of the study, namely the relation between work function of the contact layer and the behavior of the device. Work function tuneability is highly desired for solar cell design. Here, it is demonstrated that by mixing SWCNT and PEDOT:PSS the work function can be tuned with a beneficial effect on the device. Moreover, the work demonstrates that SWCNT conductivity is enhanced by the PEDOT:PSS. The candidate, making use of these results and considering light management techniques, such as PMMA antireflection coating, was able to reach the record efficiency for such heterojunction solar cell.

In the last section of the PhD work, related to the paper 4, the candidate develops further the concept of multilayer blended structure to obtain a SWCNTs-MoO3-PEDOT:PSS/SWCNT fibers transparent electrode with a sheet resistance of 17 Ω/sq with a transmittance of 90%. This represent the state of art in the field. By employing this electrode the candidate was able to improve the efficiency of SWCNT-electrode/a-Si solar cells up to a record efficiency of 8.8%. A detailed investigation is performed and a clear explanation of the reasons why the structure is so performing is given supported by experimental data.

The PhD thesis of Pramod Mulbagal Rajanna develops in a very consequential fashion, all the concepts introduced are motivated from scientific point of view, compared with existing literature and exploited at the technological level. The candidate develops a deep understanding of the field and was able to work in a team where he contributed with specific and novel activities as clearly emphasized in the thesis.

In conclusion, the thesis is well written and the candidate made a strong effort to reach scientific achievements that are well beyond the state of art (at the time of publication). This is also witnessed by the scientific production of the candidate on peer reviewed research journals. I am confident that results will impact on both scientific and engineering communities and will be also exploited at industrial level. I strongly recommend the author of this thesis for the PhD degree. The manuscript can be accepted for publication as a doctoral dissertation as it is.

Provisional Recommendation
X *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*