Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis

Name of Candidate: Evgenia Gilshteyn

PhD Program: Materials Science and Engineering

Title of Thesis: Components for Stretchable Electronic based on Single-walled Carbon Nanotubes

Supervisor: Prof. Albert Nasibulin

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

Date of Thesis Defense: 05 October 2018

Name of the Reviewer:

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature and date:**  **12/9/2018**

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

Review:

The thesis entitled: "Components for stretchable electronics based on single walled carbon nanotubes" concerns with the development of a new class of devices designed as wearable skin sensors. This is a very

timely investigation describing state of the art technology in the fast growing field of wearable sensors. A main theme in the thesis is the identification highly performing materials and proper fabrication processes. This is an extremely important and often overlooked issue. In the realm of wearable devices that are several emerging needs such as improved electrophysiological sensors and energy storage. The thesis rightfully focuses on single wall carbon nanotubes (SWCNTs) and their integration into fully functional devices. Although SWCNTs have been studies extensively for numerous applications, their integration into highly performing wearable devices has been relatively limited. In particular, previous reports included completely non-practical fabrication methods requiring wet transfer methods.

In the Thesis, SWCNT are studies in several alternative scenarios: (1) as conducting transparent and stretchable films (2) as electrodes for flexible super-capacitors and (3) piezo super-capacitors.

The thesis describes three main achievements: (1) the development of a SWCNT-based conducting, stretchable and transparent film using a transfer method which negates the need for a sacrificial layer. (2) Highly stretchable super capacitors based on SWCNTs. (3) A super capacitor with BNNT separator.
In all of these activities, devices are fully characterized using a wide range of techniques including SEM imaging, electrical conductivity measurements.

The Results section is very detailed and the Results are overall very well described.
The Results section includes some text which should be rearranged into other sections. Specifically, some of the text in page 47 should be incorporated in the Discussion section. Some of the text in Page 49 appears to belong to the Introduction section.

The **Results section** is indeed very comprehensive. There are few points that can improve the clarity of the presented results:

1. The description of the process flow applied is a bit hard to follow. A more detailed sketch of the process flow (beyond what is presently presented in Figure 6) will make it much easier to follow.
2. Current versus scan rate plots are missing in electrochemical characterization (in particular in Figure 24) to substantiate electrochemical regime.
3. The role of the contact resistance plays in the resistance measurements should be highlighted.
4. The resistance change in the stretching experiments appears to be transient. This point has to be better clarified.

Figure captions should be improved (few examples):

1. Figure 3: Which one is the SEM and which is the TEM image? (A reasonable reader can easily figure it out but the details should still be there).
2. Figure 4: details are missing for the different panels.
3. Figure 10: same as above.

The **text** is clear and well organized.
Although the thesis is generally clear, it can benefit from some careful editing. Few example:

1. In page 13 “…development of and processing” – should be corrected
2. In Page 13 “Low yield of production” should be “low production yield”

3. In page 15 “It has been already investigated…” – unclear
4. In page 16 “As the result” should be “as a result”
5. In page 20 “we use the most” should be used.
6. In page 22 “After … filter is” – should probably be “filter, it is…”
7. The term “training” in page 24 should be replaced with an explicit definition.
8. The paragraph in page 25 is unclear.
9. “a” and “b” marks in page 25 belong to Figure 9 in page 26.
10. Page 38: Floating a,b,c letters.
11. Text in Page 41 (bottom) belongs to Introduction section.
12. Page 59 – “By the moment” should be replaced with “So far”.

The **Conclusion section** can be improved by addressing the following topics: Are the processes/material used compatible with industrial processes, what are the possible next steps to guarantee such compatibility. What is the path towards biocompatibility approval? It may also be beneficial to discuss alternative substrates (to PDMS) and how they can benefit device performances. Finally, although yield is not an easy point to address systematically in an exploratory study, it makes sense to address this point in the context of the Discussion.

Overall, the thesis is very comprehensive as it describes fabrication, characterization as well as real life testing. It deals with a very important and timely challenge and offers several interesting paths for future explorations and developments. As such I recommend it for a defense after addressing the points listed above.

Provisional Recommendation (select one)

◯ *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*