Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Stepan Romanov

PhD Program: Physics

Title of Thesis: Single-walled carbon nanotubes as a source of ultrasound

Supervisor: Professor Albert Nasibulin

Name of the Reviewer: Associate Professor Mikhail Skvortsov

I confirm the absence of any conflict of interest	**Signature:**  **Date: 04-10-2020**

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

The Thesis addresses excitation of sound waves in air by applying an AC current to a free-standing SWCNT film. It contains both the thorough theoretical discussion of the underlying physics and excessive experimental work, staring with film production, characterization, device fabrication and study of its operation in various conditions. As a result of the research summarized in the Thesis, the highest ever-measured efficiency of thermophone devices was detected. This fact is a direct consequence of a very low areal heat capacity of SWCNT, making them a prospective material for thermoacoustic devices.

The Thesis contains 5 chapters. Chapters 1 and 2 provide an introduction to the thermoacoustic effect. Experimental methods used for SWCNT synthesis and their characterization are discussed in Chapter 3. Chapter 4 contains the theoretical analysis of sound wave generation via modulation of the sample temperature, including discussion of various channels of heat losses in the system and their experimental verification. It also contains the main results for the thermophones performance as a function of their thickness and addresses several ways to increase the efficiency of sound generation by various types of

SCWNT structure treatment. The last Chapter 5 contains discussion of the results obtained.

In general, the Thesis is well written. It's important to emphasize that many questions that arise during reading are discussed in further sections. Crucial aspects of the theoretical approach and experimental work are properly addressed. At various stages of research, the author is fluent in choosing adequate experimental methods.

Thought my overall estimate of the Thesis is sufficiently high, there are several questions/comments to be answered by the author:

1) It would be instructive to compare the thermoacoustic effects in free-standing SWCNT and free-standing graphene. Since the latter is the ultimately thin atomic monolayer, one could expect its performance could exceed that of SWCNT films.
2) The theoretical model developed in the first section of chapter 4 essentially assumes a 1D nature of air temperature/pressure modulation. In order for this model to be applicable one must require the length scale *l* be much smaller than the sample size *a*. How well this condition is satisfied in the relevant frequency range?
3) The rhs of Eq. 1.8-6 is complex, while the lhs is manifestly real. How can it happen?
4) How sensitive is the efficiency of heat conduction in the film (Section 1.9.2) on the area of contacts with the substrate?
5) Fig. 1.9-5 shows that T obtained under the assumption of 100% efficiency of radiation losses shows perfect agreement with experiment. It is not clear how it fits with Fig. 1.9-1.

Besides that, I'd like to suggest using a more appropriate section numeration changing with Chapters. For example, the first Section of Chapter 4 should be 4.1 rather than 1.8. This also refers to figures and equation numbering.

Also, there are some misprints/minor inconsistencies:

- Repetition of "AC alternating current" on p. 11
- Above Eq. 1.8-14, the velocity is lost at "<< v_s".
- Above Eq. 1.8-22, "than" to be replaced by "then"
- Caption to Fig. 11.1-2 and 11.1-3 on the next page.
- p. 81: determent -> determined

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*