Referee report on the PhD. thesis of Ing. Suren A. Ali-Ogly
entitled

LOW TEMPERATURE PLASMA AND NANOPARTICLES: EFFECTS OF GAS FLOW AND SURFACES

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The PhD. thesis investigates the carrier gas flow role in the magnetron-based gas aggregation cluster source and its impact on nanoparticle transport. Both the theoretical and experimental approach has been chosen. The author realized numerical simulations using fluid dynamics to study namely the effect of inlet configuration, the gas velocity and pressure on nanoparticles motion, trapping and residence time in the system. Simulations include the Brownian motion and identify it as a very important transport mechanism. The experimental part included the sputtering of modern polymer material PLA which was shown to facilitate nanoparticle adhesion.

The text is written in English with abstract page in both English and Czech languages. The total number of pages is 124 from which the text ends by the conclusion at page 106. Then follows the rich bibliography with 142 citations, list of author publications, lists of abbreviations, tables and figures and one page appendix A with basic fluid equations follow.

The list of publications with Ali-Ogly as co-author consists of 11 items and in 2 of them Ali-Ogly stands as the first author.

Chapter 1, "Introduction" presents briefly the plasma physics, plasma-surface interaction and plasma polymerization. The last subchapter includes also the magnetron sputtering and cluster source. Chapter 2 is devoted to computational fluid dynamics method. It introduces Knudsen number, boundary conditions, fluid model and finally the solid particle model which extends the fluid model.

Chapter 3 presents the experimental and simulation set-up and also the diagnostic methods. Particular experimental configurations for the PLA magnetron sputtering and gas aggregation sources with planar magnetron, with planar magnetron and an auxiliary chamber and with the post-cylindrical magnetron are described. The simulation set-up part specifies the used simulation software Siemens STAR CCM+ and shows four modelled configurations by depicting the geometrical computational domain cross sections and in tables presents the model set-up parameters. Finally, the used diagnostic methods of QCM, XPS, UV-VIS spectrometry, FTIR, ellipsometry and SEM are described.

The key 4th chapter contains the results and their discussion. Part 4.1 deals with PLA, polylactic acid polymer sputtering using the RF powered planar magnetron and its combination of this sputtering with the deposition of silver nanoparticles. Part 4.2 is focused on the planar magnetron gas aggregation source. The movement of nanoparticles is studied by their localized surface plasmon resonance (LSPR) peaks in the UV-VIS emission spectra, analysis of the forces acting on nanoparticles, simulation of the gas flow and impact of the gas inlet configuration. Part 4.3 investigates the influence of the Brownian motion on the nanoparticles motion. Part 4.4 presents the results of fluid dynamics modelling of set-up for in-flight coating of nanoparticles. The study of the GAS system with post-cylindrical magnetron, which is a promising alternative to planar magnetron, is presented in part 4.5. The measured deposition rates as well as nanoparticles size distributions are shown together with the CFD analysis, and both resulted in the optimization of this nanoparticles plasma source.

The conclusion on page 106 summarizes the thesis results in 7 paragraphs.

The thesis text is written using good English, I found no significant problems in reading it. Nevertheless, it is not difficult to find spelling errors like capitalization, end of the sentence period instead of comma, inverted red question mark representing some missing character, missing references to figures 26, 29, unexplained abbreviation PAVTD. Similarly, there is no reference to conservation laws equations summarized in appendix A which are described only by words on page 20. Problematic or at least misleading is equation (7) on page 5 where factor A is not constant with respect to the velocity. On the other hand, equations (12) to (16) on pages 23 and 24 are trivial. It seems to be also too late to mention as far as on page 42 that the fluid simulations were performed using the software Siemens START CCM+. A bad decision was to print the thesis on paper with high thickness of 0.2 mm because it complicates pages flipping and keeping the thesis open requires significant effort.

I have following comments to which I expect reaction from author:

- Some of experimental and model setups are axially symmetric, e.g., planar magnetrons in figs. 16 and 17. Numerical models usually utilize symmetries for significant calculation speed up. Is that possible in the used model?
- Figure 37 shows an interesting result that the residence time of nanoparticles has significant radial dependence. Is it also present in the velocity? From the plot in figure 36 it is not clear.
- Figure 60 on page 95 shows the velocity magnitude in the post-cylindrical magnetron but interesting in this case is the azimuthal component which probably contributes to nanoparticles trapping and release. Can it be caused by the electric vs. drag force balance?
- This may be connected to deposition rate dependence on the rotation speed of the magnetic system in figure 62 (a). There the peak at the time of 300 s is not as big in comparison with that at time 130 s and 9 RPM. It seems that the nanoparticles release appears more often than just after switching the discharge off.

The author’s expertise in fluid dynamic modelling allowed to understand the carrier gas movement in modern types of GAS. The combination of this numerical modelling with experiments already served and most probably will serve as the optimization tool for better design of GAS of different types. The author included the Brownian motion of nanoparticles into the model and showed its significant contribution to nanoparticles release from their traps near the target but also for nanoparticles loses at the walls like near the aggregation chamber orifice.

The errors that I found and mentioned above are mostly formal and not very significant. The thesis of Ing. Ali-Ogly shows authors ability of the creative scientific work. Results were already published in reviewed journals. The number of publications in which Ali-Ogly is co-author is 11 which is excellent. The topic of the thesis is actual, and thesis helped to uncover problems with the formation, transport and deposition of nanoparticles in gas aggregation sources.

The thesis fulfills all the requirements, and I can recommend, after successful defense, to award the author the PhD. title.

Prague May 5th 2023 doc. Mgr. Pavel Kudrna, Dr.