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Koszalin, 15.11.2023

REVIEW

of the dissertation of M.Sc.. **Fabian SCHODEN**

„Investigation of non-toxic dye-sensitized solar cell materials for circular design approaches”

1. Formal basis for the review”

The formal basis for the review is Resolution No. 150/223 of the Council of the Materials Engineering Discipline of the Silesian University of Technology of October 24, 2023 and a letter from the Chairman of the above-mentioned Discipline's Council of October 31, 2023.

2. The structure of the work and its general formal characteristics.

The reviewed dissertation entitled "Investigation of non-toxic dye-sensitized solar cell materials for circular design approaches" contains 182 pages. Its structure includes an introduction, four substantive chapters, a summary and general conclusions, a list of used literature, a list of figures (74 in total), a list of tables (11 in total), a list of abbreviations used and an Appendix containing information on the equipment used. Above the substantive chapters are: 2.Theoretical foundations, 3.Methodology, 4.Experimental results and 5.Discussion. The work is written in English, but its summary on pages 9-34 is in fact a shortened Polish version of the entire dissertation, which even has its own list of references, separate from the main one. The literature cited in the main, English-language part includes 171

items, of which 8 are publications co-authored by the PhD student. The dissertation for review was presented in both a printed and an electronic version.

The author formulated the main aim of this work as examining the suitability of DSSC technology and the materials used within the framework of a circular economy.

The multi-threaded nature of the research made it necessary to include in the text a literature analysis of material from many scientific fields and an extensive justification of the research objectives of the work.

The main "keyword" in relation to the thesis can be defined as the abbreviation DSSC (dye-sensitized solar cell), i.e. photoelectrochemical solar cells without a traditional P-N junction, in which the photosensitive layer is a dye or sensitized by such a dye material. With regard to such structures, the PhD student conducted a number of studies, based both on literature analysis and on his own experiments. The essential elements of the dissertation are:

- presentation of the state of knowledge in the field of the history of DSSCs; properties of materials and principles of operation of DSSC; stability of DSSC materials and the concept of using recycling for DSSCs, including details of DSSCs regeneration in a closed cycle of their existence; proposing a business model of the regeneration cycle and its implementation;
- detailed description of individual technological elements for verifying the recycling and regeneration process of DSSCs structures, including the processes of melting, preparation and analysis of the glass substrate with the determination of trace residues;
- discussion of the methodology for testing DSSCs structures at all stages of the full production, testing and recycling cycle, including testing of DSSCs and individual layers using an atomic force microscope, spectroscopic studies of the absorbance of selected layers, elemental analysis of the substrate using the SEM-EDX method, and performing elemental composition tests also with using inductively compressed plasma emission spectrometry (ISP-OES); photoconversion efficiency of DSSCs structures as solar cells under the light of a calibrated solar simulator;
- development of a prototype model for implementing the closed loop use of DSSC cells in practice, defined in the work as a business model.

The dissertation ends with the Summary and Discussion chapter, in which the PhD student summarizes all the results obtained in the work, both during work with the literature and during laboratory work. This part also summarizes estimates of potential profits in a possible technological process and formulates some practical recommendations for subsequent stages of research towards the topic of the dissertation. To sum up, I state that the subject of the doctoral dissertation concerns current and important issues both for materials engineering and related disciplines.

3. Substantive assessment of the dissertation.

The dissertation of M.Sc. Eng. Fabian Schoden was made, in my opinion, at the intersection of several research disciplines. Some aspects of the work lie in the areas of materials science, chemical technology, semiconductor physics, optoelectronics, and ecology and environmental protection. The author formulated the following research hypothesis: materials needed for the production of DSSCs can be subjected to cyclic technological processes so that the obtained stability of structural, optical and electrical parameters allows their reuse in photovoltaic devices. And after analyzing the content presented in the dissertation, I have grounds to say that the results of the PhD student's work confirm this.

As a very positive component of the work, I would like to draw attention to the original analysis of data from Web_of_Sci, presented on pages 81-84 and performed on a very large amount of bibliographic data, which strongly justifies the topicality and importance of the research performed in the work presented for review.

I would like to emphasize that the results of the experimental research presented in the work were presented and described with exceptional precision and meticulousness. All tests were performed using high-class devices, which allows us to treat the results as very reliable and unambiguous. As an example, here in the review I will provide the ISP-OES results (e.g. Table 3) of the components of uncontrolled pollutants and comparison with data from the literature. In this context, I would like to emphasize once again that the author of the dissertation not only described in detail the methodology of the research, but also presented in the Annex a detailed description of (probably) all the diagnostic and technological devices used in the work.

Fig. 3.1 should be treated as a very successful solution, integrating individual fragments of the entire work, which allows us to connect the important parts of the work in the context of recycling of DSSC structures and materials presented in chapters 3, 4 and 5.

The entire analysis of the problem arose logically from the selected topic and objectives of the work. The way in which the analysis was carried out proves that the author of the dissertation has very good general scientific preparation and knowledge both strictly related to the research topic and related matters. These related aspects include not only physical and chemical aspects (operation of DSSC cells, layered components, stability of structures, disposal and recycling methods, parameters controlled in recycling), but also economic and social aspects, such as investments in electrotechnical systems based on ecologically clean ways of generating energy and reusing materials from DSSCs. One of the interesting results of the work may be the statement of the PhD student that "It has been shown that thanks to the key processes of the circular business model, i.e. regeneration and recycling, it is possible to obtain the so-called closed material loops and non-toxic DSSC dye cells are a promising technology for generating green energy that can potentially be integrated into the material cycles of a circular economy".

The research results were presented in a series of seven (7) articles published in peer-reviewed scientific journals, including 7 articles from the A list of the Ministry of Science and Higher Education.

The entire reviewed dissertation clearly proves that the dissertation is a comprehensive scientific product that includes such necessary components as the topicality of the research subject, in-depth literature analysis, original experimental research and sufficient analysis of the results of these experiments.

In general, the layout of the dissertation, the presentation of the material in the chapters, their structure, the way of presenting illustrative materials, and the citation of literature should be considered correct.

The text was written in a clear and easily understandable way, but this ease does not simplify the scientific aspect too much. It is worth emphasizing once again that the description of most research equipment, technological and measurement procedures is given in great detail, one might say precisely, which proves the

author's high level of knowledge and mastery of his work in conducting research experiments. The author analyzes the measurement results quite logically and objectively, and the conclusions resulting from the analysis are not controversial.

In the final part of the work, the PhD student, based on the research performed and considering the results of this research, proposes a potential production process in accordance with the principles of closed loop. This approach is a new example of transforming a classic linear production process into a closed-loop process, combined with an appropriate business model.

The obtained results were presented in a series of seven (7) articles published in peer-reviewed scientific journals from the A list of the Ministry of Science and Higher Education, which more than meets the generally accepted requirements for doctoral dissertations and those included in Resolution No. 43/2023 of the Senate of the Silesian University of Technology of September 25, 2023.

To sum up the substantive assessment of the dissertation, I state that its structure, subject matter, level of presented original research as well as presentation of the author's knowledge in the field of research meet the generally accepted requirements for qualification theses, which are doctoral theses in the field of technical sciences, and the subject matter corresponds to the scientific discipline of materials engineering.

4. Critical notes

- The PhD student introduces and then uses the concept of "Circo methods" several times. After using it six times on pages 6 to 55, it is only on page 76 that he makes an attempt to explain its essence. And this translation is probably not entirely clear either. From my point of view, this is a significant mistake, especially in work in the field of Materials Engineering, rather than in economics or another branch of business.
- In Fig. 25-27, the PhD student presents the results of statistical analysis of published data from the Web of Science database, in the form of a colored "map" with colors associated with individual functional components of DSSCs. In my opinion, the description of these "maps" is not clear enough. There is no explanation of how the general outline of the "maps" was generated and how groups of points in individual colors were located in one or another place of the "map". Also noteworthy is the fact that chapter 4.1,

entitled "State-of-the-art recycling methods in the context of DSSCs - bibliographic analysis", is located in chapter 4. "Experimental results"

- In the literature list I noticed identical items no. 16 and no. 18. Was it done on purpose or was it a technical error?

5. Overall assessment and final conclusion.

The reviewed doctoral thesis of Ms. M.Sc. Eng. I fully appreciate Fabian SCHODEN positively. It fully meets the requirements contained in the wording of the Act, namely that "A doctoral dissertation, prepared under the supervision of a supervisor, should constitute "an original solution to a scientific problem, ... and demonstrate the candidate's general theoretical knowledge in a given scientific discipline."

This assessment mainly consists of:

- original, current topics with important issues in the field of Materials Science and Engineering, aimed at deepening knowledge in the field of production, properties and applications third generation solar cells (DSSG cells);
- the use of efficient, modern research methodologies and equipment by the PhD student;
- methodologically correct and consistent way of carrying out research;
- ability to analyze experimental data and draw conclusions relevant applications;
- good analysis of the state of research in the field of the work on literature database;
- obtaining and presenting new, original scientific results, which were approved in seven publications in scientific journals with the "impact factor";
- well-made graphic side of the work In a form of a dissertation.

The critical remarks and discussion questions presented above in the review do not detract the overall scientific value of the assessed dissertation and presenting this work as a work qualification.

I believe that the doctoral dissertation of M.Sc. Fabian SCHODEN entitled "Investment of non-toxic dye-sensitized solar cell materials for circular design approaches" meets all the requirements of the Act on academic degrees and titles

and on degrees and titles in the field of art of March 14, 2003 (*Journal of Laws of 2016, items 882, 1311, of 2017, items 859, 1530, as amended*) and I request that it be allowed to be publicly defended.



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