

**Referee's report on PhD thesis of Mrs. Amina LAOUID entitled:
Nanostructures and thin films of metal-organic complexes and hybrid
perovskites for applications in optoelectronics and photovoltaics**

The doctoral dissertation by Amina Laouid, entitled "Nanostructures and thin films of metal-organic complexes and hybrid perovskites for applications in optoelectronics and photovoltaics, was prepared under the supervision of Dr Hab. Anna Zawadzka, Professor NCU at the Institute of Physics of the Nicolaus Copernicus University, in the group with extensive experience in theoretical and experimental studies of various aspects of materials engineering and its physical and industrial application, and Dr Alaoui Belghiti, Professor CDU, National School of Applied Sciences (ENSA) El Jadida, Chouaib Doukkali University. This dissertation was carried out under the project: "Internationalization of PhD Schools at NCU: a platform for joint and double degree" [PhD @ NCU] executed under "STER – Internationalization of Doctoral Schools" program between the Nicolaus Copernicus University and the Polish National Agency for Academic Exchange (NAWA).

The work presented is based on an experimental and theoretical approach including experimental techniques (AFM, TEM, PL, UV-Vis, XRF and FTIR) and theoretical modeling (DFT, SCAPS simulations).

The manuscript is well structured and organized into six peer-reviewed scientific articles published between 2022 and 2024 in international learned journals. These publications have between 6 and 12 authors; in 5 of them, Ms. Amina LAOUID is listed in the first place, and statements of co-authors confirm her dominant contribution to most papers.

Article I: *In this article, a particularly noteworthy aspect of the thesis is the thorough investigation of metalorganic thin films, specifically DCM and Znq₂ systems, deposited via PVD. The candidate systematically explores the influence of doping concentrations*

on the morphological and optical properties of these films. This article includes detailed analyses of molecular interactions affecting energy level alignment and absorption characteristics, supported by experimental data and DFT calculations. Such a dual approach not only validates the experimental findings but also provides deeper insight into the electronic structure and transition mechanisms, which are critical for tuning material properties for optoelectronic functionalities.

Article II: *This article includes a photoluminescence studies conducted at room and cryogenic temperatures reveal intricate energy transfer mechanisms, notably Förster resonance energy transfer (FRET) between Znq₂ and DCM molecules. The observed spectral shifts and intensity variations highlight the potential of these materials for applications requiring tunable luminescence, such as light-emitting diodes and optical sensors.*

Article III: *In this article, the candidate presents an investigation on the nonlinear optical (NLO) properties, including second and third harmonic generation. The reported results demonstrate the feasibility of employing these composite films in advanced photonic devices, such as frequency converters and optical modulators.*

Article IV: *In this article, the candidate reports an investigation on the synthesis and characterization of ZnS thin films doped with calcium and manganese. This investigation provides a valuable insight pointing out to how dopant selection and concentration can be strategically used to engineer bandgap energies and emission profiles. The published work is significant for developing cost-effective, tunable phosphor materials with potential lighting and display technologies applications. The claimed findings underscore the candidate's comprehensive understanding of semiconductor physics and materials engineering.*

Article V: *This article constitutes the latter part of the thesis. The focus shifts to photovoltaic devices, where the candidate addresses critical challenges related to*



stability, toxicity, and efficiency in perovskite solar cells. The use of SCAPS-1D simulations to optimize $\text{RbSn}_{0.5}\text{Ge}_{0.5}\text{I}_3$ -based lead-free perovskite solar cells is particularly revealed judicious. Simulation results point out to promising power conversion efficiencies exceeding 24%. This contribution is highly relevant in the context of global efforts to develop sustainable and environmentally benign photovoltaic technologies.

Article VI: In this article, the candidate presents the fabrication and characterization of MAPbI_3 -based hybrid perovskite solar cells via co-PVD. The used approach represents a significant advancement. She underscores that the temperature-dependent studies (ranging from 10 K to 320 K) combined with long-term stability assessments provide a robust evaluation of device performance under extreme conditions, such as those encountered in applications. The results showed an efficiency of around 18.5%. This work not only demonstrates the practical viability of co-PVD as a scalable and reproducible fabrication technique but also contributes to valuable knowledge toward enhancing the durability and operational stability of perovskite-based devices.

Conclusion: This thesis provides several new highly relevant results. As previously mentioned, all results are published in learned International Journals with a correct impact factor. Moreover, the work is well-structured and the results are clearly stated. The candidate exhibits substantial skills in research field of the nanostructures and thin films of metal-organic complexes and hybrid perovskites for applications in optoelectronics and photovoltaics. I am convinced that all reported results represent significant and original contribution to the applications in optoelectronics and photovoltaics.

The submitted publication cycle fully meets the criteria for a doctoral dissertation. It presents original and impactful findings that significantly contribute to advancing optoelectronic materials, nonlinear photonics, and especially next-generation



photovoltaics. The work also enhances fundamental knowledge in physical sciences, particularly in optical and condensed matter physics. PhD candidate achievements justify awarding the academic Doctor of Physical Sciences degree.

This doctoral dissertation of Ms. Amina Laouid fully satisfies the requirements stipulated under Article 187 of the Act on Higher Education and Science of July 20, 2018 (as amended), for the award of the academic degree of Doctor in the field of Physical Sciences. I recommend that PhD candidate A. Laouid be awarded the degree of Doctor of Physical Sciences based on the submitted publication cycle. In my opinion, the quality and scope of the results go far beyond what can be expected from a doctoral dissertation, and I propose the thesis for distinction.

Recommendation: Taking into consideration the previously mentioned results, I unreservedly recommend that the Council of the Discipline of Physical Sciences at Nicolaus Copernicus University in Toruń permit the candidate to proceed with the subsequent stages of the doctoral examination and defense process, ultimately leading to the conferral of the doctoral degree.

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