1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: Precursors of Nanomaterials for Catalysis and Sensors

1.1 Project goals

- development of finding and synthesis of new precursors dedicated to specific vapor deposition techniques,
- studies of reactions in the gas phase and solid state,
- understanding mechanisms of electron/ion and laser beam interactions with adsorbed molecules,
- selection of precursors promising for individual vapor deposition methods,
- obtaining micro- and nanomaterials with defined properties,
- studies of catalytic, photocatalytic, and sensing properties of obtained materials.

1.2 Outline

Micro- and nanomaterials containing transition metals are used in electronics, optoelectronics, plasmonics, catalysis, and antimicrobial agents. They can be obtained by gas-assisted methods such as chemical vapor deposition (CVD), where one or more volatile precursors are transported by a carrier gas to the reactor chamber, and they decompose on a heated substrate. Nowadays, methods where a decomposition is initiated using other than temperature factors, are becoming more important. The advanced process, such as e.g., focused electron beam induced deposition (FEBID), focused ion beam induced deposition (FIBID), plasma enhanced CVD, or laser-assisted CVD, allows obtaining deposits of a unique composition or shape. Therefore, volatile transition metal complexes constitute a topic of intensive studies because they play a crucial role in success during the deposition, and they influence the development of nanotechnology.

With Vapor Deposition Methods, thin layers of metals and other materials and more complicated 2D and 3D nanostructures can be deposited on different and also flexible substrates. However, these methods require applying compounds, which are metal sources (so-called precursors). Metal-organic compounds generally play this role. They have the ability to generate volatile metal carriers, which are transported over a substrate where they decompose, forming the desirable material. New user-friendly precursors, which easily generate metal carriers and demonstrate low evaporation temperature, can be used in the one-step fabrication of materials are still sought.

Materials formation can be induced by heating (CVD) but also using a focused electron (FEBID) or ion (FIBID) beam, a laser beam (LACVD), or plasma. The main aim of the proposed project is to find new volatile precursors, fit them to the method, and fabricate materials with specified properties in the areas of catalysis, photocatalysis, and sensor chemistry (SERS effect). Selected deposits with high activity can be used for commercial applications.

1.3 Work plan

- Classic and mechanochemical synthesis of new potential precursors,

- Complexes composition and structure studies,
- Determination of volatility and thermal stability of the compounds,
- The use of calculations to find or confirm the relation between molecules' structure and physicochemical properties,
- Studies of molecule sensitivity to electrons or ions, a laser beam, and plasma treatment. Propose mechanisms of interactions for promising precursors,
- Fabrication of nano- and micromaterials using precursors fitted to appropriate vapor deposition method,
- Morphology, composition, and properties characteristics of obtained materials,
- Studies of catalytic, photocatalytic, and sensing activity of promising materials

1.4. Literature (max. 10 listed, as a suggestion for a PhD candidate)

1) I. Utke, P. Swiderek, K. Höflich, K. Madajska, J. Jurczyk, P. Martinović, I. B. Szymańska, *Coordination Chemistry Reviews,* 458 (2022) 213851.
2) K. Madajska, I. B. Szymańska, *Materials*, 14 (2021) 3145.
3) S. Barth, M. Huth, F. Jungwirth *J. Mater. Chem. C 2020, 8*, 15884-15919.
4) Zhou, M.; Bao, S.; Bard, A.J., *J. Am. Chem. Soc.* **2019**, *141*, 7327–7332, doi:10.1021/jacs.8b13366.
5) M. Lacko, P. Papp, I. B. Szymańska, E. Szłyk, S.Matejcik, *Beilstein J. Nanotechnol.*, 9 (2018) 384–398.
6) L. Berger, K. Madajska, I. B. Szymańska, K. Höflich, M. N. Polyakov, J. Jurczyk, C. Guerra-Nuñez, I. Utke, *Beilstein J. Nanotechno*l, 9 (2018) 224–232.
7) K. Höflich, J. M. Jurczyk, K. Madajska, M. Götz, L. Berger, C. Guerra-Nuñez, C. Haverkamp, I. Szymańska, I. Utke, *Beilstein J. Nanotechnol*, 9 (2018) 842–849.
8) Luo, S.; Zeng, Z.; Zeng, G.; Liu, Z.; Xiao, R.; Chen, M.; Tang, L.; Tang, W.; Lai, C.; Cheng, M.; *ACS Appl. Mater. Interfaces* **2019**, *11*, 32579–32598.
9) P. Martinović, M. Rohdenburg, A. Butrymowicz, S. Sarigül, P. Huth, R. Denecke, I. B. Szymańska, P. Swiderek, *Nanomaterials,* 12 (2022) 1687
10) R. Córdoba, P. Orús, S. Strohauer, T. Torres, J. M. De Teresa, *Scientific Reports*, 9 (2019) 14076.

1.5 . Required initial knowledge and skills of the PhD candidate

- Analytical thinking
- Eager to learn
- Teamwork
- Experience in basic chemical synthesis and spectroscopy
- Understanding of nano- and micromaterials synthesis and analysis
- Basic knowledge of deposition techniques
- Keen to learn new techniques, instrumentations, and calculations
- Thinking oriented on innovation and application

1.6 Expected development of the PhD candidate's knowledge and skills

- Improve analytical thinking,
- Understanding why we still need to learn,

- Organization of teamwork,
- High experience in advanced chemical synthesis and spectroscopy,
- Fluency in materials synthesis and analysis,
- Advanced knowledge of deposition techniques,
- Knowledge of modern techniques and instrumentation and ability to do calculations,
- Thinking highly oriented on innovation and application.