Short description of the Gulaim Seisenbaeva´s research profile

My research work has always been concentrated on development of chemical synthetic approaches to new materials, aiming to influence purpose characteristics of the material by varying chemical and physicochemical parameters of its synthesis. In my projects I am always trying to trace and understand the transformation from molecular precursors to materials with desired properties. The focus of my work is in the search for Molecular Chemistry approaches to nano-level defined materials. During the work at SLU for the last 18 years my research became strongly directed toward the use of bio-based materials and to applications in the Green Sector in the domains of environmental science and protection of the environment, bio-energy and bio-catalysis.

My original scientific training was in the field of chemical technology and heterogeneous catalysis. In my Master Thesis entitled “Applied ruthenium and copper-ruthenium catalysts in the liquid phase hydrogenation reactions” I investigated thermal decomposition of metal complexes at different temperatures and the influence of decomposition temperature on the activity of prepared catalysts [1]. Since then I have become interested in molecular chemistry tools for production of functional solid materials, in particular, thermal decomposition mechanisms and their influence on morphology and chemical composition of the resulting products.

The Ph.D. research work, “Tricarboxylatouranylates(VI) of protonated amines”, was devoted to the development of synthetic approaches to anionic carboxylate complexes of uranium(VI), and investigation of their thermal decomposition mechanisms leading to formation of highly disperse uranium dioxide for application in nuclear fuel blocks. There have been developed general approaches to the synthesis of anionic carboxylate complexes of uranium(VI) using interaction of uranyl carboxylates with hydrated amines in aqueous solutions of carboxylic acids. It was found out that the obtained compounds (the total of 26, of which 23 new ones) could be subdivided into different groups according to the specific features of their behavior under thermal decomposition. The mechanisms of thermal decomposition have been elucidated. Non-stoichiometric uranium dioxide samples obtained were in all the cases highly disperse, fine pyrophoric powders. Decomposition temperatures were in all cases noticeably lower, and the chemical activity of UO_{2+x} formed – higher than for the species obtained from uranium carboxylate hydrates. These results were of interest also for conservation of nuclear wastes via incorporation of uranium compounds into silicate granulates [2-7].

After graduation I worked for a short period at a private research company Technologia in Moscow, developing hybrid organic-inorganic polymer based materials and coatings on ceramics, which resulted in a patent application submitted by the company.

I continued then as researcher at the Academy of Fine Chemical Technology in Moscow working with Molecular Chemistry approaches to oxides of rhenium and to rhenium alloys. This work resulted in new insight into metal-organic chemistry of rhenium in higher oxidation states and opened new facile approaches to highly requested materials such as nanostructured pure and doped rhenium trioxide, ReO_3 [9,11,19,22]. New electrochemical approaches were then used to synthesize a family of unusual heterometallic Re-Mo and Re-W cluster compounds [8,14,18,22]. A Patent of Russian Federation for preparation of rhenium alloys via thermal decomposition was obtained [10]. I continued this direction as Postdoc at Arrhenius Laboratory, Stockholm University 1996 in collaboration with Professors Mats Nygren and Margareta Sundberg, investigating morphology and structure of the materials by scanning, transmission and high resolution electron microscopy [12,13,18], which became principal tools in my research. I became especially interested in Environmental electron microscopy, ESEM, permitting to visualize morphology and structure and get insight into function of biological samples. I received also advanced training in thermal analysis focusing on controlled transformation of solids (TPR, decomposition mechanisms etc. along with TGA in controlled atmospheres and DTG-DTA techniques).

Having then moved to SLU as researcher I got a strong focus in my studies on environmental applications and development of bio-based materials. My projects were exploiting in the beginning my expertise in heterogeneous catalysis using Re-catalysts produced by Soft Chemistry [29,38-40,52, 57,59,63,65,81] for improvement of environmental characteristics of both fossil [26] and especially biofuels [83] in which my first PhD students Pavel Schcheglov and Olesya Nikonova were involved. I got my Habilitation in Environmental Materials Chemistry at SLU in 2004 with the title "Kan materialkemi lösa miljöproblem?" (Can Materials Chemistry make principal contribution to solution of Environmental problems?). In the period 2004-2007 I was employed half-time at the Department of Bioenergy, working on projects devoted to wood biofuel – quality improvement and control of emissions – in both research and teaching (co-authoring a textbook and collection of teaching materials). My expertise in thermal analysis and ESEM turned very helpful in developing new torrefaction approaches to low-emission wood biofuels [96,97,108].

Since 2008 when the Department received an own ESEM instrument, which I have become responsible for, I got an excellent possibility for studies of both biomaterials and biological objects and also for developing environmental applications. I was actively involved in the project "Nanoparticle impurities in air express-analysis and health effects" and was co-supervising the PhD student Kai Wilkinson. My contribution was in particular in development of ESEM techniques for recognition of the chemical identity of the particles [75,78,87,91,123]. This work received a strong attention and led to several academic and industrial projects focused on development of new ESEM methodology supported, in particular, by Electrolux AB, interested in the indoor pollution at homes around the world [https://www.youtube.com/watch?v=sanohDFJx-U&app=desktop]. Other projects exploiting ESEM were dealing with such challenging tasks as finding microbial parasites in soil, wet fish tissues, quality analysis of butter spread (both industrial/confidential), revealing plant communication through morphology alteration in leaves [124], getting insight into microbial plant interactions [84, 118], and analyzing starch-based materials for food packaging [131]. With developing techniques for recognition of minerals in ESEM I got interested in nano minerals and their applications for hydrometallurgy and also in new nanotechnology approaches to water purification and to energy materials. I have developed a new approach to porous oxide materials [86,106], which turned to be attractive as both adsorbents [86,106,112] and also as electrode materials for Li-ion batteries [95,113,125]. Exploiting expertise I got through participation in the project on hybrid nano cellulose materials [102,115,117,143], I developed approaches to functional gels and paper, which I plan to develop in collaboration with the Innventia AB. Developing my expertise in microscopy I became also involved in purchase and became responsible for the new AFM instrument at the Department, using it for high resolution studies of morphology and surface properties of nanomaterials. My major research interest at present is in hybrid organic-inorganic nano adsorbents and immobilized bio-catalysts. I am developing a molecular recognition approach, combining coordination functions and enzyme grafting in materials for use in hydrometallurgy, water purification and biomedicine [93,100, 101,109,111,122,127,136,137,141,144,145].

I feel that with my expertise in both fundamental and applied inorganic and materials chemistry focused on applications in the Green Sector I can be a valuable resource for the Department in the announced position.

Short description of planned research activity

In my future work I plan to further develop Molecular Chemistry approaches to functional materials relevant for Agriculture and Environment, the so called Green sector. Major focus will be set on applications important for SLU. Our University has identified as its principal research priorities the bio-based materials and fuels and protection of the environment. I am planning to continue and strengthen activities in all these three domains, working with (1) Biopolymer and, in the first hand, cellulose based hybrid organic-inorganic materials to produce new products for bio-based electric, electronic and optical devices and new plant-based protein and microelement sources; (2) porous oxide hybrid materials for catalytic production and refinement of bio-fuels; (3) hybrid adsorbents and biocatalysts for water purification and recycling of electric and electronic materials via advanced hydrometallurgy techniques.

In the area of biopolymer based materials I have established collaboration with the Drs Hjalmar Granberg and Karl Håkansson at Innventia AB, a member of the Research Institutes of Sweden (RISE) – one of the world leaders in the domain of cellulosic materials. The idea is to apply chemical grafting of small (20 nm and less) nanoparticles of metal oxides to cellulose nanocrystals or nanofibers. We will use the resulting stable viscous colloids to produce, on one hand, functional fibers via mechanical or electrospinning, and, on the other hand, concentrate these colloids and transform them into formable molds. The fibers are attractive as optical waveguides and potentially also as components of photo activated antibacterial and self-cleaning fabrics. Very attractive preliminary results in this direction have already been obtained in the Diploma work of my student Marian Pinero Garasa. The formable molds open for building up in one step of hybrid electrodes for Li-ion batteries via thermal carbonization. Preliminary results obtained in collaboration with Ångström Advanced Battery Center (Prof. Kristina Edström at Uppsala University, and Prof. Vilas Pol at Purdue University, USA) are encouraging and grant applications for development of this area have been submitted to, in particular, Swedish Energy Agency. Another class of biopolymers that can offer new exciting knowledge and applications are hybrids based on chemically coupled oxides and protein fibers. In collaboration with the group of Prof. Maud Langton at the Department of Molecular Sciences, SLU (MolSci) we have started to investigate fibrillation of plant proteins in the presence of surface functionalized oxide nanoparticles using in particular AFM and magnetic AFM. One very exciting application can be creation of fibrous iron-rich protein material as a microelement delivering food additive. In addition to revealing fundamental forces driving protein fibrillation enhanced by inorganic oxide materials, an interesting perspective there is to induce the control of morphology and functionality by chemical interactions and magnetic field. The first joint publication in this area is under preparation.

In the domain of porous oxide catalysts the major challenge is in building up chemically stable but highly active porous inorganic-inorganic hybrids with controlled functionality. The applicant has already accumulated expertise in constructing such complex structures using tailored molecular precursors [81, 83] and specific conditions of inorganic synthesis [86, 106, 116]. The approaches for catalytic application were to combine building (nano) blocks with different functions, for example, RedOx-active and acidic or esterifying (Lewis acidic) and Brönsted basic, within the same porous matrix. Attractive preliminary results have been obtained in synthesis of nanostructured photo catalysts [126,134] and magnetically removable catalysts [120]. The idea for new generation of such materials is to combine a reductive (especially photo reductive) blocks with those providing esterifying activity. The aim is to produce energy efficient and non-fouling catalysts for efficient conversion of microbially produced lipids into bio-diesel fuel. Collaboration in this direction has been initiated with the group of Dr. Volkmar Passoth at MolSci and we have submitted joint grant applications.

Development of hybrid adsorbents combining an inorganic matrix (often with a magnetic component for easy retraction) and specific organic functions for catching inorganic or organic pollutants or functional components in aqueous solutions (often together with an enzymatic bio-catalyst) is the dominating direction in my present activities. It is also where the major support is received and applied for (EU, ERA-MIN and Olle Engqvist Foundation grants). I am a member in the newly created Water Center at SLU (led by Prof. Karin Wiberg) and National Center for Magnetic Materials (Prof. Peter Svedlindh). Postdoc Ievgen Pylypchuk and Diploma student Sara Bacaicoa are working under my supervision and a recruitment of a new PhD student is planned. In water purification the major challenge at present lies in, on one hand, in accumulation of persistent organic pollutants such as anti-biotic, anti-inflammatory and painkiller medicines originating from human activity, and, on the other hand, increase in concentration of heavy metals caused by enhanced leaching under the press of the climate change. The medicines accumulating in water sources are mostly aromatic carboxylates or substituted phenols. The only chance to remove them is either via relatively complex treatment with extremely strong oxidants, for example, via ozonolysis, or by using enzymatic catalysts that need to become stable in time and be immobilized on a solid carrier to make their use economically feasible. The presence of hazardous metal pollutants such as Cd, Pb, Hg, Cu etc. are usually deteriorating the enzyme activity. The idea of the projects is to stabilize the enzyme functions via grafting onto solid porous matrices composed of biocompatible oxides and also to combine bio-catalyst function with a complex-forming function capable to protect the enzyme against interaction with unwanted metal cations. For applications in recycling of electronic and electric materials the main targets are in separation of rare earth elements in batteries and magnets from transition metals present together with them such as Fe, Ni and Cu. The aim is to produce materials with tailored organic functions displaying so called molecular recognition behavior, i.e. possessing a surface with much stronger activity versus distinct target element. We have already proved principal feasibility of this approach through combination of surface engineering of the inorganic matrix in combination with structure design for the grafted organic functions [111, 127, 137, 141, 144]. However, a lot of studies will need to be performed until technically and economically sustainable solutions for recycling of most relevant materials are produced. The activities will be run in close collaboration with Swedish industrial actors, in particular, Pharem Biotech AB.

Development of all these directions based on Molecular Chemistry and leading to functional materials will require advanced insight into their morphology and structure at different levels. I am planning to continue a strong engagement in the activities of the MAX-lab X-ray synchrotron facility and in future to actively be using also the European Spallation Source.

In my future work I am planning additionally to continue applying advanced expertise in ESEM and AFM for further fostering collaborations in the topics of prime interest for SLU. I am looking forward to contribute to research in such areas as development of spider silk based protein hybrids materials (in collaboration with Prof. Vadim Kessler, MolSci, and Prof. Anna Rising, Veterinary Medicine faculty, VH). These materials are of interest in tissue engineering and bioelectronics applications. I am also planning to contribute to studies of particle impurities in air and their health effects in collaboration with Swedish Institute of Environmental Medicine (IMM, Assoc. Prof. Lena Palmberg) and Swedish Toxicology Research Center (Swetox), in established and upcoming collaborations respectively. Other important domains, where this expertise is crucial are studies of starch-based food and food packaging materials (Dr. Kristine Koch and Prof. Roger Andersson, both Molsci) and investigation of plant-microbial interactions (Prof. Vadim Kessler, MolSci, and Prof. Johan Meijer, Plant Biology Department at SLU) and plant-plant and plant-insect interactions (Dr. Velemir Ninkovic, Department of Ecology, SLU).

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