Closing research report

Research results

Summary
The project was based on the synergy of the Thai and Hungarian research groups. The Hungarian partner had wide experience in nanomaterials preparation, while the Thai partner was an expert in nanofluid synthesis and characterization. The knowledge transfer was very successful, and as a result of this grant nanofluid research has become an established research direction also at the Hungarian laboratory, with several PhD, MSc and BSc students working in this field now.
According to the work plan, various oxide and carbon nanostructures were prepared with the potential to be used in nanofluids. The synthesis of these nanomaterials, as well as their morphology, composition and structure were thoroughly studied. In the published papers about these materials, other applications (photocatalysis, gas sensing) than nanofluids were also investigated. In these cases, the materials characterization part is related to the present project. Later the as-obtained samples were used to prepare nanofluids. It was tested which nanopowder concentration, which base fluid(s), which pH and surfactant should be applied to get a stable suspension. When suitable nanofluids were prepared, then the nanofluid properties (heat conductivity, zeta potential, viscosity, density) were measured. In several instances, the obtained parameters were the basis of further simulations and calculations. Applied studies in pool heat boiling application were done. Further heat transfer research directions were established, e.g. phase change materials. During the project, an atomic layer deposition (ALD) reactor was purchased as new research infrastructure, and ALD was used to prepare several composite nanomaterials and nanofluids.

Synthesis of oxide nanomaterials
Several oxide nanomaterials were prepared with the aim to be tested in nanofluid applications. These oxide nanostructures included various nanoparticles, nanofibers, nanotubes and nanosheets.
For synthesizing oxide nanofibers and nanotubes, the combination of electrospinning, annealing and atomic layer deposition was very effective.
Poly(vinylpyrrolidone)/titanium tetraisopropoxyde (PVP/TTIP) composite nanofibers were prepared by electrospinning from their alcoholic solutions. Consecutively, the as-spun PVP/TTIP fibers were annealed in air at 550 °C, 900 °C in order to obtain anatase and rutile TiO_2 nanofibers, respectively [Journal of Thermal Analysis and Calorimetry, 2019, 137, 1249-1254].
A new electrospinning process was developed for preparing TiO_2 nanofibers using a water-soluble Ti-precursor, [bis(kappa1O-hydroxo)(bis(kappa2O,O'-lactato)titanium(IV)] commonly known as titanium(IV) bis (ammonium lactato) dihydroxide (TiBALDH). The importance of the study is justified by the fact that Ti-precursors used for electrospinning, sol-gel, hydrothermal and other fiber synthesis processes are mostly non-water soluble. Accordingly, anatase TiO_2 nanofibers of diameter between 20-140 nm were synthesized by electrospinning and annealing [Journal of Thermal Analysis and Calorimetry, 2020, 139, 555-565].
Using the as-developed electrospinning method above, TiO_2/WO_3 nanofibers were prepared in a one-step process by electrospinning. TiBALDH and ammonium metatungstate (AMT) were used in varying ratios as water-soluble Ti and W precursors, respectively. The polymer part was removed by annealing to obtain TiO_2/WO_3 composite nanofibers. The results showed a growth in the fiber diameter with increasing WO_3 amount [Nanomaterials 2020, 10, 882]. When the same TIBALDH/AMT fibers were heated in argon atmosphere, TiO_2/WO_3/C/N composite nanofibers were prepared [Nanomaterials 2021, 11, 351].
In a similar way, 90-110 nm thick TiO_2-MoO_3 composite nanofibers were synthesized using electrospinning and annealing. For electrospinning, the aqueous solutions of TIBALDH and ammonium molybdate tetrahydrate were applied in varying ratios [Materials Science in Semiconductor Processing 2022, 147, 106699].
Amorphous and crystalline TiO_2 nanotubes were made in such a way that at first poly(vinyl alcohol) (PVA) and PVP nanofibers were electrospun. They were covered with a 100 nm thick amorphous TiO_2 layer by atomic layer deposition at 50 °C. When the polymer templates were removed by dissolution, amorphous TiO_2 nanotubes were the products. While removing the templates by annealing yielded

crystalline TiO_2 nanotubes, since during heating the amorphous TiO_2 crystallized [Molecules 2021, 26, 5917].
Hydrothermal synthesis was also used to prepare various oxide nanoparticles, nanosheets and nanorods. The effects of various anions (SO_4^{2-}, ClO_4^- and PO_4^{3-}) were investigated on the hydrothermal reaction of Na_2WO_4 and HCl at 180 and 200 °C. Depending on the reaction conditions, hexagonal (h-) WO_3 nanorods and $WO_3 \cdot 0.33\ H_2O$ nanoparticles were prepared [Journal of Nanoscience and Nanotechnology, 2019, 19, 498-501].
Furthermore, the usage of very low pH (0.1) in the same hydrothermal reaction was studied as well. As a result, monoclinic (m-) m-WO_3 was successfully prepared for the first time hydrothermally without any post-calcination. The m-WO_3 samples had nanosheet or nanorod morphology, depending on the used additives and reaction temperatures [Journal of Solid State Chemistry, 2020, 281, 12104].
The influence of various parameters on the hydrothermal preparation of MoO_3 was investigated using ammonium heptamolybdate tetrahydrate and nitric acid as precursors, applying various reaction times, temperatures and additives ($CrCl_3$ and CTAB). At 90 °C h-MoO_3 was obtained, while at 240 °C orthorhombic (o-) MoO_3 formed with hexagonal rod-like and nanofibrous morphology, respectively. The significance of the study is that m-MoO_3 was prepared for the first time successfully by hydrothermal synthesis when $CrCl_3$ was applied as additive [Nanomaterials 2020, 10, 891].
Bi_2WO_6 nanosheets were prepared by hydrothermal method using the reaction of $Na_2WO_4 \cdot 2H_2O$, $Bi(NO_3)_3 \cdot 5H_2O$ and NaOH. The effects of reaction temperature (150/ 170/ 200 °C), reaction time (6/ 12/ 24 h) were investigated [Materials 2019, 12, 1728].
Finally, *sol-gel* method was combined with *ALD* to produce core/shell oxide nanoparticles.
Amorphous SiO_2 nanoparticles were synthetized by sol-gel using the Stöber method. On them, amorphous and crystalline TiO_2 thin films as well as amorphous Al_2O_3 and crystalline ZnO layers were deposited by ALD. As a result, core/shell SiO_2/TiO_2, SiO_2/Al_2O_3 and SiO_2/ZnO nanoparticles were obtained. The SiO_2 nanoparticles had a diameter of 100-150 nm, while the shell layers were 10-20 nm thick [Periodica Polytechnica Chemical Engineering, 2019, 63, 378-387].

Synthesis of carbon nanomaterials

Several carbon nanomaterials were prepared with the aim to be tested in nanofluid applications, similar to the oxide nanomaterials described above. These include carbon aerogels, carbon nanopowder, graphene oxide (GO), carbon nanospheres (CNS), carbon nanotubes (CNTs) and their composites with ALD oxide materials.
At first the improved Hummers' synthesis of graphene oxide (GO) from graphite was investigated to monitor how the functional groups formed during the synthesis steps (reaction with H_2SO_4 and $KMnO_4$ followed by washing with HCl and water). In addition, the as-prepared GO was reduced with ascorbic acid to get reduced GO (rGO) as well [Journal of Thermal Analysis and Calorimetry, 2018, 131, 2267-2272].
This GO sample was used afterwards as substrate to prepare various GO/oxide nanocomposites. Acconrdingly, TiO_2, Al_2O_3 and ZnO were grown by ALD at 80 °C on GO, and GO/amorphous TiO_2, GO/amorphous Al_2O_3 and GO/crystalline ZnO nanostructures were obtained [Applied Surface Science, 2018, 453, 245-251].
It was also studied how the composition, structure, functional groups might be tuned, when GO was reduced. The abovementioned GO was annealed in various atmospheres (oxidizing, inert and reducing) and various temperatures (200, 300, 900 °C). As a result, the functional groups were released, the structure was getting more ordered, and the degree of reduction was tunable with the process parameters [Nanomaterials 2020, 10, 2313].
Another type of carbon nanomaterials studied were carbon nanotubes. TiO_2 and ZnO single and multilayers were deposited on hydroxyl functionalized multi-walled carbon nanotubes using atomic layer deposition. Accordingly, single shell layer CNT-ZnO and CNT-TiO_2, as well as double shell layer CNT-ZnO-TiO_2 and CNT-TiO_2-ZnO samles were prepared [Nanomaterials 2020, 10, 252].
Carbon nanospheres were obtained hydrothermally using sucrose as precursor. They were coated with sol-gel TiO_2 layers and carbon nanospheres/TiO_2 core/shell structures were obtained. After removing the carbon core, hollow TiO_2 nanospheres were also produced [Materials 2019, 12, 109].
Finally, carbon aerogels and their composites with oxide materials were synthesized. The polymer gel was supercritically dried with CO_2, and the carbonization of the resulting polymer aerogel under nitrogen

atmosphere at 900 °C yielded the carbon aerogel [Journal of Thermal Analysis and Calorimetry, 2018, 134, 933-939]. Consecutively amorphous and crystalline TiO_2 layers were grown by ALD 80 °C and 250 °C onto the resorcinol-formaldehyde polymer aerogel (RFA) and its carbon aerogel (RFCA) derivative. The ALD layers uniformly coated the organic nanoparticles of the RFA and RFCA [Carbon, 2019, 146, 476-482]. In addition, nitrogen doped carbon aerogels were also synthesized using melamine as additional precursor. On these aerogels, TiO_2 and ZnO layers were deposited via ALD, with two different thicknesses for each metal oxide [Journal of Materials Chemistry C, 2020, 8, 6891-6899].

Nanofluid studies

The above described oxide and carbon nanomaterials were prepared with the aim to be used as the solid phase in nanofluids. In some cases stable nanofluids could not be obtained, although the concentration, pH and surfactants were varied (e.g. as-prepared WO_3 nanoparticles). However, in the case of other nanomaterials, stable nanofluid dispersions could be made (e.g. carbon nanospheres and its composites, SiO_2 and TiO_2 nanoparticles and composites, some 1D nanomaterial nanofluids). Other promising nanofluids are still being tested at this moment (e.g. GO and its composites, CNT and its composites, SiO_2/ZnO, etc). For 1D halloysite nanofluids, applied pool boilding investigations were also made. For several nanofluids model calculations were done. Below those results are discussed in detail which have been already published.

At first, hybrid oxide nanofluids were tested, which are the colloidal dispersion of two or more kinds of nanoparticles with the base fluid, and they offer the synergy of the separate nanofluids. Accordingly the thermal conductivity and viscosity of SiO_2-P25 TiO_2 (1:1) hybrid nanofluid were investigated. The nanoparticles with different nanoparticle volume concentrations (0.5 vol%, 1.0 vol% and 1.5 vol%) at five various temperatures (20 °C, 30 °C, 40 °C, 50 °C and 60 °C) were dispersed in a 5:1 mixture of water and ethylene glycol. The thermal conductivity enhancement of the hybrid nanofluid was higher than the pure nanofluid. In particular, with 1.0 vol% concentration, the maximum enhancement of SiO_2, TiO_2 and SiO_2-P25 TiO_2 nanofluids were 7.5%, 9.9% and 10.5%, respectively. Beside experimental work, modelling was also part of the study. The regression correlation equations of thermal conductivity and viscosity for SiO_2-P25 TiO_2 nanofluid was developed [Journal of Thermal Analysis and Calorimetry, 2021, 146, 493-507].

Using the obtained experimental nanofluid parameters, in a further study computer flow dynamics (CFD) simulation was done regarding the SiO_2-P25 TiO_2 hybrid nanofluid. The heat transfer performance of SiO_2-P25 nanofluids passing through a circular tube was investigated by CFD with constant heat flux and constant wall temperature. During the analysis, a comprehensive treatment of the turbulent heat transfer was offered by mentioning different known but often ignored details of the turbulent heat transfer phenomena [Nanomaterials 2022, 12, 3014].

Modification of the particles' surface can be useful to get more specialized nanofluids, and ALD is a very promising method for that. However, there are very scarce previous results in this field, and our studies are pioneer in applying ALD coated nanomaterials in nanofluids. Hence, surface-modified SiO_2 nanoparticles were used upon immersion in an applied base fluid (ethylene glycol: water= 1:1). ALD was introduced to obtain a TiO_2 thin layer covering the surface of SiO_2 particles. In terms of thermal conductivity, the pure SiO_2 particles caused only a 2-10% increase, whereas the modified particles caused a rise between 5-28 %. Although the ethylene glycol-water ratio was different when the hybrid SiO_2-TiO_2 nanofluid was applied, the SiO_2 particles were used from the same batch, so the changes of the effects might be comparable. When the hybrid nanofluid was used, the thermal conductivity increased 1.71 times better compared to the simple SiO_2 nanofluid. However, the SiO_2/ALD TiO_2 composite particles caused a 3.22 times greater change on average than the SiO_2 particles. Finally, the regression correlation equations of thermal conductivity and viscosity for composite TiO_2 nanofluid were developed [Nanomaterials 2022, 12, 3014].

Carbon nanomaterials were also studied in nanofluids. At first the comparative research on stability, viscosity (μ), and thermal conductivity (k) of carbon nanosphere (CNS) and carbon nanopowder (CNP) nanofluids was performed. The CNP nanofluids had the highest k enhancement of 10.61% for 1.5 vol% concentration compared to the base fluid, while the CNS did not make the thermal conductivity of nanofluids (k_{nf}) significantly higher. The studied nanofluids were Newtonian. The relative μ of CNS and CNP nanofluids was 1.04 and 1.07 at 0.5 vol% concentration and 30 °C. These results could be explained by the different sizes and crystallinity of the used nanoparticles [Nanomaterials 2021, 11, 608].

The carbon nanospheres and carbon nanopowder were used as substrates for core/shell composite nanofluids, similar to SiO_2 particles. The nanocomposites were again produced by atomic layer deposition of amorphous TiO_2. The thermal conductivity and viscosity of nanofluids containing novel ALD surface-modified carbon nanosphere (ALD-CNS) and carbon nanopowder (ALD-CNP) core-shell nanocomposites were investigated. The significant difference compared to the unmodified CNS nanofluids was that stable nanofluids were prepared without surfactant with the ALD application. Also, the thermal conductivity enhancement was larger due to the additional TiO_2 layer. The highest thermal conductivity rise compared to the applied base fluids was 4.6 % for the ALD-CNS and 10.8 % for the ALD-CNP [Nanomaterials 2022, 12, 2226].
Beside nanoparticles, also 1D nanomaterials were applied successfully in nanofluids. The nanofluids obtained from halloysite and de-ionized water (DI) were prepared by using surfactants and changing the pH. The halloysite nanotube (HNT) nanofluids were studied for several volume fractions (0.5, 1.0, and 1.5 vol%) and temperatures (20, 30, 40, 50, and 60 ^oC). With surfactants, the HNT nanofluids had the highest thermal conductivity increment of 18.30 % for 1.5 vol% concentration in comparison with the base fluid. The thermal conductivity enhancement of nanofluids containing surfactant was slightly higher than nanofluids with pH=12. Empirical correlations of viscosity and thermal conductivity for these nanofluids were proposed for practical applications [Nanomaterials 2020, 10, 1834].
The results with halloysite nanofluid were very promising, and hence this material was selected for further applied studies to improve the pool boiling heat transfer (PBHT) at atmospheric pressure. The nanofluids were prepared from halloysite nanotubes, deionized water, and sodium hydroxide (NaOH) solution for making pH = 12 medium. The nanofluid concentrations were from 0.01 to 0.5 vol%. The performance of PBHT was studied via pool boiling curve and pool boiling heat transfer coefficient (PBHTC) with a copper heated test pipe, which had a thickness of 1 mm and a diameter of 22 mm and was placed inside the chamber pool. The results showed an improvement of PBHTC for halloysite nanofluids compared to the base fluid [Molecules 2022, 26, 5917].
A new research direction opened up during the grant, which is also related to heat transfer. Phase change materials (PCMs) are limited to be widely used in thermal storage because of their poor conductivity and lack of multi driving energy. Therefore, to overcome the above problems, new functional composite PCMs (PEG-$CaCl_2$/EG) with high electrical and thermal conductivity were synthesized by ligand substitution using PEG-$CaCl_2$ as PCM and expanded graphite (EG) as high electrical and thermal conductivity enhancing framework material [International Journal of Energy Research, 2021, 45, 7675-7688].

Research visits

Already, shortly before the project start (Year 0), a Thai experienced researcher (Dr. Omid Mahian) travelled to the Hungarian partner. In Year 1 of the project Dr. Mahian also travelled to Hungary for two weeks. In Year 2, Dr. Mahian spent one week in Budapest, while two Hungarian students (PhD Thong Le Ba and Msc Dániel Karajz) visited the Thai partner for one week. In Year 3 due to the Covid situation, an additional year was requested for the project (Year 4). Due to Covid, In Year 3-4 no travels between the Thai and Hungarian partner were realized. The correspondence was maintained on-line.

Joint activities in scientific social life

A special issue called Nanofluid Today was published in Year 2 (Jan 2019) in the Journal of Thermal Analysis and Calorimetry. The guest editor was Dr. Mahian from the Thai partner, while the editor-in-chief of the journal is the Hungarian PI. Another special issue called Advances in Heat Transfer Enhancement Using Passive Techniques was published in Year 3 in the Journal of Thermal Analysis and Calorimetry, guest edited by Dr. Mahian. He was invited by Dr. Szilágyi to be a senior associate editor at the journal starting at 2020 (Year 3).
The Hungarian PI was the chair of the 2nd Journal of Thermal Analysis and Calorimetry Conference and 7th V4 (Joint Czech-Hungarian-Polish-Slovakian) Thermoanalytical Conference (JTACC+V4 2019), 18-21 June 2019, Budapest, Hungary (www.jtac-jtacc.com). At the conference, nanofluids and heat transfer played a significant part. The conference was one of the largest and most innovative thermoanalytical conferences in the recent decades worldwide with 530 registered participants, digital

poster section, mobile application, on-line questions&answers during sessions (sli.do), online participant map, etc. The conference was supported by the Ministry of Innovation and Technology and the Hungarian Academy of Sciences, and the patron of the conference was Dr. László Palkovics, minister for innovation and technology.

New research collaborations

During the research grant new research collaborations were established. The Department of Energy Engineering, Budapest University of Technology (BME) is partner in heat conductivity measurements and pool boiling nanofluid experiments. The School of Chemical Engineering and Technology, Xi'an Jiaotong University, China is cooperating in nanofluid research. The School of Mechanical Engineering, Southwest Jiaotong University, China is a collaborator in phase change material research.

New research infrastructure

According to the research plan, a new atomic layer deposition (ALD) reactor was purchased from the present research grant combined with another (VEKOP-2.3.2-16-2017-00013) grant. The supplier company (Okyaytech) and the research group of the PI started a long-term research collaboration. The new ALD reactor was installed in a completely renovated, dedicated laboratory (Fig. 1).

Figure. 3. The new ALD reactor

Publications

The project resulted in 31 international journal papers (3 review articles and 28 research articles) and a book chapter. The review papers are discussed in a separate chapter below, while the research papers were cited in the Research results chapter. The sum of impact factors is: 134,930.
During the project, 50 conference presentations (11 plenary/invited, 26 oral, 13 poster) were given related to the obtained results. The plenary/invited lectures are given in detail below; while the oral and poster presentations are listed in the Appendix.
Related to the project results, 9 BSc, 11 MSc and 4 PhD theses were written and defended. Two more PhD defences will be in the coming months and two additional PhD students are still doing their experiments.

Plenary and invited lectures

During the grant period the participants of the grant gave 11 plenary or invited lectures. The topic of these were nanofluids, atomic layer deposition, thermal analysis, nanostructured materials (used as well in nanofluids). Below is the list of the plenary/invited lectures:

1. Szilágyi Imre Miklós: Atomi rétegleválasztással előállított szén nanoszerkezet kompozitok [Carbon nanostructure composites prepared by atomic layer deposition*]. 2D anyagtudomány Magyarországon 2022. MTA Fizikai-kémiai Tudományos Bizottság, SZAB Kémiai Szakbizottság [2D materials science in Hungary 2022. Physical Chemistry Scientific Committee of the Hungarian Academy of Sciences, Szeged Committee of the Hungarian Academy of Sciences – Chemistry Workgroup]*, 17 June **2022,** Szeged, Hungary
2. Imre Miklós Szilágyi: Composite nanofluids prepared by atomic layer deposition. *48th National Conference on Fluid Mechanics and Fluid Power. (FMFP 2021),* 27-29 December **2021,** BITS, Pilani, RS, India
3. Imre Miklós Szilágyi: Thermal properties of photocatalytic and gas sensing carbon nanostructures and nanocomposites. *International Symposium on Applications of Thermal Analysis and Calorimetry (SATAC-2021),* 21-22 December **2021,** Magadh University, Bodh Gaya, India
4. Imre Miklós Szilágyi: Success and challenges at the Journal of Thermal Analysis and Calorimetry. *2nd International Conference on Loss Prevention, Process Safety, and Thermal Analysis in Chemical and Coal Industries (LPSSTA2021),* 11-12 December **2021,** Xi'an, China

5. Imre Miklos Szilagyi: Thermal Properties of Photocatalytic and Gas Sensing Carbon Nanostructures and Nanocomposites. *30th Symposium on Thermal Analysis and Calorimetry "Eugen Segal" of the Commission for Thermal Analysis and Calorimetry of the Romanian Academy,* 15-16 October **2021,** Bucharest, Romania (plenary lecture)
6. Imre Miklos Szilagyi: Success and challenges at the Journal of Thermal Analysis and Calorimetry. *30th Symposium on Thermal Analysis and Calorimetry "Eugen Segal" of the Commission for Thermal Analysis and Calorimetry of the Romanian Academy,* 15-16 October **2021,** Bucharest, Romania (plenary lecture)
7. I.M. Szilágyi: Thermal properties of photocatalytic and gas sensing carbon nanostructures and nanocomposites. *XII Congresso Brasileiro de Análise Térmica e Calorimetria (XI Brazilian Congress of Thermal Analysis and Calorimetry, CBRATEC XI) and V Congresso Pan-Americano de Análise Térmica e Calorimetria (V Pan-American Congress of Thermal Analysis and Calorimetry, CPANATEC V,* 03-06 August, **2021,** Araraquara, Brazil (plenary lecture)
8. Imre Miklós Szilágyi: Nanostructured photocatalysts prepared by atomic layer deposition. *5th International Conference on New Photocatalytic Materials for Environment, Energy and Sustainability (NPM -5) and 6th International Conference on Photocatalytic and Advanced Oxidation Technologies for the Treatment of Water, Air, Soil and Surfaces (PAOT-6),* 24-27 May **2021,** Szeged, Hungary
9. Imre Miklós Szilágyi: Atomic layer deposition in nanotechnology. *Webinar organized by the Faculty of New Science and Technologies and the International Scentific Collaborations Office, Semnan University, Iran*, 18 February **2021,** Iran (on-line invited lecture)
10. Imre Miklós Szilágyi, Orsolya Kéri, Nóra Justh, László Bakos, Joshua Mensah, Dávidné Nagy, Krisztina László, Zoltán Hórvölgyi, Klára Hernádi, Zoltán Erdélyi, Bence Parditka, Zsófia Baji: Nanostructured photocatalysts prepared by atomic layer deposition. *International Conference on Physical Chemistry and Functional Materials (PCFM 2019),* 25-27 June **2019,** Urgup, Turkey (invited lecture)
11. I.M. Szilágyi: Trends in thermal analysis. *XI Congresso Brasileiro de Análise Térmica e Calorimetria (XI Brazilian Congress of Thermal Analysis and Calorimetry, CBRATEC XI),* 22-24 April, **2018,** Rio de Janeiro, Brazil (plenary lecture)

Review papers

A joint review paper was published by the Thai and Hungarian partners about the use of graphene related nanostructures in nanofluid application [*Journal of Thermal Analysis and Calorimetry*, **2020,** 142, 1145-1172]. Another review paper was prepared by them about the use of sonication to prepare nanofluids [Ultrasonics-Sonochemistry, 2019, 58, 104701]. ALD is a central preparation method for making nanomaterials in the project, and a review paper was prepared about the synthesis of nanomaterials by ALD [Magyar Kémiai Folyóirat, 2018, 124, 127-134.]. A review paper was published about the career of the PI, as a successful young researcher [Magyar Kémikusok Lapja, 2020, 75, 218-221].

Involving young researchers and students in the project

The Hungarian PI introduced nanofluids and ALD at his university teaching activities. He was the supervisor of two groups at the Industrial Planning Practice BSc course in 2019 and 2020, and the semester topics were Analytical chemistry study of nanofluids and Analytical methods for ALD grown layers. He talks about nanofluids during his Thermal analysis lecture and lab practice in the Analytical and Structural Elucidation Methods BSc course and in his lab practices in the Analytical Chemistry II MSc course.
Several PhD, MSc and BSc thesis works were prepared related to the theme of the research grant (preparation of oxide or carbon nanomaterials and their composites, nanofluid application).
List of PhD theses: 2019 - Nóra Justh: Photocatalytic carbon nanostructure/semiconductor oxide composites prepared by atomic layer deposition; 2019 - Orsolya Kéri: Photocatalyic core/shell nanocomposites by atomic layer deposition; 2020 - Teodóra Nagyné Kovács – Tungsten oxide, tungstate and molybdenum oxide nanostructures by hydrothermal synthesis; 2021 – László Péter Bakos – Preparation and investigation of carbon nanostructure based photocatalytic materials.
Beside the four defended PhD theses, two more will be defended in the coming months: planned defence in 2022 - Vincent Otieno Odhiambo: Preparation of oxide nanofibres by electrospinning; planned defence in early 2023 – Le Ba Thong: Numerical and experimental investigation on thermal applications of nanofluids. Furthermore, there are two active PhD students who has research topics about nanofluids:

Marcell Bohus: Carbon nanocomposite based nanofluids; Zalán István Várady: Oxide nanocomposite based nanofluids.

List of MSc thesis works: 2018 - Gubakhanim Shahnazarova - Hydrothermal synthesis of Bi_2WO_6 nanoparticles; 2018 - Joshua Mensah - Preparation of nitrogen doped carbon aerogel/metal oxide composites using atomic layer deposition; 2018 - Ádám Patak – Sol-gel prepared core/shell composites; 2019 - Levente Studnicka: Preparation of nanosize molybdenum oxides by hydrothermal synthesis; 2020 - Alkurdi Ahmed Qani: Preparation and Investigating the use of halloysite nano-fluid, improving its stability, and investigation of thermal conductivity enhancement with halloysite nanoparticles; 2020 - Ulisses Carlo Moura da Silva Bezerra da Costa - Photocatalytic carbon nanotube-multiwalled TiO_2-ZnO and ZnO-TiO_2 composites prepared by atomic layer deposition; 2021 - Abdullah Ahmed Baqer - Pool boiling experiments with the use of halloysite nanofluids; 2021 - Chra Rasool M. Mustafa - Characterization of TiO_2/WO_3/C/N composite nanofibers prepared by electrospinning; 2022 - Máté Bakó – Zinc oxide films prepared by atomic and molecular layer deposition; 2022 - Marcell Bohus – Preparation and characterization of atomic layer deposition surface modified carbon nanostructure based nanofluids; 2022 - Zalán István Várady – Synthesis and study of composite TiO_2-SiO_2 nanofluids.

List of BSc thesis works: 2019 - Aizat Ongarbayeva: Synthesis of TiO_2/WO_3 composite nanofibers by electrospinning; 2019 - Agócs Csilla – Synthesis and study of photocatalytic and gase sensing core/shell nanoparticles; 2020 - Péter Bárdos – Preparation and investigation of polymer/metal oxide nanofibers and nanotubes; 2020 - Marcell Bohus: Preparation and study of carbon nanostructure based nanofluid; 2020 - Edina Csáki: Preparation of titanium dioxide nanofibers by electrospinning from water soluble precursors; 2020 - Lőrinc Sárvári: Preparation and investigation of graphene oxide and reduced graphene oxide; 2020 – Ferenc Sipos: Preparation of nanosize MoO_3-TiO_2 crystals by hydrothermal and atomic layer deposition methods; 2020 - Zalán István Várady: Preparation and study of SiO_2-TiO_2 hybride nanofluid; 2022 - Csenge Fónay – Heat treatment induced change of atomic layer deposited films

APPENDIX

Conference presentations – lectures

1. Bohus Marcell, Le Tab Thong, Igricz Tamás, Erdélyi Zoltán, Parditka Bence, Lukács István, Hernádi Klára, Szilágyi Imre Miklós: Atomi rétegleválasztással előállított szén nanokompozitok alkalmazása nanofolyadékban [Application of carbon nanocomposites prepared by atomic layer deposition in nanofluids]. *MTA Termoanalitikai Munkabizottságának ülés, Meeting of the Thermoanalytical Workgroup of the Hungarian Academy of Sciences],* 03 December **2021,** Budapest, Hungary
2. Szilágyi Imre Miklós: Sikerek és kihívások a Journal of Thermal Analysis and Calorimetry újságnál [Successes and challenges at the Journal of Thermal Analysis and Calorimetry]. *MTA Termoanalitikai Munkabizottságának ülés, Meeting of the Thermoanalytical Workgroup of the Hungarian Academy of Sciences],* 03 December **2021,** Budapest, Hungary
3. Imre Miklós Szilágyi: Nanostructured photocatalysts prepared by atomic layer deposition. *3rd Forum of French-Hungarian Scientific Research,* 07 October **2021,** Budapest, Hungary
4. Imre Miklós Szilágyi: Nanostructured photocatalysts prepared by atomic layer deposition. *EMRS (European Materials Research Society) Fall Meeting,* 13-17 September **2021,** Warsaw, France
5. Zalán István Várady, Thong Le Ba, Imre Miklós Szilágyi: Experimental investigation of rheological properties and thermal conductivity of SiO_2–P25 TiO_2 hybrid nanofluids. *3rdEuropean Symposium on Nanofluids (ESNf2019),* 9-10 September **2021,** Iasi, Romania
6. Marcell Bohus, Thong Le Ba, Imre Miklós Szilágyi: Investigation of carbon based nanofluids containing carbon nanospheres and carbon nanopowder. *3rdEuropean Symposium on Nanofluids (ESNf2019),* 9-10 September **2021,** Iasi, Romania
7. Imre Miklós Szilágyi, Nóra Justh, László Bakos, Joshua Mensah, Krisztina László, Klára Hernádi, Zoltán Erdélyi, Bence Parditka, Pawel Pasierb: Thermal properties of photocatalytic and gas sensing carbon nanostructures and nanocomposites. *XLII National Conference on Calorimetry, Thermal Analysis and Applied Thermodynamics (AICAT-2020),* 27-28 January **2021,** Udine, Italy (on-line lecture)
8. Vincent Otieno Odhiambo, Aizat Ongarbayeva, Chra Rasool, Orsolya Kéri, László Simon, Imre Miklós Szilágyi: Synthesis of TiO_2/WO_3 Composite Nanofibers by a Water-Based Electrospinning Process and Their Application in Photocatalysis. *„PhD hallgatók anyagtudományi napja XX" - MTA Anyagtudományi és Szilikátkémiai Munkabizottság ülése [PhD Students Materials Science Day XX - Meeting of the Materials Science and Silicate Chemistry Work Group of the Hungarian Academy of Sciences],* 16 November **2020,** Veszprém, Hungary
9. Thong Le Ba, Ahmed Qani Alkurdi, Imre Miklós Szilágyi: Investigation of thermal conductivity and viscosity of nanofluids containing halloysite. *„PhD hallgatók anyagtudományi napja XX" - MTA Anyagtudományi és Szilikátkémiai Munkabizottság ülése [PhD Students Materials Science Day XX - Meeting of the Materials Science and Silicate Chemistry Work Group of the Hungarian Academy of Sciences],* 16 November **2020,** Veszprém, Hungary
10. Klára Hernádi, Tamás Gyulavári, Balázs Réti, László Péter Bakos, Gábor Veréb, Zsolt Pap, Zoltán Erdélyi, Imre Miklós Szilágyi: Fabrication of semiconductor hollow nanostructures: advantage in photocatalysis. *International Conference on Functional Nanomaterials and Nanodevices (Nanomat2019),* 11-13 September **2019,** Prague, Czech Republic
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17. Imre Miklós Szilágyi: Trends in thermal analysis. *12th European Symposium on Thermal Analysis and Calorimetry (ESTAC12),* 27-30 August **2018**, Brassó (Brasov), Romania
18. O. Kéri, E. Kocsis, Zs. K. Nagy, T. Igricz, B. Parditka, Z. Erdélyi, I. M. Szilágyi: Preparation of TiO_2 nanofibers and TiO_2 nanotubes. *12th European Symposium on Thermal Analysis and Calorimetry (ESTAC12),* 27-30 August **2018**, Brassó (Brasov), Romania
19. László Péter Bakos, Joshua Mensah, Krisztina László, Bence Parditka, Zoltán Erdélyi, Imre Miklós Szilágyi: Preparation of nitrogen doped carbon aerogel/metal oxide composites using atomic layer deposition. *12th European Symposium on Thermal Analysis and Calorimetry (ESTAC12),* 27-30 August **2018**, Brassó (Brasov), Romania
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24. Orsolya Kéri, Imre Miklós Szilágyi: Atomi rétegleválasztással előállított fotokatalitikus mag/héj nanokompozitok. [Photocatalytic core/shell nanocomposites prepares by atomic layer deposition.] *Analitikai Napok 2018 – Magyar Kémikusok Egyesülete [Analytical Days 2018 – Hungarian Chemical Society],* 23-24 April **2018,** Balatonszemes, Hungary
25. Gubakhanim Shahnazarova, Teodora Nagyne-Kovacs, Imre Miklos Szilagyi: Hydrothermal synthesis of photocatalytic Bi_2WO_6 nanoparticles and nanocomposites. *15th International Conference "Students for Students,*17-22 April **2018,** Kolozsvár [Cluj], Romania.
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Conference presentations – posters

1. Zalán István Várady, Thong Le Ba, Bence Parditka, Zoltán Erdélyi, Klara Hernádi, Gábor Karacs, Gyula Gróf, Imre Miklós Szilágyi: Investigation of rheological properties and thermal conductivity of SiO_2-TiO_2 composite nanofluids prepared by atomic layer deposition. *4h George Oláh Conference, XX Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology,* 26 September **2022,** Budapest, Hungary
2. Marcell Bohus, Thong Le Ba, Klara Hernadi, Gyula Gróf, Zoltán Erdélyi, Bence Parditka, Imre Miklós Szilágyi: Atomic layer deposition surface mofified carbon nanosphere and carbon nanopowder nanofluids for thermal conductivity enhancement. *4h George Oláh Conference, XX Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology,* 26 September **2022,** Budapest, Hungary
3. Vincent Otieno Odhiambo, Aizat Ongarbayeva, Chra Rasool, Orsolya Kéri, László Simon, Imre Miklós Szilágyi: Synthesis of TiO_2/WO_3 Composite Nanofibers by a Water-Based Electrospinning Process and Their Application in Photocatalysis. *BME-VBK Oláh György Doktori Iskola XVIII. konferenciája [XVIII Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology].* 28 September **2020,** Budapest, Hungary
4. Thong Le Ba, Imre Miklós Szilágyi: Investigation of thermal conductivity and viscosity of nanofluids containing halloysite. *BME-VBK Oláh György Doktori Iskola XVIII. konferenciája [XVIII Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology].* 28 September **2020,** Budapest, Hungary
5. Thong Le Ba, Omid Mahian, Zalan Istvan Varady, Imre Szilagyi Miklos: Numerical investigation of natural convection of SiO_2-TiO_2 hybrid water-based nanofluids with heated square cavity. B*ME-VBK Oláh György Doktori Iskola XVII. konferenciája [XVII Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology].* 23 September **2019,** Budapest, Hungary
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8. Vincent Otieno Odhiambo, Orsolya Kéri, Imre Miklós Szilágyi: Synthesis of TiO_2-WO_3 composite nanofibers by electrospinning for application in photocatalysis. *BME-VBK Oláh György Doktori Iskola XVI. konferenciája [XVI Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology].* 31 January **2019,** Budapest, Hungary
9. Vincent Otieno Odhiambo, Orsolya Kéri, Imre Miklós Szilágyi: Synthesis of TiO_2-WO_3 composite nanofibers by electrospinning for application in photocatalysis. *20th Annual Conference of the Materials Research Society of Serbia (YUCOMAT 2018),* September 3–7, **2018,** Hercegi Novi, Montenegro
10. Teodora Nagyne Kovacs, Levente Studnicka, Gubakhanim Shahnazarova, Imre Miklos Szilagyi, Istvan Lukacs,. Gyorgy Pokol: Preparation of photocatalytic tungsten and molydenum oxides and tungstates by hydrothermal method. *EMRS (European Materials Research Society) Spring Meeting,* 18-22 June **2018,** Strasbourg, France
11. Orsolya Kéri, Eszter Kocsis, Lenke Kócs, Zoltán Hórvölgyi, Levente Kárpáti, Bence Parditka, Zoltán Erdélyi, Imre Miklós Szilágyi: ALD coated photocatalytic polymer and inorganic nanomaterials. *EMRS (European Materials Research Society) Spring Meeting,* 18-22 June **2018,** Strasbourg, France
12. Vincent Odhiambo, Orsolya Kéri, Imre Miklós Szilágyi: Synthesis of TiO_2-WO_3 composite nanofibers by electrospinning for application in photocatalysis and fuel cells. *EMRS (European Materials Research Society) Spring Meeting,* 18-22 June **2018,** Strasbourg, France
13. Orsolya Kéri, Eszter Kocsis, Zsombor Kristóf Nagy, Tamás Igricz, Bence Parditka, Zoltán Erdélyi, Imre Miklós Szilágyi: Preparation and analysis of metal-oxide nanotubes. *BME-VBK Oláh György Doktori Iskola XIV. konferenciája [XIV Conference of the George Olah PhD School, Faculty of Chemical Technology and Biotechnology, Budapest University of Technology].* 01 February **2018,** Budapest, Hungary