SYNTHESIS, CHARACTERIZATION, STABILITY AND PHOTOCATALYTIC ACTIVITY INVESTIGATION OF Ag-CONTAINING MATERIALS

Doctoral (Ph.D.) theses

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1. Introduction and objectives

Earth's population has increased significantly in the last 120 years; along with it, water and food consumption increased exponentially. Water purification technologies have evolved significantly to ensure sufficient quantity and quality drinking water. In the middle of the 20th century, traditional water treatment technologies became obsolete. The application of advanced oxidation processes was a breakthrough, especially heterogeneous photocatalysis, which is based on a semiconductor, excitable by different light sources with a specific wavelength.

The current work aimed to synthesize, characterize Ag-containing photoactive materials, and investigate their photocatalytic performance and stability. The combined effect of several synthesis approaches (solvothermal, precipitation and chemical reducing methods) and parameters (precursors and reaction conditions) were studied.

Another issues of the present work were the deposition of Ag nanoparticles on the surface of the semiconductor during either photocatalyst synthesis or photocatalytic reaction, and their effect on the photocatalytic activity and stability of semiconductors. Thereby, our objectives included synthesis, characterization, and investigation of the photocatalytic activity of three types of Ag-containing materials: silver halides, oxoacid salts of silver, and TiO_2 composites with Ag-containing nanoparticles.

The effect of the different shape-tailoring agents (cationic, anionic, and non-ionic polymer) and different halide sources on the photocatalytic activity and stability of the resulting silver halides were investigated.

The next objective was to enlighten the effect of the precursors on the synthesis of Ag_2CO_3 and Ag_3PO_4. In the case of Ag_2CO_3, the effect of the reaction temperature was investigated, whereas, in the case of Ag_3PO_4, the precursor concentration (0.1 M↔0.2 M) was analyzed.

The effect of different crystal phases of TiO_2 was investigated in-detail on the formation of Ag/Ag_xO on the surface of the composites, in the Ag/TiO_2 composite systems.

2. Experimental methods and procedures

Ag-containing materials were obtained by using different precursors. Solvothermal crystallization was applied for the synthesis of silver halides using different shape-tailoring agents (polyvinylpyrrolidone (PVP); cetyltrimethylammonium bromide (CTAB) and sodium dodecyl sulfate (SDS)) and various halides sources (**Cl**$^-$: H^+; Na^+; K^+; **Br**$^-$: H^+; Li^+; Na^+; K^+; Rb^+; Cs^+; **I**$^-$: Na^+; K^+). A different synthesis approach was applied for the synthesis of Ag_2CO_3 and Ag_3PO_4, namely the precipitation method. The precursors of Ag nanoparticles were added to TiO_2 (rutile and anatase mixtures) to synthesize Ag/TiO_2 composites. The Ag nanoparticles were obtained by $NaBH_4$ reduction.

The crystal structure of the materials was determined using a *Rigaku MiniFlex Type II* powder X-ray diffractometer (**XRD**). The primary crystallite size values were also calculated using the Scherrer equation. The intensity ratios of the different Miller indexed reflections were also calculated and analyzed.

Scanning and transmission electron microscopes (**SEM**: *Hitachi S-4700 Type II* and **TEM**: *FEI Technai G2 20 X-TWIN*) were used to examine the morphological properties of the semiconductors and the potential presence of Ag/Ag_xO nanoparticles on the surface of the semiconductor.

A *JASCO 6200 Infrared spectrophotometer* (**IR**) was used to demonstrate the presence of surface residues of shape-tailoring agents. The appearance of the pyrophosphates in Ag_3PO_4 samples was also investigated. Moreover, we used IR to monitor the reactant adsorption in the photocatalytic tests.

A *SPECS PHOIBOS 150 MCD photoelectron spectroscope* (**XPS**) was used to determine the different oxidation states of the surface atoms.

A *JASCO-V650 UV-visible spectrophotometer* equipped with an *ILV-724* integrative sphere (**DRS**) was used to determine the optical properties of the samples. The first-order derivatives ($dR/d\lambda$) of the spectra were calculated to determine the light absorption capacity of different crystal phases mixtures. The presence of the typical localized surface plasmon resonance bands of Ag nanoparticles and the characteristic absorption of Ag_2O were analyzed. The band gap energy values of the samples were calculated by using the Kubelka-Munk theory.

A *JASCO LP-6500* spectrofluorometer (with epifluorescence accessory: *EFA 383 module*) was used to identify the excitation properties at 325 nm irradiation wavelength.

The hydrophilicity of the catalysts was evaluated by using a *Dataphysics O.C.A. 15EC* type optical contact angle meter (*Dataphysics Contact Angle System OCA15Pro* software).

An aqueous solution of methyl orange, phenol, or oxalic acid was used to investigate the photocatalytic activity of the semiconductors. The photocatalytic measurement was performed in a double-walled *Pyrex* glass reactor equipped with a magnetic stirrer, continuous air supply, and thermostat at 25 ºC. The concentration of the suspension was 1 $g \cdot L^{-1}$. The photoreactor was surrounded with 6×6 W (λ_{max} = 365 nm) UV lamps and 4×24 W (DÜVI 25920/R7S; λ_{max} = 545 nm) visible light emitting lamps. The concentration change of phenol and oxalic acid was monitored using a *Merck-Hitachi L-7100* high-performance liquid chromatograph. On the other hand, the concentration change of methyl orange was examined using an *Agilent 8453* spectrophotometer (λ_{max} = 484 nm).

The samples were characterized again after the reusability process. The structural stability of the samples was analyzed by using two different recycling experiment types: sequential and regenerated catalysts mode.

3. Summary of the new scientific results

T1. It was demonstrated that the anion from the halide source affected the photocatalytic activity and stability of silver halides

T1.1 We have shown that a clear sequence can be established between the photocatalytic activity of silver halides, even though the synthesis of silver halides has been varied over a relatively wide range using different halide precursors (alkali and hydrogen halides) and different shape-tailoring agents. While AgCl degraded methyl orange between 0-33% efficiency, AgBr resulted in a 44-92% conversion rate, whereas AgI did not show any photocatalytic activity under the same conditions.

T1.2 It was shown that the formation of Ag nanoparticles on the surface of the silver halides depended on the type of AgX, since in the case of silver chloride Ag or Ag_2O particles were formed during the synthesis, while in the case of silver bromide only during the photocatalytic processes. AgI did not show the formation of Ag or Ag_2O. Furthermore, the synthesis of AgI resulted in the mixture of β-AgI and γ-AgI crystal phases.

T1.3 It was concluded that the applicability of AgCl and AgBr was questionable as photocatalysts due to the uncontrolled deposition of Ag-containing species on the surface of the semiconductor, which contributed to the inhibition of the photoactivity.

T2. It was found that the shape-tailoring agents used in the synthesis affected the morphology and photocatalytic activity of AgCl and AgBr

T2.1 It was found that the photocatalytic activity of the polyvinylpyrrolidone-modified samples was higher than those obtained in the presence of ionic cetyltrimethylammonium bromide and sodium dodecyl sulfate shape-tailoring agents, as these samples had the highest degradation efficiencies, regardless of

the type of silver halide. This can be related to the smaller particle size and polyhedral morphology induced by the presence of PVP during the synthesis.

T2.2 The samples modified with sodium dodecyl sulfate provided lower or equal conversion compared to the samples synthesized without any additives, despite the emerging polyhedral morphology achieved by using sodium dodecyl sulfate.

T2.3 It was demonstrated that the photocatalytic activity of the samples obtained in the presence of cetyltrimethylammonium bromide is affected by the different alkali metal bromides used. A volcano-type curve was obtained when analyzing the dependence of the photocatalytic conversion values from the used bromide source, the maximum value being at the samples achieved with using NaBr.

T2.4 The amount of PVP affected the photocatalytic activity of the silver halides as well. The most efficient sample was obtained at a molar ratio of Ag:PVP=1:1.63 (the other Ag:PVP molar ratios were as follows: 0.27; 0.546; 1.09; 1.63; 2.18, 2.72 and 3.27 relative to a unit of silver).

T3. It was demonstrated that the cation salt of the halogen precursors indirectly affects the optical properties of the resulting materials. Using the K^+-containing salts, regardless of the shape-tailoring and the silver halides, band gap energy values were the same.

T4. It was established that the types and concentration of the applied phosphate sources during the synthesis affected the photocatalytic activity and stability of Ag_3PO_4

T4.1 It was demonstrated that the presence of NaH_2PO_4 as opposed to Na_2HPO_4 and $Na_3PO_4 \cdot 12\ H_2O$ resulted in the appearance of pyrophosphate ($Ag_4P_2O_7$), which may affect negatively the photocatalytic activity.

T4.2 Ag/Ag_xO nanoparticles formed on the surface of Ag_3PO_4 after the degradation processes. The appearance of the mentioned species had a weaker

deactivating effect than in the case of silver halides. Ag_3PO_4 showed a much smaller decrease in activity in increased reusability compared to AgBr.

T5. It was shown that the TiO_2 crystal phase affected the nature and stability of Ag-containing nanoparticles

T5.1 The ratio of Ag/Ag_xO nanoparticles on the surface of the TiO_2 can be modified by the anatase: rutile ratio. It was confirmed by XRD, DRS, and XPS that AgO nanoparticles formed on the surface of anatase, while Ag nanoparticles were deposited on the surface of rutile regardless of the TiO_2 crystal phase ratios used (AA:AR=0:100, 10:90, 25:75, 50:50, 75:25, 90:10 and 100:0 w/w%).

T5.2 The Ag-containing composites were found to be more efficient in the degradation of oxalic acid and phenol (under UV light irradiation) than commercial TiO_2 composites when they contained anatase and rutile crystal phases together. In the case of Ag-containing composites, a conversion of 19-50% was achieved during the degradation of oxalic acid, while in the degradation of phenol it was between 36.7-50%, in contrast to the commercial composites, where degradation of oxalic acid resulted in only 6.8-24% conversion and 32.5-43% for phenol. The composition of 75% anatase and 25% rutile showed outstanding activity in the photocatalytic degradation of phenol and oxalic acid.

T5.3 Ag nanoparticles on the surface of rutile can slowly transform into Ag_2O nanoparticles after several months or directly after the photocatalytic degradation of a model pollutant. The as-obtained Ag_2O nanoparticles can be reverted to Ag after another photocatalytic test. Interestingly, AgO remains stable both in time and during photocatalytic degradation of oxalic acid.

4. Applicability of the scientific results

The aim of this doctoral thesis was to obtain different types of silver-containing materials. The effect of the synthesis parameters on the photocatalytic activity and stability of the materials was analyzed in-detail. Comprehensive characterization demonstrated that some Ag-containing microcrystals can be synthesized with high purity. The obtained materials and composites are suitable for other types of applications despite the difficulties shown during their application in visible and UV light-driven photocatalytic processes. The properties of the semiconductors were analyzed after the degradation processes as well. It was found that in several cases (AgCl, AgBr, and Ag_2CO_3), the materials have lost entirely/partially their photocatalytic activity and transformed into other Ag-containing compounds. The AgI and Ag_3PO_4 microcrystals were stable compared to other materials mentioned above. In addition, Ag_3PO_4 has proven to be a re-usable photocatalyst, and Ag/Ag_xO nanoparticles formed on their surface increase its efficiency. It was also shown that the ratio of different TiO_2 crystal phases affected the ratio of Ag/Ag_xO nanoparticles, which could be a new application of TiO_2.

4. Publications and conference participations

Hungarian Scientific Bibliography (MTMT) identifier: 10062468

Publications related to the scientific topic of the dissertation

[1] **Zs.-R. Tóth**, K. Hernadi, L. Baia, G. Kovács, Zs. Pap: *Controlled formation of Ag-Ag_xO nanoparticles on the surface of commercial TiO_2 based composites for enhanced photocatalytic degradation of oxalic acid and phenol*,
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[2] **Zs.-R. Tóth**, Zs. Pap, J. Kiss, L. Baia, T. Gyulavári, Zs. Czekes, M. Todea, K.Magyari, G. Kovács, K. Hernadi, *Shape tailoring of AgBr microstructures: effect of the cations of different bromide sources and the applied surfactants*,
RSC Advances, 2021, 11, 9709-9720 (DOI: 10.1039/D0RA09144H)
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[4] **Zs.-R. Tóth**, D. Debreczeni, T. Gyulavári, I. Székely, M. Todea, G. Kovács, K. Magyar, L. Baia, Zs. Pap K. Hernadi**,** *Rapid synthesis method of Ag_3PO_4 re-usable semiconductor*
manuscript in preparation

$\sum$IF = 12.464

Other publication:

[1] Zs. Pap, **Zs. R. Tóth**, V. Danciu, L. Baia, G. Kovács, *Differently shaped au nanoparticles: A case study on the enhancement of the photocatalytic activity of commercial TiO_2*,
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[2] **Zs.-R. Tóth**, G. Kovács, K. Hernádi, L. Baia, Zs. Pap, *The investigation of the photocatalytic efficiency of spherical gold nanocages/TiO_2 and silver nanospheres/TiO_2 composites*,
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[3] **Zs.-R. Tóth**, Zs. Pap, V. Danciu, V. Cosoveanu, L. Baia, G. Kovács, *Detailed investigation of phenol degradation on Au/TiO_2 composite materials*,
Journal of Nanoscience and Nanotechnology 19 (2019) 407-413.
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[4] K. Magyari, **Z. R. Tóth**, Zs. Pap, E. Licarete, D.C. Vodnar, M. Todea, T. Gyulavári, K. Hernadi, L. Baia, *The impact of copper oxide nanoparticles on the structure and applicability of bioactive glasses*,

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IF=2.008

[5] A. Szabó, L. P. Bakos, D. Karajz, T. Gyulavári, **Zs.-R. Tóth**, Zs. Pap, I. M. Szilágyi, T. Igricz, B. Parditka, Z. Erdélyi, K. Hernadi, *Decoration of Vertically Aligned Carbon Nanotubes with Semiconductor Nanoparticles Using Atomic Layer Deposition*,
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[6] K. Magyari, Zs. Pap, **Z. R. Tóth**, Zs. Kása, E. Licarete, D. C. Vodnar, K. Hernadi L. Baia, *Insights into the effect of gold nanospheres, nanotriangles and spherical nanocages on the structural, morphological and biological properties of bioactive glasses,*
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[11] Z. Kovács, Cs. Molnár, T. Gyulavári, K. Magyari, **Zs. Toth**, L. Baia; K. Hernadi, Zs. Pap *Solvothermal synthesis of ZnO spheres: tuning the structure and morphology from nano- to micro-meter range and its impact on their photocatalytic activity*, Catalysis Today,
submitted manuscript
IF=5.825

∑IF = 29.116

$\sum\sum_{total}$IF = 41.58

∑Citations = 31 (Independent: 15)

National and international conference participations:

[1] **Tóth Zsejke Réka**, Kovács Gábor, Pap Zsolt, Danciu Virginia, Vulpoi Adriana, Magyari Klára, Dombi András, Hernádi Klára, Baia Lucian: *Különböző formájú arany nanorészecskék hatása kereskedelmi fotokatalizátorok aktivitására*
XIX. International Conference on Chemistry, Baia Mare, Romania (2013) – poster presentation

[2] **Tóth Zsejke Réka**: *Különböző alakú arany nanorészecskék hatása kereskedelmi fotokatalizátorok aktivitására*
XVII. Erdélyi Tudományos Diákköri Konferencia,
Cluj Napoca, Romania (2014) – oral presentation

[3] **Tóth Zsejke Réka**, Kovács Gábor, Pap Zsolt, Virginia Danciu, Dombi András, Hernádi Klára, Lucian Baia: *Kereskedelmi TiO_2 és különböző alakú arany nanorészecskék által alkotott kompozitok fotokatalitikus aktivitása modell szennyezők lebontására és a keletkező köztitermékek vizsgálata*
XX. International Conference on Chemistry, Cluj Napoca, România (2014) – poster presentation

[4] **Tóth Zsejke-Réka**: *Különböző alakú arany nanorészecskék hatása kereskedelmi fotokatalizátorok aktivitására*
XXXII. Országos Tudományos Diákköri Konferencia, Kémiai és Vegyipari Szekció, Veszprém, Hungary (2015) – oral presentation

[5] **Tóth Zsejke Réka**, Kovács Gábor, Pap Zsolt, Virginia Danciu, Dombi András, Hernádi Klára, Lucian Baia: *Kereskedelmi TiO_2 és különböző alakú arany és ezüst nanorészecskék által alkotott kompozitok fotokatalitikus aktivitásának vizsgálata*
XXI. International Conference on Chemistry, Șumuleu, Romania (2015) – poster presentation

[6] **Tóth Zsejke-Réka**: *The influence of Ag and Au nanoparticles shapes on the activity of commercial TiO_2 photocatalysts*
13th International Conference „Student for Students”
Cluj Napoca, Romania (2016) – oral presentation

[7] **Tóth Zsejke Réka**: *Au- és Ag-TiO_2 nanokompozitok fotokatalitikus hatékonyságának vizsgálata*
XIX. Erdélyi Tudományos Diákköri Konferencia,
Cluj Napoca, Romania (2016) – oral presentation

[8] **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Baia Lucian, Kovács Gábor
Kereskedelmi TiO_2 fotokatalizátorok, arany nanoketrecekkel való módosítása és aktivitására való hatása
22nd International Symposium on Analytical and Environmental Problems
Szeged, Hungary (2016) – poster presentation
[9] Fodor Szilvia & **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Kovács Gábor, Baia Lucian: *Különböző geometriájú nemesfém nanorészecskékkel módosított TiO_2 fotokatalizátorok hatása fenol bontásában*
V. Környezetkémiai Szimpózium, Tihany, Hungary (2016) – oral presentation

[10] **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Baia Lucian, Kovács Gábor:
Nemesfém/TiO_2 kompozitok alkalmazása szerves szennyezők lebontására és fotokatalitikus H_2 fejlesztésre
XXII. International Conference on Chemistry, Timisoara, Romania (2016) – oral presentation

[11] **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Lucian Baia, Kovács Gábor: *TiO_2 aktivitásának befolyásolása Au és Ag nanorészecskékkel és a keletkezett kompozitok fotokatalitikus aktivitásának vizsgálata*
XV. Erdélyi Természettudományi Konferencia
Cluj Napoca, Romania (2016) – poster presentation

[12] **Zsejke-Réka Tóth**, Péter-Szabó Márk, Klára Hernádi, Lucian Baia, Zsolt Pap
Synthesis and photocatalytic activity of silver-halide nanoparticles
5th European Conference on Environmental Applications of Advanced Oxidation Processes
Prague, Czech Republic (2017) – poster presentation

[13] Eszter Orbán, **Zsejke-Réka Tóth**, Zsolt Pap, Gábor Kovács, Klára Hernádi, Virginia Danciu, Lucian Baia: *Application of TiO_2/WO_3 composites in the photocatalytic degradation of dye molecules*
5th European Conference on Environmental Applications of Advanced Oxidation Processes
Prague, Czech Republic (2017) – poster presentation

[14] **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Lucian Baia, Kovács Gábor: *Ezüst-halogenid (AgX, $X=Cl^-$, Br^-) látható fényben aktív fotokatalizátorok előállítása, jellemzése és alkalmazása modellszennyezők lebontására*
XXIII. International Conference on Chemistry, Deva, Romania (2017) – poster presentation

[15] Kovács Zoltán & **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Lucian Baia, Kovács Gábor: *AgBr/ZnO fotokatalizátorok jellemzése és fotokatalitikus aktivitásának vizsgálata*
XXIII. International Conference on Chemistry, Deva, Romania (2017) – poster presentation

[16] **Zsejke-Réka Tóth**, Gábor Kovács, Lucian Baia, Zsolt Pap, Klára Hernádi: *Synthesis, characterization and photocatalytic activity of spherical gold nanocages/TiO_2 and silver nanospheres/TiO_2 composites*
3rd International Symposium on Nanoparticles/Nanomaterials and Applications,
Lisbon, Portugal (2018) – poster presentation

[17] **Tóth Zsejke-Réka**
Metilnarancs színezék bontása látható fényben aktív Ag alapú katalizátorok felhasználásával
Interdiszciplinaritás a Kárpát – Medencében ELTE MÁSZ PhD-konferencia,
Debrecen, Hungary (2018) – oral presentation

[18] **Zsejke-Réka Tóth**, János Kiss, Klára Hernádi, Lucian Baia, Gábor Kovács, Enikő Eszter Almási, Zsolt Pap: *Stability investigations of AgBr photoactive materials*
II. Sustainable Raw Materials International Project Week And Scientific Conference,
Szeged, Hungary (2019) – oral presentation

[19] **Zsejke-Réka Tóth**, Zsolt Pap, Emilia Licarete, Klára Hernádi, Lucian Baia, Klára Magyari: *Effect of differently shaped gold nanoparticles on the bioactive glasses*

30th Annual Conference of the European Society for Biomaterials,
Dresden, Germany (2019) – poster presentation

[20] **Zsejke-Réka Tóth**, Alexandra Feraru, Zsolt Pap, Milica Todea, Dan C. Vodnar, Klára Hernádi, Lucian Baia, Klára Magyari: *Optimization of the synthesis of noble metal-based microcrystals and applicability studies bioactive glass-based composites*
30th Annual Conference of the European Society for Biomaterials
Dresden, Germany (2019) – poster presentation

[21] **Tóth Zsejke-Réka**, Debreczeni Diána, Pap Zsolt, Hernádi Klára, Milica Todea, Dan. C. Vodnar, Lucian Baia, Magyari Klára: *Ag_3PO_4 tartalmú bioaktív üveg kompozitok előállítása, jellemzése és antibakteriális hatásának a vizsgálata*
XXVI. International Conference on Chemistry, online (2020) – oral presentation

National and international conference participations as co-author:

[1] Szilvia Fodor, **Zsejke Réka Tóth**, Zsolt Pap, Lucian Baia, Virginia Danciu, Adriana Vulpoi, Klára Magyari, András Dombi, Klára Hernádi, Gábor Kovács: *The influence of Pt/Au nanoparticles' shape on activity of commercial TiO_2 photocatalysts*
European Materials Research Society Spring Meeting, Lille, France (2014) – poster presentation

[2] Kovács Gábor, **Tóth Zsejke Réka**, Fodor Szilvia, Pap Zsolt, Danciu Virginia, Dombi András, Hernádi Klára, Baia Lucian: *Differently shaped Pt/Au nanoparticles: activity enhancement of commercial TiO_2 photocatalysts*
8th European Meeting on Solar Chemistry and Photocatalysis: Environmental Applications – Thessaloniki, Greece (2014) – poster presentation

[3] Pap Zsolt, Kovács Gábor, Székely István, Kedves Zsolt, Saszet Kata, Hampel Boglárka, Fodor Szilvia, Orbán Eszter, Kovács Zoltán, Hernádi Klára, Dombi András, Kása Zsolt, **Tóth Zsejke-Réka**, Vajda Krisztina, Karácsony Éva, Virginia Danciu, Adriana Vulpoi, Veronica Coșoveanu, Lucian Baia: *Nano-sized photocatalysts and their composites – shape tailoring and activity*
XX. International Conference on Chemistry, Cluj Napoca, Romania (2014) – oral presentation

[4] Pap Zsolt, Kovács Gábor, **Tóth Zsejke-Réka** *et al.*: *The Functioning Mechanism of Photocatalytic Systems from the Charge Transfer Point of View. "The Adventure of the Electron"*
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[5] Pap Zsolt, Fodor Szilvia, Gyulavári Tamás, Kovács Gábor, **Tóth Zsejke-Réka**, *et al.*
Új nanokompozitok és nanoszerkezetek a víztisztításban
XXII. International Conference on Chemistry, Timisoara, Romania – oral presentation

[6] Péter-Szabó Márk, **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Kovács Gábor: *Ezüst-bromidok előállítása és fotokatalitikus aktivitásának vizsgálata*
XXIII. International Conference on Chemistry, Deva, Romania (2017) – poster presentation

[7] Gombkötő Dániel, **Tóth Zsejke-Réka**, Pap Zsolt, Hernádi Klára, Kovács Gábor, Szőllősi György: *Au-laponit-alapú kompozitok előállítása, szerkezeti és morfológiai vizsgálata*
XXIII. International Conference on Chemistry, Deva, Romania (2017) – poster presentation

[8] Magyari Klára, Nagy-Simon Tímea, **Tóth Zsejke-Réka**, Pap Zsolt, Adriana Vulpoi, Emilia Licarete, Radu A. Popescu, Hernádi Klára, Lucian Baia: *Bioaktív üveg-arany nanorészecske kompozitok biokompatibilitási teljesítménye*
XXIII. International Conference on Chemistry, Deva, Romania (2017) – oral presentation

[9] **Tóth Zsejke-Réka**, Kovács Gábor, Pap Zsolt, Hernádi Klára: *Ezüst-halogenid (AgX, X=Cl^-, Br^-, I^-) látható fényben aktív fotokatalizátorok stabilitásának a vizsgálata*
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Sovata, Romania (2018) – poster presentation

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