Doctoral (Ph. D.) Theses

Characterization of optically active perovskite electrodes

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I. Introduction and Objectives

The emergence of hybrid organic-inorganic perovskites (HOIPs) as active components in solar cells has sparked a rapidly growing interest in the scientific community. A steep rise was witnessed in the power conversion efficiencies, which currently peaks at a certified value of 22.1 %.

HOIPs are extremely versatile, as a large portion of elements (or even organic molecules) can be used as the building blocks of the perovskite lattice. The criteria that these elements must meet are mainly size constraints (i.e., *Goldschmidt tolerance* and *octahedral factor*). This interchangeability in composition is the reason behind the fact that several properties of HOIPs are exceptionally fine-tunable.

Simple solution processes can be used to prepare efficient HOIP based materials (e.g., *one-step, two-step and vacuum assisted processes*). Throughout the years several different methods (or improvements on an already existing one) aimed to gain better control over the crystallization process of HOIPs. The optoelectronic properties of HOIPs show extreme tunability and versatility. Their *large absorption coefficient* and *composition dependent bandgap* makes them ideal materials for light absorbing and emitting applications. The charge carrier generation in these materials is mainly non-excitonic in nature (*low exciton binding energy*), which ensures efficient charge carrier generation. Furthermore, their defect tolerant crystal structure (e.g., *dominance of shallow point defects* and the *absence of impurity states*) suppress charge carrier recombination processes and their ambipolar charge transport improves charge carrier extraction. These qualities are the underlying reasons for the remarkable efficiency of the derived solar cells.

Currently the limiting factor of the commercialization of HOIP based devices is their sensitivity towards several environmental factors (e.g., *humidity, heat, light*). Furthermore, device architecture, operational conditions (such as *built in electric fields*) and other components of the devices (*interfacial layers*, *electrode corrosion*) can also detrimentally affect device performance.

Electrochemistry as a *characterization tool,* has started to gain a foothold in the evaluation of HOIP materials. Currently the field is in its infancy, however the first studies are already available of HOIP based electrodes in different electrochemical applications (e.g., *Li-ion batteries, electrochemiluminescence*). Electrochemical techniques can offer valuable information about the *charge carrier generation and transport* in HOIPs. With the aid of coupled techniques, *chemical changes* upon charge carrier generation can also be unraveled. Fundamental optoelectronic properties can also be studied (e.g., *band edge positions, distribution of trap states*). In addition, electrochemical methods can be also used as synthetic tools. The use of *HOIP photoelectrodes* to drive certain reduction reactions (e.g., CO_2 reduction) is an especially lucrative concept. Furthermore, electrochemistry can also aid the *assembly of HOIP based devices*. All these opportunities call for coherent stability tests, so the degradation of the HOIP based electrodes could be avoided.

During my research I aimed to find answers to the questions raised in the introduction:

- *What is the impact of long-term light irradiation (or light soaking) on the performance of mixed halide perovskite solar cells*?

- *What is the electrochemical window to safely conduct electrochemical experiments and what are the redox events that were left unexplained?*

- *How does the nature of the electron transport layer/perovskite interface influence the charge recombination process?*

- *Is it possible to employ electrochemical deposition methods and use conducting polymers as hole transport layers in HOIP based solar cells in a n-i-p design?*

As the first step, I aimed to establish a solvent/electrolyte system, where electrochemical measurements could be carried out. For these experiments, the chosen model systems were FTO/TiO_2/$CsPbBr_3$ and FTO/TiO_2/$CH_3NH_3PbI_3$. My aim was to identify the redox alterations of these materials and to ultimately determine an electrochemical stability window. As a next step, I coupled transient absorption spectroscopy with electrochemical methods to elucidate the role of TiO_2 in the charge recombination process. As electrochemistry can be also used as a synthetic tool, I also investigated the electrosynthesis of a poly(3,4-ethylenedioxithiophene) (PEDOT) hole transport layer in $CH_3NH_3PbI_3$ electrodes, thus forming a regular *n-i-p* junction solar cell. As an introduction to solar cell characterization, I also studied the interaction of light with mixed halide solar cells. I investigated the effect of phase segregation on the optical and electronic properties of mixed halide solar cells.

II. Experimental Methods

The presented work relies on three different architectures (***Figure 1***). The PSCs consisted of a FTO layer coated with a thin blocking-TiO_2 layer, a mesoporous-TiO_2 layer, the perovskite absorber layer, a spiro-MeOTAD layer and a gold contact completed the solar cell (***Figure 1*A**). To study light induced segregation phenomena solar cell architectures without the top gold contact were also prepared (***Figure 1*B**). To mimic the solar cell architectures, the electrodes for the electrochemistry studies were prepared almost identically. The preparation procedure was the same until the perovskite deposition. A thinner layer of perovskite was used, to ensure significant transmittance of the layers in a wide wavelength range. In the case of electrodes, the upper HTL and gold contacts were omitted (***Figure 1*C**).

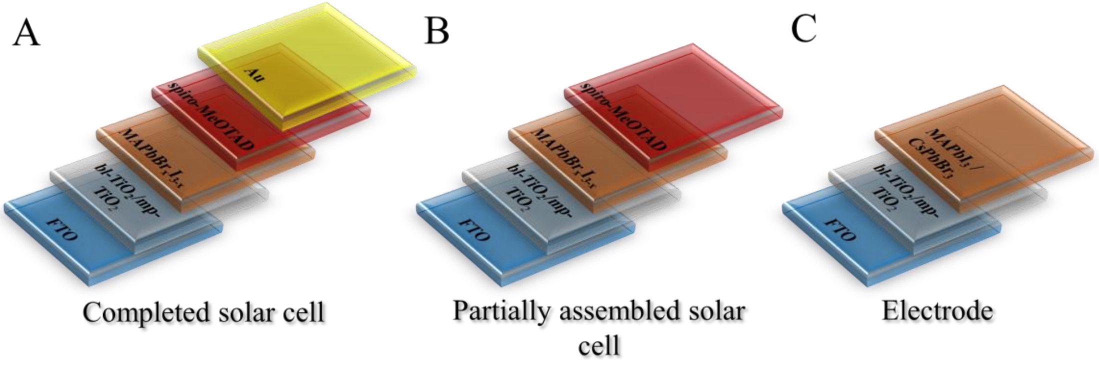

Figure 1. *Schematic representation of the different architectures used throughout the experiments.* ***A:*** *Complete solar cell,* ***B:*** *partially complete solar cell, and* ***C:*** *electrode.*

The electrochemical measurements were carried out with a Gamry potentiostat in a standard three-electrode setup. The FTO/TiO_2/perovskite electrodes functioned as the working electrode, a Pt mesh (1 cm^2) as the counterelectrode (cleaned by "Piranha solution", water and finally dicholormethane), and a Ag/AgCl wire as a pseudo-reference electrode. Its potential was calibrated before and after the experiments, by measuring the formal potential of the ferrocene/ferrocenium redox couple in dichloromethane (0.01 M ferrocene and 0.1 M Bu_4NPF_6). Cyclic voltammetry was used, and the formal potential was found to be $E = +0.45 \pm 0.04$ V vs. our Ag/AgCl. All cells were assembled in a glovebox (N_2 atmosphere, $H_2O < 0.1$ ppm, $O_2 < 0.1$ ppm) and sealed hermetically to ensure inert conditions. To determine the electrochemical stability window spectroelectrochemical measurements were carried out. The electrochemical cell was placed in a spectrophotometer (Varian Cary 50 Bio) and the spectra of the electrode was recorded during cyclic voltammetry scans. Separate experiments were carried out for the identification of the oxidation and the reduction events. By correlating these redox events on the voltammograms with the absorbance changes, the stability window of the electrodes was determined.

The electrodeposition of PEDOT hole transporter on the FTO/TiO_2/$CH_3NH_3PbI_3$ electrodes was carried out from a 0.01 M bis-EDOT and 0.1 M Bu_4NPF_6 containing dichloromethane electrolyte. The deposition potential and the growth of the PEDOT layers were monitored by potentiodynamic methods coupled with spectroelectrochemistry. Ultimately, however potentiostatic deposition was used to control the thickness of the deposited PEDOT layers, by controlling the polymerization charge density. To remove the contribution of the charging/discharging of the electrochemical double layer to the passed charge density a pretreatment step was introduced prior to the electrodeposition at E = +0.5 V for 60 s in the polymerization media. After the polymerization was finished the solar cells were rinsed with dichloromethane (as-is solar cells).

A Clark MXR-2010 laser system (775 nm fundamental, 1 mJ/pulse, FWHM=150 fs, 1 kHz repetition rate) was used to perform the ultrafast transient spectroelectrochemistry measurements. The fundamental beam was separated in an intensity ratio of 95/5, where the 95 % was doubled in frequency to generate the 387 nm excitation pump. The remaining 5 % was used to generate a white light continuum via a CaF_2 crystal. This light was used as the probe for all measurements. The intensity of the excitation pump was modulated so that the maximum change in absorbance remained constant in all measurements ($\Delta A_{520nm} \sim -0.25$), which corresponded to a pump excitation of about 12 μJ cm^{-2}. This was done to ensure that similar amounts of charge carriers were generated in each measurement. A three-armed electrochemical cell with a fused silica cuvette body was placed at the spatial overlap of the pump and the probe. The electrode was kept at a constant potential while the transient absorption spectra were recorded. The sampling spot was adjusted between every measurement to ensure the sampling of a fresh electrode area.

To induce phase segregation in mixed halide solar cells, they were subjected to white light irradiation with an incident power density of 100 mW cm^{-2} for 30 minutes. The light from a Xe-lamp source was passed through an AM 1.5 filter beforehand. To ensure that thermal effects have miniscule contribution to the phase segregation process, a water filter was placed in front of the samples. After the light irradiation the solar cells were placed in a dark chamber, where the recovery process immediately began.

The X-ray photoelectron spectroscopy (XPS) was performed with a PHI VersaProbe II system. The binding energy scale was corrected by fixing the main C 1s component to 284.8 eV, corresponding to the adventitious carbon.

Top-down and cross-sectional scanning electron microscopic (SEM) images were captured using a FEI Helios NanoLab™ DualBeam™ instrument.

X-Ray diffraction (XRD) patterns were collected using a Bruker D8 DISCOVER instrument with Cu K_α X-ray source ($\lambda = 1.5406$ Å), in the 20−80 ° range, with a 2 ° min^{-1} scan rate.

Raman spectroscopic measurements were performed on a DXR Raman Microscope using a green laser ($\lambda = 532$ nm), operating at 10 mW laser power at room temperature.

The characterization of the solar cells was performed in a 2-electrode setup on a Princeton Applied Research PARStat 2273 potentiostat under 1 sun conditions. The voltage was swept with a 50 mV s^{-1} sweep rate.

The incident photon to current efficiency (IPCE) measurements were taken with a Newport Oriel Quantum Efficiency Measurement System.

III. Summary of New Scientific Results

T1 The electrochemical stability window was determined for two hybrid organic-inorganic perovskites ($CH_3NH_3PbI_3$ and $CsPbBr_3$) using spectroelectrochemical measurements.

Bu_4NPF_6/dichloromethane was found to be a suitable electrolyte to conduct electrochemical measurements, because even after 2 hours no sign of substantial degradation of the electrodes was observed. Spectroelectrochemical experiments revealed multiple redox events coupled to distinct absorbance change of the layers. Ultimately a −1.0 V – +0.6 V vs Ag/AgCl for $CsPbBr_3$ and −0.65 V – +0.55 V vs Ag/AgCl for $CH_3NH_3PbI_3$ stability window was determined.

T2 The degradation pathways of FTO/TiO_2/$CsPbBr_3$ electrodes outside of their electrochemical stability window were identified and characterized.

XPS and XRD studies revealed that during oxidation $CsPF_6$ is formed on the electrode surface, together with the dissolution of the perovskite structure. This degradation is accompanied by morphological changes, as SEM images revealed the formation of rectangular particles on the surface of the electrodes, together with the partial dissolution of the layers (through the formation of Pb^{2+} and Br^{-}). During reduction, the formation of Pb was observed, which is partially re-oxidized to PbO upon air exposure. The morphology of the electrodes was also heavily impacted, as the degradation was severe enough to expose the underlying TiO_2 layer. Furthermore, formation of dendritic structures was also seen on certain parts of the electrodes.

T3 The in situ combination of transient absorption spectroscopy with electrochemical techniques was achieved. The combined technique was capable of probing the effect of external bias on the charge carrier recombination kinetics of FTO/TiO_2/$CsPbBr_3$ electrodes.

On FTO/TiO_2/$CsPbBr_3$ electrodes the rate constant of charge carrier recombination showed small variation at 0.0 V vs. Ag/AgCl and more negative potentials. On the other hand, at more positive than 0.0 V vs. Ag/AgCl, a faster decay kinetics was observed. Since electrons were depleted from the TiO_2 layer under anodic bias, photogenerated electrons in $CsPbBr_3$ were injected into the TiO_2 film. This competing charge injection process resulted in faster bleaching recovery at anodic bias.

T4 Transient spectroelectrochemical measurements revealed that the substrate had a pronounced effect on the charge carrier recombination kinetics of $CsPbBr_3$ electrodes.

Experiments on FTO/$CsPbBr_3$ (i.e., without TiO_2 layer) showed that the bleaching recovery was not influenced by the applied electrochemical bias (within the studied time-range).

T5 Light induced phase segregation in mixed halide perovskite solar cells affected both their optical and electronic properties.

After 30 minutes of white light illumination of $CH_3NH_3PbBr_{1.5}I_{1.5}$ solar cells a decrease in absorbance at 620 nm was observed, which suggests the disappearance of the mixed halide phase. Simultaneously, a concurrent increase in the absorption at shorter and longer wavelengths was observed that represented the formation of bromide and iodide rich phases. This segregation process had a marked impact on the IPCE values. Inducing segregation caused a 50 % drop in the IPCE, which detrimentally affected the performance of such solar cells.

T6 The phase segregation process was found to be reversible, when the devices were stored in the dark. However, the recovery of the optical and electronic properties occurred on a different timescale.

The complete recovery time of the absorbance was found to be less than 3 hours. However, the recovery of the IPCE was a much slower process, as it took up to 36 hours. The slower recovery of the electronic properties suggests that charge carrier extraction from the devices was hindered. This was attributed to the lingering effect of the formed residual traps in the devices.

T7 Electrodeposition was used to deposit poly(3,4-ethylenedioxythiophene) hole transporter on $CH_3NH_3PbI_3$ electrodes forming a regular *n-i-p* junction solar cell.

For the electrodeposition of PEDOT the monomer bis-EDOT was used to ensure conservation of the $CH_3NH_3PbI_3$ layer. Potentiostatic electropolymerization allowed the deposition of PEDOT with controlled thicknesses, by controlling the polymerization charge density.

T8 The properties of the hole transporting material (thickness, oxidation state) affected the efficiency of the prepared solar cells.

To improve the efficiency of the prepared solar cells, electrochemical post-treatment techniques were used. The reduction of the PEDOT layer improved the open-circuit voltage of the devices. This post-reduction step, however degraded the underlying $CH_3NH_3PbI_3$ layers. Three milder post-reduction techniques were evaluated and a champion device with a power conversion efficiency of 5.9 % was achieved. We carried out femtosecond transient absorption spectroscopic measurements on the champion architecture. These studies revealed that electrodeposited PEDOT was indeed an effective hole transporter for perovskite solar cells.

IV. List of Publications

Hungarian Scientific Bibliography (MTMT) identifier: 10040508

Google Scholar link: https://scholar.google.hu/citations?user=aIPTi40AAAAJ&hl=hu

Publications related to the scientific topic of the dissertation

Book Chapters:

[1] **G. F. Samu**, C. Janáky
Tailoring the interfaces in conducting polymer composites by controlled polymerization in V. K. Thakur, M. K. Thakur, R. K. Gupta
Hybrid Polymer Composite Materials: Structure and Chemistry (Chapter 5, 101-127), Woodhead Publishing, Elsevier, 2017

Articles:

[1] **G. F. Samu**, C. Janáky, P. V. Kamat
A Victim of Halide Ion Segregation. How Light Soaking Affects Solar Cell Performance of Mixed Halide Lead Perovskites
ACS Energy Letters, 2, 1860-1861 (2017)
$\mathbf{IF_{2017}}$ = NA

[2] R. A Scheidt, **G. F. Samu**, C. Janáky, P. V. Kamat
Modulation of Charge Recombination in $CsPbBr_3$ Perovskite Films with Electrochemical Bias
Journal of American Chemical Society, 140, 86-89 (2018)
$\mathbf{IF_{2017}}$ = 13.858

[3] **G. F. Samu**, R. A Scheidt, P. V. Kamat, C. Janáky
Electrochemistry and Spectroelectrochemistry of Lead Halide Perovskite Films: Materials Science Aspects and Boundary Conditions
Chemistry of Materials, 30, 561–569 (2018) – **Featured on the cover of the journal**
$\mathbf{IF_{2017}}$ = 9.466

[4] **G. F. Samu**, R. A Scheidt, G. Zaiats, P. V. Kamat, C. Janáky
Electrodeposition of Poly(3,4-ethylenedioxythiophene) Hole-transporter on Methylammonium Lead Iodide Layers: a New Tool to Assemble Perovskite Solar Cells
ACS Energy Letters, submitted for publication
$\mathbf{IF_{2017}}$ = NA

ΣIF = 23.324

Other publications:

[5] P. S. Tóth, **G. F. Samu**, B. Endrődi, C. Visy
Hyphenated in situ conductance and spectroelectrochemical studies of polyaniline films in strongly acidic solutions

Electrochimica Acta, 110, 446-451 (2013)
IF$_{2013}$ = 4.086

[6] Á. Veres, J. Ménesi, C. Janáky, **G. F. Samu**, M. K. Scheyer, Q. Xu, F. Salahioglu, M. V. Garland, I. Dékány, Z. Zhong
New insights into the relationship between structure and photocatalytic properties of TiO_2 catalysts
RSC Advances, 5, 2421-2428 (2015)
IF$_{2015}$ = 3.289

[7] **G. F. Samu**, C. Visy, K. Rajeshwar, S. Sarker, V. (Ravi) Subramanian, C. Janáky
Photoelectrochemical Infiltration of a Conducting Polymer (PEDOT) into Metal-Chalcogenide Decorated TiO_2 Nanotube Arrays
Electrochimica Acta, 151, 467-476 (2015)
IF$_{2015}$ = 4.803

[8] **G. F. Samu**, K. Pencz, C. Janáky, K. Rajeshwar
On the electrochemical synthesis and charge storage properties of WO_3/polyaniline hybrid nanostructures
Journal of Solid State Electrochemistry, 9, 2741-2751 (2015)
IF$_{2015}$ = 2.327

[9] Thomas, C. Janáky, **G. F. Samu**, M. N. Huda, P. Sarker, J. P. Liu, V. Nguyen, E. H. Wang, K. A. Schug, K. Rajeshwar
Time- and Energy-Efficient Solution Combustion Synthesis of Binary Metal Tungstate Nanoparticles with Enhanced Photocatalytic Activity
ChemSusChem, 10, 1652-1663 (2015)
IF$_{2015}$ = 7.116

[10] B. Endrődi, **G. F. Samu**, D. Fejes, Z. Németh, E. Horváth, A. Pisoni, P. K. Matus, K. Hernádi, C. Visy, L. Forró, C. Janáky
Challenges and rewards of the electrosynthesis of macroscopic aligned carbon nanotube array/conducting polymer hybrid assemblies – **Featured on the inside cover of the journal**
Journal of Polymer Science Part B: Polymer Physics, 53, 1507–1518 (2015)
IF$_{2015}$ = 3.318

[11] B. Endrődi, **G. F. Samu**, M. A. Azam, C. Janáky, C. Visy
Electrochemical synthesis and characterization of poly(3-hexylthiophene)/single-walled carbon nanotube array hybrid materials
Journal of Solid State Electrochemistry, 11, 3179–3187 (2016)
IF$_{2016}$ = 2.316

[12] **G. F. Samu**, Á. Veres, S. P. Tallósy, L. Janovák, I. Dékány, A. Yepez, R. Luque, C. Janáky
Photocatalytic, photoelectrochemical, and antibacterial activity of benign-by-design mechanochemically synthesized metal oxide nanomaterials
Catalysis Today, 284, 3-10 (2017)

IF_{2016} = 4.636

[13] E. Varga, K. Baán, **G. F. Samu**, A. Erdőhelyi, A. Oszkó, Z. Kónya, J. Kiss
The Effect of Rh on the Interaction of Co with Al_2O_3 and CeO_2 Supports
Catalysis Letters, 9, 1800-1807 (2016)
$\mathrm{IF}_{2015/2016}$ = 2.799

[14] **G. F. Samu**, Á. Veres, B. Endrődi, E. Varga, K. Rajeshwar, C. Janáky
Bandgap-engineered Quaternary $M_xBi_{2-x}Ti_2O_7$ (M: Fe, Mn) Semiconductor Nanoparticles: Solution Combustion Synthesis, Characterization, and Photocatalysis
Applied Catalysis B: Environmental, 208, 148-160 (2017)
IF_{2016} = 9.446

[15] M. K. Hossain, **G. F. Samu**, K. Gandha, S. Santhanagopalan, J. P. Liu, C. Janáky, K. Rajeshwar
Solution Combustion Synthesis, Characterization, and Photocatalytic Activity of $CuBi_2O_4$ and its Nanocomposites with CuO and α-Bi_2O_3
Journal of Physical Chemistry C, 121, 8252-8261 (2017)
$\mathrm{IF}_{/2016}$ = 4.536

[16] Sápi, A. Varga, **G. F. Samu**, D. Dobó, K. L. Juhász, B. Takács, E. Varga, Á. Kukovecz, Z. Kónya, C. Janáky
Photoelectrochemistry by Design: Tailoring the Nanoscale Structure of Pt/NiO Composites Leads to Enhanced Photoelectrochemical Hydrogen Evolution Performance – **Featured on the cover of the journal**
Journal of Physical Chemistry C, 121, 12148–12158 (2017)
IF_{2016} = 4.536

[17] D. Roy, **G. F. Samu**, M. K. Hossain, C. Janáky, K. Rajeshwar
On the measured optical bandgap values of inorganic oxide semiconductors for solar fuels generation
Catalysis Today, 300, 136-144 (2018)
IF_{2016} = 4.636

[18] A. Varga, **G. F. Samu**, C. Janáky
Rapid Synthesis of Interconnected $CuCrO_2$ Nanostructures: A Promising Electrode Material for Photoelectrochemical Fuel Generation
Electrochimica Acta, Submitted for Publication

ΣΣIF = 81.168

Conference lectures and posters

Posters:

[1] **G. F. Samu**, C. Visy, K. Rajeshwar, C. Janáky
Photoelectrodeposition of conducting polymers onto inorganic semiconductor nanoarchitectures
10th International Workshop on Electrodeposited Nanostructures (EDNANO10)
2014. March 20-24, Oberwesel, Germany

[2] **G. F. Samu**, C. Visy, K. Rajeshwar, C. Janáky
Mechanistic aspects of the photoelectrochemical polymerization of 3,4-ethylenedioxythiophenes
22th International Conference on Science and Technology of Synthetic Metals
2014. June 30 – July 5, Turku, Finland

[3] **G. F. Samu**, C. Visy, K. Rajeshwar, C. Janáky
Photoelectrosynthesis of Hybrid Nanostructured Materials
6th Szeged International Workshop on Advances in Nanoscience (SIWAN6)
2014. October 15-18, Szeged, Hungary

[4] **G. F. Samu**, K. Pencz, K. Rajeshwar, C. Janáky
Electrochemical synthesis of WO_3*/Pani hybrid materials and the evaluation of their charge storage properties*
Workshop on the Electrochemistry of Electroactive Materials (WEEM 2015)
2015. May 31 – June 5, Bad Herrenalb, Germany

[5] **G. F. Samu**, K. Rajeshwar, C. Janáky
Solution Combustion Synthesis of $Bi_2Ti_2O_7$ *and Parallel Bandgap Engineering through Foreign Ion Incorporation*
7th Forum on New Materials (CIMTEC 2016)
2016. June 5-9, Perugia, Italy

[6] **G. F. Samu**, A. Thomas, Á. Veres, B. Endrődi, K. Rajeshwar, C. Janáky
Solution Combustion Synthesis of Metal Oxide Semiconductors for Photocatalytic Environmental Remediation
9th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications (SPEA)
2016. June 13-17, Strasbourg, France

Lectures:

[1] **G. F. Samu**, A. Thomas, Á. Veres, B. Endrődi, K. Rajeshwar, C. Janáky
Solution Combustion Synthesis of Metal Oxide Semiconductors for Photocatalytic Environmental Remediation – **Student flash oral talk**
9th European meeting on Solar Chemistry and Photocatalysis: Environmental Applications (SPEA)
2016. June 13-17, Strasbourg, France

[2] **G. F. Samu**, K. Rajeshwar, C. Janáky
Bandgap engineering of $Bi_2Ti_2O_7$ *through foreign ion incorporation via solution combustion synthesis*
253rd ACS National Meeting
2017. April 02-06, San Francisco, USA

[3] **G. F. Samu**, S. Sarker, V. Subramanian, C. Visy, K. Rajeshwar, C. Janáky
Photoelectrochemical synthesis of conducting polymer/inorganic semiconductor assemblies
21st Topical Meeting of the International Society of Electrochemistry
2017. April 23-26, Szeged, Hungary

Co-author of conference lectures and posters

Posters:

[1] B. Endrődi, **G. F. Samu**, D. Fejes, Z. Németh, C. Janáky, K. Hernádi, L. Forró, C. Visy
Thermoelectric and supercapacitive properties of self-standing highly-ordered conducting polymer/carbon nanotube structures
ChemOnTubes
2014. March 30 - April 3, Riva del Garda, Italy

[2] B. Endrődi, **G. F. Samu**, D. Fejes, Z. Németh, C. Janáky, K. Hernádi, L. Forró, C. Visy
Electrosynthesis of macroscopic MWCNT array – conducting polymer hybrids: all-carbon nanoarchitectures for energy applications
22th International Conference on Science and Technology of Synthetic Metals
2014. June 30 – July 5, Turku, Finland

[3] Á. Veres, J. Ménesi, C. Janáky, **G. F. Samu**, M. K. Scheyer, Q. Xu, F. Salahioglu, M. V. Garland, I. Dékány, Z. Zhong
Various TiO_2 *Nanostructures Derived from Acidic Hydrothermal Treatment of Hydrogen Titanate Nanofibres: Structural Characterisation and Photocatalytic Property*
6th Szeged International Workshop on Advances in Nanoscience (SIWAN6)
2014. October 15-18, Szeged, Hungary

[4] A. Varga, **G. F. Samu**, C. Janáky
Synthesis and characterization of $CuCrO_2$ *for* CO_2 *reduction*
5th International Conference from Nanoparticles and Nanomaterials to Nanodevices and Nanosystems (IC4N)
2016. June 26-30, Porto Heli Peloponnese, Greece

[5] A. Varga, **G. F. Samu**, C. Janáky
Solution combustion synthesis of $CuCrO_2$ *and application for* CO_2 *reduction*
21st Topical Meeting of the International Society of Electrochemistry
2017. April 23-26, Szeged, Hungary

Lectures:

[1] B. Endrődi, E. Kriván, M.A. Azam, **G. F. Samu**, A. Varga, C. Visy
Thermoelectric and Electrochemical Properties of Highly Ordered Conducting Polymer/Carbon Nanotube Structures
7th International Workshop on the Electrochemistry of Electroactive Materials
2012. June 3-8. Hódmezővásárhely, Hungary

[2] C. Janáky, **G. F. Samu**, K. Rajeshwar
Electrosynthesis of Quantum Dot-Sensitized Solid-State Solar Cells
247th ACS National Meeting
2014. March 16-20, Dallas, USA

[3] **G. F. Samu**, K. Rajeshwar, C. Janáky
In situ Photo-Electrosynthesis of Conducting Polymers as Hole Transporters in Perovskite-Sensitized Solid-State Solar Cells
22th International Conference on Science and Technology of Synthetic Metals
2014. June 30 – July 5, Turku, Finland

[4] C. Janáky, K. Rajeshwar, **G. F. Samu**
(Photo)Electrochemically Prepared Organic/Inorganic Hybrid Assemblies for Energy Conversion and Storage
227th ECS Meeting
2015. May 24-28, Chicago, USA