Szakmai záróbeszámoló

Sebők Dániel

„Adszorpciós/adhéziós kölcsönhatások jellemzése polarizációs reflektometria interferencia spektroszkópiával”

c. (PD 116224) kutatásához

Project closing report

Dániel Sebők:

„ Characterization of adsorption/adhesion interactions by polarization reflectometric interference spectroscopy”

(PD 116224)

Szeged, 2019. 09. 30.

NEMZETI KUTATÁSI, FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

UNIVERSITAS SCIENTIARUM SZEGEDIENSIS · SZEGEDI TUDOMÁNYEGYETEM ·

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1. Aims of the project

The main goal of the research *"PD116224-Characterization of adsorption/adhesion interactions by polarization reflectometric interference spectroscopy"* was the development of the previously not demonstrated PRIfS method and its application in molecule adsorption/ nanoparticle adhesion experiments in gas- and aqueous medium.

Its subtasks were 1) the synthesis of the nanoparticles (ZnO, TiO_2, Ag, Ag-TiO_2, Au, Pt etc.) or other nanostructured systems (e.g. hexagonally ordered mesoporous SiO_2); 2) preparing thin films by using this particles and/or different polyelectrolytes (PAA, PSS, PEI etc.) with layer-by-layer or Langmuir-Blodgett methods; 3) testing these thin films and the PRIfS technique in adsorption/adhesion measurements.

The main results will be listed and grouped according to the publications in Chapter 2.

I. Publications closely linked to the project.

Ch. 2.1: Results in the gas phase (Sensor Actuat B Chem, 243: 1205-1213, 2017).

Ch. 2.2: Development of the polarized RIfS method (Photonics, 6: p. 76, 2019).

Ch. 2.3: Results in the aqueous phase (Submitted to Analytical and Bioanalytical Chemistry).

II. Publications partially linked to the project

Ch. 2.4: Several publications were produced during the supported period which are partially related to the original project plan, but the support of NKFIH is indicated. The reasons are the followings:

- *several unexpected technical issues have arisen and the downtime have been utilized to participate in other related ongoing projects (e.g. Surf Coat Tech 326: 316-326, 2017).*
- *the nanostructured systems synthesized related to this project were tested in other cooperating projects (e.g. Journal of Physical Chemistry C 121: (9) 5130-5136, 2017).*
- *measurement techniques related to this project were utilized in other research (e.g. Carbohydrate Polymers 188: pp. 159-167., 2018).*
- *the salary of the PI was provided by NKFIH during the supported period therefore in the publications, which the PI contributed to and were produced in this period, the support of NKFIH is indicated (e.g. Journal of Applied Microbiology 123: pp. 1335-1345., 2017).*

2. Main results of the project (grouped by the publications)

2.1. Adsorption results in the gas phase

The aim of the work in the first period of the 3-year long research was the development and optimization of the application of reflectometric interference spectroscopy in the investigation of adsorption interactions on solid/gas (S/G) interface. Furthermore, the main goal of the first period was the improvement in the room temperature ethanol sensing characteristics of the previously developed reflectometric interference sensor, namely the achievement of the sub-ppm ethanol concentration detection limit (LOD).

According to the objectives adsorption of volatile organic compounds (VOCs) on S/G interface were investigated. The molecules were methanol, ethanol and propanol as alcohols, xylene and toluene as aromatic, and n-hexane as aliphatic hydrocarbons, focusing mainly on ethanol, because the main goal in the first period was the improvement in room temperature ethanol sensing properties of the reflectometric interference device.

A number of nanoparticles, nanostructures and other colloidal units were synthesized, the charge, the size and many structural parameters were characterized by streaming potential measurements, dynamic light scattering (DLS) and X-ray techniques (powder diffraction, small-angle scattering, XRD, SAXS). Several types of hybrid thin films were prepared from the synthesized nanostructures (Fig. 1.): a number of nanoparticle and/or polyelectrolyte and/or mesoporous nanostructure combinations were tested. The mesoporous silica (MPS) containing thin films had outstanding beneficial properties, therefore the further experiments were carried out with these hybrids.

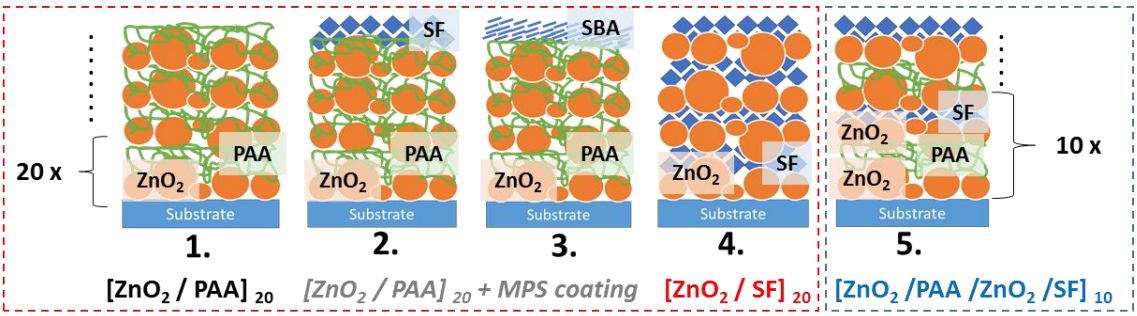

Fig. 1. The schematic view of the prepared and applied hybrid thin films. *(Fig. 2. in publication)*

The refractive index and layer thickness of the films were determined by reflectometric interference spectroscopy (RIfS) and ellipsometry. The previously described analytical method for determining optical parameters was improved by an extreme finding process based on function differentiation.

Zinc-peroxide/poly(acrylic acid) (PAA), zinc-peroxide/mesoporous silica and zinc-peroxide/ polyelectrolyte/mesoporous silica foam hybrid thin films were applied as sensing surfaces in sensorial tests. It was established that sub-ppm (ca. 500 ppb) detection limit can be achieved by using mesoporous component, as well as, linear sensitivity can be obtained when using zinc-peroxide/polyelectrolyte/mesoporous silica foam hybrids.

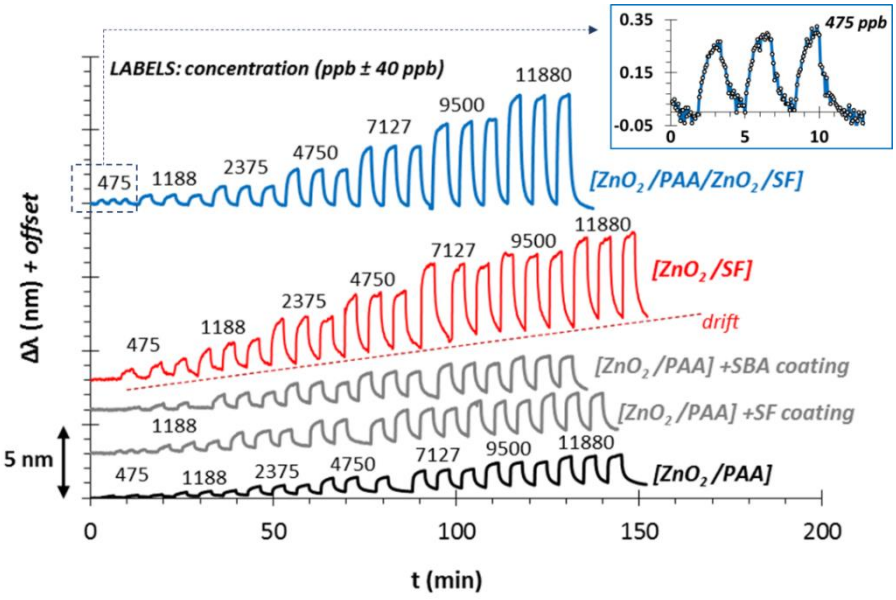

Fig. 2. Ethanol sensing tests: Δλ vs. t curves for the tested thin films (labels: structure of the thin film and the ethanol concentration steps); inset: response of $[ZnO2/PAA/ZnO2/SF]_{10}$ mixed structure for c=475 ppb EtOH *(Fig. 6.a in publication).*

Summarizing it can be established that, according to the first year work plan, a number of nanoparticles, nanostructures were synthesized, by using polyelectrolyte as binding material many hybrid thin films were prepared, which are able to be used as sensing surface of a room temperature ethanol sensor with a sub-ppm detection limit with proper selectivity, response time and reproducibility.

The main result were summarized in an article in a prestigious international journal: *Sebők et al: Room temperature ethanol sensor with sub-ppm detection limit: Improving the optical response by using mesoporous silica foam, Sensors and Actuators B: Chemistry 243 (2017) 1205-1213, doi: 10.1016/j.snb.2016.12.097 (IF: 5.667, Q1, D1).*

Furthermore, the results were presented in an international conferences: Dániel Sebők et al: Low ppm-range reflectometric ethanol sensor at room temperature: improving the optical response by using mesoporous materials, Poster presentation, 7th Szeged International Workshop on Advances in Nanoscience (SIWAN 7), Szeged, Hungary, October 12-15, 2016.

Dániel Sebők et al: Room temperature ethanol sensor with sub-ppm detection limit: improving the optical response by using mesoporous silica foam, Poster presentation, 22nd International Symposium on Analytical and Environmental Problems (ISAEP 22), Szeged, Hungary, October 10, 2016.

** Furthermore, a conference proceeding paper was presented with the same authors and title.*

2.2. Development of the polarized RIfS method

As it was previously mentioned, the main goal of the research was the development of the previously not demonstrated polarized RIfS (PRIfS) method and its application in molecule adsorption/ nanoparticle adhesion experiments in gas- and aqueous medium.

In publication "*Janovák L., Dékány I., Sebők D.: The Theoretical Concept of Polarization Reflectometric Interference Spectroscopy (PRIFS): An Optical Method to Monitor Molecule Adsorption and Nanoparticle Adhesion on the Surface of Thin Films, Photonics, 6: p. 76, 2019, doi: 10.3390/photonics6030076"* the principles, implementation and application (in gas and aqueous phase) of the technique was presented. The journal MDPI Photonics is an open access journal, the views and downloads since 30 June 2019 (in 3 months) are 573 and 498, respectively (30 September, 2019).

In this article we presented the measurement method, i.e. the optical setup (Fig.3.) and the equations of PRIfS, namely the measurement of the ratio of the s- and p-polarized components, by applying a polarizer in the optical setup.

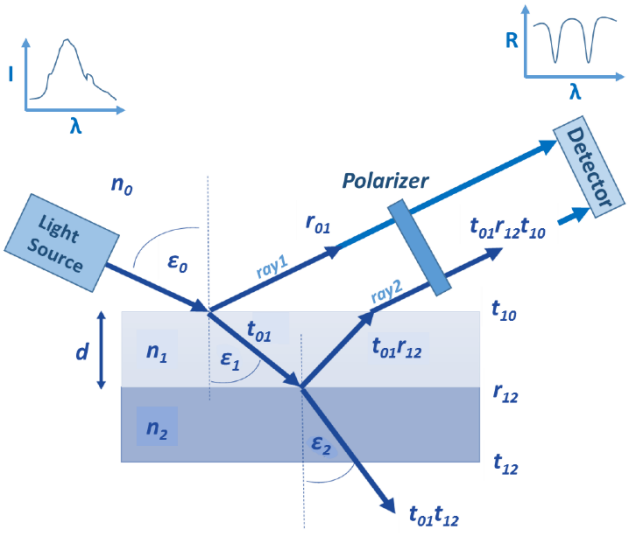

Fig. 3. The schematic diagram of a typical reflectometric interference setup and thin film model for the calculations: n, ε, r and t mark refractive index, refraction angle, reflection and transmission amplitudes (calculated by Fresnel equations), and the indices 0, 1 and 2 represent medium, thin film and substrate, respectively. The curves show the spectrum of the light source and the measured reflectance (which is defined here as the ratio of the s- and p-polarized component) *(Fig. 1. in publication).*

We presented the effect of some explicit and implicit parameters, such as layer thickness, refractive indices of the substrate and the thin film (both in gas and liquid phase), the angle of incidence. Latter is a critical parameter: we observed that there is a transition region around a critical angle, between the low angles and the Brewster angle, where the contrast of the PRIfS curves considerably decreased, but near this domain the efficiency of the technique significantly increased (Fig. 6.).

Simulated model experiments revealed that the sensitivity of the PRIfS method is nearly four times higher (RIfS: 550 nm/RIU, PRIfS: 1825 nm/RIU) in the gas phase, due to the variation

of 0.004 in the sensing layers refractive index, caused by the adsorption/immobilization of test molecules (Fig. 4.).

Similarly, in simulations run in the aqueous phase the difference in was seven-fold: RIfS: 566 nm/RIU, PRIfS: 3966 nm/RIU (Fig. 5.).

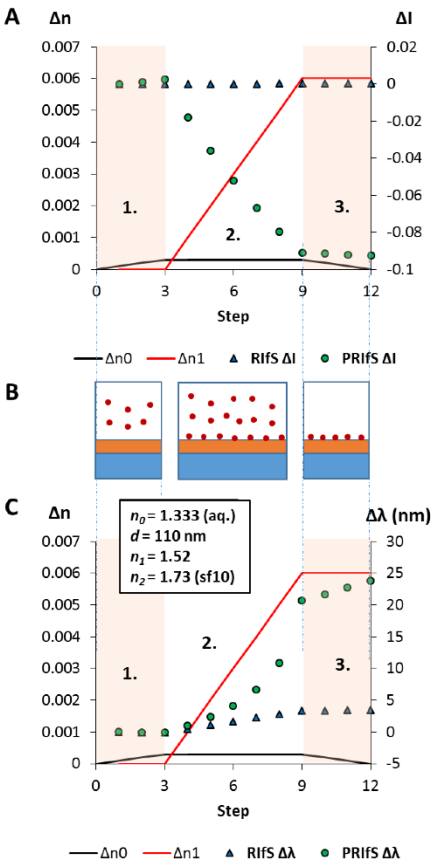

Fig. 4. The results of the simulated model experiment: (A) The ΔI curves for the conventional (RIfS ΔI) and the polarized (PRIfS ΔI) cases due to Δn0 = ± 0.0003 (steps 1. and 3.) or Δn1 = 0.006 (adsorption, step 2.); (B) Schematic drawings of the steps: 1. the dilute solution of the analyte reaches the measurement cell, 2. the immobilization process, 3.rinsing of the measurement cell; (C) The Δλ curves for the conventional (RIfS Δλ) and the polarized (PRIfS Δλ) cases due to Δn0 = ± 0.0003 (ranges 1. and 3.) or Δn1 = 0.006 (adsorption, range 2.).

(Fig. 7. in publication).

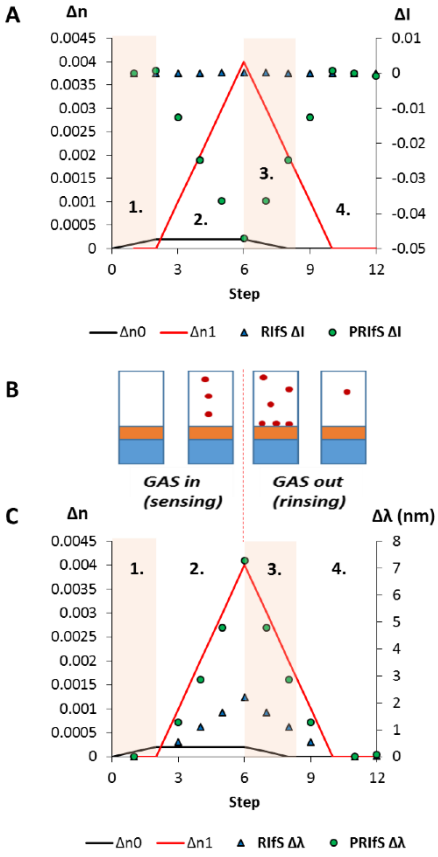

Fig. 5. The results of the simulated model experiment: (A) The ΔI curves for the conventional (RIfS ΔI) and the polarized (PRIfS ΔI) cases due to Δn0 = ±0.0002 (steps 1. and 3.) or Δn1 = ±0.004 (adsorption, step 2.; desorption, step 4.); (B) Schematic drawing of the steps: 1. the tested molecules reach the measurement cell by the carrier gas (e.g., N2) flow; 2. the adsorption process occurs; 3. the measurement cell is rinsed by the pure carrier gas; while 4. the weakly physisorbed test molecules leave the surface and the pores; (C) The Δλ curves for the conventional (RIfS Δλ) and the polarized (PRIfS Δλ) cases due to Δn0 = ±0.0002 (ranges 1. and 3.) or Δn1 = ±0.004 (adsorption, range 2.; desorption, range 4.).

(Fig. 11. in publication).

Considering these values and assuming a spectral resolution of 10^{-3} nm, a sensitivity of 10^{-5}–10^{-6} RIU can be achieved by the polarization reflectometric interference technique, which is comparable with the sensitivity of the spectroscopic ellipsometry and surface plasmon resonance methods.

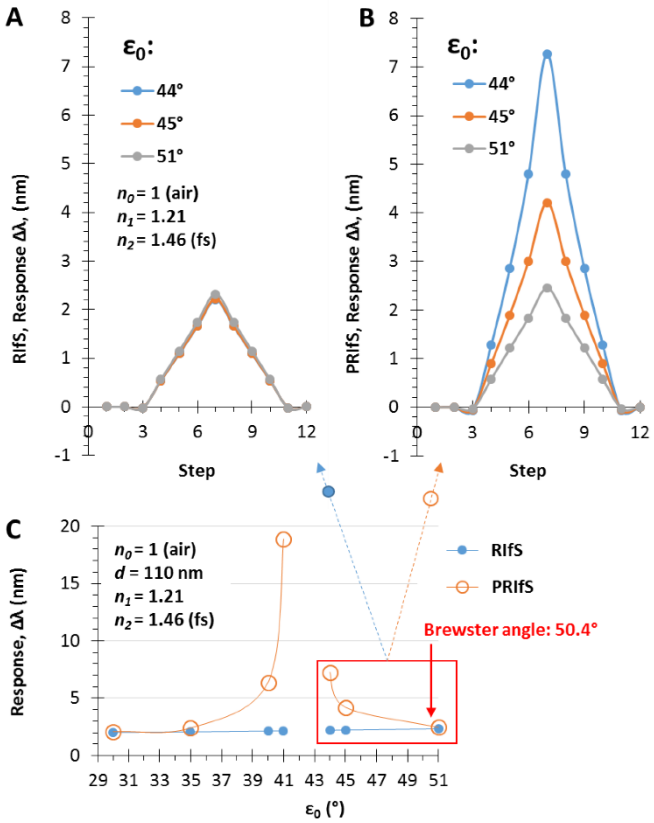

Fig. 6. Δλ sensorgrams of (A) RIfS and (B) PRIfS techniques at different incident angles (ε0 = 44, 45 and 51°), due to Δn1 = ±0.004 refractive index changes (steps #4–9), in the case of a thin film with d = 110 nm and n1 = 1.21 on fused silica substrate, in air; (C) Maximal Δλ responses of RIfS (yellow) and PRIfS (blue) techniques due to Δn0 = 0.0002 and Δn1 = 0.004 refractive index changes as the function of the incident angle ε0. *(Fig. 12. in publication).*

2.3. Results in the aqueous phase

The third main objective of the project was the studying of the nanoparticle adhesion on functionalized surfaces by optical methods, especially by polarized reflectometric interference spectroscopy.

Our group received a very honorable invitation from the journal Analytical and Bioanalytical Chemistry (ABC) in the topic of Direct Optical Detection. The guest editors of this collection are Günter Gauglitz (University of Tübingen, Institute of Physical and Theoretical Chemistry, Tübingen, Germany) and Jiri Homola (Institute of Photonics and Electronics, Czech Academy of Sciences, Praha, Czech Republic), they are the most respected researchers in the field of optical sensing methods (RIfS and SPR). Therefore, we accepted this invitation, the submission deadline is September 30, 2019.

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Tuebingen, 05 July 2019

Direct Optical Detection as a Topical Collection for ABC

Dear Imre,

In the year 2020, the journal Analytical and Bioanalytical Chemistry (ABC) will be publishing a collection of papers for publication in a topical paper collection of 'Analytical and Bioanalytical Chemistry' (ABC) featuring selected contributions focussing on **Direct Optical Detection.** As the Guest Editors of this collection of papers, we are writing to you to invite you to contribute a Research Paper or Communication on your current research activities *OR* a Critical Review on recent developments and likely future Trends in the area of direct optical detection.

Dates:
ABC scheduled publication of the paper collection for **May 15, 2020**. The submission deadline for the contributions has thus been set as **September 30, 2019**. Earlier submissions are encouraged, and papers will be published online within about 20 days after acceptance, fully citable by DOI (Digital Object Identifier) prior to print publication in the special ABC issue featuring this topical collection.
As a special feature, each paper is displayed in an online list on Springerlink showing all published contributions to this topical collection, thus facilitating readers to find each contribution even before the topical paper collection is published in an ABC issue.

Image. 1. The invitation letter to the contribution in Analytical and Bioanalytical Chemistry, Direct Optical Detection.

This paper will contain our results in the characterization of the adhesion of gold nanoparticles by optical methods, such as UV-Vis extinction measurement and PRIfS methods, which are the following:

In this paper, a rapid optical method for characterizing plasmonic (gold) nanoparticle (AuNP) adhesion is presented. Two different ways were used for AuNPs preparation: the well-known Turkevich-method resulted in particles with negative surface charge; for preparing AuNPs with positive surface charge stainless steel was used as reducing agent. The solid surface for the adhesion was provided by a column packed with pristine or surface modified glass beads (GB). The size of the nanoparticles was studied by transmission electron microscopy (TEM) and small-angle X-ray scattering (SAXS), the surface charge of the components was determined by streaming potential measurements. The characterization of the adhesion was performed in a flow-system by UV-Vis spectroscopy. During the adhesion experiments the role of the surface charge, the particle size and the pH were studied, as well as, the adhered amount of gold

nanoparticles and the surface coverage values. The results are verified by polarization reflectometric interference spectroscopy (PRIfS) method: silica nanoparticles with a few hundred (d ~ 450) nanometers were immobilized on the surface of glass substrate by Langmuir-Blodgett method, the surface was modified similar to the 3D (continuous-flow packed column) system, and gold nanoparticles from different pH solutions were adhered during the measurements. These kind of modified surfaces allow the investigation of biomolecule adsorption in the same reflectometric setup.

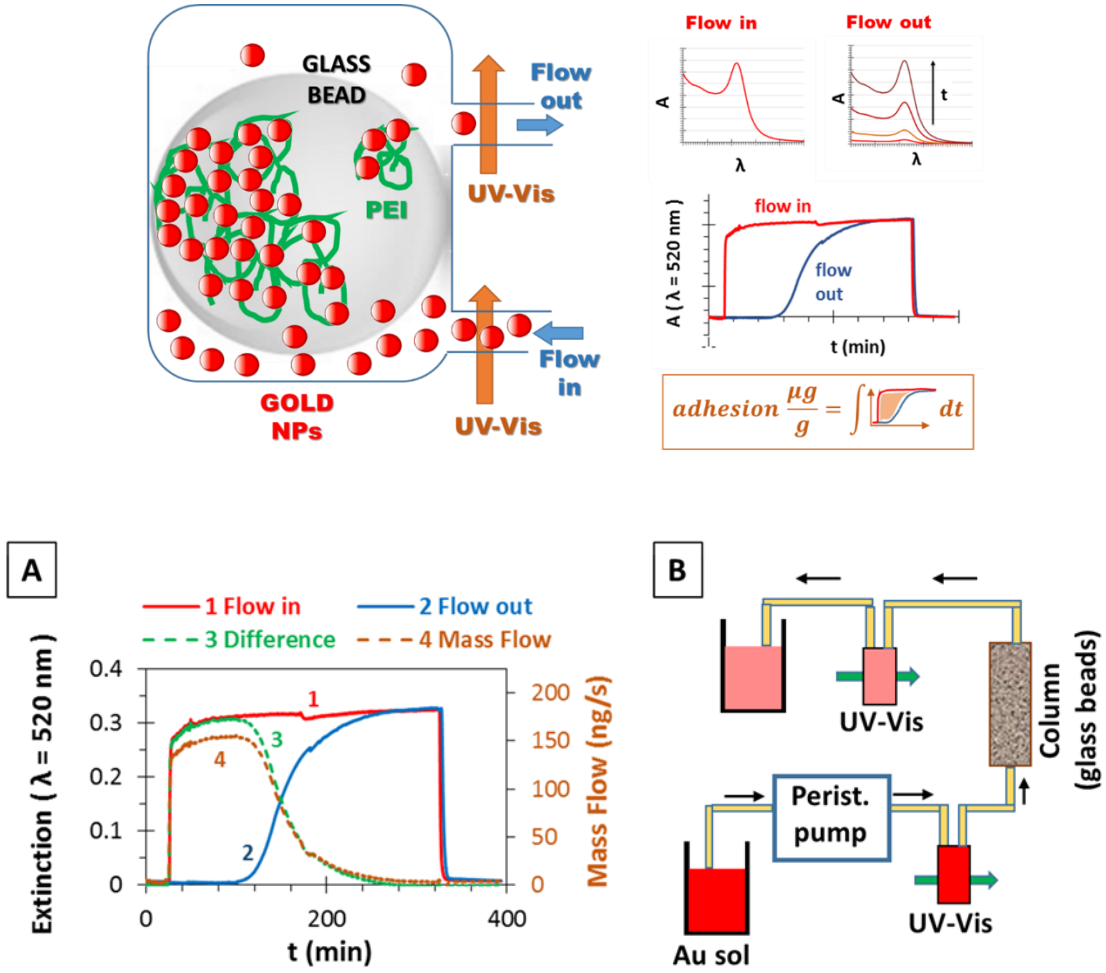

Fig. 7. The graphical abstract of the article (upper); the schematic view of the measurement principle (A) and the setup (B): the determination of the adhered gold nanoparticle amount on the surface of the original and functionalized glass beads is based on the differential measurement of the flow-in and the flow-out extinction/concentration values.

Figure 8. shows the results of the surface charge dependency experiments in the case of AuNP/GB56: -/+, +/-, -/- and +/+ pairs. As expected, both the time and the extent of the adhesion are negligible in the case of the uniformly charged units: the adhered mass of AuNPs is in the few µg/g range, while the adhesion time is less than 15 minutes. Slightly stronger interaction was observed for the AuNP(+)/GB56(-) pair, and a significant adhesion interaction was found between the AuNP(-)s and GB56(+)s. Having regard to the strong attraction between the negatively charged AuNPs and the PEI modified, therefore positively charged GBs, the pH

dependency experiments were carried out by using the GB274(+) glass beads, because they have lower surface energy.

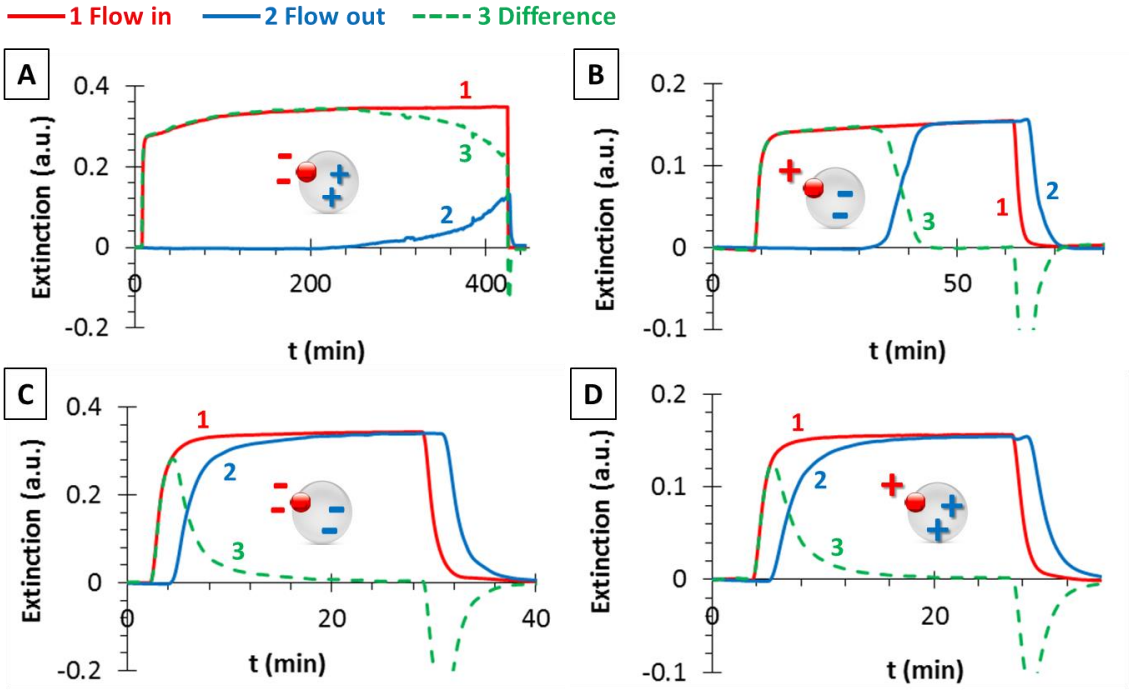

Fig. 8. Investigation the role of the surface charge: (A) negatively charged Au nanoparticles (AuNPs) on the surface of functionalized, positively charged glass beads (GB); (B) interaction of AuNP+ and GB-; (C) interaction of AuNP- and GB-; (D) interaction of AuNP+ and GB+.

For the investigation of the pH dependency of the adhesion process gold sols of 20 mg/ml concentration were used, at different pH levels (pH= 3, 5, 7 and 9) on the larger (GB274) glass beads. A rapid increase in the adhesion time was observed with the decreasing pH, while with increasing the pH the amount of adhered gold greatly decreased, which can be explained by the pendant -NH2 groups of the PEI, which covers the surface of the glass beads becoming increasingly protonated with the decreasing pH, while the –COOH and –COO- groups of the citrates that covers the gold nanoparticles are neutrally or slightly negatively charged (pKA = 2), thus allowing the formation of a strong interaction. Obviously, the increasing pH causes a deprotonation on the –NH2 groups of the PEI, the net positive charges are compensated by the negative surface charges of the glass beads, thus the adhesion interaction weakens. There is also a visually detectable color change of the adhered gold at different pH levels (Fig. 9): at pH = 9 the color barely changes, at pH = 7 and 5 the specific wine red color of the citric gold nanoparticles could be observed, with a deeper color at the lower pH, which indicated the larger amount of adhered gold, while at pH = 3 the color became dark purple, which can be an evidence of the strong aggregation of the particles. The state of the column shows that this process did not saturated even after more than 300 minutes.

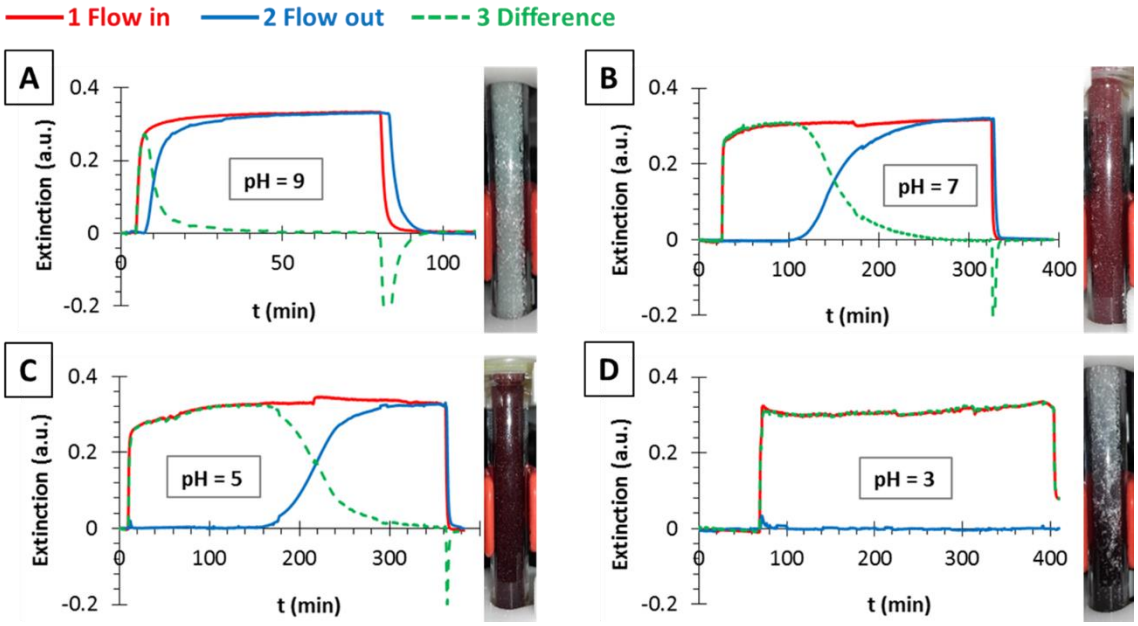

Fig. 9. Investigation the role of the pH of the (AuNP-) gold sol: (A) pH=9; (B) pH=7; (C) pH=5; (D) pH=3. The decreasing pH value causes strongly increasing negative surface charge, therefore strongly increasing adhered amount of AuNPs.

The experiments in the aqueous flow system (bulk, 3D) were verified by polarization reflectometric interference spectroscopy (PRIfS) measurements, with the difference that the surface for the adhesion was not GB, but a thin film formed by d = 450 nm SiO_2 particles. After the preparation of the thin film the surface was modified by PEI by dip-coating technique. Given the fact that this method is based on thin film technique, both the flow rate and the concentration of the AuNP(-) sol were reduced compared to the previously presented flow-system. The flow rate in these experiments was I = 50 µL/min and the concentration of the gold sol was 2 mg/L. Figure 10. shows the results: similarly to the results presented in Ch. "pH dependency", significantly increasing adhered amounts of AuNP(-)s and adhesion process times were observed with the decrease in pH, as expected. The explanation is the same: the decreasing pH causes a protonation on the –NH2 groups of the PEI, thus the adhesion interaction between the protonated –NH3+ groups and the AuNP(-)s intensifies.

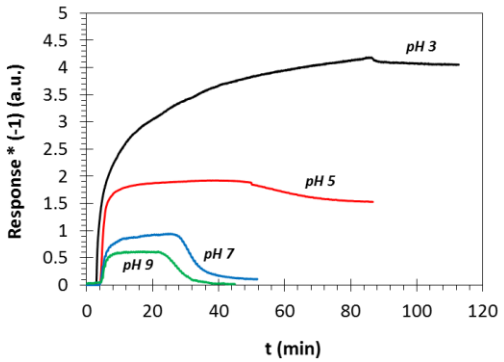

Fig. 10. PRIfS sensorgrams in the case of pH=9,7,5,3 AuNP(-) gold sol on the surface of PEI functionalized SiO_2 nanoparticles (prepared by Langmuir-Blodgett method).

In this work a model experiment of adhesion of gold nanoparticles on glass bead solid surfaces was presented, addressing the effect of the charge state of the components (+/-, -/+, -/-, +/+), the glass bead size (d = 56 and 274 μm) and the pH (= 3, 5, 7 and 9) on the adhesion process in both (static) equilibrium and (dynamic) flow systems. The dynamic measurements were carried out in a liquid-flow platform, which consist of a column containing glass beads as a solid phase, with a concentration detection on both ends, which allows to investigate the adhered amount of gold nanoparticles and the strength of the adhesion. The size of the glass beads seemed to have a significant effect on the amount of adhered gold: with the increasing size the adhered amount decreased, due to the smaller surface energy and charge density of the larger glass beads. The investigation of the effect of charge served the expected results: the interaction between the equally charged component was negligible, while the interaction of the opposing charges was significantly stronger, especially in case of the AuNP(-) and the PEI modified glass beads, due to the protonatable groups of the polymer. A similar effect was observed in case of the pH dependency investigation, where the decrease of the pH resulted in a rapid increase of the protonation of the polyelectrolyte, as well as the adhered amount of gold and the level of aggregation. The result of the static and dynamic investigations were in a good agreement, despite the non-equilibrial nature of the dynamic system, therefore the adhesion of these components seems to be irreversible. During the static measurements a precipitation reaction occurred in case of the gold sol produced by a metal-matrix reduction reaction, which prohibited the measurement of adhesion, however in case of the gold sol reduced and stabilized by citrate and the PEI modified glass beads the adhesion was easily observable and the outcome showed good agreement with the results of the dynamic measurements. In this case the precipitant formation was restrained by the brief interaction of the nanoparticles and the glass beads, which prevented the occurrence of the surface reaction. The results of the 3D measurements were verified by using reflectometric interference technique: both the adhered amount of AuNP(-)s and the adhesion process time were significantly increased with the decrease in pH of the gold sol, because the decreasing pH causes a protonation on the –NH2 groups of the PEI, thus the adhesion interaction between the –NH3+ groups and the AuNP(-)s intensifies.

The results were presented in the annual meeting of the Colloid Chemistry Working Comitee of the Hungarian Academy of Sciences (MTA Kolloidkémiai Munkabizottság) in Budapest, on 20 May 2019, in the form of oral presentation (Sebők Dániel (SZTE): Adhéziós kölcsönhatások jellemzése optikai módszerekkel, különös tekintettel a polarizációs reflektometria interferencia spektroszkópiára).

2.4. Discrepancies

As it was indicated in an earlier report, the investigation of the binary mixtures of organic solvents (toluene, xylene, alcohols etc.) has not been realized because of the insufficient sealing of the measurement cell. The sealing O-ring of the cell for one type of solvent has been swelled from the other type of solvent in the mixtures.

3. Summary and utilization

During the implementation of the research plan several nanostructures were synthesized: semiconductor nanoparticles (ZnO, TiO2), metal nanoparticles (Au, Pt), and mesoporous silica (SiO2) materials with different morphology. The synthesized nanostructures were used mainly for preparing thin films and coatings, which were tested in sensorial and other materials science applications. From these results I would highlight two publications which are closely related to the research plan. Firstly, an optical ethanol sensor operating at room temperature with a sub-ppm detection limit using (ZnO/mesoporous silica) was demonstrated, which has a linear response in the 0.5 to 12 ppm concentration range with a sensitivity of 0.6 nm / ppm (Sebők et al, Sensors and Actuators B 243 (2017) pp. 1205-1213, IF: 5.667, Q1, D1). In another, a previously unpublished measurement principle was presented, namely the polarization reflectometric interference spectroscopy (PRIfS) and its applications for the characterization of adsorption interactions in gas or liquid phase (Sebők et al, Photonics 6 (2019) p. 76, open access, views: 528, downloads: 437, in the last 2 months). A third publication, closely related to the research (characterization of nanoparticle adhesion with an optical sensor) is submitted. Other applications of the synthesized nanostructures that are partially related to the research are presented in another 7 publications.

The cumulative impact factor of the publications is 34,893.

During the implementation of the research plan the principle of the Polarized Reflectometric Interference Spectroscopy (PRIfS) was developed and presented in an international scientific peer-reviewed open access journal (Sebők et al, Photonics 6, 2019, p. 76, doi: 10.3390/photonics6030076). The method is suitable for the characterization of molecule adsorption and/or nanoparticle adhesion in aqueous or gas phase with higher sensitivity than the RIfS technique operating with unpolarized light. The new measurement principle can open new directions for research and can provide new, more accurate results on adsorption/adhesion interactions.

4. Publications in (international) scientific peer-reviewed journals

Publication data	IF	Support of NKFI is indicated
1. Janovák L, Deák Á, Tallósy PS, Sebők D, Csapó E, Bohinc K, Abram A, Palinko I, Dékány I: ***Hydroxyapatite-enhanced structural, photocatalytic and antibacterial properties of photoreactive TiO2/HAp/polyacrylate hybrid thin films***, SURF COAT TECH 326: 316-326, 2017 ***doi: 10.1016/j.surfcoat.2017.07.072***	2.906, Q1	yes
2. Bogdanov A, Janovák L, Lantos I, Endrész V, Sebők D, Szabó T, Dékány I, Deák J, Rázga Z, Burián K, Virok DP: ***Non-Activated Titanium-Dioxide Nanoparticles Promote the Growth of Chlamydia trachomatis and Decrease the Antimicrobial Activity of Silver Nanoparticles***, JOURNAL OF APPLIED MICROBIOLOGY 123: pp. 1335-1345., 2017 ***doi: 10.1111/jam.13560***	2.160, Q2	yes
3. Sápi András, Dobó Dorina G, Sebok Daniel, Halasi Gyula, Juhász Koppány L, Szamosvölgyi Akos, Pusztai Peter, Varga Erika, Kálomista Ildikó, Galbács Gábor, Kukovecz Akos, Kónya Zoltán: ***Silica Based Catalyst Supports Are Inert, Aren't They? – Striking Differences in Ethanol Decomposition Reaction Originated from Meso- & Surface Fine Structure Evidenced by Small Angle X-ray Scattering***, J PHYS CHEM C 121: (9) 5130-5136, 2017 ***doi: 10.1021/acs.jpcc.7b00034***	4.484, Q1	yes
4. Sebők Dániel, Janovák László, Kovács Dániel, Sápi András, Dobó Dorina G, Kukovecz Ákos, Kónya Zoltán, Dékány Imre: ***Room temperature ethanol sensor with sub-ppm detection limit: Improving the optical response by using mesoporous silica foam***, SENSOR ACTUAT B CHEM 243: 1205-1213, 2017 ***doi: 10.1016/j.snb.2016.12.097***	5.667, Q1	yes
5. L Janovák, Á Dernovics, L Mérai, Á Deák, D Sebők, E Csapó, A Varga, I Dékány, C Janáky: ***Microstructuration of poly(3-hexylthiophene) leads to bifunctional superhydrophobic and photoreactive surfaces***, CHEMICAL COMMUNICATIONS 54: (6) pp. 650-653., 2018 ***doi: 10.1039/c7cc07671a***	6.164, Q1	yes
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11. Dániel Sebők et al: Room temperature ethanol sensor with sub-ppm detection limit: improving the optical response by using mesoporous silica foam, Conference Proceeding Paper, 22nd International Symposium on Analytical and Environmental Problems (ISAEP 22), Szeged, Hungary, October 10, 2016.	-	yes
12. Book chapter in "Az MTA Kolloidkémiai munkabizottságának 50 éve: 1966–2016" (50 years of the Committee of Colloid Chemistry of the Hungarian Academy of Sciences: 1966-2016), p.156-157, Sebők Dániel: **Adszorpciós kölcsönhatások jellemzése reflektometria interferencia spektroszkópiával.** https://www.energia.mta.hu/~kolloidmb/files/kotet_teljes.pdf	-	yes
13. Sebők D. et al. : ***Fast optical method for characterizing plasmonic nanoparticle adhesion on functionalized surfaces***, *Submitted to* Analytical and Bioanalytical Chemistry, 2019. 09. 30.	3.286, Q1 *	yes

* *Not yet included in MTMT, but indicates the support of NKFIH and is submitted to a journal.*

5. Presentations

Presentation data	Support of NKFI is indicated
Dániel Sebők et al: Low ppm-range reflectometric ethanol sensor at room temperature: improving the optical response by using mesoporous materials, Poster presentation, 7th Szeged International Workshop on Advances in Nanoscience (SIWAN7), Szeged, Hungary, October 12-15, 2016.	yes
Dániel Sebők et al: Room temperature ethanol sensor with sub-ppm detection limit: improving the optical response by using mesoporous silica foam, Poster presentation, 22nd International Symposium on Analytical and Environmental Problems (ISAEP 22), Szeged, Hungary, October 10, 2016.	yes
Sebők Dániel: Adhéziós kölcsönhatások jellemzése optikai módszerekkel, különös tekintettel a polarizációs reflektometria interferencia spektroszkópiára, Oral presentation, Annual Meeting of the Colloid Chemistry Working Comitee of the Hungarian Academy of Sciences (MTA Kolloidkémiai Munkabizottság), Budapest, Hungary, 20 May 2019.	yes
"Dániel Sebők, László Janovák, Ágota Deak, Dániel Kovács, András Sápi, Imre Dékány, COMPARATIVE STUDY OF ADSORPTION AND SCATTERING TECHNIQUES TO DETERMINE THE SURFACE FRACTAL DIMENSION OF NANOSTRUCTURED MATERIALS, Oral presentation, MaCKiE International Conference on Mathematics in (bio)Chemical Kinetics and Engineering, May 25-27, 2017, Budapest, Hungary"	yes