Doctoral (Ph.D.) theses

Preparation and characterization of metal-oxide coated multi-walled carbon nanotube composites

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1. Introduction, objectives

Since the lecture of Nobel laureate Richard P. Feynman in 1959 nanotechnology has become a dominant factor in the development of mankind. It is not disputed that the results of nanotechnology research essentially defined the last two decades of modern material science. We already come across products manufactured with nanotechnology processes in many areas of life (e.g. electronics, medical technology, medicine).

Carbon nanotubes are one of the protagonists of present and future nanotechnology. After the first reports in the 50's, Iijima's paper in Nature in 1991 was the breakthrough with the discovery of carbon nanotubes. Carbon nanotubes are built of sp^2 hybridized carbon atoms like graphite. We can imagine the structure of carbon nanotubes as a rolled up graphene sheet with few nanometers in diameter. The average lengths of nanotubes are at least in the micrometer range. The diameter of single walled carbon nanotubes are 1-2 nm while the diameter of multi walled carbon nanotubes are mostly a few tens of nanometers. It follows that the aspect ratio is very high, so these materials physically can be considered as one dimensional structures. Due to their extraordinary properties carbon nanotubes are promising candidates in a wide range of applications. Production of carbon nanotube composites with various inorganic oxide coating might also find potential applications.

Composite materials (also called composition materials or shortened to composites) are materials made of two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. Due to the widespread utilization of carbon nanotube based composites in recent years numerous publications and review articles have been published for the preparation of various inorganic layers for both single walled and multi walled carbon nanotubes. As-prepared composites can be used in the field of catalysis, chemical sensors, energy conversion, hydrogen storage, optics and electronics.

Recently the synthesis, characterization and application of carbon nanotubes have been extensively studied at the Department of Applied and Environmental Chemistry at University of Szeged. During my PhD work I have prepared metal oxide covered multi-walled carbon nanotube based nanocomposites using different synthesis techniques. Keeping potential nanotechnology applications in mind my research work covered the investigation of titanium-dioxide and tin-dioxide covered multi-walled carbon nanotubes. The obtained nanocomposites were tested in catalytic and sensor applications.

2. Experimental methods

In the first part of my experimental work TiO_2/MWCNT nanocomposites were prepared by impregnation technique using four different titanium precursors. Experiments were carried out under both solvent and solvent-free conditions. In view of the obtained results $TiBr_4$/MWCNT/EtOH and $TiCl_4$/MWCNT/acetone systems were created again under different conditions in order to investigate the effect of the speed of hydrolysis on the structure of nanocomposite obtained. In the next step the hydrolysis process was studied using desiccators and closed systems. Inside the desiccators different relative humidity (RH) values were adjusted by varying the concentration of sulphuric acid-water mixture. In order to transform the amorphous inorganic coatings on the surface of carbon nanotubes into a crystalline phase samples were heat treated at 400°C or 700°C for 3 hours in each case. Obtained TiO_2/MWCNT nanocomposite was sensitized with Pd nanoparticles and then their catalytic activity was tested in the enantioselective hydrogenation of α,β-unsaturated carboxylic acids.

In the second part of my thesis we have studied the production and possible gas sensor application of SnO_2/MWCNT nanocomposites. One of our main goals was to compare the results of impregnation and hydro-, solvothermal synthesis techniques. During syntheses $SnCl_2 \times 2H_2O$ was used as precursor while ethanol and water were used as solvents. During our researches the effect of change of mass ratio was also examined. The following MWCNT: SnO_2 mass ratios were applied 1:4, 1:8, 1:16, 1:32 and 1:64, respectively. Obtained nanocomposites, which were produced with different preparation methods, were heat treated in order to transform the amorphous inorganic coatings on the surface of carbon nanotubes into a crystalline phase. Heat treatment was performed at 450°C for 3 hours.

Structural and morphological characterization of the nanocomposites was investigated by transmission (TEM) and scanning electron microscopy (SEM). In order to analyze the samples and to detect the presence of the components nanocomposites were examined by energy dispersive X-ray spectroscopy (EDS) technique. Crystal structure of the inorganic layer on the surface of carbon nanotube was identified by X-ray diffraction (XRD). Chemical bond formed between metal-oxide nanoparticles and carbon nanotubes was confirmed by confocal Raman microscopy and Fourier transformed infrared spectroscopy (FT-IR). While N_2 gas adsorption was used to determine of the specific surface area of nanocomposites, the thermal decomposition of samples was studied by thermogravimetric analysis (TG). Products of hydrogenation reactions over Pd/TiO_2/MWCNT catalysts and the ratio of saturated-unsaturated carboxylic acids were identified by gas chromatography equipped with mass selective detector (GC-MSD). A gas chromatograph equipped with a flame ionization detector (GC-FID) was used to investigate the enantioselectivity. Sensor sensitivity of Ru/SnO_2/MWCNT nanocomposites was studied by automated gas sensor measurement setup.

2. Summary of new scientific results

T1. Preparation of TiO_2/MWCNT nanocomposites

1.1. Preliminary results revealed that production of TiO_2/MWCNT nanocomposites were feasible using reactive titanium halides under solvent-free conditions. Electron microscopy images showed relatively uniform homogeneous inorganic layer formed on the surface of the MWCNTs for both of $TiCl_4$ and $TiBr_4$ precursors. However, separated aggregates of TiO_2 nanoparticles were also observed under solvent-free conditions.

1.2. By applying appropriate solvents the amount of segregated TiO_2 particles were successfully reduced in the resulting TiO_2/MWCNT nanocomposites samples. Due to the different polarity of solvents (ethanol, acetone, toluene, dimethylformamide) different quality of inorganic coatings formed since competitive adsorption occurred on the surface of carbon nanotubes. Comparing coated materials, in general it can be concluded that those prepared from $TiBr_4$ precursor produced more homogeneous coverage. Strong interaction between solvent molecules and carbon nanotubes could inhibit the adsorption of precursors in case of titanium-alkoxides. Formation of the inorganic layer, − "nucleation" − is assumed to start at the defect sites of MWCNTs produced by CVD process. Moreover, this is combined with the extraordinary reactivity of $TiBr_4$ and $TiCl_4$. Applying these precursors more homogeneous surface layers were obtained under solvent conditions than using $Ti(OC_3H_7)_4$ and $Ti(OC_2H_5)_4$ precursors.

1.3. In order to investigate the hydrolysis of precursors we applied „slow" and „fast" hydrolysis processes. It was found that the speed of hydrolysis of precursor molecules fundamentally influences the synthesis of TiO_2/MWCNT nanocomposites and the homogeneity of the resulting inorganic layer. Using slow hydrolysis speed it is easier to control the structure of resulting TiO_2 layer and in addition the amount of aggregated inorganic oxide in the samples is reduced significantly .

1.4. In order to control the speed of hydrolysis more precisely, desiccators and different relative humidity values were applied. SEM analysis revealed that relative humidity range of 10-20% was the most favourable for the formation of homogeneous surface layers. With increasing relative humidity the amount of separated inorganic material increased in the sample. Using confocal Raman microscope we could confirm that chemical bond formed between MWCNTs and TiO_2 nanoparticles.

T2. Preparation of SnO_2/MWCNT nanocomposites

2.1. Preparation of SnO_2/MWCNT nanocomposites was carried ot successfully applying both the impregnation and hydro- and solvothermal synthesis methods. From the preparation of nanocomposites with different weight ratios it was concluded that the structure of as-prepared nanocomposite can be controlled easier by using hydro- and solvothermal synthesisindependently from the applied solvent.. Raman and FT-IR measurements confirmed that chemical bond formed between the MWCNTs and SnO_2 nanoparticles.

T3. Application of TiO_2/MWCNT and SnO_2/MWCNT nanocomposites

3.1. TiO_2/MWCNT nanocomposite sensitized by Pd nanoparticles was tested in the enantioselective hydrogenation of α,β-unsaturated carboxylic acids. Based on the results of GC-MS and GC-FID measurements it was confirmed that the initial rate of hydrogenation exhibits good catalytic activity, however, moderate enantioselectivity was observed during the catalytic test reactions over Pd/TiO_2/MWCNT nanocomposites.

3.2. SnO_2/MWCNT nanocomposite samples produced in EtOH by solvothermal method with 1:4 and 1:8 weight ratios were sensitized by Ru nanoparticles fortests in gas sensor applications. Results revealed that obtained nanocomposites are suitable materials principally for the detection of ethanol and methanol. Sensitization with Ru nanoparticles positively influenced the sensitivity of nanocomposites in all cases.

1. Scientific publications

Publications related to the scientific topic of the dissertation

1. Hernádi Klára, **Németh Zoltán**
   A szén nanocsövekről dióhéjban
   Magyar Kémikusok Lapja, 1 (2009) 4-7.

2. Gy. Szőllősi, **Z. Németh,** K. Hernádi, M. Bartók
   Preparation and characterozation of TiO_2 coated multi-walled carbon nanotube-supported Pd and its Catalytic performance in the asymmetric hydrogenation of α,β-unsaturated carboxylic acids
   Catalysis Letters 132 (2009) 370-376.
   IF=2.021

3. **Z. Németh,** C. Dieker, Á. Kukovecz, D. Alexander, L. Forró, J.W. Seo, K. Hernádi
   Preparation of homogeneous titania coating on the surface of MWNT
   Composite Science and Technology 71 (2011) 87-94.
   IF=3.144

4. B. Korbély, **Z. Németh**, B. Réti, JW. Seo, A. Magrez, L. Forró, K. Hernadi
   Fabrication of homogeneous titania/MWNT composite materials
   Materials Researc Bulletin 46 (2011) 1991-1996.
   IF=2.105

5. V.M. Aroutiounian, A.Z. Adamyan, E.A. Khachaturyan, Z.N. Adamyan, K. Hernadi, Z. Pallai, **Z. Nemeth**, L. Forro, A. Magrez, E. Horvath
   Study of surace-ruthenated SnO_2/MWCNTs nanocomposite thick-film gas sensors
   Sensors and Actuators B 177 (2013) 308-315.
   $IF_{(2012)}$=3.535

6. **Z. Németh,** Z. Pállai, B. Réti, Z. Balogh, O. Berkesi, K. Baán, A. Erdőhelyi, E. Horváth, L. Forró, K. Hernádi
   Synthesis and comparative characterization of SnO_2/MWCNT nanocomposite materials
   Submitted

7. **Z. Németh,** E. Horváth, B. Réti, A. Magrez, L. Forró, K. Hernádi
   Preparation of TiO_2 covered MWCNT films by controlled hydrolysis
   In preparation

Other publications

1. D. Fejes, **Z. Németh,** K. Hernádi
CVD synthesis of spiral carbon nanotubes over asymmetric catalytic particles
Reaction Kinetics and Catalysis Letters 96 (2009) 297-404.
IF=0.557

2. **Z. Németh,** B. Réti, C. Dieker, Á. Kukovecz, D.T.L. Alexander, J.W. Seo, L. Forró, K. Hernádi
Preparation of homogeneous titania coatings on the surface of MWNTs
Phys. Status Solidi B, Nos. 11-12 (2010) 2683-2686.
IF=1.344

3. **Z. Németh**, K. Markó, A. Erdőhelyi, L. Forró, K. Hernádi
Controllable synthesis and characterization of alumina/MWNT composites
Phys. Status Solidi B 248, No. 11 (2011) 2480-2483.
IF=1.316

4. K. Németh, **Z. Németh**, D. Fejes, B. Réti, Z. Balogh, K. Hernádi
The effect of alkaline doped catalysts ont he CVD synthesis of carbon nanotubes
Phys. Status Solidi B 248, No. 11 (2011) 2471-2474.
IF=1.316

5. K. Vajda, K. Mogyorósi, **Z. Németh**, K. Hernádi, L. Forró, A. Magrez, A. Dombi
Photocatalytic activity of TiO_2/SWCNT and TiO_2/MWCNT nanocomposites with different carbon nanotube content
Phys. Status Solidi 248, No. 11 (2011) 2496-2499.
IF=1.316

6. K. Hajdú, T. Szabó, M. Magyar, G. Bencsik, **Z. Németh**, K. Nagy, A. Magrez, L. Forró, Gy. Váró, K. Hernádi, L. Nagy
Photosynthetic reaction center protein in nanostructures
Phys. Status Solidi B 248, No. 11 (2011) 2454-2457.
IF=1.316

7. B. Réti, K. Németh, **Z. Németh**, K. Mogyorósi, K. Markó, A. Erdőhelyi, A. Dombi, K. Hernádi
Photocatalytic measurements of TiO_2/MWCNT catalysts having different surface coverage
Phys. Status Solidi B 248, No. 11 (2011) 2475-2479.
IF=1.316

8. K. Hajdu, Cs. Gergely, M. Martin, L. Zimanyi, V. Agarwal, G. Palestino, DS. Leza, K. Hernadi, **Z. Nemeth,** L. Nagy
Porous silicon/photosynthetic reaction center hybrid nanostructure
European Biophisics Journal with Biophysics Letters 40 (2011) 175-176.
IF=2.139

9. K. Hajdu, Cs. Gergely, M. Martin, L. Zimanyi, V. Agarwal, G. Palestino, DS. Leza, K. Hernadi, **Z. Nemeth,** L. Nagy
Light-harvesting biomaterial using porous silicon and photosynthetic reaction center
Nanoscale Researc Letters 7:400 (2012)
IF=2.726

10. K. Hajdu, Cs. Gergely, M. Martin, T. Cloitre, , L. Zimanyi, K. Tenger, P. Khoroshy, G. Palestino, V. Agarwal, K. Hernadi, **Z. Nemeth,** L. Nagy
Porous silicon/photosynthetic reaction center hybrid nanostructure
Langmuir 28 (32) (2012) 11866-11873.
IF=4.187

11. T. Szabo, G. Bencsik, M. Melinda, B. Endrodi, Cs. Visy, Z. Nemeth, K. Hernadi, E. Horvath, A. Magrez, L. Forro, L. Nagy
Charge stabilization by reaction center protein immobilized to carbon nanotubes functionalized by amine groups and poly(3-thiophene acetic acid) conducting polymer
Phys. Status Solidi B 248, No. 11 (2012) 2386-2389.
IF=1.489

12. P. Berki, **Z. Németh**, B. Réti, O. Berkesi, A. Magrez, V. Aroutiounian, L. Forró, K. Hernadi
Preparation and characterization of multiwalled carbon nanotube/In_2O_3 composites
Carbon 60 (2013) 266-272.
IF$_{(2012)}$=5.868

13. V.M. Aroutiounian, V.M. Arakelyan, E.A. Khachaturyan, G.E. Shahnazaryan, M.S. Aleksanyan, L. Forro, A. Magrez, K. Hernadi, **Z. Nemeth**
Manufacturing and investigations of i-butane sensor made of SnO_2/multiwall-carbon nanotube nanocomposite
Sensors and Actuators B 173 (2012) 890-896.
IF=3.535

14. V.M. Arakelyan, M.S. Aleksanyan, R. V. Hovhannisyan, G. E. Shahnazaryan, V.M. Aroutiounian, K. Hernadi, **Z. Nemeth**, L. Forro
Gas sensors made of multiwall carbon nanotubes modified by tin dioxide
Journal of Contemporary Physics 48 (4) (2013) 173-180.
IF$_{(2012)}$=0.250

15. A. Vass, P. Berki, Z. Nemeth, B. Reti, K. Hernadi
Preparation and characterization of multi walled carbon nanotube/WO_3 nanocomposite materials
Phys. Status Solidi B 250, No.12 (2013) 2554-2558.
IF$_{(2012)}$=1.489

Σ_{IF} = 40.969

International conference lectures and posters:

1. S.B. Ötvös, P. Berenji, **Z. Németh**, O. Berkesi
   IR and theoretical investigations of aromatic basic zinc carboxylates, precursors for the most popular MOF-s
   13th International Symposium for Students in Chemistry
   Timisoara, Romania (2008), **oral presentation**

2. **Z. Németh,** K. Hernádi
   Preparation of homogeneous titania coating on the surface of MWNT with $TiBr_4$ and $TiCl_4$ precursors
   Nanolab Workshop Drvengrad, Serbia (2009), **oral presentation**

3. **Z. Németh,** C. Dieker, Á. Kukovecz, D. Alexander, L. Forró, JW. Seo, K. Hernádi
   Preparation of homogeneous TiO_2/MWNT composites by impregnation method
   International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
   Kirchberg, Austria (2010), **poster**

4. **Z. Németh,** C. Dieker, D. Alexander, L. Forró, JW. Seo, K. Hernádi
   Preparation of homogeneous TiO_2/MWNT composites by impregnation method
   9th Conference on Solid State Chemistry (SSC)
   Prague, Czeh Republic (2010), **poster**

5. **Z. Németh,** E. Bartfai, B. Reti, C. Dieker, JW Seo, L. Forro, K. Hernadi
   Preparation of MWNT based composite materials for photocatalysis,
   1thInternational Conference on Composite and Nanocomposites, (ICNC)
   Kottayam, India (2011), **oral presentation**

6. **Z. Németh**, K. Markó, A. Erdőhelyi, L. Forró, K. Hernadi
   Controllable synthesis and characterization of alumina/MWNT composites
   International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
   Kirchberg, Austria (2011), **poster**

7. K. Hajdú, T. Szabó, M. Magyar, G. Bencsik, **Z. Németh**, K. Nagy, A. Magrez, L. Forró, Gy. Váró, K. Hernadi, L. Nagy
   Photosynthetic reaction center protein in nanostructures
   International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
   Kirchberg, Austria (2011), **poster**

8. B. Réti, K. Németh, **Z. Németh**, K. Mogyorósi, K. Markó, A. Erdőhelyi, A. Dombi K. Hernadi
   Photocatalytic measurements of TiO_2/MWCNT catalysts having different surface coverage
   International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
   Kirchberg, Austria (2011), **poster**

9. K. Németh, **Z. Németh**, D. Fejes, Z. Balogh, K. Hernadi
   The effect of alkaline doped catalysts on the CVD synthesis of carbon nanotubes
   International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
   Kirchberg, Austria (2011), **poster**

10. K. Vajda, K. Mogyorósi, **Z. Németh,** L. Forró, K. Hernadi, A. Dombi
Photocatalytic activity of TiO_2/SWCNT and TiO_2/MWCNT nanocomposites with different carbon nanotube content
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2011), **poster**

11. K. Hernadi, **Z. Németh**, E. Bártfai, B. Réti, Z. Pállai, A. Magrez, L. Forró
Fabrication of carbon nanotube based inorganic nanocpmposite materials
EuroNanoForum,
Budapest, Hungary (2011), **poster**

12. K. Hajdú, Cs. Gergely, M. Martin, Z. Zimányi, V. Agarwal, G. Palestino, D. Leza, K. Hernadi, **Z. Németh**, L. Nagy
Porous silicon/photosynthetic reaction center hybrid nanostructure
8^{th} European Biophysics Congress
Budapest, Hungary (2011), **poster**

13. K. Hernadi, **Z. Németh**, A. Magrez, E. Bártfai, Z. Pállai, L. Forró
Controllable fabrication of nanocomposite materials based on multiwalled carbon nanotubes
8^{th} International Conference on Semiconductor Micro and Nanoelectronics (ICSMN)
Yerevan, Armenia (2011), **oral presentation**

14. **Z. Németh**, E. Horváth, A. Magrez, L. Forró, K. Hernadi
Electron microscopy study of TiO_2 covered MWNT films
10^{th} Multinational Congress on Microscopy (MCM)
Urbino, Italy (2011), **poster, poster award**

15. T. Szabó, M. Magyar, **Z. Németh**, K. Hernádi, B. Endrődi, G. Bencsik, E. Horváth, A. Magrez, L. Forró, L. Nagy
Charge stabilization by reaction center protein immobilized to carbon nantubes functionalized by amine groups and poly(3-thiophene acetic acid) conductive polymer
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

16. L. Nagy, K. Hajdu, M. Magyar, **Z. Németh**, E. Horváth, A. Magrez, K. Nagy, Gy.Váró, K. Hernádi, L. Forró
Strategies to link photosynthetic reaction centers to carbon nanotubes for efficient light energy conversion
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

17. K. Hajdu, **Z. Németh**, K. Nagy, Gy. Váró, A. Magrez, E. Horváth, L. Forró, K. Hernádi, L. Nagy
Light energy conversion by photosynthetic reaction center linked specically to carbon nanotubes
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

18. D. Fejes, E. Horváth, D. Carnelli, M. Geuss, A. Karimi, **Z. Németh**, B. Réti, A. Magrez, L. Forró, K. Hernádi
Water assisted CVD synthesis of millimetre-long and aligned coiled carbon nanotube forest
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

19. K. Hernadi, Z. Pallai, **Z. Nemeth**,V.M. Aroutiounian, A.Z. Adamyan, E.A. Khachaturyan, Z.N. Adamyan, A. Magrez, L. Forro
Synthesis and comparative characterization of SnO_2-MWNT nanocomposite materials
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

20. **Z. Nemeth**, E. Bartfai, K. Marko, A. Erdohelyi, A. Magrez, L. Forro, K. Hernadi
Preparation and photocatalytic properties of ZnO/MWNT nanocomposites
International Winterschool on Electronic Properties of Novel Materials, (IWEPNM)
Kirchberg, Austria (2012), **poster**

21. K. Hajdu, Cs. Gergely, M. Martin, L. Zimányi, V. Agarwal, G. Palestino, K. Hernadi, **Z. Németh**, L. Nagy
Light-Harvesting biocomposites using porous silicon and photosynthetic reaction centers
Porous semiconductors – Science and Technology Conference (PSST)
Malaga, Spain (2012), **poster**

22. K. Hernadi, A. Magrez, **Z. Nemeth**, Z. Pallai, P. Berki, L. Forro
Preparation and characterization of MWNT based inorganic nanocomposite materials
E-MRS Spring Meeting
Strasbourg, France (2012), **poster**

23. D. Fejes, E. Horvath, **Z. Nemeth**, A. Magrez, L. Forro, K. Hernadi
Growth and mechanical properties of millimeter long and vertically aligned coiled carbon nanotube forest
E-MRS Spring Meeting
Strasbourg, France (2012), **poster**

24. **Z. Nemeth,** D. Fejes, E. Horvath, A. Magrez, L. Forro, K. Hernadi
Controllable synthesis and characterization of TiO_2 covered MWNT films and carpets
E-MRS Spring Meeting
Strasbourg, France (2012), **poster**

25. V.M. Aroutiounian, V.M. Arakelyan, G.E. Shahnazaryan, E.A. Khachaturyan, M.S. Aleksanyan, L. Forro, A. Margez, K. Hernadi, **Z. Nemeth**
i-Butane sensor made of SnO_2/multiwall-carbon-nanotube nanocomposite
14th International Meeting on Chemical Sensors (IMCS)
Nuremberg, Germany (2012), **poster**

26. V.M. Aroutiounian, A.Z. Adamyan, E.A. Khachaturyan, Z.N. Adamyan, K. Hernadi, Z. Pallai, **Z. Nemeth**, L. Forro, A. Magrez
Methanol and ethanol vapor sensitivity of MWCNT/SnO_2/Ru nanocomposite structures
14th International Meeting on Chemical Sensors (IMCS)
Nuremberg, Germany (2012), **poster**

27. A.Z. Adamyan, Z.N. Adamyan, V.M. Aroutiounian, K. Hernadi, **Z. Nemeth**
Influence of applied voltage and catalyst layer thickness on SnO_2 hydrogen sensor performance
14th International Meeting on Chemical Sensors (IMCS)
Nuremberg, Germany (2012), **poster**

28. V. Aroutiounian**,** V. Arakelyan, G. Shahnazaryan, E. Khachaturyan, M. Aleksanyan, L. Forro, A. Margez, K. Hernadi, **Z. Nemeth,** Z. Pallai
Detection of i-butane by SnO_2/MWCNT sensors
2nd International Conference on Materials and Applications for Sensors and Transducers (IC-MAST)
Budapest, Hungary (2012), **poster**

29. **Z. Nemeth**, P. Berki, A. Magrez, L. Forro, V. Aroutiounian, K. Hernadi
Preparation and comparative characterization of MWNT/In_2O_3 nanocomposite materials
XI International Conference on Nanostructured Materials (NANO 2012)
Rhodes, Greece (2012), **poster**

30. D. Fejes, E. Horváth, M. Geuss, A. Karimi, M. Spina, **Z. Németh**, B. Réti, A. Magrez, L. Forró, K. Hernádi
Catalytic CVD synthesis and elastic properties og millimetre-height coiled carbon nanotube forest
XI International Conference on Nanostructured Materials (NANO 2012)
Rhodes, Greece (2012), **poster**

31. **Z. Nemeth**, E. Horvath, A. Magrez, L. Forro, K. Hernadi
Preparation of TiO_2 covered MWCNT films by controlled hydrolysis
21th annual international conference on composites/nano engineering (ICCE-21)
Tenerife, Canary Islands, Spain (2013), **oral presentation**

32. E.P. Kriván, D. Ungor, Zs. Lukacs, **Z. Nemeth**, Cs. Visy
Synthesis and characterization of nanostructred ZnO-conducting polymer composites for photovoltaic applications
64th Annual Meeting of the International Society of Electrochemistry (ISE)
Santiago de Queretaro, Mexikó (2013), **poster**