Materials Reference List

Quantum Dots

1. Xuan, T.-T.; Liu, J.-Q.; Xie, R.-J.; Li, H.-L.; Sun, Z. Microwave-Assisted Synthesis of CdS/ZnS: Cu Quantum Dots for White Light-Emitting Diodes with High Color Rendition. *Chem. Mater.* **2015**, *27*, 1187–1193. DOI: 10.1021/cm503770w.
   - Professor Hui-Li Li, Engineering Research Center for Nanophotonics & Advanced Instrument, Ministry of Education, Department of Physics, East China Normal University, Shanghai, China
   - Synthesized via a green microwave method
   - Quantum dots absorbed strongly in the blue light region and emitted in the red light region with a maximum quantum yield of 40%

2. Hughes, B.K.; Blackburn, J.L.; Kroupa, D.; Shabaev, A.; Erwin, S.C.; Efros. A.L.; Nozik, A.J.; Luther, J.M.; Beard, M.C. Synthesis and Spectroscopy of PbSe Fused Quantum-Dot Dimers. *J. Am. Chem. Soc*. **2014**, *136*, 4670–4679. DOI: 10.1021/ja413026h.
   - Matthew C. Beard at the National Renewable Energy Laboratory, Chemical and Material Sciences Center, Golden, CO
   - Quantum-dot dimers synthesized in a CEM Discover® S-class microwave
   - Synthesized by oriented attachment of quantum dot monomers
   - Able to correlate dimer splitting with quantum dot monomer size

3. Strauss, V.; Margraf, J.T.; Dolle, C.; Butz, B.; Nacken, T.J.; Walter, J.; Bauer, W.; Peukert, W.; Spiecker, E.; Clark, T.; Guldi, D.M. Carbon Nanodots: Toward a Comprehensive Understanding of their Photoluminescense. *J. Am. Chem. Soc.* **2014**, *136*, 17308–17316.
   DOI: 10.1021/ja510183c.
   - Profesor Dirk M. Guldi, Department of Chemistry and Pharmacy & Interdisciplinary Center for Molecular Materials (ICMM), Friedrich-Alexander-Universitat Erlangen-Nurnberg, Germany
   - Synthesis of carbon nanodots in a microwave reactor
   - Formation of carbon nanodots with consistent optical properties

4. Atkins, T. M.; Thibert, A.; Larsen, D. S.; Dey, S.; Browning, N. D.; Kauzlarich, S. M. Femtosecond Ligand/Core Dynamics of Microwave-Assisted Synthesized Silicon Quantum Dots in Aqueous Solution. *J. Am. Chem. Soc.* **2011**, *133*, 20664–20667.
   DOI: 10.1021/ja207344u.
   - Professors Delmar S. Larsen and Susan M. Kauzlarich, Department of Chemistry, University of California, Davis
   - Researchers synthesized silicon quantum dots (QDs) in as little as 12 minutes under microwave conditions as opposed to conventional syntheses which take days
   - Methodology proved to be efficient and reproducible
   - Si QDs could be tuned to optimize the charge-transfer process, alluding to possible applications in multicomponent systems and optoelectronics

5. Han, H.; Francesco, G. D.; Maye, M. M. Size Control and Photophysical Properties of Quantum Dots Prepared via a Novel Tunable Hydrothermal Route. *J. Phys. Chem. C* **2010**, *114*, 19270–19277. DOI: 10.1021/jp107702b.
   - CdSe core shell dots were synthesized in a Discover® microwave at 60 –180 °C for only two minutes
   - $Cd(ClO_4)_2$, $Me_2NCSeNH_2$, $Zn(ClO_4)_2$, $MeCSNH_2$ were used as core and shell sources with water as the solvent
   - Higher temperatures produced bigger dots with a higher quantum yield. abs from 490 – 580 nm, depending on [Cd]:[Se] ratio
   - Quantum yield drastically improved from shelling

6. Song, A; Ai, X.; Topuria, T.; Rice, P. m.; Alharbi, F. H.; Bagabas, A.; Bahattab, M.; Bass, j. D.; Kim, H-C.; Scott, J. C.; Miller, R. D. Microwave-assisted Synthesis of Monodispersed CdTe nanocrystals. *Chem. Commun.* **2010**, *46*, 4971–4973. DOI: 10.1039/c0cc00576b.
   - Scientist from IBM Almaden Research Center and The National Nanotechnology Center and the Petrochemicals Research Institute in Riyadh Saudi Arabia prepared monodispersed CdTe quantum dots
   - CdO and TeTBP (tributylphosphine) were combined in the presence of tetradecylphosphonic acid in octadecene
   - The contents were heated in a CEM Discover® microwave with 300 W fixed power to temperatures ranging from 180-280 °C for 1-90 min
   - The high quality crystals were monodispersed with a size distribution of less than 5%
   - Tunable emission spectra (516 nm to 650 nm)by varying reaction time and temperature
   - Highly reproducible microwave assisted method for preparing CdTe nanocrystals

7. Li, W.; Li, D.; Zhang, W.; Hu, Y.; He, Y.; Fu, X. Microwave Synthesis of $Zn_xCd_{1-x}S$ Nanorods and Their Photocatalytic Activity under Visible Light. *J. Phys. Chem. C* **2010**, 114, 2154–2159. DOI: 10.1021/jp9066247.
   - Professor Danzhen Li at the Research Institute of Photocatalysis, State Key Laboratory Breeding Base of Photocatalysis, Fuzhou University
   - TEM showed MW method gave a more homogeneous nanorod compared to conventional heating
   - Precursors heated to 140 – 160 °C for only 10 min
   - Nanorods were monodispersed with diameters of 10 nm
   - MW sample had higher surface area and faster conversion of methy orange degradation

8. Schumacher, W.; Nagy, A.; Waldman, W. J.; Dutta, R. K. Direct Synthesis of Aqueous CdSe/ZnS-Based Quantum Dots using Microwave Irradiation. *J. Phys. Chem. C* **2009**, *113*, 12132–12139. DOI: 10.1021/jp901003r.

- Professor Prabir Dutta, Department of Chemistry and Pathology, The Ohio State University
- One-pot synthesis of CdSe/ZnS core/shell quantum dots using readily available and cheap starting material in water
- CdSe nanocrystals from NaHse and Cd-MPA (3-mercaptopropionic acid) were heated in a MARS™ digestion vessel with $Zn(NH_3)_4^{2+}$ solutions at 140 – 170 °C for 45 – 120 min to give 5 nm particles
- MW synthesized QDs at 20 nM were readily detected within the macrophages after 20 min of incubation

9. Washington, A. L.; Strouse, G. F. Microwave Synthetic Route for Highly Emissive TOP/TOP-S Passivated CdS Quantum Dots. *Chem. Mater.* **2009**, *21*, 3586–3592. DOI: 10.1021/cm900624z.

- Professor Geoffrey Strouse, Department of Chemistry and Biochemistry, Florida State University
- Through selective microwave absorption, they demonstrate the ability to activate TOPS as an efficient sulfur donor, allowing the rapid (18 m) growth of highly emissive (PLQY=33%), Zn blended CdS quantum dots (QDs) passivated by TOP/TOPS in the 4-6 nm size regime (5% size dispersity)
- The CdS QDs exhibited sharp absorption features and band edge photoluminescence even for the largest CdS sample
- The use of MW chemistry for QD formation allows a highly reproducible synthetic protocol that is fully adaptable to industrial applications

10. Washington, A. L.; Strouse, G. F. Selective Microwave Absorption by Trioctyl Phosphine Selenide: Does it Play a Role in Producing Multiple Sized Quantum Dots in a Single Reaction? *Chem. Mater.* **2009**, *21*, 2770–2776. DOI: 10.1021/cm900305j.

- Professor Geoffrey Strouse, Department of Chemistry and Biochemistry, Florida State University
- Demonstrate unprecedented control over nucleation, growth, and Ostwald ripening in the formation of CdSe quantum dots (QDs), the quintessential quantum dot
- The selectivity of the MW reactions is demonstrated by the ability to generate multiple, different sized QDs in the same reaction, where each QD component exhibits 6-7% size dispersity
- The number of QDs in solution translates to color saturation (intensity), and the size of the QD translated to color index and is completely controlled by temperature and concentration in the MW reaction
- The ability to repetitively generate nucleation and growth events in which a specific color index with defined color saturation is isolated from a single reaction offers potential for preparing mixed QD compositions for applications in optical barcoding, white light emitting diodes (LEDs), and photovoltaics (PVs)

11. Zheng, W.; Wang, Z.; Wright, J.; Gouldie, B.; Dalal, N. S.; Meulenberg, R. W.; Strouse, G. F. Probing the Local Site Environments in Mn:CdSe Quantum Dots. *J. Phys. Chem. C* **2011**, *115*, 23305–23314. DOI: 10.1021/jp2082215.

- Professor Geoffrey Strouse, Florida State University, Department of Chemistry
- Manganese doping used to probe efficiency of CdSe quantum dot micro-environments
- Quantum dots were synthesized in only 30 s at 220 °C under an increased pressure

12. He, Y. et al. Microwave Synthesis of Water-Dispersed CdTe/CdS/ZnS Core-Shell-Shell Quantum Dots with Excellent Photostability and Biocompatibility. *Adv. Mater.* **2008**, *20*, 3416–3421. DOI: 10.1002/adma.200701166.

- Professor Wei Huang and Lian-Hui Wang at the Institute of Advanced Materials, Nanjing University of Posts and Telecommunication and Laboratory of Advanced Materials, Fudan University
- Synthesized CdTe/CdS/ZnS (this is a QD with a CdTe center, encased in a layer of CdS, followed by an outer layer of ZnS) QDs using MW irradiation
    - CdTe MW, 100 °C, 1 min
    - CdTe/CdS MW, 100 °C, 5 min
    - CdTe/CdS/ZnS, MW, 60 °C, 5 min. Final size of 3.4 – 4.5 nm.
    - Quantum Yield increased drastically from CdTe (30%) to CdTe/CdS/ZnS (80%)
- This was the first example of water dispersed QDs that are made in water -which was assisted by MW irradiation

13. Roy, M. D.; Herzing, A. A.; Lacerda, S. H.; Becker, M. L. Emission-Tunable Microwave Synthesis of Highly Luminescent Water Solube CdSe/ZnS Quantum Dots. *Chem. Commun.* **2008**, 2106–2108. DOI: 10.1039/b800060c.

- Dr. Matthew Becker Polymers Division and Surface and Microanalysis Science Division, National Institute of Standards and Technology
- Water soluble CdSe/ZnS nanoparticles with emission maxima from 511 nm to 596 nm and quantum efficiencies ranging from 11% to 28% were synthesized using MW irradiation
- Particle size controlled by heating times. Reactions were run at lower temperatures (145 – 150 °C) under ambient atmosphere with shorter reaction times when compared to conventional reactions - This approach offered a great deal of control of particle size and particles were very monodispersed

14. Lovingood, D. D.; Strouse, G. F. Microwave Induced In-Situ Active Ion Etching of Growing InP Nanocrystals. *Nano Lett.* **2008**, *8*, 3394–3397. DOI: 10.1021/nl802075j.
    - Professor Geoffrey Strouse, Florida State University, Department of Chemistry
    - Used MW irradiation and fluorinated ionic liquids to etch InP nanoparticles. Conventional procedure required HF. This technique eliminates the need for HF, making it much safer and more practical
    - 280 °C, 300 W, times of 70 s to 20 min

15. Washington, A. L.; Strouse, G. F. Microwave Synthesis of CdSe and CdTe Nanocrystals in Nonabsorbing Alkanes. *J. Am. Chem. Soc.* **2008**, *130*, 8916–8922. DOI: 10.1021/ja711115r.
    - Professor Geoffrey Strouse, Florida State University, Department of Chemistry
    - Synthesis of CdSe and CdTe quantum dots
        - Were found to be temperature, time, and power dependent in the presence of an Ionic Liquid and minohexadecane (strong MW absorbing solvents)
        - Temperature and time dependent in non MW absorbing solvent
    - By varying the reaction temperature, time, power, or a combination of both, Strouse and co-workers were successful in controlling particles size and quantum yields
    - Typical diameters were 2.5 – 5 nm, depending on power, temperature, and time
    - Typical Temperatures were 180 – 280 °C, time ranging from 30 – 600 sec, power 67 – 400 W
    - Higher temperatures and longer reaction times lead to larger particles with lower quantum yields
    - The higher the power the faster the ramp to temperature-which resulted in a higher quality QD
    - Cooling at the end of this reaction played a crucial role in QD size. Slow cooling from the reaction temperature to ambient conditions resulted in larger size dispersity

16. Gerbec, J. A.; Magana, D.; Washington, A.; Strouse G. F. Microwave-Enhanced Reaction Rates for Nanoparticle Synthesis. *J. Am. Chem. Soc.* **2005**, *127*, 15791–15800. DOI: 10.1021/ja052463g.
    - See above reference

17. Firth, A. V.; Tao, Y.; Wang, D.; Ding, J.; Bensebaa, F. Microwave Assisted Synthesis of CdSe Nanocrystals for the Straightforward Integration into Composite Photovoltaic Devices. *J. Mater. Chem.* **2005**, *15*, 4367–4372. DOI: 10.1039/b505891k.
    - Dr. Andrea Firth, National Research Council, Ottawa Canada
    - A preparative route for a nanocrystalline CdSe/polymer nanocomposite was developed with microwave irradiation
    - Microwave assisted synthesis is used to initiate the reaction of relatively safe, inexpensive and air stable precursors
    - Particles size may be varied from 20 A° to 60 A° in diameter. The CdSe nanocrystals show near band-edge photoemission, are crystalline and may be incorporated into a poly(9,9-dioctylfluorene-2,7-diylalt-9-octylcarbazole-3,6-diyl) copolymer
    - Polymer/CdSe composite can be directly cast, without complicated work-up, for the preparation of photovoltaic devices

Inorganic Nanomaterial

18. De Keukeleere, K.; De Roo, J.; Lommens, P.; Martins, J.C.; Van Der Voort, P.; Van Driessche, I. Fast and Tunable Synthesis of ZrO_2 Nanocrystals: Mechanistic Insights into Precursor Dependence. *Inorg. Chem.* **2015**, *54*, 3469–3476. DOI: 10.1021/acs.inorgchem.5b00046.
    - Sol-Gel Centre for Research on Inorganic Powders and Thin Films Synthesis, Ghent University, Belgium
    - 12 fold reduction in reaction time using microwave vs. conventional methods
    - Crystallographic phase can be modified by changing the zirconium starting materials

19. Singh, S.; Hong, S.; Jeon, W.; Lee, D.; Hwang, J.-Y.; Lim, S.; Kwon, G.D.; Pribat, D.; Shin, H.; Kim, S.W.; Baik, S. Graphene-Templated Synthesis of c-Axis Oriented Sb_2Te_3 Nanoplates by the Microwave-Assisted Solvothermal Method. *Chem. Mater.* **2015**, *27*, 2315-2321. DOI: 10.1021/cm502749y.
    - Professor Seunghyun Baik, School of Mechanical Engineering, Sungkyunkwan University, Korea
    - Synthesized by a microwave assisted solvothermal method
    - Analysis revealed a high temperature of graphene relative to the solution during synthesis

20. De Roo, J.; Van den Broeck, F.; De Keukeleere, K.; Martins, J.C.; Van Driessche, I.; Hens, Z. Unravelling the Surface Chemistry of Metal Oxide Nanocrystals, the Role of Acids and Bases. *J. Am. Chem. Soc.* **2014**, *136*, 9650–9657. DOI: 10.1021/ja5032979.
    - Professor Zeger Hens, Physics and Chemistry of Nanostructures (PCN), Ghent University, Belgium
    - Synthesis that took days in an autoclave reduced to 3 hours using microwave
    - Nanocrystals synthesized in benzyl alcohol could be transferred to nonpolar media using a mixture of carboxylic acids and amines resulting in a stable, aggregate-free dispersion

21. Ding, K.; Lu, H.; Zhang, Y.; Snedaker, D.; Liu, D.; Macia-Agullo, J.A.; Stucky, G.D. Microwave Synthesis of Microstructured and Nanostructured Metal Chalcogenides from Elemental Precursors in Phosphonium Ionic Liquids. *J. Am. Chem. Soc.* **2014**, *136*, 15465–15468. DOI: 10.1021/ja508628q.

- Professor Galen Stucky, Department of Chemistry and Biochemistry, University of California, Santa Barbara, California
- Synthesis of micro and nanostructured chalcogenides from their elemental precursors on relatively large scale
- Use of ionic liquids improves solubility and allows for easy separation of the products

22. Zhons, S.; Jing, H.; Li, Y.; Yin, S.; Zeng, C.; Wang, L. Coordination Polymer Submicrospheres: Fast Microwave Synthesis and Their Conversion Under Different Atmospheres. *Inorg. Chem.* **2014**, *53*, 8278–8286. DOI: 10.1021/ic5005769.

- Professor Lei Wang, College of Chemistry and Chemical Engineering, Jiangxi Normal University, China
- Microwave heating of pyridine-2,5-dicarboxylic acid and rare earth nitrates produce coordination polymer submicrospheres
- Prepared in 5 minutes using microwave heating
- Calcination of the coordination polymers under different atmospheres produced materials of varying composition

23. Sivasankara, R.E.; Ramadoss, A.; Nithiyanantham, U.; Anantharaj, S.; Kundu, S. Bio-Molecule Assisted Aggregation of ZnWO4 Nanoparticles (NPs) into Chain-like Assemblies: Material for High Performance Supercapacitor and as Catalyst for Benzyl Alcohol Oxidation. *Inorg. Chem.* **2015**, *54*, 3851-3863. DOI: 10.1021/acs.inorgchem.5b00018.

- Subrata Kundu, Electrochemical Materials Science Division, CSIR-Central Electrochemical Research Institute, India
- $ZnWO_4$ nanoparticles aggregate into chain-like structures on DNA framework under microwave irradiation in under 5 minutes
- Material proved functional as a supercapacitor and catalyst for benzyl alcohol oxidation

24. Mehta, R. J.; Zhang, Y.; Karthik, C.; Singh, B.; Siegel, B.; Borca-Tasciuc, T.; Ramanath, G. A New Class of Doped Nanobulk High-Figure-of-Merit Thermoelectrics by Scalable Bottom-Up Assembly. *Nature Materials* **2012**, *11*, 233–240. DOI: 10.1038/nmat3213.

- Professors Theodorian Borca-Tasciuc and Ganpati Ramanath, Rensselaer Polytechnic Institute
- Researchers synthesize new classes of p- and n-type alloys with ZT>1
- Microwave synthesis of nanoplates complete in only 30-60 s in a CEM Discover®
- Bulk pellets fabricated from the nanoplates exhibited 25-250% higher ZT than their non-structured counterparts

25. Njoki, P. N.; Wu, W.; Lutz, P.; Maye, M. M. Growth Characteristics and Optical Properties of Core/Alloy Nanoparticles Fabricated via the Layer-by-Layer Hydrothermal Route. *Chem. Mater.* **2013**, *25*, 3105-3113. DOI: 10.1021/cm401286w.

- Professor Mathew M. Maye, Department of Chemistry, Syracuse University
- Researchers used a CEM Discover® to rapidly synthesize core/alloy nanoparticles with subnanometer precision
- Microwave heating allowed for precise and reproducible control of particle size

26. Dahal, N.; García, S.; Zhou, J.; Humphrey, S. M. Beneficial Effects of Microwave-Assisted Heating versus Conventional Heating in Noble Metal Nanoparticle Synthesis. *ACS. Nano.* **2012**, *6*, 9433–9446. DOI: 10.1021/nn3038918.

- Professor Simon M. Humphrey, Department of Chemistry and Biochemistry, The University of Texas at Austin
- Thorough study compared conventional and microwave syntheses of Rh, Pd, and Pt nanoparticles by a new one-pot method
- Using a CEM MARS™ in open vessel mode, researchers could add precursors to the reaction solution while taking advantage of microwave heating to improve growth kinetics
- Microwave prepared samples exhibited better monodispersity, more uniform morphology, and higher crystallinity than conventional particles
- Rh nanoparticles synthesized via microwave displayed twice the catalytic activity of conventionally formed particles

27. Muthuswamy, E.; Iskander, A. S.; Amador, M. M.; Kauzlarich, S. M. Facile Synthesis of Germanium Nanoparticles with Size Control: Microwave versus Conventional Heating. *Chem. Mater.* **2012**, *25*, 1416–1422. DOI: 10.1021/cm302229b.

- Professor Susan Kauzlarich, Department of Chemistry, The University of California Davis
- In a CEM Discover® , researchers developed a simple and safe way to synthesize Ge nanoparticles
- Using microwave heating crystalline, monodisperse particles are created from a GeI_2 precursor using oleylamine as surfactant, capping, and reducing agent rather than the conventionally used Na, Li, or F compounds
- When compared to conventional heating methods, the microwave methodology was completed at lower temperatures and in shorter times

28. Kou, J.; Varma, R. S. Beet Juice-Induced Green Fabrication of Plasmonic AgCl/Ag Nanoparticles. *ChemSusChem* **2012**, *5*, 2435–2441. DOI: 10.1002/cssc.201200477.

- Dr. Rajender Varma, National Risk Management Research Laboratory, U.S. Environmental Protection Agency
- Novel approach to nanoparticles uses beet juice as a reducing agent to form AgCl/Ag nanoparticles in less than 5 minutes using a CEM Discover® microwave
- Unique top-down synthesis forms particles smaller than precursors displaying good photocatalytic activity

29. Yersak, T. A.; Macpherson, H. A.; Kim, S. C.; Le, V.-D.; Kang, C. S.; Son, S.-B.; Kim, Y.-H.; Trevey, J. E.; Oh, K. H.; Stoldt, C.; Lee, S.-H. Solid State Enabled Reversible Four Electron Storage. *Adv. Energy Mater.* **2013**, *3*, 120–127. DOI: 10.1002/aenm.201200267.
    - Professor Se-Hee Lee, Department of Mechanical Engineering, University of Colorado at Boulder
    - Pyrite (FeS_2) was synthesized using a CEM Discover® SP
    - The material was incorporated into a novel solid-state battery architecture capable of reversible, four electron storage

30. Park, K.-S.; Xiao, P.; Kim, S.-Y.; Dylla, A.; Choi, Y.-M.; Henkelman, G.; Stevenson, K. J.; Goodenough, J. B. Enhanced Charge-Transfer Kinetics by Anion Surface Modification of $LiFePO_4$. *Chem. Mater.* **2012**, *24*, 3212–3218. DOI: 10.1021/cm301569m.
    - Professor John B. Goodenough, Texas Materials Institute, University of Texas at Austin
    - $LiFePO_4$ was synthesized in only 15 minutes in a CEM MARS™
    - The sample was used to probe the chemical bonding surface features
    - A high barrier for charge transfer results from undercoordinated Fe^{2+}/Fe^{3+}; stabilization by nitrogen or sulfur improves the performance

31. Brancolini, G.; Kokh, D. B.; Calzolai, L.; Wade, R. C.; Corni, S. Docking of Ubiquitin to Gold Nanoparticles. *ACS. Nano.* **2012**, *6*, 9863–9878. DOI: 10.1021/nn303444b.
    - Drs. Giorgia Brancolini and Stefano Corni, Center S3, CNR Institute Nanoscience
    - Gold nanoparticles for this study were synthesized by Turkevich method, using the open vessel feature of the CEM Discover®
    - Ubiquitin binding was studied using ab initio calculations and experimental data to construct a model for nanoparticle/protein interaction

32. Yu, M.; Funke, H. H.; Noble, R. D.; Falconer, J. L. H_2 Separation Using Defect-Free, Inorganic Composite Membranes. *J. Am. Chem. Soc.* **2011**, *133*, 1748–1750. DOI: 10.1021/ja108681n.
    - Professor Miao Yu, Department of Chemical and Biological Engineering, University of Colorado
    - Using a CEM MARS™ with Teflon vessels, SAPO-34 zeolite seed crystals were prepared for membrane synthesis
    - Molecular layer deposition (MLD) was used to deposit a thin, porous layer of alumina upon the zeolite support
    - Composite membranes showed much higher ability to separate H_2 from N_2 and CO_2 than conventional SAPO-34 membranes

33. Truong, T. T.; Liu, Y.; Ren, Y.; Trahey, L.; Sun, Y. Morphological and Crystalline Evolution of Nanostructured MnO_2 and Its Application in LithiumAir Batteries. *ACS Nano*. **2012**, *6*, 8067–8077. DOI: 10.1021/nn302654p.
    - Dr. Yugang Sun, Center for Nanoscale Materials, Argonne National Laboratory
    - Using a CEM Discover® , scientists synthesized a varied of MnO_2 nanostructures with possible applications in batteries
    - Reaction time studies demonstrated the evolution of the nanostructures from nanosheets, to wires, to tubes
    - Further investigation revealed the role of the two-step Ostwald ripening process in the transitions between morphologies

34. Köhler, D.; Heise, M.; Baranov, A. I.; Luo, Y.; Geiger, D.; Ruck, M.; Armbrüster, M. Synthesis of BiRh Nanoplates with Superior Catalytic Performance in the Semihydrogenation of Acetylene. *Chem. Mater.* **2012**, *24*, 1639–1644. DOI: 10.1021/cm300518j.
    - Professor Marc Armbrüster, Max-Planck Institute, Germany
    - BiRh nanoplates were synthesized using a CEM MARS™ with Teflon vessels after 1 hour of heating at 240 °C
    - 60 nm plates show a peculiar plate normal [421] morphology
    - Unsupported BiRh nanoplates displayed excellent selectivity for the semi-hydrogenation of acetylene

35. He, D.; Hu, B.; Yao, Q.-F.; Wang, K.; Yu, S.-H. Large-Scale Synthesis of Flexible Free-Standing SERS Substrates with High Sensitivity: Electrospun PVA Nanofibers Embedded with Controlled Alignment of Silver Nanoparticles. *ACS Nano*. **2009**, *3*, 3993–4002. DOI: 10.1021/nn900812f.
    - Professor Shu-Hong Yu, Division of Nanomaterials & Chemistry, Hefei National Laboratory for Physical Sciences at Microscale, The School of Chemistry & Materials, University of Science and Technology of China
    - Silver nanoparticles were synthesized by microwave irradiation in 10 s at 150 °C
    - Resultant particles were dimerized then incorporated into poly vinyl alcohol polymer, which was electrospun and cast into a film
    - Superior performance as compared to other conventional surface-enhanced Raman scattering (SERS) substrates makes material perfect choice for practical SERS detection

36. Meher, S. K.; Rao, G. R. Effect of Microwave on the Nanowire Morphology, Optical, Magnetic and Pseudocapacitance Behavior of Co_3O_4. *J. Phys. Chem. C.* **2011**, *115*, 25543–25556. DOI: 10.1021/jp209165v.
    - Professor Sumanta Kumar Meher, Department of Chemistry, Indian Institute of Technology Madras
        - Co_3O_4 nanowires were synthesized comparing conventional-reflux and microwave assisted methods
    - Reflux samples required 12 h at 120 °C to reach completion while the microwave nanowires were synthesized in only 15 minutes at the same temperature
    - Lower-dimensional Co_3O_4 nanowires which displayed superior surface properties were created using the conventional method while the higher-dimension order of the microwave nanowires showed better high rate cyclic stability

37. Wong, R. M.; Gilbert, D. A.; Liu, K.; Louie, A. Y. Rapid Size-Controlled Synthesis of Dextran-Coated, ^{64}Cu-Doped Iron Oxide Nanoparticles. *ACS Nano.* **2012**, *6*, 3461–3467. DOI: 10.1021/nn300494k.

- Professor Angelique Y. Louie, Department of Chemistry, University of California, Davis
- Dextran coated, iron oxide nanoparticles were synthesized and doped with Cu or ^{64}Cu
- Microwave synthesis was complete in as little as 5 minutes, using both time and power controls to tune the size of the particles
- Conventional methods normally require 2 hours of heating at reflux, and can often lead to significant decay of radiolabeled products

38. Laera, S.; Ceccone, G.; Rossi, F.; Gilliland, D.; Hussain, R.; Siligardi, G.; Calzolai, L. Measuring Protein Structure and Stability of Protein–Nanoparticle Systems with Synchrotron Radiation Circular Dichroism. *Nano. Lett.* **2011**, *11*, 4480–4484. DOI: 10.1021/nl202909s.

- Dr. Luigi Calzolai, European Commission, Joint Research Centre
- Gold nanoparticles synthesized byTurkevich method in 20 min / silver nanoparticles were synthesized in only 5 min
- Nanoparticles used to probe structural and stability changes to proteins interacting with the particles
- Synchrotron radiation circular dichroism (SRCD) used to acquire experimental data about nanotoxicology for key biological proteins

39. Mehta, R. J.; Zhang, Y.; Zhu, H.; Parker, D.; Belly, M.; Singh, D. J.; Ramprasad, R.; Borca-Tasciuc, T.; Ramanath, G. Seeback and Figure of Merit Enhancement in Nanostructured Antimony Telluride by Antisite Defect Suppression through Sulfur Doping. *ACS Nano.* **2012**, *12*, 4523–4529. DOI: 10.1021/nl301639t.

- Professor Ganpati Ramanath, Rensselaer Polytechnic Institute
- Microwave synthesis was used to create sulfur doped, antimony telluride nanostrutures
- Sulfur doping resulted in a thermoelectric figure of merit (ZT) three times higher than non-doped materials

40. Martineau, C.; Bouchevreau, B.; Tian, Z.; Lohmeier, S.-J.; Behrens, P.; Taulelle, F. Beyond the Limits of X-ray Powder Diffraction: Description of the Nonperiodic Subnetworks in Aluminophosphate-Cloverite by NMR Crystallography. *Chem. Mater.* **2011**, *23*, 4799–4809. DOI: 10.1021/cm2021033.

- Dr. Charlotte Martineau, Tectospin - Institut Lavoisier de Versailles
- Aluminum cloverite compound LUH-2 was synthesized by microwave irradiation at 160 °C for 1 hour
- Nonperiodic subnetworks of the cloverite were characterized using novel NMR crystallography techniques
- Combination of PXRD and NMR crystallography approaches provided insight into the key steps for crystal formation for porous solids

41. Wang, H.-E.; Zheng, L.-X.; Liu, C.-P.; Liu, Y.-K.; Luan, C.-Y.; Cheng, H.; Li, Y. Y.; Martinu, L.; Zapien, J. A.; Bello, I. Rapid Microwave Synthesis of Porous TiO_2 Spheres and Their Applications in Dye-Sensitized Solar Cells. *J. Phys. Chem. C* **2011**, *115*, 10419–10425. DOI: 10.1021/jp2011588.

- Professors Juan Antonio Zapien and Igor Bello, Department of Physics and Materials Science and Center of Super-Diamond and Advanced Films (COSDAF), City University of Hong Kong
- Porous TiO_2 nanospheres constructed in only 10 minutes by microwave synthesis in a CEM Discover®
- Products displayed good morphology and better electrochemical efficiency than commercially available nanopowders

42. Vernon, J. P.; Fang, Y.; Cai, Y.; Sandhage, K. H. Morphology-Preserving Conversion of a 3D Bioorganic Template into a Nanocrystalline Multicomponent Oxide Compound. *Angew. Chem. Int. Ed.* **2010**, *49*, 7765–7768. DOI: 10.1002/anie.201003170.

- Professor Kenneth H. Sandhage, School of Materials Science and Engineering, Georgia Institute of Technology
- A layer -by-layer surface sol-gel process was used to convert the structure of Morpho helenor butterfly wings to $BiTiO_3$ replicas
- CEM MARS™ used for the final step, microwave hydrothermal conversion of anatase TiO_2 to $BaTiO_3$
- The general process can be applied to microscale nanostructured bioorganic or synthetic organic templates

43. Mehta, R. J.; Karthik, C.; Jiang, W.; Singh, B.; Shi, Y.; Siegel, R. W.; Borca-Tasciuc, T.; Ramanath, G. High Electrical Conductivity Antimony Selenide Nanocrystals and Assemblies. *Nano Lett.* **2010**, *10*, 4417–4422. DOI: 10.1021/nl1020848.

- Professor Ganpati Ramanath, Rensselaer Polytechnic Institute, Department of Materials Science and Engineering
- One-dimensional nanocrystals of sulfurized antimony selenide were synthesized in a rapid and scalable manner
- 10^4-10^{10} times higher electrical conductivity than non-nanostructured bulk or thin film forms
- Control of microwave heating times showed changes in wire morphology

44. Cai, R.; Liu, Y.; Gu, S.; Yan, Y. Ambient Pressure Dry-Gel Conversion Method for Zeolite MFI Synthesis Using Ionic Liquid and Microwave Heating. *J. Am. Chem. Soc.* **2010**, *132*, 12776–12777. DOI: 10.1021/ja101649b.

- Professor Yushan Yan, Department of Chemical and Environmental Engineering, University of California Riverside
- CEM MARS™ used to heat dry gel precursor (DGP) in an ionic liquid
- Method combines benefits of ionothermal synthesis, dry-gel conversion, and microwave irradiation to produce MFI zeolite crystals in a fast and efficient manner

45. Geng, J.; Song, G.-H.; Jia, X.-D.; Cheng, F.-F.; Zhu, J.-J. Fast One-Step Synthesis of Biocompatible ZnO/Au Nanocomposites with Hollow Doughnut-Like and Other Controlled Morphologies. *J. Phys. Chem. C* **2012**, *116*, 4517–4525. DOI: 10.1021/jp212092h.

- Professor Jun-Jie Zhu, State Key Laboratory of Analytical Chemistry for Life Science, School of Chemistry and Chemical Engineering, Nanjing University
- ZnO/Au nanocomposites of varied morphology were synthesized by a general procedure in only 30 min
- Researchers concluded that microwave heating resulted in improved crystallinity and uniform size

46. Wang, H. Q.; Nann, T. Monodisperse Upconverting Nanocrystals by MW Assisted Synthesis. *ACS Nano.* **2009**, *3*, 3804–3808. DOI: 10.1021/nn100270n.

- Professor Thomas Nann, School of Chemistry, University of East Anglia, Norwich
- Nanocrystals consisting of different ratios of Na, Er, Y, and Li were synthesized
- A microwave assisted synthesis approach allows for the synthesis of such monodisperse and luminescent upconverting nanocrystals within 5 min in a closed reaction vessel (even though the same reactants and solvents as with classical conductive heating reactions were used)
- Microwave-assisted synthesis resulted in differently sized and shaped particles and provided superior reaction control. The nucleation and growth mechanism follows a La Mer scheme and can be controlled extremely accurately

47. Dai, Q.; Foley, M. E.; Breshike, C. J.; Lita, A.; Strouse, G. F. Ligand Passivated Eu:Y2O3 Nanocrystals as a Phosphor for White Light Emitting Diodes. *J. Am. Chem. Soc.* ***2011**, 133*, 15475–15486 DOI: 10.1021/ja2039419.

- Professor Geoffrey F. Strouse, Department of Chemistry and Biochemistry, Florida State University
- Eu(III) – doped Y_2O_3 nanocrystals were synthesized in only 15 minutes at 240 °C, drastically more efficient than conventional hydrothermal methods (1-12h)
- Excitation of surface passivated acetylacetonate (acac) led to a strong white light emission, competitive with current commercial lighting
- Provides a novel method to use acac as a molecular antenna for efficient energy transfer

48. Gao, F.; Lu, Q.; Meng, X.; Komarneni, S. CdS Nanorod-Based Structures: From Two- and Three-Dimensional Leaves to Flowers. *J. Phys. Chem. C.* **2008**, *112*, 13359–13365. DOI: 10.1021/jp804533z.

- Professor Sridhar Komarneni, Materials Research Institute,The Pennsylvania State University
- Common biomolecule templates (amino acids, peptides, proteins, etc.) used as templates for complex and varied CdS nanorod based structures
- Using a CEM MARS™, reactions were completed at 160 °C in only 1 hour while conventional methods required 15 hours at the same temperature
- Varied 3-D and 2-D morphologies were seen to correspond to the used biomolecules' type and structure

49. Baruwati, B.; Polshettiwar, V.; Varma, R. S. Glutathione Promoted Expeditious Green Synthesis of Silver Nanoparticles in Water using Microwaves. *Green Chem.* **2009**, *11*, 926–930. DOI: 10.1039/b902184a.

- Varma at the EPA developed rapid, green synthesis of Ag, Pt, Pd, and Cu nanoparticles in Glutathione (benign antioxidant)
- Reaction time of 30 – 60 sec at 50 W for Ag, and 45 – 60 sec at 75 W for Pt, Pd, and Cu
- Completed at very low temperatures: 40 – 60 °C. Conventional temperatures > 150 °C
- Monodispersed particles of 5 – 10 nm

50. Anumol, E. A.; Kundu, P.; Deshpande, P. A.; Madras, G.; Ravishankar, N. New Insights into Selective Heterogeneous Nucleation of Metal Nanoparticles on Oxides by Microwave-Assisted Reduction: Rapid Synthesis of High-Activity Supported Catalysts. *ACS Nano.* **2011**, *5*, 8049–8061. DOI: 10.1021/nn202639f.

- Professor Narayanan Ravishankar, Materials Research Centre and Department of Chemical Engineering, Indian Institute of Science
- This paper studies the thermodynamic and kinetic aspects of metal salt reduction to identify optimal conditions for homogeneous metal nucleation using a CEM MARS™
- Metal particles undergo selective nucleation to solid support surfaces using microwave irradiation with a uniform distribution of Pt on CeO_2 and TiO_2 supports
- Microwave synthesized catalysts showed greater reactivity than previously synthesized supported catalysts

51. Bolink, H. J.; Cappelli, L.; Coronado, E.; Grätzel, M.; Nazeeruddin, M. K. Efficient and Stable Solid-State Light-Emitting Electrochemical Cell Using Tris(4,7-diphenyl-1,10-phenanthroline)ruthenium(II) Hexafluorophosphate. *J. Am. Chem. Soc.* **2006**, *128*, 46–47. DOI: 10.1021/ja0565065.

- Professor Henk Bolink, Institute of Molecular Science at the University of Valencia
- The title compound was prepared in a CEM Discover®, in only 5 minutes with a yield of 89% as compared to conventional reactions which can take days and generate <5% desired product
- $Ru(dpp)_3^{+2}$ incorporated into electrochemical cells demonstrating a high power efficiency of 1.9 Lum/W and luminous brightness of 390 cd/m^2

52. Yang, M.; Ding, B.; Lee, S.; Lee, J.-K. Carrier Transport in Dye-Sensitized Solar Cells Using Single Crystalline TiO_2 Nanorods Grown by a Microwave-Assisted Hydrothermal Reaction. *J. Phys. Chem. C.* **2011**, *115*, 14534–14541. DOI: 10.1021/jp2025126.

- Professor Jung-Kun Lee, Department of Mechanical Engineering and Materials Science, University of Pittsburgh
- In a CEM MARS™, microwave heating was used in conjunction with hydrothermal methods to synthesize TiO_2 nanorods
- Combination of methods resulted in longer nanorods in less time (100 minutes) than conventional hydrothermal methods(>20 hours)

53. Bilecka, I.; Elser, P.; Niederberger, M. Kinetic and Thermodynamic Aspects in the Microwave-Assisted Synthesis of ZnO Nanoparticles in Benzyl Alcohol. *ACS Nano.* **2009**, *3*, 467–477. DOI: 10.1021/nn800842b.

- Professor Markus Niederberger- Laboratory for Multifunctional Materials, Department of Materials. ETH Zurich
- Comparison of the microwave mediated route with conventional heating showed that microwave irradiation greatly accelerates nanoparticle formation by:
  - facilitating the dissolution of the precursor in the solvent
  - increasing the rate constants for the esterification reaction by 1 order of magnitude, resulting in faster production of monomer and consequently in an earlier nucleation event
  - increasing the rate constants k growth for the crystal growth from 3.9 nm/min (conventional heating) to 15.4 nm/min (microwave heating)

54. Quan, Z.; Yang, P.; Li, C.; Yand. J.; Yang, D.; Jin. Y.; Lian, H.; Li, H.; Lin, J. Shape and Phase Controlled Synthesis of KMgF Colloidal Nanocrystals via Microwave Irradiation. *J. Phys. Chem. C* **2009**, *113*, 4018–4025. DOI: 10.1021/jp810714k.

- Professor Jun Lin at the State Key Laboratory of Rare Earth Resource Utilization, Changchun Institute of Applied Chemistry, Academy of Sciences in collaboration with Graduate University of the Chinese Academy of Sciences
- One step route to colloidal $KMgF_3$ nanocrystals via thermolysis using MW irradiation
- Shape of nanocrystals readily controlled resulting in the well defined near-spherical nanoparticles and nano-plates of cubic-phased $KMgF_3$ and nanorods of tetragonal-phased MgF_2
- Substrates heated in MW at 100 °C for 10 min under inert atmosphere, then 290 °C for 30 min
- Morphology and size were controlled by changing the heating temperature, time, and by altering the ratio of surfactants

55. Hu, X.; Gong, J.; Zhang, L.; Yu, J. C. Continuous Size Tuning of Monodisperse ZnO Colloidal Nanocrystal Clusters by a Microwave-Polyol Process and Their Application for Humidity Sensing. *Adv. Mater.* **2008**, *20*, 4848–4850. DOI: 10.1002/adma.200801433.

- Dr. Xianluo Hu and Professor Jimmy Yu. Key Laboratory of Pesticide and Chemical Biology of Ministry of Education, College of Chemistry Central China Normal University with the Department of Chemistry, The Chinese University of Hong Kong
- Reaction is run under open vessel conditions - the NP size is directly controlled by the amount of Zn Acetate stock solution added
- Open vessel allows Zn solution to be added during the reaction-this was crucial for monodispersed nanoparticle formation
- Small ZnO nuclei are generated by the rapid MW induced hydrolysis of Zn^{2+} and dehydration of resulting Zn complexes at 180 °C. This is achieved by the polar, and thus strong microwave absorbing, characteristic of Zn and ZnO, creating a super hot surface, speeding up nanocrystal growth

56. Nadagouda, M. N.; Varma, R. S. Microwave Assisted Shape Controlled Bulk Synthesis of Ag and Fe Nanorods in PEG Solutions. *Cryst. Growth Des.* **2008**, *8*, 291–295. DOI: 10.1021/cg070473i.

- Raj Varma at EPA synthesized Ag and Fe nanorods and nanoparticles using MW.
- Also synthesized Ag supported Pt nanocubes
- 100 °C for 1 h. Same conditions with conventional heating yielded no product at all
- Morphology controlled by ratio of solvent (PEG) to metal precursor

57. Hu, B.; Wang, S-B.; Wang, K.; Zhang, M.; Yu, S-Y. Microwave-Assisted Rapid Facile "Green" Synthesis of Uniform Silver Nanoparticles: Self-Assembly into Multilayered Films and Their Optical Properties. *J. Phys. Chem. C* **2008**, *112*, 11169–11174. DOI: 10.1021/jp801267j.

- Professor Yu , Division of Nanomaterials and Chemistry and Hefei National Laboratory for Physical Sciences at Microscale, the School of Chemistry and Materials, University of Science and Technology of China
- Synthesized uniform Ag nanoparticles using water, soluble starch (dextrin) as a protecting agent, and basic amino acids L-lysine and L-arginine as mild, renewable, and nontoxic reducing agents
- The reaction was heated using microwave irradiation to 150 °C and held for 10 s. The authors noted that higher power settings lead smaller nanoparticles. This could be due to faster ramp times, therefore decreasing the total crystal growth time, or that the higher energy could promote he generation of more nuclei
- Using MW irradiation shortened the reaction time by 2-3 orders of magnitude when compared to conventional hydrothermal methods
- Recovered nanoparticles were more uniform in dimension than their conventional partners

58. Suib, S. L. et al. Systematic Control of Particle Size in Rapid Open Vessel Microwave Synthesis of K-OMS-2 Nanofibers. *J. Phys. Chem. C* **2008**, *112*, 6786–6793. DOI: 10.1021/jp800672m.

- Professor Steven Suib, Department of Chemistry and Department of Chemical, Materials and Biomolecular Engineering. University of Connecticut
- Typical reaction conditions using an oil bath require anywhere from hours to days, multiple procedures under hydrothermal and refluxing conditions, and generally have no direct control of nanoparticle size and surface area-which play a crucial role in determining the catalytic properties of the material
- Developed a systematic approach to control particle size by using MW irradiation and varying the amount of co-solvent (DMSO) from 0 – 50% v/v in water
- Microwave irradiation formed nanofibers, ranging from 4 – 12.2 nm. These results could not be duplicated using an oil bath. No ordered nanoparticles were recovered after 90 min of reflux using conventional heating methods and poorly ordered manganese oxide with particle diameter of around 100 nm formed at room temperature. Well-formed needle-like fibers were only formed with the addition of microwave irradiation. The needle diameter was varied by changing the ratio of solvent to co-solvent

59. Jood, P.; Mehta, R. J.; Zhang, Y.; Peleckis, G.; Wang, X.; Siegel, R. W.; Borca-Tasciuc, T.; Dou, S. X.; Ramanath, G. Al-Doped Zinc Oxide Nanocomposites with Enhanced Thermoelectric Properties. *Nano. Lett.* **2011**, *11*, 4337–4342. DOI: 10.1021/nl202439h.

- Professor Ganpati Ramanath, Materials Science and Engineering Department, Rensselaer Nanotechnology Center, Rensselaer Polytechnic Institute
- ZnO nanocrystals doped with aluminum were synthesized using the CEM Discover®
- These crystals display enhanced thermoelectric properties and can be prepared in a rapid and scalable fashion using microwave irradiation
- Pressed and sintered nanocrystals possess a high ZT for possible applications in low-cost waste heat harvesting

60. Mihalcea, I.; Volkringer, C.; Henry, N.; Loiseau, T. Series of Mixed Uranyl–Lanthanide (Ce, Nd) Organic Coordination Polymers with Aromatic Polycarboxylates Linkers. *Inorg. Chem.* **2012**, *51*, 9610–9618 DOI: 10.1021/ic3005757.

- Professor Thierry Loiseau, Unitéde Catalyse et Chimie du Solide (UCCS), Universitéde Lille Nord de France
- A CEM MARS™ was used to synthesize pure phase uranyl-lanthanide organic coordination polymers, while conventional hydrothermal methods led to either irreproducible results or multiple phases, and required more than 10x longer heating times

61. Zhu, j-F.; Zhu, Y-J.; Ma, M-G.; Yan, L-X.; G, L. Simultaneous and Rapid Microwave Synthesis of Polyacrylamide – Metal Sulfide (Ag_2S, Cu_2S, HgS) Nanocomposites. *J. Phys. Chem. C* **2007**, *111*, 3920–3926 DOI: 10.1021/jp0677851.

- Professor Ying-Ji Zhu at the State Key Laboratory of high Performance Ceramics and superfine Microstructures and Shanghai Institute of Ceramics, Chinese Academy of Sciences
- Fast, microwave assisted synthesis of polyacrylamide metal sulfides using metal salt, sulfur powered, and acrylamide monomer
- Heated in ethylene glycol, which acted as solvent and reducing agent. Created low-cost preparation of polymeric metal sulfide nanoparticles without additional need for initiator or surfactant
- Reaction run in open vessel format, samples heated to 125 °C or 190 °C for 15 – 60 min
- Took over 2 h to complete in oil bath
- Overall, variable heating times, temperatures resulted in monodispersed, size control synthesis of metal sulfide nanoparticles

Magnetic Metal Materials

62. Zeng, M.; Laromaine, A.; Feng, W.; Levkin, P.A.; Roig, A. Origami Magnetic Cellulose: Controlled Magnetic Fraction and Patterning of Flexible Bacterial Cellulose. *J. Mat. Chem. C* **2014**, *2*, 6312–6318. DOI: 10.1039/C4TC00787E.

- Anna Laromaine and Anna Roig, Institut de Ciencia de Materials de Barcelona, Campus UAB, Bellaterra, Spain
- Microwave mediated formation of bacterial cellulose nanocomposited with iron oxide in only 5 minutes
- Magnetic Fraction could be controlled by changing the cellulose starting material or iron concentration
- Films with low magnetic fraction were transparent

63. Motte, L.; Milosevic, I.; Jouni, H.; David, C.; Warmont, F.; Bonnin, D. Facile Microwave Process in Water for the Fabrication of Magnetic Nanorods. *J. Phys. Chem. C* **2011**, *115*, 18999–19004. DOI: 10.1021/jp205334v.

- Professor Laurence Motte, Laboratoire CSPBAT, UMR 7244 CNRS/University Paris 13
- A facile microwave method to access magnetic nanorods using dopamine as a shape-control agent
- Structural and magnetic properties can be manipulated by controlling microwave irradiation cycles

64. Yi, D. K.; Lee, S. S.; Ying, J. Y. Synthesis and Applications of Magnetic Nanocomposite Catalysts. *Chem. Mater.* **2006**, *18*, 2459–2461. DOI: 10.1021/cm052885p.

- Dr. Jackie Y. Ying, Institute of Bioengineering and Nanotechnology, Singapore
- Synthesis of Pd coated SiO_2/Fe_2O_3 nanoparticles
- Microwave irradiation allowed synthesis of more uniform and finer palladium particles than conventional methods
- Particles showed dramatically increased catalytic ability over commercial Pd/C

65. Liang, Y.-C.; Hwang, K. C.; Lo, S.-C. Solid-State Microwave-Arcing-Induced Formation and Surface Functionalization of Core/Shell Metal/Carbon Nanoparticles. *Small* **2008**, *4*, 405–409. DOI: 10.1002/smll.200700808.

- Professor Kuo Chu Hwang, Department of Chemistry, National Tsing Hua University
- Silicon pieces and ferrocene powder were arced to form Fe/C nanoparticles which could then be surface functionalized
- Reactions were performed in the solid-state, and without the formation of carbon nanotubes
- Similar nanoparticles could be prepared using Ni or Co metallocenes

66. Amstad, E.; Gillich, T.; Bilecka, I.; Textor, M.; Reimhult E. Ultrastable Iron Oxide Nanoparticle Colloidal Suspensions using Dispersants with Catechol-Derived Anchor Groups. *Nano Lett.* **2009**, *9*, 4042–4048. DOI: 10.1021/nl902212q.

- Professor Erick Reimhult at the Laboratory of Surface Science and Technology and Laboratory for Multifunctional Mateirals, ETH Zurich
- $Fe(ac)_2$ in BnOH were heated for 3 min at 180 °C
- Monodispersed 6 nm Fe_3O_4
- Dispersants later added to stabilize iron oxide in water

67. Taylor, K. M.; Rieter, W. J.; Lin, W. Manganese – Based Nanoscale Metal – Organic Frameworks for Magnetic Resonance Imaging. *J. Am. Chem. Soc.* **2008**, *130*, 14358–14359. DOI: 10.1021/ja803777x.

- Professor Wenbin Lin, Department of Chemistry, University of North Carolina at Chapel Hill
- There was a remarkable difference in the synthesis of Manganese Based Metal Organic Frameworks when microwave irradiation was utilized (CEM MARS™). Spiral nanorods (50 –100 nm x 1000-2000 nm) were obtained under room temperature conditions while three dimensional nanocubes (50 – 300 nm) were synthesized via microwave irradiation
- MW conditions: 120 °C for 10 min, 800 W
- Nanocubes could not be duplicated under conventional conditions

68. Wang W. W.; Zhu, Y. J.; Ruan, M. L. Microwave – Assisted Synthesis and Magnetic Property of Magnetite and Hematite Nanoparticles. *J. Nanopart. Res.* **2007**, *9*, 419–426. DOI: 10.1007/s11051-005-9051-8.

- Professor Ying-Jie Zhu, State Key Laboratory of High Performance Ceramics and Superfine Microstructure and the Chinese Academy of Sciences and Analysis and Testing Center for Inorganic Materials Shanghai Institute of Ceramics
- MW irradiation led to Fe_2O_3 ellipsoid nanocrystals (50 x 100 nm), while conventional heating, under the same conditions, lead to irregular nanorods and particles
- Conditions: 100 °C, 10 min

69. Sreeja, V.; Joy, P.A. Microwave-Hydrothermal Synthesis of Fe_2O_3 Nanoparticles and their Magnetic Properties. *Mater. Res. Bull.* **2007**, *42*, 1570–1576. DOI: 10.1016/j.materresbull.2006.11.014.

- Professor P.A. Joy, Physical and Materials Chemistry Division, National Chemical Laboratory
- It is shown that microwave–hydrothermal method offered a convenient, fast and single step process for the synthesis of nanoparticles of γ-Fe_2O_3
- Nanoparticles of γ-Fe_2O_3 could be synthesized at 150 °C in short time duration of 25 min by the microwave hydrothermal method

70. Nguyen, H. L.; Howard, l. E. M.; Giblin, S. R.; Tanner, B. K.; Terry, I.; Hughes, A. K.; Ross, i. M.; Serres, A.; Burckstummer, H.; Evans, J. S. O. Synthesis of Monodispersed fcc and fct FePt/FePd Nanoparticles by Microwave Irradiation. *J. Mater. Chem.* **2005**, *15*, 5136–5143. DOI: 10.1039/b511850f.

- Professor John Evans, Department of Chemistry, University Science Laboratories, University of Durham, in collaboration with Department of Physics and Department of Electronic and Electrical Engineering
- Monodispersed superparamagnetic fcc FePt and fct FePd nanoparticles were synthesized in short reaction times, 6 – 90 min at high temperatures (150 – 282 °C)
- For maximum power, several of the reactions were run in open vessel format under inert atmosphere at 282 °C

71. Wu, L.; Yao, H.; Hu, B.; Yu, S.-H. Unique Lamellar Sodium/Potassium Iron Oxide Nanosheets: Facile Microwave-Assisted Synthesis and Magnetic and Electrochemical Properties. *Chem. Mater.* **2011**, *23*, 3946–3952. DOI: 10.1021/cm2013736.

- Professor Shu-Hong Yu, Division of Nanomaterials and Chemistry, University of Science and Technology of China
- Lamellar sodium/potassium iron oxide nanosheets and iron oxide nanoparticles were synthesized in only 5 min at high temperature (180 °C)
- Electrochemical properties of sheets have potential applications in lithium-ion batteries
- Facile method allows synthesis of other lamellar metal oxide nanomaterials

72. Katsuki, H.; Komarneni, S. Microwave-Hydrothermal Synthesis of Monodispersed Nanophase α-Fe_2O_3. *J. Am. Ceram. Soc.* **2001**, *84*, 2313–2317. DOI: 10.1111/j.1151-2916.2001.tb01007.x.

- Dr. Hiroaki Katsuki and Professor Sridhar Komarneni at Saga Ceramics Research Laboratory and Materials Research Laboratory and Department of Agronomy, The Pennsylvania State University
- “Red, spherical α-Fe_2O_3 particles, 50–100 nm in diameter, were formed with β-FeOOH crystals after 13 h via the C-H reaction. α-Fe2O3, 100–180 nm in diameter, was preferentially formed after 24 h of treatment.... <u>With the M-H reaction at 100°C, monodispersed α-Fe2O particles, 31 nm in diameter, were formed in 2 h without the formation of β-FeOOH.”</u>

Organic Nanostructures

73. Hirai, K.; Reboul, J.; Morone, N.; Heuser, J.E.; Furukawa, S.; Kitagawa, S.; Diffusion-Coupled Molecular Assembly: Structuring of Coordination Polymers across Multiple Length Scales. *J. Am. Chem. Soc.* **2014**, *136*, 14966–14973. DOI: 10.1021/ja507971r.

- Professor Susumu Kitagawa, Department of Synthetic Chemistry and Biological Chemistry, Graduate School of Engineering, Kyoto University, Katsura, Japan
- Synthesis of a box-type structure through microwave irradiation of porous coordination polymers
- Box structure enhances the kinetics of hydrocarbon separation

74. Hao, D.; Zhang, J.; Lu, H.; Leng, W.; Ge, R.; Dai, X.; Gao, Y. Fabrication of a COF-5 Membrane on a Functionalized a-Al_2O_3 Ceramic Support using Microwave Irradiation Method. *Chem. Commun.* **2014**, *50*, 1462–1464. DOI: 10.1039/C3CC48065H.

- Professor Rile Ge, China Ionic Liquid Laboratory and State Key Laboratory of Catalysis (SKLC), Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China
- COF-5 (Covalent Organic Framework) was linked to an Al_2O_3 ceramic support using 3-aminopropyltriethoxysilane and 4-formylphenylboronic acid
- Modification of COF-5 on the ceramic support was achieved using microwave irradiation

75. Phang, W.J.; Lee, W.R.; Yoo, K.; Ryu, D.W.; Kim, B.; Hong, C.S. pH-Dependent Proton Conducting Behavior in a Metal-Organic Framework Material. *Angew. Chem. Int. Ed.* **2014**, *53*, 8383 – 8387. DOI: 10.1002/anie.201404164.

- Professor Chang Seop Hong, Department of Chemistry, Korea University, Seoul
- MOFs were synthesized in a CEM Discover® microwave
- Soaking the MOFs in solutions of varying pHs changed the proton conductivity, peaking at 2.2 x 10^{-2}at pH 1.8

76. Silva, P.; Vieira, F.; Gomes, A. C.; Ananias, D.; Fernandes, J. A.; Bruno, S. M.; Soares, R.; Valente, A. A.; Rocha, J.; Paz, F. A. A. Thermal Transformation of a Layered Multi-Functional Network into a Metal-Organic Framework based on a Polymeric Organic Linker. *J. Am. Chem. Soc.* **2011**, *133*, 15120–15138. DOI: 10.1021/ja205243w.

- Professor Filipe A. Almeida Paz, Department of Chemistry, CICECO, University of Aveiro
- Layered [La(H3nmp)] was synthesized using both dynamic hydrothermal methods and microwave synthesis
- Conventional reaction required 2 days at 165 °C while microwave reactions completed in only 1 minute at 140 °C
- Further heating above 300 °C converted the layered solid to a three-dimensional metal organic framework (MOF)
- [La(H_3nmp)] MOF was shown to have excellent selectivity and reactivity as a heterogeneous catalyst in epoxide ring opening reactions

77. Merino, E.; Verde-Sesto, E.; Maya, E. M.; Iglesias, M.; Sánchez, F.; Corma, A. Synthesis of Structured Porous Polymers with Acid and Basic Sites and Their Catalytic Application in Cascade-Type Reactions. *Chem. Mater.* **2013**, *25*, 981–988. DOI: 10.1021/cm400123d.

- Professor Avelino Corma, Instituto de Tecnología Química, UPV-CSIC
- Researchers synthesized a porous polymeric aromatic framework (PPAF) through a Pd catalyzed Suzuki coupling
- The (PPAF) was functionalized with acid and base active sites and used as a bifunctional catalyst

78. Zhuang, G.-L.; Chen, W.-X.; Zhao, H.-X.; Kong, X.-J.; Long, L.-S.; Huang, R.-B.; Zheng, L.-S. Two Three-Dimensional 2p–3d–4f Heterometallic Frameworks Featuring a Ln6Cu24Na12 Cluster as a Node. *Inorg. Chem.* **2011**, *50*, 3843–3845. DOI: 10.1021/ic200077r.

- Professors Xiang-Jian Kong and La-Sheng Long, State Key Laboratory of Physical Chemistry of Solid Surface and Department of Chemistry, College of Chemistry and Chemical Engineering, Xiamen University
- Microwave heating used to synthesize two heterometallic metal organic frameworks (MOFs) containing either Gd or Dy
- Nodes of MOF feature rare copper-sodium-lanthanide nanocluster
- Testing of magnetic and electrical properties performed demonstrate ferrimagnetism and proton conductivity respectively

79. Rodrigues, M. O.; Dutra, J. D. L.; Nunes, L. A. O.; de Sá, G. F.; de Azevedo, W. M.; Silva, P.; Paz, F. A. A.; Freire, R. O.; Júnior, S. A. Tb^{3+}→Eu^{3+} Energy Transfer in Mixed-Lanthanide-Organic Frameworks. *J. Phys. Chem C.* **2012**, *116*, 19951–19957. DOI: 10.1021/jp3054789.

- Professors Marcelo O. Rodrigues and Severino A. Júnior, Instituto de Química, Universidade de Brasília
- A Tb/Eu organic framework was synthesized in 10 min using the CEM Discover®
- Experimental and theoretical data from this study contributed to a more complete understanding of Tb→ Eu energy transfer

80. Hettiarachchi, C. A.; Melton, L. D.; Gerrard, J. A.; Loveday, S. M. Formation of β-Lactoglobulin Nanofibrils by Microwave Heating Gives a Peptide Composition Different to Conventional Heating. *Biomacromolecules* **2012**, *13*, 2868–2880. DOI: 10.1021/bm300896r.
    - Professor Laurence D. Melton, Riddet Institute and School of Chemical Sciences, University of Auckland - Researchers performed identical conventional heating and microwave reactions to induce the self-assembly of β-lg nanofibrils
    - After only 2 h, microwave heating furnished yields that required 16 h of conventional heating
    - Microwave synthesized nanofibrils were composed of longer peptides and secondary organization into β-sheets with higher surface hydrophobicity than their conventionally synthesized counterparts

81. Ren, S.; Bojdys, M. J.; Dawson, R.; Laybourn, A.; Khimyak, Y. Z.; Adams, D. J.; Cooper, A. I. Porous, Fluorescent, Covalent Triazine-Based Frameworks Via Room-Temperature and Microwave-Assisted Synthesis. *Adv. Mater.* **2012**, *24*, 2357–2361. DOI: 10.1002/adma.201200751.
    - Professor Andrew Cooper, University of Liverpool, Department of Chemistry and Centre for Materials
    - Using the CEM Discover® with camera accessory, researchers synthesized porous organic polymers (POPs) in 30 min
    - Conventional reaction procedure requires an overnight reaction
    - Materials exhibit BET surfaces exceeding 1100 $m^2 g^{-1}$ and exceptional CO_2 capacities up to 4.17 mmol g^{-1}

82. Liu, Y.-Y.; Couck, S.; Vandichel, M.; Grzywa, M.; Leus, K.; Biswas, S.; Volkmer, D.; Gascon, J.; Kapteijn, F.; Denayer, J. F. M.; Waroquier, M.; Speybroeck, V. V.; Voort, P. V. D. New V^{IV}-Based Metal–Organic Framework Having Framework Flexibility and High CO_2 Adsorption Capacity. *Inorg. Chem.* **2012**, *52*, 113–120. DOI: 10.1021/ic301338a.
    - Professor Pascal Van Der Voort, Center for Ordered Materials, Organometallics and Catalysis, Department of Inorganic and Physical Chemistry, Ghent University
    - Researchers synthesized a vanadium based metal organic framework (MOF) capable of controllable pore deformation at different temperatures
    - The “breathing” effect of pore shape changes predictably alters the sorption behavior towards gases such as CO_2 and CH_4
    - The flexibility of the MOF was dependent on the ratio of V^{III} to V^{IV} found in the framework

83. Chiu, P. L.; Mastrogiovanni, D. D. T.; Wei, D.; Louis, C.; Jeong, M.; Yu, G.; Saad, P.; Flach, C. R.; Mendelsohn, R.; Garfunkel, E.; He, H. Microwave and Nitronium Ion Enabled Rapid and Direct Production of Highly Conductive Low Oxygen Graphene . *J. Am. Chem. Soc.* **2012**, *134*, 5850–5856. DOI: 10.1021/ja210725p.
    - Professor Huixin He, Chemistry Department, Rutgers University
    - Simply method uses nitronium ions generated from 1:1 nitric acid:sulfuric acid and microwave irradiation to produce large, highly conductive graphene sheets from graphite powder
    - Sheets are produced in only 30 seconds in the microwave, while conventional methods result in over oxidation to graphene oxide
    - Dispersions are clean and well separated as opposed to established Hummer’s method

84. Rifai, S.; Breen, C. A.; Solis, D. J.; Swager, T. M. Facile in Situ Silver Nanoparticle Formation in Insulating Porous Polymer Matrices. *Chem. Mater.* **2006**, *18*, 21–25. DOI: 10.1021/cm0511419.
    - Professor Timothy M. Swager, Department of Chemistry, Massachusetts Institute of Technology
    - Silver/poly(aryl ether) (PAE) nanoparticles were synthesized using varied microwave pulses
    - Resultant structures showed good uniformity and could be synthesized in as quickly as 5 minutes
    - Ag/PAE particles were then incorporated into an insulating polymer matrix resulting in a “relatively uniform polymer-ion thin film”

85. Wang, X.; Xia, T.; Ntim, S. A.; Ji, Z.; Meng, H.; Zhang, H.; Castranova, V.; Mitra, S.; Nel, A. E. Quantitative Techniques for Assessing and Controlling the Dispersion and Biological Effects of Multiwalled Carbon Nanotubes in Mammalian Tissue Culture Cells. *ACS Nano* **2010**, *4*, 7241–7252. DOI: 10.1021/nn102112b.
    - Professor Andre E. Nel , Division of NanoMedicine, Department of Medicine, and California NanoSystems Institute, UCLA
    - CEM MARS™ used for purification and functionalization of multiwalled carbon nanotubes (MWCNT)
    - Modified nanotubes used to assay dispersion of MWCNT in tissue culture media
    - It was determined that hydrophobicity is the major factor determining agglomeration

86. Dössel, L.; Gherghel, L.; Feng, X.; Müllen, K. Graphene Nanoribbons by Chemists: Nanometer-Sized, Soluble, and Defect-Free. *Angew. Chem. Int. Ed.* **2011**, *50*, 2540–2543. DOI: 10.1002/anie.201006593.
    - Professor Klaus Müllen, Max-Planck-Institut für Polymerforschung
    - Researchers detail a bottom-up organic synthesis of defect-free graphene nanoribbons
    - Microwave irradiation was used to construct polymer precursors which were efficiently converted to graphene nanoribbons by an intramolecular Scholl reaction

87. Centrone, A.; Yang, Y.; Speakman, S.; Bromberg, L.; Rutledge, G. C.; Hatton, T. A. Growth of Metal – Organic Frameworks on Polymer Surfaces. *J. Am. Chem. Soc.* **2010**, *132*, 15687–15691 DOI: 10.1021/ja106381x.

- Scientist at MIT synthesized metal organic frameworks (MOFs) directly on polyacrylonitrile using microwave irradiation
- Growth of MOF was studied by varying microwave irradiation time
- Reagents were heated in DI water to 200 °C for 5 s to 30 min
- MOF agglomerates formed on the polymer after just 5 s of MW irradiation. The MOFs were only found on the polymer and not in the bulk solution
- Provides rapid, reproducible method to coat polymer fibers with MOFs

88. Lhoste, J.; Rocquefelte, X.; Adil, K.; Dessapt, R.; Jobic, S.; Leblanc, M.; Maisonneuve, V.; Bujoli-Doeuff, M. A New Organic–Inorganic Hybrid Oxyfluorotitanate $[Hgua]_2 \cdot (Ti_5O_5F_{12})$ as a Transparent UV Filter. *Inorg. Chem.* **2011**, *50*, 5671–5678. DOI: 10.1021/ic200407h.

- Prof. V. Maisonneuve and Dr. M. Bujoli-Doeuff, Faculté des Sciences et Techniques, Université du Maine and IMN, France
- A unique UV absorber with the structure $[Hgua]_2 \cdot (Ti_5O_5F_{12})$ was synthesized using microwave hydrothermal synthesis
- Heating materials in a CEM MARS™ with Teflon vessels to 190 °C for 1 hour generated the desired product efficiently
- Investigations of the atomic, optical, and electrical properties show that this hybrid may have unique applications for UV shielding

89. Centrone, A.; Harada, T.; Speakman, S.; Hatton, T. A. Facile Synthesis of Vanadium Metal – Organic Frameworks and their Magnetic Properties. *Small* **2010**, *15*, 1598–1602 DOI: 10.1002/smll.201000773.

- Scientist at MIT presented a microwave synthesis of MIL-47 and 6 new vanadium MOF's
- Precursors were heated to 200 °C for only 10 min
- Represents a very fast and reproducible method for MOF's

90. Blackburn, J. L; Engtrakul, C.; Bult, J. B.; Hurst, K.; Zhao, Y.; Xu, Q.; Parilla, P. A.; Simpson, L. J.; Rocha, J.-D. R.; Hudson, M. R.; Brown, C. M.; Gennett, T. Spectroscopic Identification of Hydrogen Spillover Species in Ruthenium-Modified High Surface Area Carbons by Diffuse Reflectance Infrared Fourier Transform Spectroscopy. *J. Phys. Chem. C.* **2012**, *116*, 26744–26755. DOI: 10.1021/jp305235p.

- Doctor Jeffrey Blackburn, National Renewable Energy Laboratory, Colorado
- Only two minutes of microwave irradiation at 250 W were required to deposit Ru nanoparticles on a high surface area carbon monolith
- Ru decorated carbon and spectroscopic methods were used experimentally confirm hydrogen spillover phenomena responsible for reversible hydrogen storage in fuel cells

91. McDonald, T. M.; Lee, W. R.; Mason, J. A.; Wiers, B. M.; Hong, C. S.; Long, J. R. Capture of Carbon Dioxide from Air and Flue Gas in the Alkylamine-Appended Metal–Organic Framework mmen-Mg_2(dobpdc). *J. Am. Chem. Soc.* **2012**, *134*, 7056–7065. DOI: 10.1021/ja300034j.

- Professor Jeffrey Long, Department of Chemistry, University of California, Berkeley
- Researchers created two new Zn and Mg metal organic frameworks (MOFs) using a combination of solvothermal and microwave assisted methods, related to MOF-74
- The microwave synthesis of $Mg_2(dobpdc)(DEF)_2 \cdot DEF_{1.5} \cdot H_2O$ (DEF-2) was complete in only 30 minutes
- DEF-2 was functionalized with N,N'-dimethylethylenediamine to afford a material with exceptional CO_2 capture properties

92. Economopoulos, S. P.; Pagona, G.; Yudasaka, M.; Iijima, S.; Tagmatarchis, N. Solvent-free Microwave-Assisted Bingel Reaction in Carbon Nanohorns. *J. Mater. Chem.* **2009**, *19*, 7326–7331. DOI: 10.1039/b910947a.

- Dr. Nikos Tagmatarchis at the Theoretical and Physical Chemistry Institute- National Hellenic Research Foundation (Athens, Greece) and in collaboration with the Nanotube Research Center, National Institute of Advanced Industrial Science and Technology(Higashi, Japan) and NEC Corporation(Ibaraki, Japan)
- Functionalized carbon nano-horns with fluorescent linkers through Bingel reaction without solvent
- MW irradiation provided a high degree of functionalization
- Pulse method: 5 – 45 second of MW irradiation was used. Total reaction time of 5 min with a max temp of 120 – 140 °C
- Conventional synthesis: 60 °C for 20 h

93. Fujita, D.; Takahashi, A.; Sato, S.; Fujita, M. Self-Assembly of Pt(II) Spherical Complexes via Temporary Labilization of the Metal–Ligand Association in 2,2,2-Trifluoroethanol. *J. Am. Chem. Soc.* **2011**, *133*, 13317–13319. DOI: 10.1021/ja2059236.

- Professor Makoto Fujita, Department of Applied Chemistry, School of Engineering, The University of Tokyo, and CREST, Japan Science and Technology Agency
- Researchers used solvent conditions and metal ion selection to control geometry and self-assembly of spherical complexes
- Previous syntheses of complexes required 4h or more of reaction time under conventional conditions; microwave reactions complete in 30 minutes or less

94. Wang, Y.; Su, F.; Lee, J. Y.; Zhao, X. S. Crystalline Carbon Hollow Spheres, Crystalline Carbon–SnO_2 Hollow Spheres, and Crystalline SnO_2 Hollow Spheres: Synthesis and Performance in Reversible Li-Ion Storage. *Chem. Mater.* **2006**, *18*, 1347–1353. DOI: 10.1021/cm052219o.

- Professor Jim Yang Lee, Department of Chemical and Biomolecular Engineering, National University of Singapore
- SnO_2 nanoparticles prepared with microwave heating showed uniform dispersion and no agglomeration on carbon hollow sphere surface as compared to conventional heating methods
- Microwave synthesis completed in only 3 minutes; conventional heating required 3 hours
- Electrochemical testing of different products demonstrated potential applications of tin composite nanostructures in Li-ion storage

95. Sun, C.-L.; Chang, C.-T.; Lee, H.-H.; Zhou, J.; Wang, J.; Sham, T.-K.; Pong, W.-F. Microwave-Assisted Synthesis of a Core–Shell MWCNT/GONR Heterostructure for the Electrochemical Detection of Ascorbic Acid, Dopamine, and Uric Acid. *ACS Nano* **2011**, *5*, 7788–7795. DOI: 10.1021/nn2015908.

- Professor Chia-Liang Sun, Department of Chemical and Materials Engineering, Chang Gung University
- Microwave irradiation used to “unzip” multiwalled carbon nanotubes (MWCNTs) upon treatment with strong acids and $KMnO_4$, forming graphene oxide nanoribbons
- Reactions were completed in only 6 minutes, much shorter than previously reported literature examples
- Composite core-shell MWCNT/GONR materials exhibited electrochemical properties exceeding the efficiency of MWCNTs and graphene alone

96. Campbell, N. L.; Clowes, R.; Ritchie, L. K.; Cooper, A. I. Rapid Microwave Synthesis and Purification of Porous Covalent Organic Frameworks. *Chem. Mater.* **2009**, *21*, 204–206. DOI: 10.1021/cm802981m.

- Professor Andrew Cooper at University of Liverpool – Dept of Chemistry and materials discovery
- MW irradiation offered a convenient and rapid synthesis of covalent organic frameworks.
- 200 times faster than conventional methods
- Reactions were run in closed vessel and open vessel format at 100 °C, 200W
- Reaction times as low as 20 min
- COFs had surface area equal to or greater than conventional made COF’s and synthesized 200 times faster

97. Economopoulos, S. P.; Rotas, G.; Miyata, Y.; Shinohara, H.; Tagmatarchis, N. Exfoliation and Chemical Modification Using Microwave Irradiation Affording Highly Functionalized Graphene. *ACS Nano* **2010**, *4*, 7499–7507. DOI: 10.1021/nn101735e.

- Dr.Nikos Tagmatarchis, Theoretical and Physical Chemistry Institute, National Hellenic Research Foundation
- Used MW to multi-functionalize graphene
- Series of electrochemical, spectroscopic, gravimetric, and thermal experiments performed to fully characterize new material

98. Brunetti, F. G.; Herrero, M. A.; Munoz, J. M.; Diaz-Ortiz, A.; Alfonsi, J.; Meneghetti, M.; Prot, M.; Vazquez, E. Microwave-Induced Multiple Functionalization of Carbon Nanotubes. *J. Am. Chem. Soc.* **2008**, *130*, 8094–8100. DOI: 10.1021/ja801971k.

- Professor Maurizio Prato and Professor Ester Vazquez. Universita degli Studi di Trieste and Universidad de Castilla-La Mancha
- Used MW to multi-functionalize CNTs
- Conventional conditions generally require high temperatures and/or pressures, long reaction times, and organic solvents or mineral acids
- MW reduced amount of organic waste, and reduced the reaction time from 5 days to 2.5 hours
- Typical temperatures for [3+2] cycloaddition step was 160 °C for 90 min (100 W), and no solvent, the reaction was done under neat conditions. Arene addition step: 80 °C, 90 min (100 W) and in water

99. Brunetti, F. G.; Herrero, M. A.; Munoz, J. M.; Giordani, S.; Diaz-Ortiz, A.; Filppone, S.; Ruaro, G.; Meneghetti, M.; Prot, M.; Vazquez, E. Reversible Microwave-Assisted Cycloaddition of Aziridines to Carbon Nanotubes. *J. Am. Chem. Soc.* **2007**, *129*, 14580–14581. DOI: 10.1021/ja077927k.

- See previous reference

100. Jin, Y.; Voss, B. A.; McCaffrey, R.; Baggett, C. T.; Noble, R. D.; Zhang, W. Microwave-Assisted Syntheses of Highly CO_2-Selective Organic Cage Frameworks (OCFs). *Chem. Sci.* **2012**, *3*, 874–877. DOI: 10.1039/C1SC00589H.

- Professor Wei Zhang, Department of Chemistry and Biochemistry, University of Colorado, Boulder
- CEM Discover® used to perform Sonogashira couplings of three dimensional cage building blocks
- After microwave irradiation at 100 °C for 1 h, resulted in novel organic framework useful in gas separation
- Material demonstrated high (213/1) selectivity for adsorption of CO_2 over N_2

Reviews

101. Kitchen, H.J.; Vallance, S.R.; Kennedy, J.L.; Tapia-Ruiz, N.; Carassiti, L.; Harrison, A.; Whittaker, A.G.; Drysdale, T.D.; Kingman, S.W.; Gregory, D.H. Modern Microwave Methods in Solid-State Inorganic Materials Chemistry: From Fundamentals to Manufacturing. *Chem. Rev.* **2014**, *114*, 1170–1206. DOI: 10.1021/cr4002353.

102. Khan, N.A.; Jhung, S.H. Synthesis of Metal-Organic Frameworks (MOFs) with Microwave or Ultrasound: Rapid Reaction, Phase-Selectivity, and Size Reduction. *Coord. Chem. Rev.* **2015**, *285*, 11–23. DOI: 10.1016/j.ccr.2014.10.008.

103. Gawande, M.B.; Shelke, S.N.; Zboril, R.; Varma, R.S. Microwave-Assisted Chemistry: Synthetic Applications for Rapid Assembly of Nanomaterials and Organics. *Acc. Chem. Res.* **2014**, *47*, 1338–1348. DOI: 10.1021/ar400309b.

104. Zhu, Y.-J.; Chen, F. Microwave-Assisted Preparation of Inorganic Nanostructures in Liquid Phase. *Chem. Rev.* **2014**, *114*, 6462-6555. DOI: 10.1021/cr400366s.

105. Baghbanzadeh, M.; Carbone, L.; Cozzoli, P. D.; Kappe, C. O. Microwave-Assisted Synthesis of Colloidal Inorganic Nanocrystals. *Angew. Chem. Int. Ed.* **2011**, *50*, 11312–11359. DOI: 10.1002/anie.201101274.