
ENERGY in SABANCI UNIVERSITY

January 2015

Istanbul International Center of Energy & Climate (IICEC)

IICEC is a future-oriented independent research and policy center designed to conduct objective, high-quality economic and policy studies in energy and climate. IICEC efforts will help the development of solutions to a sustainable energy future for the region and the world.

Working with governments, partners from industry, international organizations, think-tanks and other research bodies, establishing a network of cooperation with other universities in the region and in the world; IICEC aims to inform policy makers, industry, academics and opinion leaders on key energy challenges and provide them with objective and genuine analysis. We foster the exchange and development of ideas by providing a distinguished platform gathering key stakeholders involved in energy and climate fields.

The decision to form the Istanbul International Centre for Energy and Climate was motivated by the growing role of Turkey in the international energy landscape and the strategic position of Istanbul, where Europe and Asia meets. The Center, at Sabancı University Karaköy Minerva Palace in Istanbul, is located at the crossroads of almost all current and emerging energy players, both on the producing and consuming sides of global energy markets. Utilizing this strategic position, IICEC will serve to fill the need for an international approach with international resources to the future of energy and climate topics, as a globally recognized networking center.

Energy Technologies & Management (ETM) Professional Master Program

Energy as a strategic subject...

Energy security has a strategic importance in the global economy. Renewable, sustainable, reliable, safe, efficient and smart solutions to energy production and distribution play a major role in development and affluence of nations. Linking with public, environmental, industrial, and international policies, energy administration requires a strong knowledge background in multiple disciplines.

Human resources

Demand for educated professionals in energy technologies and management is ever increasing with the growth of the energy sector and investments globally and nationally. Executives in the energy sector need continuing education and following the latest developments in energy technologies, resources and national and international policies and regulations.

The scope

The program is designed to provide for the participants and the energy sector on the fundamental principles:

1. Educate the professionals with the multi-disciplinary approach and the content that provide for the exigencies of the energy sector.
2. Development of hands-on-skills by discussion style lectures delivered by high level executives of the energy sector.
3. Nurturing projects-based environment for students to promote interactions between the industry and the academia

Energy Research

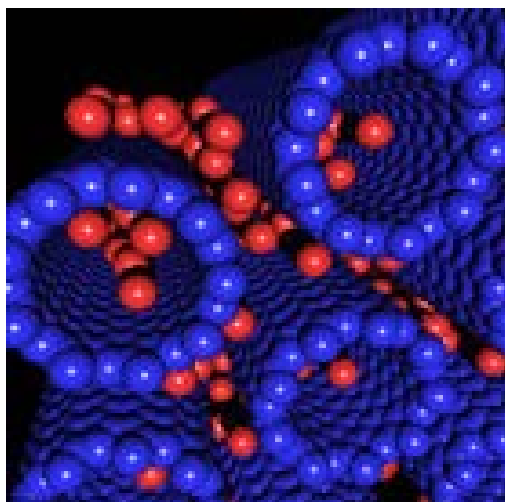
- *Advanced materials for batteries & fuel cells*
- *Advanced materials & processes for energy efficiency*
- *Renewable & energy efficient systems*
- *Energy Economics, Policy and Markets*

Advanced materials for batteries & fuel cells

- *Chemistry of energy storage*
- *New electrode materials for rechargeable lithium-ion batteries based on carbon nanofibers and nanoparticles*
- *High energy capacity electrodes for Li-ion batteries with long-cycle life*
- *Graphene-based composite electrodes for fuel cells*
- *Pilot-scale graphene production from recycled carbon by a green and simple technique*
- *PEM fuel cells with low catalyst loading*
- *Graphene nanocomposites & functionalized graphene as catalyst supports for PEM fuel cells*
- *Development of nanocatalysts for fuel cells*
- *Green wet-laying process to produce fuel cell electrodes*
- *Water-free proton conducting membranes for high temperature PEM fuel cells*
- *Radiation grafted membranes for fuel cells*
- *Polymer assisted fabrication of nanoparticles on electrospun nanofibers for fuel cell catalysts*
- *Functional and conductive polymer thin films*
- *Hybrid supercapacitors from vertically aligned carbon nanotubes and conducting polymers*

Chemistry of Energy Storage

Increasing pressure of global industrialization continues to drive research in areas related to efficient fuel utilization, improved energy storage, and better waste management and reduction. A new fundamental understanding of how nature works is necessary to direct and control matter at the quantum, atomic, and molecular levels in order to meet the global need for abundant, clean, and economical energy.

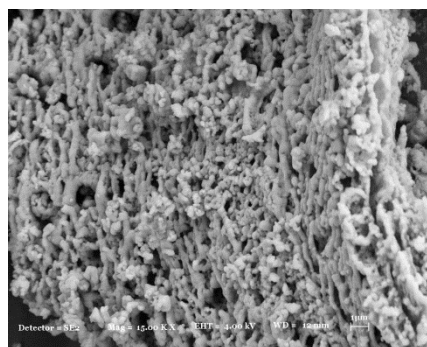


Adsorption of hydrogen on carbon nanotubes

Hydrogen is a clean and abundant fuel for 21st century energy but its storage is one of the key issues for the hydrogen based fuel-cell vehicles. Various carbon-based adsorbents have been investigated for the safe and efficient storage of hydrogen.

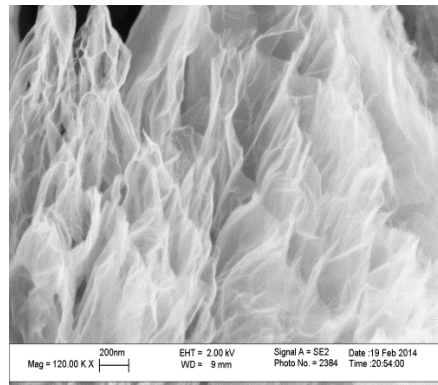
One of the keys to advances in energy storage lies in both finding novel materials and in understanding how current and new materials function.

Sabancı University's researchers under Prof. Yürüm supervision seek improvement of energy storage density by conducting studies in branches of high surface area and porous materials such as graphene and MCM41/ Zeolite.



SEM image of MCM-41

The performance of storage technologies by using Intelligent Gravimetric Analyzer (IGA) which is specifically designed as a versatile gravimetric analysis system to accurately measure gas sorption isotherms from vacuum to high pressure.



SEM image of graphene

New Electrode Materials for Rechargeable Lithium-ion Batteries Based on Carbon Nanofibers and Nanoparticles

Lithium-ion batteries have become the rechargeable energy storage system of choice for portable electronic devices due to their high energy density and specific energy capacity compared to other commercial battery technologies. They have enabled important development possible especially in portable consumer electronics such as smart phones, laptop computers since their first use in 1991. However, even the best batteries available provide insufficient energy density and durability for emerging electric transportation systems, including hybrid and fully electric vehicles (EVs). One way to address the capacity and cycle requirement of batteries for EVs is to pursue the development of new electrode materials.

Commercial lithium-ion batteries use graphite as anode material, which has a theoretical specific capacity of only 372 mAh g⁻¹. Lithium (Li) reacts with graphite via intercalation mechanism, which is the insertion/extraction of Li ions in interstitial sites of the host lattice. In contrast, anode materials such as Si, Ge and Sn, which react with Li via alloying/de-alloying mechanism, show much higher specific capacities because they can host much higher concentrations of Li compared to graphite. However, the bonds between host atoms break during the alloying with Li, causing drastic structural changes. Although the theoretical specific capacities of these alloying anodes are very high (Si, 4200 mAh g⁻¹; Ge, 1623 mAh g⁻¹; Sn, 994 mAh g⁻¹), they suffer from a rapid decay of the specific capacity and loss of electrical connection with cycling due to the dramatic volume changes, which induces mechanical stress and pulverization of anode material.

In order to overcome these problems, the advantage of these alloying anode materials' high capacity is combined with carbon's high electrical conductivity and mechanical strength.

Production of Si Decorated CNF Composite Structures

A number of nanostructured Si electrodes have been demonstrated for enhanced cycle lives; however, most of them have limited scalability because of the expensive and complicated experimental

conditions used in the generation of Si nanostructures.

In this project, CNF/Si nanostructures will be produced using affordable and easy-to-disperse Si precursors, instead of expensive and hard-to-disperse commercial Si nanoparticles. For this purpose, first electrospun nanofibers of novel silane copolymers and polymer nanofibers containing Si precursor will be produced. CNF/Si nanocomposites with homogeneously dispersed Si nanoparticles will be produced in a single step reaction with high pressure.

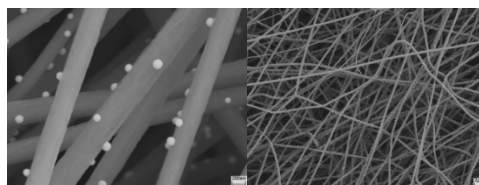
The study is supported by TÜBİTAK under the 3501 – Career Development Program (PI: Serap Hayat Soytaş).

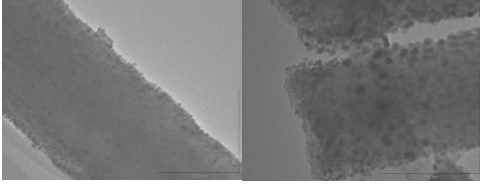
Development of CNF based Anode Materials

CNF/Sn nanocomposite anode materials are produced via cost-effective electrospinning method followed by a carbonization process. In this way, it is possible to obtain ultrafine Sn at the atomic scale embedded in the conductive CNFs as well as Sn nanoparticles dispersed on the surface of the conductive CNFs. It has been demonstrated that the size and distribution of nanoparticles and the size, structure and conductivity of the CNFs can be controlled by the alteration of several experimental conditions. Therefore; desirable nanocomposite design can be obtained for best battery performance.

These CNF/Sn nanocomposites are able to accommodate larger strains than bulk Sn, thus reduce the extent of pulverization and provide good electrical contact resulting in higher capacities with longer cycle life.

The study is supported by TÜBİTAK under the 2218 – Postdoctoral Fellowship Program (PI: Serap Hayat Soytaş).





Sn nanoparticles dispersed on CNFs

Development of Nanostructured Anode Materials

This study is an extension of the previous work to develop high capacity anode materials for lithium-ion batteries with long cycle life to be used in the electric vehicles. CNF/CNT/Sn nanocomposite anode materials will be produced in larger scale. The addition of CNTs will enable to use these anode

materials without any binder or conductive additive by increasing its electrical conductivity.

The production of the nanocomposite anode materials will be extended to the pilot scale and finally to the full production scale. Finally, successful pouch cells will be used to construct a full battery module for EVs in cooperation with TÜBİTAK MAM and industrial partners.

The study is accepted for support by TÜBİTAK under the 1007 – KAMAG Program (PI: Serkan Ünal).

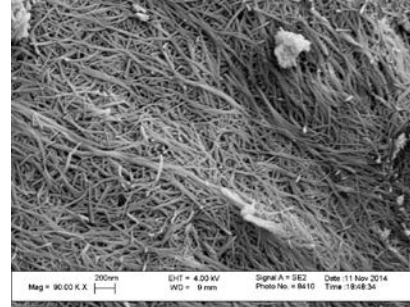
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High Energy Capacity Electrodes for Li-ion Batteries with Long-Cycle Life

With the development of technology, the demand of energy increases day by day. However this increasing demand brought issues for storing energy efficiently. Nowadays it is expected from energy storing systems to be less harmful for the environment, to be cheaper, to be able to store more energy and to be lighter. Since lithium-ion batteries meet these requirements very well, they are used in many electronic devices and get started to be used in electric vehicles. Nevertheless electric and hybrid vehicles need batteries that can operate at high temperatures, having high energy capacities and maintain its capacity at high currents.

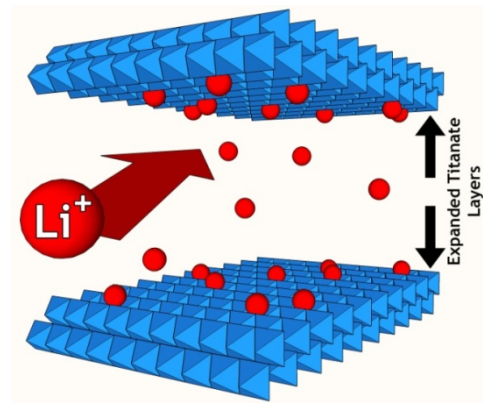
Lithium-ion batteries for vehicles in usage show low performance at high temperature and their energy capacities drops very fast when high currents are needed. In addition to that rechargeable batteries lose their capacities quickly with usage. For these reasons, researches that will be done on that subject are quite important.

In this project, temperature resistant nano structured titanate ($\text{H}_2\text{Ti}_3\text{O}_7$) electrodes with a novel approach. This approach may change the way Li-ion battery materials are synthesized. Electrode materials with high energy capacities but more importantly the materials keep their high energy capacity for a long period of time, have been developed. For that purpose titanium dioxide (TiO_2), which is a cheap raw material, is converted to high capacity materials like nanotubes. These nanotubes have a multilayered structure. The key idea here is to expand these layers.



The figure shows the multilayered titanate nanotubes which is the starting material for the novel electrodes

When the layers are expanded, energy capacity increases and the material keep its capacity for a longer period of time. Since, after expansion, Li ions can move more freely, the capacity drop at high load applications is reduced.



Li ions move freely in the expanded titanate structure. Also since more surfaces are exposed, the energy capacity increases.

The work is supported by the Project Grants: The Enhancement of Lithium-Ion Batteries' Capacity and Life with the Development of Lithium Ion Mobility Between the Layers of Titanate Based Electrodes, 2013-2016, supported by TUBITAK 1001 Program (PI: A. Yürüm, Researcher: S. Alkan Gürsel;)

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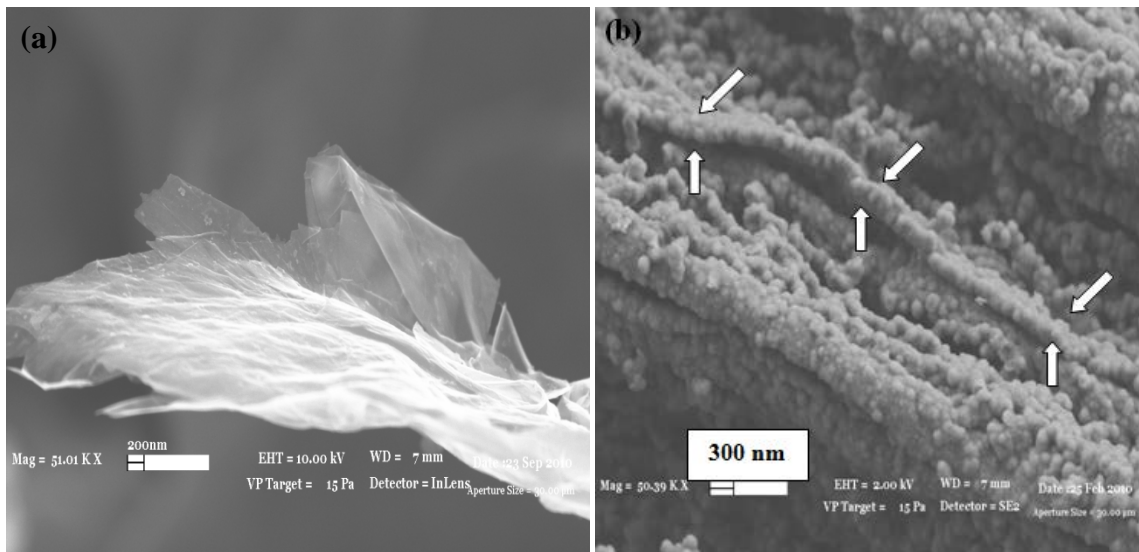
Graphene-based composite electrodes for fuel cells

Fuel cells are clean, compact and modular energy generation devices that generate electricity by a chemical reaction between a fuel and an oxidant. Polymer electrolyte membrane fuel cell (PEMFC) offers several advantages for both mobile and stationary applications yet it is necessary to develop low cost and more efficient PEMFCs. The heart of the PEMFC is the membrane electrode assembly composed of a proton exchange membrane sandwiched between two porous gas diffusion electrodes. At this point, graphene is a promising candidate as catalyst support material for PEMFCs due to its outstanding mechanical, structural, and electronic properties. Herein, the support material becomes significant to get high catalytic performance of catalysts by lower catalyst

loadings. For the production of advanced type of gas diffusion layers, the distinguished properties of graphene are combined with the structural properties of conducting polymers and the impregnation of low-amount of Pt catalysts on graphene surface by the proposed simple and low-cost fabrication technique.

This research is conducted by Dr. Burcu Saner Okan in the scope of her PhD thesis between 2007-2011 under supervision of Prof. Dr. Yüda Yürüm.

The part of this Project is granted by Tubitak 1003 between 2015-2018 (WP leaders: Dr. Burcu Saner Okan, Prof. Yusuf Menceloglu and Assoc. Prof. Mehmet Yıldız).



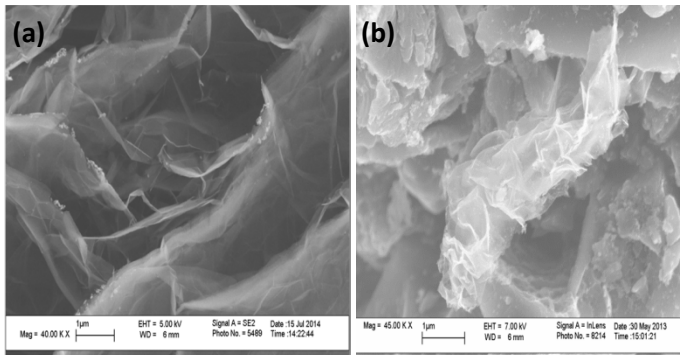
SEM images of (a) graphene nanosheets
(b) layer-by-layer polypyrrole coated graphene nanosheets

Pilot-scale Graphene production from recycled carbon by a green and simple technique

Graphene has been attracting great interest due to its extraordinary electronic, thermal, and mechanical properties, resulting from its two-dimensional structure, and to its potential applications such as energy, wind turbines, construction, defence, automotive, aeronautics and aerospace applications. In last decades, there are numerous works about graphene synthesis and its applications in laboratory scale but mass production of graphene has still doubts and obstacles. One of the applicable methods is graphite oxidation to reduce the strong bonding between graphene sheets in graphite and obtain single layer graphene. In the present work, graphene nanosheets were produced in pilot scale by improved, safer and mild chemical route. The proposed technique provided to reduce the average number of graphene layers steadily from 105 in the raw graphite to 20-25 in graphene

nanosheets by stepwise chemical procedure. Additionally, graphene obtained from recycled carbon source was a scalable, cost effective and environmentally friendly. After the production of high quality and high quantity graphene, graphene based composites were produced by using different thermoset and thermoplastic polymers. The mechanical and thermal properties of the materials were improved and significant weight reduction was provided by the addition of graphene in matrix material in low loadings changing from 0,05 to 5%. As a result, more reliable and long lasting composite production is possible by using graphene in polymer composites.

This project is granted by Tubitak 1512 Multiphase Entrepreneurship Grant Program. Co-founders of Nanografen Co: Dr. Burcu Saner Okan, Prof. Dr. Yusuf Menciloglu and Inovent A. S.)



SEM images of (a) thermally exfoliated graphene oxide and (b) Graphene from recycled carbon



Graphene oxide in bulk quantities produced by Nanografen Co.

PEM Fuel Cells with Low Catalyst Loading

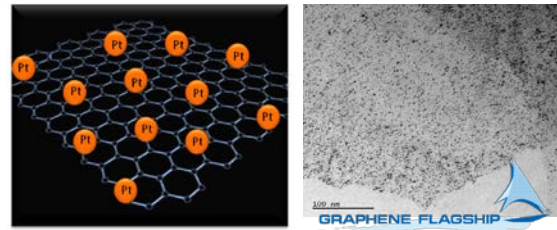
Despite enormous progress in polymer electrolyte membrane (PEM) fuel cells, development of catalysts with maximum activity and durability and minimum loading are still the core challenges. Catalyst supports are also very important in this respect. Generally, proper catalyst support materials must have large specific surface areas to support catalyst nanoparticles, high electrical conductivity to promote fast electron transfer, strong affinity towards the nanoparticles and stability under the operating conditions to provide stable catalyst structures.

The most commonly used catalyst support material is commercial carbon blacks. However, carbon blacks have various drawbacks and limitations which cause the degradation of catalyst activity and performance.

Graphene, the two dimensional allotrope of carbon, exhibits excellent electrical, thermal and mechanical properties and large surface area. It is expected that the unique structure and properties of graphene can fulfill all the requirements of an ideal catalyst support.

Platinum (Pt) nanoparticles have been known as the best catalyst for especially for oxygen reduction reaction at the cathode. However, Pt is still the most expensive component of PEM fuel. In this respect, we develop graphene based electrodes and electrode fabrication methods to enhance the dispersion, utilization and the durability of the Pt catalyst at the same time to reduce the Pt loading. The reduction of catalyst amount in the electrode without sacrificing the performance and thus lowering the cost of fuel cell is the ultimate goal

Surface area and catalytic activity of supported nanoparticles depend on preparation method. In this project, impregnation methods based on reduction of suitable Pt-precursors have been employed.



Graphene based
electrode

The resultant graphene supported Pt nanoparticles have exhibited superior properties compared to commercial carbon black supported Pt nanoparticles. Uniform distribution of Pt nanoparticles and enhanced electrocatalytic activities have been achieved.

The work is supported by the Project Grant: Graphene-Driven Revolutions in ICT and Beyond-EU Future Emerging Technology (FET) Graphene Flagship, 2013-..., supported by EU (FP7 and Horizon 2020) (PI: S. Alkan Gürsel)

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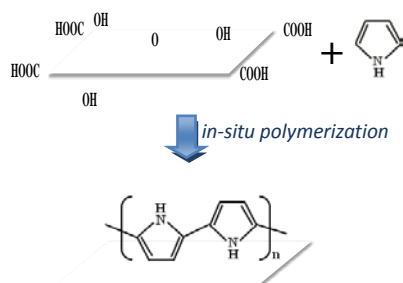
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Graphene Nanocomposites & Functionalized Graphene as Catalyst Supports for PEM Fuel Cells

Graphene is an increasingly important nano-material with distinct electronic conductivity, high contact surface area and enormous stability. Therefore, graphene has been used as a promising catalyst support in energy conversion and storage systems. In general, catalysts with supports are often prepared by solution-based approaches that require the supports have good dispersion in solvents such as water and/or organic solvents without aggregation for high specific surface area and are able to uniformly adsorb and grow the catalysts on supports.

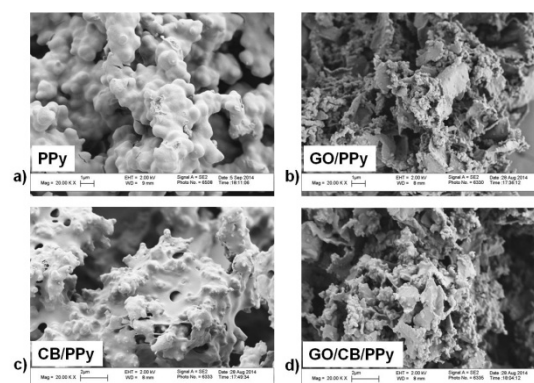
Specifically guided growth of catalyst on graphene support surface with delicate controllability is also highly preferred to achieve high catalytic activity although it is still very challenging. In order to meet those challenges, our aim is to develop graphene based nanocomposites and functionalization of graphene with effective functional groups as the most promising catalyst supports.



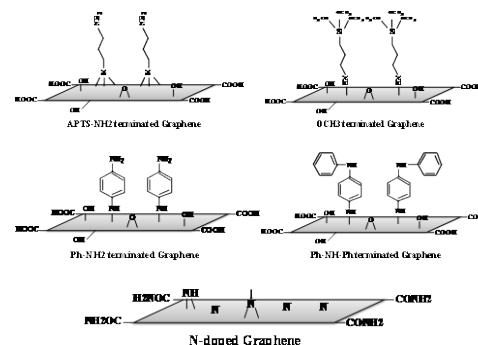
PPy Nanoparticles / Graphene Nanocomposite

We synthesize graphene oxide/polypyrrole nanocomposites (GO/PPy) with the simultaneous reduction of graphene oxide as a superior catalyst support for significantly improved catalytic performance of metal nanoparticles. The SEM results

of PPy nanocomposites with GO, CB, and their hybrids suggest that the carbonaceous type material significantly influence the PPy particle size, distribution and nanocomposite properties.



We also functionalize GO with various effective functional groups to support the catalyst growth efficiently. These types of functionalized GOs are expected to have better dispersibility in solvents and serve as effective catalyst support by enhancing catalyst growth or anchoring Pt nanoparticles



The work is supported by the Project Grant: Graphene-Driven Revolutions in ICT and Beyond-EU Future Emerging Technology (FET) Graphene Flagship, 2013-..., supported by EU (FP7 and Horizon 2020) (PI: S. Alkan Gürsel)

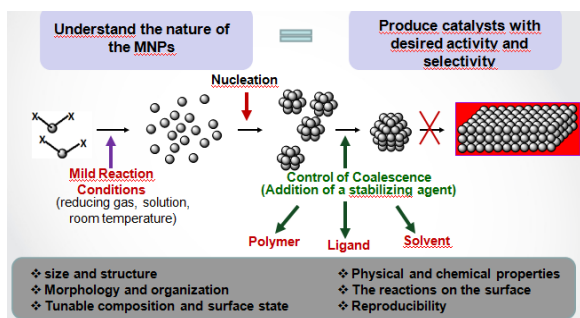
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Development of Nanocatalysts for Fuel Cells

MNPs) can combine both homogeneous and heterogeneous properties of catalysts: an exceptionally high surface area and a controlled surface with desired catalytic activity and selectivity. MNPs with their small size are highly interesting systems due to their high proportion of surface atoms offering numerous active sites. In addition, they have unique electronic properties at the frontier between the molecular and metallic states.

The ligands present on the surface as stabilizing agents may alter the electronic structure as well as the physical properties of the MNPs. Among many synthesis methods (e.g. pyrolysis, chemical vapor deposition, etc.), organometallic synthesis approach is very effective in achieving stable and homogeneous MNPs since the decomposition of an organometallic precursor takes place under mild conditions (low pressure reducing gas and temperature, low concentration of stabilizer etc.). For instance, platinum nanoparticles (Pt NPs) of ca. 2 nm were synthesized in CNRS at Chaudret & Philippot's Labs with this approach by the decomposition of $Pt_2(dba)_3$ and in the presence of a diphosphine ligand and either H_2 or CO atmosphere.



In the last decades, fuel cells have gained increased attention as alternative electrical power

sources due to their high efficiency and low pollution levels. It is an environmentally friendly device as it operates with hydrogen; producing water as the exhaust product while generating electricity. Membrane electrode assembly, regarded as the hearth of fuel cells, consists of two gas diffusion electrodes and a proton exchange membrane in between and allows the diffusion of hydrogen as fuel and the electrochemical reaction to occur. Therefore, the production of high quality fuel cell electrodes with small and thus catalytically very active MNPs and a strong support with high surface area is essential.

Our aim in this project is to develop graphene supported mono- and bimetallic Pt NPs for developing effective and high performance fuel cell electrodes. Our efforts are towards achieving small and homogeneous MNPs and their homogeneous dispersion on the graphene support. The usage of graphene in all application fields has increased in the recent years since it is a widely investigated material with a two dimensional structure that has a very high surface area and remarkable electrical and physical properties. These properties combined with our synthesis technique for the desired metal nanoparticles will enable us achieve high performance fuel cell electrodes.

The work is supported by the Project Grant: Development of Fuel Cell Electrodes based on Platinum Nanoparticles with Carbon Black and Graphene Support Materials, 2014-2016, supported by TUBITAK 2232 Return to Country Research Fellowship Program (PI: Solen Kinnayığit, Academic Advisor: Selmiye Alkan Gürsel)

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Green Wet-Laying Process to Produce Fuel Cell Electrodes

With the growing cost of oil and concern about global warming, people are interested in cleaner, more fuel-efficient vehicle engines powered by bio-fuels or hydrogen, or by alternative energy technologies such as fuel cells.

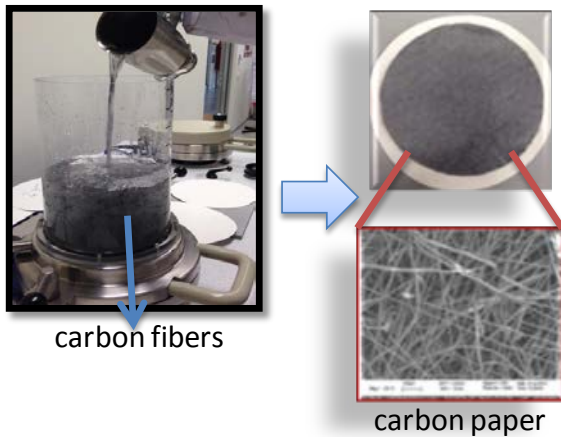
Among others polymer electrolyte membrane (PEM) fuel cell attributes advantages such as high power density, quick start-up time, pollution free operation and all solid-compact construction especially for portable applications. Even the PEM fuel cell is a green alternative energy production system, the production process of its components still remains as a question mark.

Aqueous polymers are promising green candidates as new binder or additive for any electrochemical cell electrode. In particular, natural cellulose, the most abundant renewable material, is intrinsically greener than any industrially synthesized polymer. In this work, natural cellulose, dissolved in fully recyclable ionic liquids, is used as the binder in the PEM fuel cell electrode.

In this study, wet-laying process, mostly used in pulp and paper-textile industry, is used to produce gas diffusion electrodes for PEM fuel cell from aqueous fiber dispersions. Wet laid carbon fiber based and carbon fiber-cellulose based electrically conducting electrode structures can be prepared in a flexible form and in excellent uniformity to enhance especially cathode electrode performance to improve the lifetime and efficiency of PEM fuel cell. Cellulose is going to be removed by phase inversion process from the electrode structure. As a result, electrodes can be manufactured without the need of polluting volatile organic compounds for greener and environmentally friendly electrode structure.

The work is supported by the Project Grants:

1. *Fabrication and Characterization of High Quality Membrane Electrode Assemblies for Polymer Electrolyte Membrane Fuel Cells, 2013-2015, supported by SANTEZ (PI: S.Alkan Gürsel*
2. *Development of Graphene based High Quality Gas Diffusion Electrodes for PEM Fuel Cells, 2014-2017, supported by TUBITAK 1003 Program (PI: L. Işık Şanlı, Selmiye Alkan Gürsel*



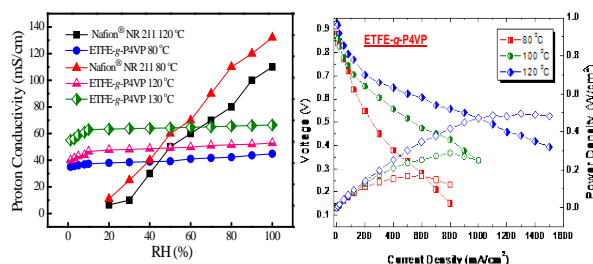
Water Free Proton Conducting Membranes for High Temperature PEM Fuel Cells

Fuel cells are one of the most promising electro-chemical power sources both for mobile and stationary applications. Among others, the polymer electrolyte membrane (PEM) fuel cell has received great attention due to their high power density, quick start-up time, pollution free operation and compact structure. The main challenges for this technology are poor reaction kinetics at the cathode, low tolerance of Pt catalyst to carbon monoxide poisoning, and complexity of integration of hydrogen reformer technology.

Most of those shortcomings arise when the operation temperature is limited to below 100 °C (typically 60-80 °C), at atmospheric pressure which is in turn limited by the current state-of-the-art membranes such as Nafion® because of its water assisted conduction mechanism. Nafion® membranes have advantages such as high mechanical and chemical stability at temperatures below 100 °C and high proton conductivity in hydrated form as well. However, the water requirement in the membrane limits the operation temperature to below 100 °C in theory. Thus, the synthesis and characterization of proton conducting membranes constitutes a significant step for the development of high temperature PEM fuel cells.

This study's main focus is the preparation of phosphoric acid doped proton exchange membranes to operate at high temperature (especially above boiling point of water) and water free conditions for PEM fuel cells. Owing to a simple manufacturing process, radiation-induced grafting, the procedure that is offered to fabricate high temperature membranes is able to overcome

casting (or manufacturing) problems of other high temperature membrane candidates. Nitrogen containing monomers are selected since strong interaction with phosphoric acid to create N-H interaction to operate at high temperature is expected.



The resultant membranes exhibit promising thermal and mechanical properties, lower water uptake and encouraging proton conductivity. Moreover, both the *ex situ* proton conductivity measurements and fuel cell testing prove that these membranes are very promising to operate at high temperature and dry PEMFC operation conditions.

The work is supported by the Project Grants:

- 1) *The Synthesis of Low Cost Alternative Proton-Exchange Membranes for Fuel Cells and the Utilization of Conducting Polymers as the Catalyst Support, 2008-2011, supported by TUBITAK 1001 Program (PI: S. Alkan Gürsel)*
- 2) *Polymer Electrolyte Membrane Fuel Cell with the Dead-End Anode and Large Active Area, 2014-2017, supported by TUBITAK 1003 Program (Researchers: S. Alkan Gürsel, Y. Karataş; PI: S. Yeşilyurt)*

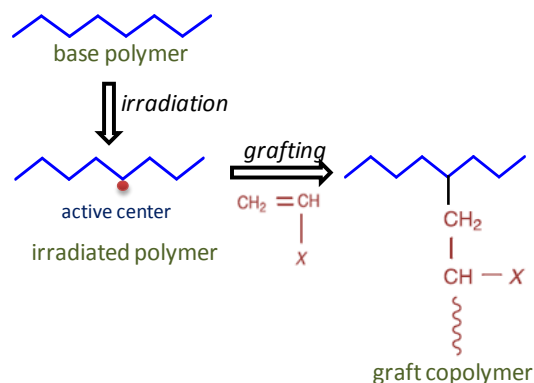
Radiation Grafted Membranes for Fuel Cells

The proton exchange membranes are utilized as both the electrolytes and separators for PEM fuel cells. The development of cost effective proton exchange membranes to replace the state-of-the-art high cost perfluorinated membranes (e.g., Nafion® and derivatives) is an important challenge. The radiation induced grafting, a versatile technique allowing the functionalization of the base material for the introduction of a desired property, offers several advantages. First of all, there is no need to use an initiator or catalyst during polymerization. Secondly, since the starting polymer is already in the film form, there is no need for solution casting of electrolyte. Moreover, materials can be readily crosslinked during polymerization. In addition to these, materials are available at low cost.

Radiation induced grafting is based on irradiation of a base polymer by e-beam or gamma rays to create active reaction centers (mostly radicals). Then irradiated polymer is treated with vinyl monomer to produce a graft copolymer which can be sulfonated or doped to introduce proton conductivity.

Various base polymers (in the film form) and monomer combinations have been employed for the development of membranes by radiation grafting. Moreover, novel approaches for the synthesis of homogenous, highly conducting and low cost proton exchange membranes have been proposed. Unlike traditional radiation grafting method in which base polymer in the film form is used, base polymer in the powder form has been used in this study. Moreover, a novel monomer sodium styrene sulfonate has been used to eliminate tedious sulfonation step. Then, proton conducting membranes in the form of thin films have been obtained from copolymer powder simply by casting. By this means, the integration of base polymer and the monomer, and the uniform distribution of grafted chains have been achieved

and consequently homogenous membranes have been obtained



Another approach for the synthesis of highly stable, durable, and low cost proton exchange membranes is to use of vinyl monomers containing a spacer (atom or a group) between the double bond and aromatic ring have been employed during radiation grafting. It was shown that the spacer in the monomer enhanced the stability of the graft component against oxidative degradation in fuel cell environment.

The work was supported by the Project Grants:

- 1) *Fabrication and Characterization of High Quality Membrane Electrode Assemblies for Polymer Electrolyte Membrane Fuel Cells, 2013-2015, supported by SAN-TEZ Program (PI: S. Alkan Gürsel)*
- 2) *Synthesis and Characterization of Polyphosphazene based Proton Exchange Membranes for Fuel Cell Applications, 2011-2014, supported by TUBITAK 3501 Program (PI: Y. Karataş, Advisor: S. Alkan Gürsel)*
- 3) *Polymer Electrolyte Membranes with High Durability and Stability for Fuel Cells, 2010-2011, supported by L'OREAL Young Women in Science Award Program (PI: S. Alkan Gürsel)*

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Polymer Assisted Fabrication of Nanoparticles on Electrospun Nanofibers for Fuel Cell Catalysts Applications

The need for novel nanoparticles is a wide concern of scientific community. But the ways of producing of these extraordinary properties is another concern. Different methodologies and processing techniques are used for manipulating the properties of nanoparticles in atomic dimensions. Most of them came with the same conclusion:

“It is obligatory to prevent the agglomeration of nanoparticles for size control and distribution.”

The most efficient and universal way to overcome these problems is to use polymer-assisted fabrication of inorganic nanoparticles and hybrid polymer–inorganic nanocomposites. Electrospinning is a versatile method that will satisfy the primary needs for the in situ synthesis of nanoparticles within a polymer matrix. The very basic nature of the nanofibers produced by electrospinning i.e. very large surface area to volume ratio, flexibility in surface functionality, and superior mechanical performance compared with any other known form of the materials makes it the best choice for maneuvering nanoparticle properties.

The aim of this work was to suggest an alternative way for synthesizing nanoparticles through the electrospinning process. By maneuvering the macromolecular architecture of chosen polymers, we mediated to the controlled synthesis of nanoparticles.

Electrospinning parameters were discussed in detail throughout this research. The change of polymer concentration and solution conductivity affected resulting fiber diameters. Fiber diameters increased with polymer concentration and addition of extra metal salts into polymer solutions favored in the formation of more uniform and thinner fibers.

By appropriately choosing reduction solvents and heat treating cycles, enhanced control of nanoparticle sizes at different reduction mediums and temperatures was achieved on different processing conditions.

The results of this study showed that choosing an appropriate polymer template would determine the size and distribution of nanoparticles. Synthesized blocky-copolymers of acrylonitrile with acrylic acid, vinyl phosphonic acid 2-acrylamido-2-methylpropane sulfonic acid yielded agglomerated nanoparticles. The change of polymer architecture to a random structure poly(acrylonitrile-co-n-vinylpyrrolidinone), the size of nanoparticles could be reduced to several nanometers. Effective control of macromolecular design by altering the copolymer structure enabled the size tuning for nanoparticle crystals.

By the application of methods proposed in this research it was possible to confine sub 10nm's nanoparticles with uniform distributions throughout the fiber structures even at elevated temperatures. Rather than other literature findings, nanoparticles could be generated even at order of 2-5 nm at 600°C, and 10-17 nm at 1000°C, which were the smallest among the similar researches.

The catalytic activities of metal nanoparticles on carbon nanofibers showed an electroactive active surface area of 34,6 m²/g for Pt and 22.4 m²/g for Pd. These results confirmed the viability of use of metalized nanoparticles on carbon nanofibers as catalysts for fuel cell applications.

These results proved the concept of this research that by selectively choosing the processing conditions and the production techniques, generation of nanoparticles in uniform and smaller dimensions was possible.

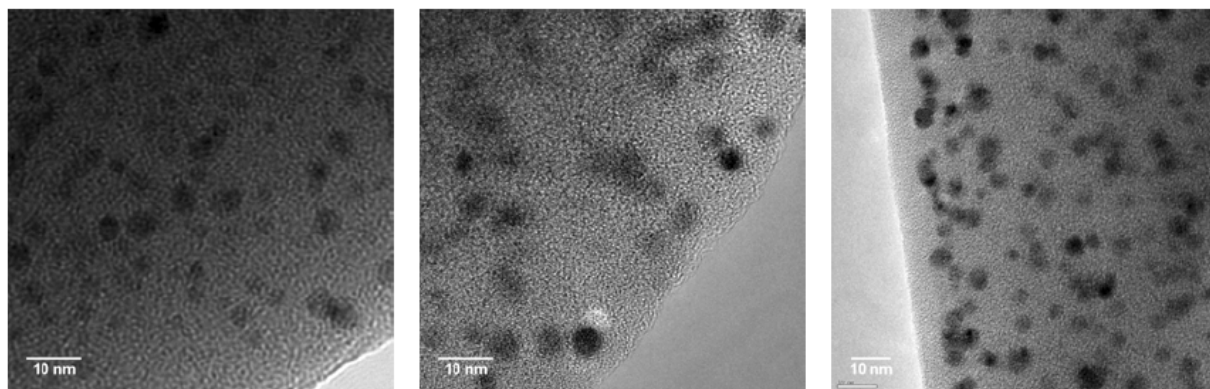


Figure 1. P(AN-co-5VPYR)-5Pd-heating treatment effects-TEM analyses a) 600°C-0,1°C/min -30min (5.1 nm average particle size) b) 600°C -1°C /min-30min (4.8 nm average particle size) c) 600°C -1°C /min (4.7 nm average particle size)

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Functional and Conductive Polymer Thin Films

Functional polymer thin films find uses in wide range of energy applications as separation membranes for fuel cells or as electrodes in batteries. Low costs, flexible nature and tailored functionalities make the polymer thin films better alternatives compared to their metal counterparts. Our research efforts focus mainly on conductive polymer thin films and selectively permeable ultra thin functional polymers.

Synthesis of the ultra thin polymer films is achieved by chemical vapour deposition technique where the precursors are introduced to a deposition chamber in vapour phase. For the synthesis of the functional thin films, vapour phase radicals are used to initiate the polymerization reaction on the substrate surface by reacting with the vinyl bonds of the adsorbed monomers. Peroxide based initiator precursors are used to form the radicals through thermal decomposition upon contact with heated filaments. The conductive polymer films on the other hand are synthesized via the reaction of oxidant molecules with adsorbed monomers forming conjugated polymers. Depending on the monomer-oxidant pair used the doping takes place either during polymerisation reaction or post-processing.

The low substrate temperatures and chamber pressures used during the deposition process enable coating of delicate substrates such as paper or textile. Furthermore the thickness of the polymer coatings can be controlled in the nm-level, thus ultra-thin layers of polymers can be coated. As the polymerisation occurs on the substrate surface and the precursors are in the vapour phase, conformal coatings of high aspect ratio structures or rough surfaces can be coated homogeneously.

The chemical composition of the polymer thin films can be controlled by varying the precursor ratios and the system parameters, such as the substrate temperature and chamber pressure which control the precursor concentration on the substrate. The decoupling of the system parameters and separate control of the film thickness enable fine tuning of the chemical and physical

properties of the polymer thin films according to the applications.

Functional Polymer Thin Film Membranes:

Our polymer thin film membrane studies focus on fabrication of free-standing ultra thin polymeric membranes for controlled diffusion and selective permeation of model molecules. The polymer coatings are deposited on sacrificial layers which are subsequently etched to release the free-standing polymer layers. These permeation characteristics of the polymer membranes are then tested under different flow and pressure conditions. The selectivity and the permeability of the membranes can be controlled by tuning the mesh size and the exposed functional groups of the polymer coatings. Mainly hydrogels with different crosslink densities are used to study the effect of mesh size. Poly(hydroxyethyl methacrylate) and poly(N-isopropylacrylamide) are examples to the functional polymers studied. The effects of the mechanical properties of thin films are studied using membranes of glassy and rubbery polymers, such as poly(butyl acrylate) or poly(dimethylsiloxane).

Free standing copolymer films with carboxylic acid and fluorocarbon groups are also studied with potential applications as proton exchange membranes for fuel cells. The concentrations of the monomer precursors are varied and the effect of the composition on the conductivity is investigated. The carboxylic acid group concentrations in the polymer, which affect the proton conductivity of the membranes, in addition to the swelling ratios can be tuned by varying the precursor concentrations. This enables tuning of polymer properties for improved proton conductivities.

Conductive Polymer Thin Films and Nanostructures:

Our studies on conductive polymer thin films focus mainly on depositions of conjugated polymers that are doped during deposition or post-deposition for improved conductivity. The effects of deposition conditions, such as substrate temperature or precursor flowrates, on the composition of the conjugated polymers are investigated.

The surface roughness of the thin films which is related to the deposition rate can also be adjusted. Thin films of polyaniline, polypyrrole and polythiophene polymers as potential electrode materials are studied and the relation between their deposition conditions and conductivity is investigated.

Control of the deposition rate is crucial for conformal deposition of thin films on patterned surfaces. One major part of our research efforts focus on fabrication of polymeric nanotubes. The

nanotubes are formed by depositing polymer thin films inside the pores of a track etch membrane and subsequently etching the membrane away to release the nanotubes. This way nanotubes of different functionalities and physical properties could be formed. While these nanostructures can be used for controlled delivery applications upon triggering, conductive nanostructures can also be used in energy storage applications due to their large surface to volume ratios and high densities.

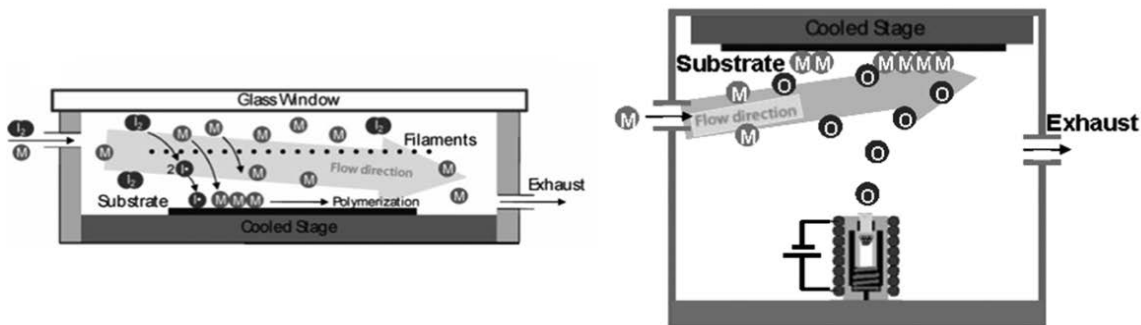


Figure 1: The schematics of the (a) functional polymer deposition and (b) conductive polymer deposition mechanisms inside the CVD reactors are shown.

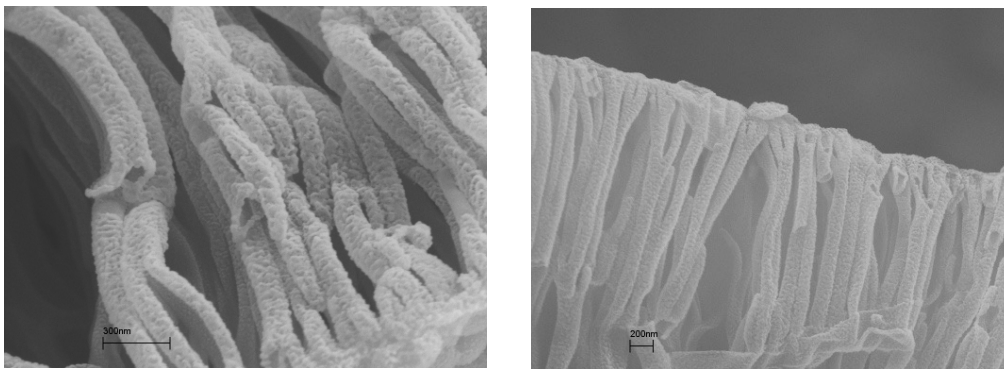


Figure 2: Nanotubes of functional polymers fabricated using templates CVD technique.

These projects are supported by the following grants:

1. Development of Smart Composite Membranes For Molecular Separation Applications, TÜBİTAK 3501.
2. Fabrication and Characterization of Coaxial Conducting Polymer Nanotubes for Molecule Storage and Controlled Release Applications, TÜBİTAK 1001.

Hybrid Supercapacitors from Vertically Aligned Carbon Nanotubes and Conducting Polymers

Researching for better electrode architectures for advanced hybrid supercapacitors and batteries using vertically aligned carbon nanotubes, conjugated polymers and/or transition metal oxides.

One of the most important energy storage systems is supercapacitors or electrochemical capacitors (ECs) due to their unmatched cycle life, and fast response time make them useful in applications such as unmanned aeronautical vehicles, submarines, cranes etc. and complementary in energy conversion systems used as range extender. However for the next generation applications, key improvements are needed in their overall performance to achieve energy densities on par with Li-ion batteries.

Exponential advancements in nanotechnology have brought forth a vast number of possibilities for new materials as nanoporous or subnanoporous carbon materials (e.g. carbon nanotubes) having high surface area that results in greater capacitance. Our objective will be to develop new types of hybrid supercapacitors using carbon nanomaterials, conducting polymers and metallic nanostructures.

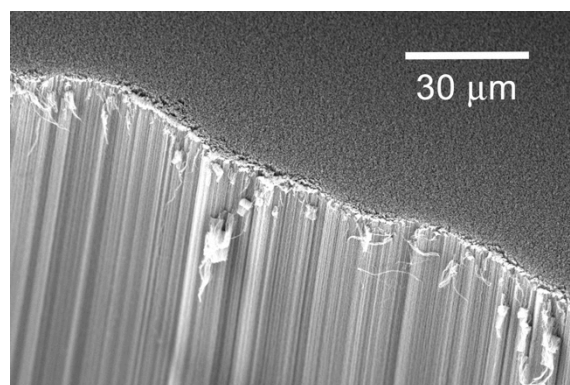
Conventional capacitors offer very high specific power, but extremely low specific energy, making them impractical for applications requiring high energy. The major differences between a capacitor and a battery are their materials and the mechanism of charge storage. Briefly, a battery stores energy chemically and its energy limitation is the electrode mass. The mechanical stability and chemical reactions irreversibility determine the cycle life of batteries whereas ECs offer exceptional cycle life.

The implementation of conducting polymers or other redox active components into ECs can provide higher capacitance and higher power capacity in comparison to conventional carbon-based capacitors. A capacitor containing a redox active component is often called a pseudocapacitor or hybrid capacitor. These types of capacitors can be designed in the form of redox active conducting polymer electrodes. Even higher capacitances can be obtained by metal oxides, the use of conduct-

ing polymers present innumerable advantages over metal oxides such as low cost, flexibility of design, the potential for lightweight devices, and environmental friendliness compared to heavy metal containing oxides.

The ECs store energy physically and its energy limitation is the electrode surface area. Implementing carbon nanotubes with extremely high surface area into hybrid ECs structure with a conducting polymer ensures to achieve enhanced capacitance behavior. Controlled morphology of carbon nanotubes with a preferential orientation in vertical direction offers fast ion transport and variability in packing density with improved mechanical strength assuring a great candidate as an electrode material with exceptional cycle life.

The main objective is to tailor and design hybrid supercapacitors with vertically aligned carbon nanotubes as an active electrode component and conducting polymer and/or transition metal oxides as a redox active component. For the active electrode, vertically aligned carbon nanotubes will be synthesized by a modified chemical vapor deposition technique.



Vertically aligned multi-walled carbon nanotube forests.

Image courtesy of the researchers.

The study was funded by TÜBİTAK under the 3501- Career Development Program.

Advanced materials & processes for energy efficiency

- *Boosting solar cell efficiency*
- *Energy-efficient building materials*
- *Nanoparticle coatings to improve energy efficiency*
- *Improving energy efficiency in buildings through nanoparticle coatings*
- *Oxide-oxide artificially layered structures for high density, high power capacitors*
- *Energy efficiency with nanostructured surfaces-pool boiling applications*
- *Energy efficiency with pHEMA coated surfaces*
- *Heat transfer enhancement in microtubes with nanofluids for energy efficiency*
- *Micro scale cavitation and its energy efficient biomedical applications*
- *Ferrofluid actuation for energy efficient micropumping and cooling applications*
- *Effect of nanostructure distribution on energy efficiency of thermal-fluidic systems*
- *"THINK outside the box" for structural COMPOSITES*

Boosting Solar Cell Efficiency

The research team led by SU materials scientist Cleva OW-YANG demonstrated that engineering the electrode/active layer interface by nanostructuring enabled tuning the amount of photo-excited charge collected in a polymer-based solar

cell. By applying the technology through solution processing on the industry-standard solar cell, the charge collection efficiency was doubled by as much as two-fold.

Energy-Efficient Building Materials Program

Long Persistence Ceramic Phosphors: In this virtual laboratory, we seek to understand the mechanism of extended persistence in long afterglow ceramic phosphor powders. Through using ceramic powder processing routes, we synthesize luminescence converters with structural characteristics that enable the application of spectroscopic

and advanced transmission electron microscopy techniques to elucidate the mechanisms of extended afterglow. With this knowledge, we are developing technological applications exploiting these optical properties, such as for earthquake, mines and road safety.

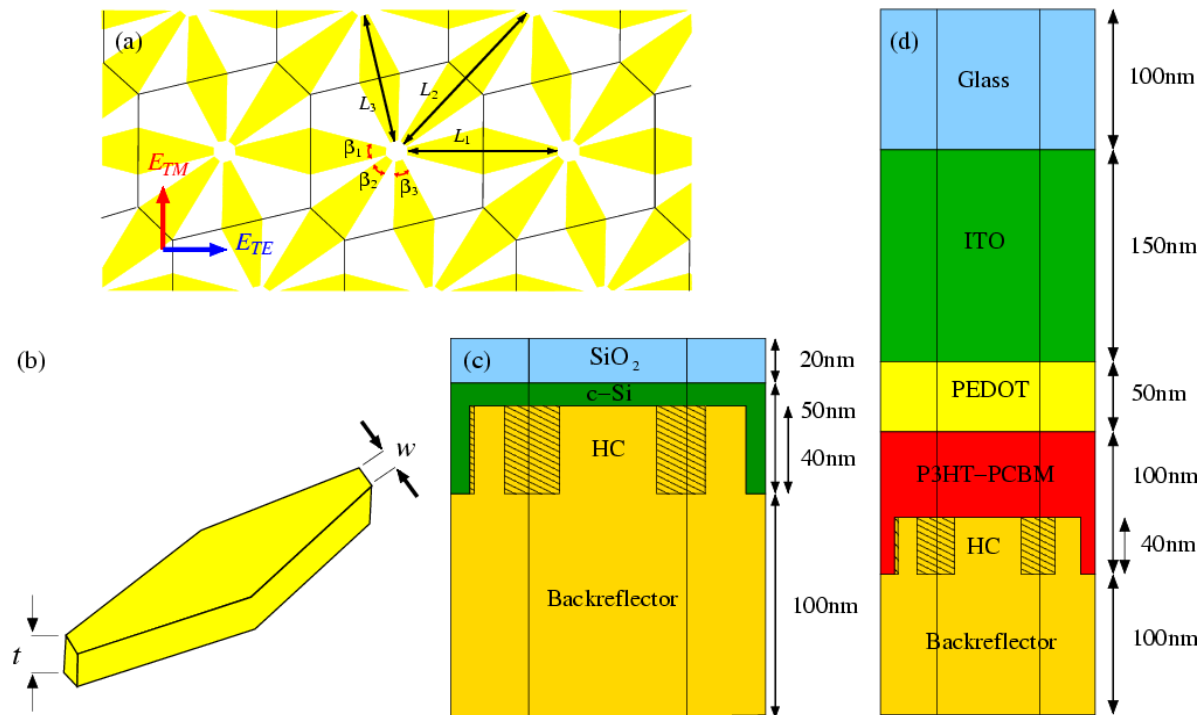
Contact: Assoc. Prof. Cleva Ow Yang, cleva@sabanciuniv.edu

Nanoparticle coatings to improve energy efficiency

In the quest for more efficient renewable energy technology, solar cells offer significant promise. Sabancı University researchers have recently demonstrated that by embedding plasmonic honeycomb nanoantenna arrays into the active layers of inorganic (c-Si) and organic (P3HT:PCBM/PEDOT:PSS) thin film solar cells, absorption efficiency can be improved.

Efficient absorption of light in the active layer of solar cells and non-radiative recombination rates of charge carriers are two competing factors in conventional solar cell technology. By increasing the thickness of the active layer, light can be efficiently absorbed, however, charge carriers travel a longer path in the active material due to the increased thickness. This increase results in a high non-radiative charge recombination rate without

contributing to the current generation, which reduces the overall energy conversion efficiency. By employing thin film solar cells, charge collection can be improved at the expense of low absorption efficiency. By decreasing the thickness of the active material layer, the distance that light travels is not sufficient for efficient absorption of a wide range of photon energies close to the band gap. This reduces absorption efficiency and energy conversion efficiency. While possible to obtain high power conversion efficiencies above 20% for some single crystalline materials with a thickness of a few hundred micrometers, high cost and energy demand to fabricate c-Si motivates research on thin film solar cells with nanoantennas for efficient absorption.



(a) Schematic illustration of the top view of the honeycomb array. (b) Schematic illustration of an individual particle. t is the thickness and w is the width of the apex of the particles. (c) Schematic illustration of c-Si thin film solar cell with a honeycomb structure embedded in the solar cell (d) Schematic illustration of a P3HT:PCBM/PEDOT:PSS thin film solar cell with a honeycomb structure embedded in the solar cell.

Sabancı University researchers achieved improved solar cell efficiency via a nanoantenna array struc-

ture that has a absorption spectrum conformal to solar radiation. Sabancı University researchers

achieved the spectral broadening by breaking the symmetry within the Wigner-Seitz unit cell on a uniform hexagonal grid. For optimized designs, absorption efficiency enhancements of 106.2% and 20.8% are achieved for c-Si and P3HT:PCBM/PEDOT:PSS thin film solar cells, respectively.

To demonstrate this effect, Sabancı University researchers have used the structures that are shown in Fig. 1. This figure illustrates the schematic representation of the solar cells when honeycomb nanoantennas are embedded in c-Si and P3HT:PCBM/PEDOT:PSS solar cells, with active layer thicknesses of 50 nm and 100 nm, respectively.

In the literature, plasmonic nanostructures have been shown to increase the absorption efficiency in thin film solar cells via various mechanism, which include: (i) scattering of light by resonant plasmonic nanoparticles in active material at large

angles to efficiently trap light in the active layer, (ii) increasing field intensity by localized plasmon modes around plasmonic nanoparticles embedded in the active layer, and (iii) trapping light by coupling it into surface plasmon polaritons propagating on the back metal-active layer interface. In this research, Sabancı University researchers identified that the localized modes are primarily responsible for the absorption enhancement with the honeycomb structures.

An additional crucial finding in this research is identifying the modes that are related to absorption enhancement in solar cells. Sabancı University researcher have demonstrated that the transverse modes are responsible for the enhancement in c-Si solar cells, whereas both the longitudinal and transverse modes, albeit weaker, are the main enhancement mechanism for P3HT:PCBM/PEDOT:PSS solar cells.

Improving Energy Efficiency in Buildings through Nanoparticle Coatings

A significant portion of energy consumption occurs in residential and nonresidential buildings. Improving the energy efficiency in buildings can have a significant impact on energy consumption. As a result of this need, engineering smart coatings to improve the energy efficiency of buildings is a crucial area in reducing the energy deficit. Sabancı University researchers have demonstrated novel nanoparticle coatings, through which the absorption and reflection of surfaces can be engineered to the desired properties. Such coatings can substantially improve the energy efficiency in buildings.

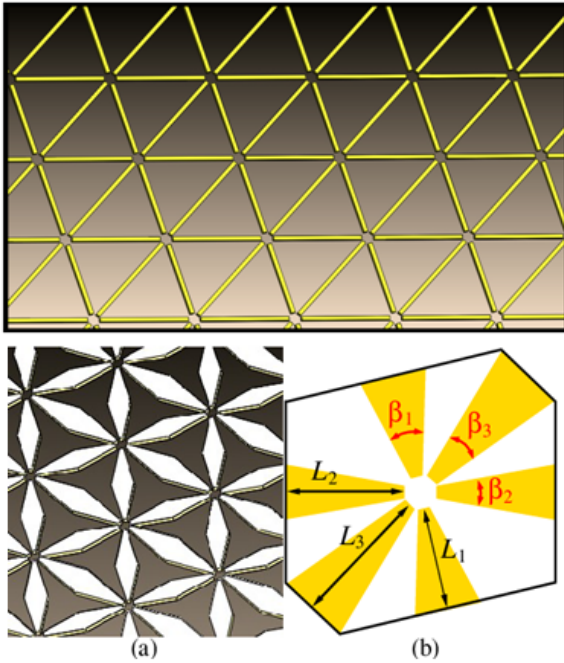


Figure 1: Schematic illustration of the nanoparticle coatings to improve energy efficiency.

Novel nanoparticle coatings on buildings need to operate over a wide spectrum to improve the absorption and reflection profiles of buildings. Such nanoparticle coatings are promising candidates to improve the energy efficiency of build-

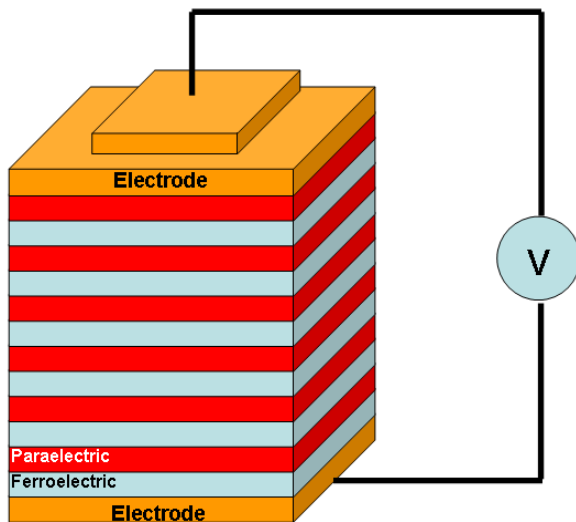
ings. While promising, achieving such novel nanoparticle coating is challenging because they require spectral engineering over a broad energy spectrum. To achieve such absorption and reflection profiles over a broad spectrum, Sabancı University researchers have used close-packed nanoparticle arrays due to the strong correlation between the particle geometry and hexagonal grid, particle coupling within unit cells, and interaction between neighboring unit cells.

Sabancı University researchers have demonstrated that the spectral distribution of large scale surfaces can be effectively tailored over a wide-band spectral range using close-packed nanoparticle coatings. Sabancı University researchers unveiled the coupling-mechanisms responsible for the spectral response of the nanoparticle coatings and they demonstrate the geometrical restrictions limiting the bandwidth of the spectral response.

To overcome these limitations, Sabancı University researchers have proposed a more general nanoparticle coating made up of a honeycomb structure by introducing additional morphological parameters within the Wigner-Seitz unit cell. The proposed morphological parameters provide additional flexibility for manipulating the spectrum by relaxing geometrical restrictions due to a strong correlation between the unit-cell and nanoparticle morphology. Furthermore, Sabancı University researchers achieved spectral broadening by breaking the symmetry within a Wigner-Seitz unit cell on a hexagonal grid, rather than breaking the symmetry of the hexagonal grid itself via generalized honeycomb arrays. In addition, the Sabancı University researchers demonstrated the advantages of close-packed arrays in terms of spectral response and electric field enhancement over large surfaces.

Oxide-oxide artificially layered structures for high density, high power capacitors

Storing high densities of charge in confined volumes such as electronic circuits is becoming an increasingly demanded but also challenging need in ever shrinking devices. Burç Mısırlıoğlu of Sabancı University together with his collaborators Arkadi Levanyuk (University of Washington) and Pamir Alpay (University of Connecticut) has shown the possibility to obtain very large dielectric response from sub micron ferroelectric-paraelectric artificially layered, periodically repeating structures, namely superlattices.



Such structures are on the agenda of research groups for charge storage in confined volumes but have often been studied with unrealistic assumptions and speculations. A full realistic treatment and understanding of these materials is unavoidable as with any other serious attempt for device design, which has become the main emphasis of this research followed by the prediction of very interesting properties of these systems.

Understanding how such structures achieve dielectric constants of a few thousand in a relatively wide range of temperatures is far from trivial. Ferroelectric oxides have a “intrinsic” polarization (permanent electric dipoles, a property only a handful of materials possess) that gives these materials their unique features. Measuring dielectric constant values around 100 or 200 from these materials is common practice and values of a few thousand can be reached near

a critical temperature at which the ferroelectric polarization ceases to exist. Ferroelectric oxides such as BaTiO_3 and PbTiO_3 have rather high critical temperatures but doping these materials with other elements such as Sr that replace Ba and Pb atoms in the material have come about to be a way to reduce the critical temperature to near room temperature where very high dielectric response becomes a possibility. Very high density capacitors thus become a possibility.

Another option to precisely control the composition and therefore the properties is to engineer layered structures such as a layer of BaTiO_3 followed by another layer of SrTiO_3 and repeat the same process as many times as needed. While this is possible with today’s modern processing equipment and techniques, predicting what the final properties and the capacitance (ability to store charge) of such a construct will turn out to be is not straightforward. How many layers does one need? Moreover, it is not even clear to the skeptical researcher right away whether high dielectric response is achievable by bringing two materials into contact in a periodic manner with each layer having a dielectric constant of around 100. It turns out that exposing the layers to one another as often as possible leads to stronger interactions between the layers that is mostly of electrostatic origin. It is this simple electrostatic interaction that triggers highly non-linear phenomena in the layers.

In this research, using a thermodynamic approach, we were able to correlate the capacitance behavior of such structures to the number of layers needed, how thick each layer should be and the mechanism behind the experimental observation of dielectric constants at the order of thousands in these artificially engineered materials. We tried to address the question: How can one get a dielectric constant of a few thousand from two insulating materials with each having a dielectric constant not exceeding 100 or 200? The answer to this question lies within the small, periodic structural distortions occurring in the ferroelectric layer upon contacting the non-ferroelectric one. The nature

of the interface between the two materials dictate the ferroelectric layers to form alternating polarization patterns propagating through the planes of the layers, namely “domains” which are absolutely responsible for very large dielectric responses that can be obtained from these structures. There exists a range of thickness and layer period when these “domains” in the ferroelectric layer can easily be manipulated to give rise to unprecedented dielectric constant and

therefore capacitance even in very small volumes. We also demonstrated that this is a different mechanism than what has been obtained via doping of pure ferroelectrics. Our results point the way to fabricate submicron structures with very large dielectric constants for high density charge storage in low energy consumption devices and microelectronics in addition to tunability of properties depending on the need.

Contact: Assoc. Prof. Burc Misirlioglu

Energy Efficiency with Nanostructured Surfaces-Pool Boiling Applications

With the miniaturization of electronic devices, the functionality of such devices greatly increased due to the improvements in their packaging. While benefiting from miniaturization process, heat dissipated per unit area by such devices significantly increased. Therefore, the development of more effective and equally miniaturized cooling systems with enhanced surfaces generated by micro/nanostructures became a priority in order to preserve the functionality and stability of such devices.

An experimental study was conducted to investigate the effect of nanorod length on pool boiling heat transfer of water from nanostructured surfaces.

Three nanostructured plates featuring Si nanorods of three different lengths (900, 1800 and 3200 nm), which were etched through single crystal p-type silicon wafers using metal-assisted chemical etching (MaCE), were utilized to enhance pool boiling heat transfer. A visualization study on bubble formation and release from individual plates was conducted using a high speed camera to bolster the experimental results. The novelty of this study lies on its separation of the effect of varying nanorod length on heat removal performance in pool boiling.

This study proves positive effects of utilizing nanostructured plates on pool boiling heat transfer and reveals the effect of nanorod length on boiling heat transfer performance. Significant enhancement in heat transfer coefficients in boiling regions (up to 254 %) is achieved using nanostructured plates with Si nanorods.

Due to the increased active nucleation site density, and heat transfer area, nanostructured surfaces could enhance boiling heat transfer performance. Nanostructured surfaces significantly increase the bubble release frequency. As the length of the nanorods increases, the enhancement in heat removal performance deteriorates with the decrease in the bubble release frequency. Further enhancements with optimization studies using important nanorod parameters (nanorod size, spacing and length) are possible so that performance enhancements could become comparable to the existing commercially

available enhanced surfaces. SEM images of the plates after the tests are obtained in order to prove the durability of the nanostructures under stringent operating conditions of this study.

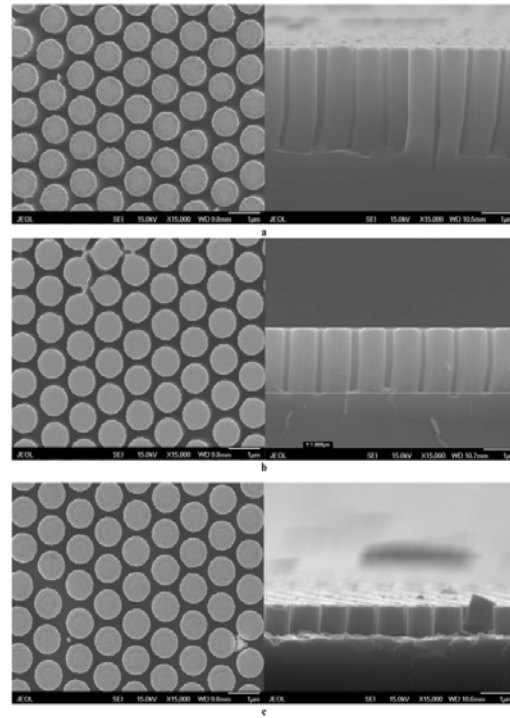


Figure 1: Top-view and cross-sectional view Scanning Electron Microscope (SEM) images of single crystal-line silicon nanorods a) After 160 s etching (3200 nm rods) b) After 80 s etching (1800 nm rods) c) After 40 s etching (900 nm rods)

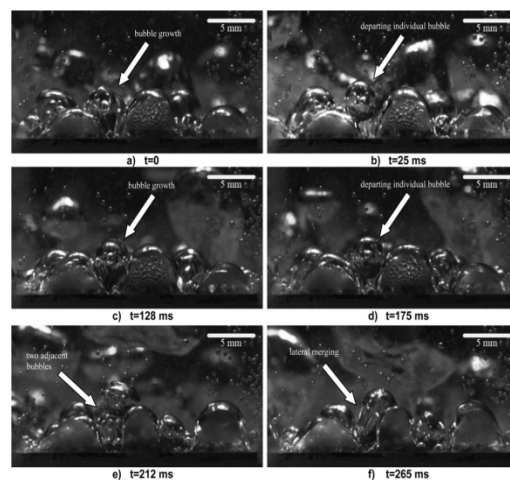


Figure 2: Boiling over Nanostructured surfaces

Energy Efficiency with pHEMA Coated Surfaces

Recently, the size of fluidic systems is shrinking from macro to micro size leading to more compact systems. Such emerging microfluidic systems find many applications in many areas such as electronics cooling, chemical reactors, micromixers, biotechnology, drug delivery, micropropulsion, and fuel cells. Due to their extensive use and need, heat and fluid flow in such microfluidic systems attracted attention of many scientists, so that many studies were performed in this promising field.

First generation microfluidic systems consisted of plain microchannel configurations. Heat and mass transfer and fluid flow in such plain microchannel systems have been extensively studied in the last decade. Although there remain still many issues with plain microchannels, the state-of-the-art knowledge in the field is such that the heat transfer community is ready to face new challenges. Moreover, there is a strong need for more sophisticated second generation microfluidic systems to have a better performance. This project addresses this lack of information about second generation microfluidic systems having microchannels with modified surfaces.

Flow boiling in mini/microtubes was investigated with surface enhancements provided by crosslinked polyhydroxyethylmethacrylate (pHEMA) coatings, which were used as a crosslinker coating type with different thicknesses (~50 nm, 100 nm and 150 nm) on inner microtube walls. Flow boiling heat transfer experiments were conducted on microtubes coated with crosslinked pHEMA coatings. pHEMA nano-films were deposited with initiated chemical vapor deposition (iCVD) technique. De-ionized water was utilized as the working fluid in this study. Experimental results obtained from coated microtubes were compared to their plain surface counterparts at two different mass fluxes (5.000 kg/m²s and 20.000 kg/m²s), and significant enhancements in Critical Heat Flux (up to 29.7 %) and boiling heat transfer (up to 126.2 %) were attained. iCVD was proven to be a very practical method for pHEMA coatings in micro scale channels/tubes.

Crosslinked pHEMA coating improves boiling heat transfer performance and increases the energy efficiency since it increases the nucleation site density by offering more active nucleation sites due to its porous structure, raises bubble generation fre-

quency from the surface, and improves liquid replenishment to the surface after bubble departures. pHEMA coatings could improve boiling heat transfer for micro scale cooling applications, where enhancement may be not possible with common surface enhancement and microfabrication methods.

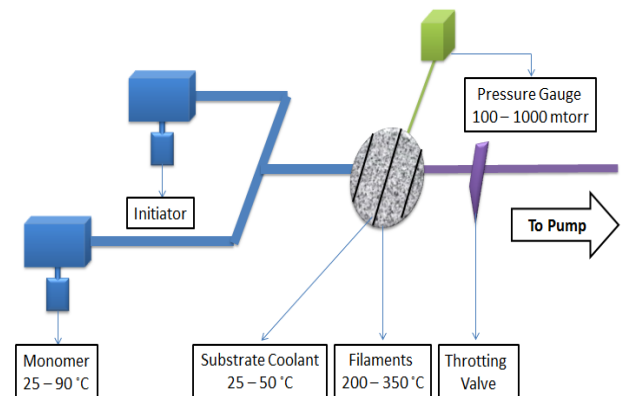


Figure 1: iCVD method implemented in this study

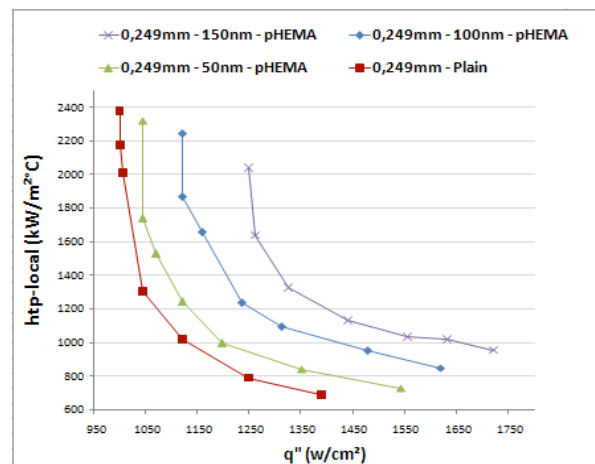


Figure 2: Two phase heat transfer coefficient for plain surface microtubes and pHEMA coated microtubes (50nm, 100nm and 150nm thick coatings) with an inner diameter of 249 μm at the mass flux of 5,000 kg/m²s.

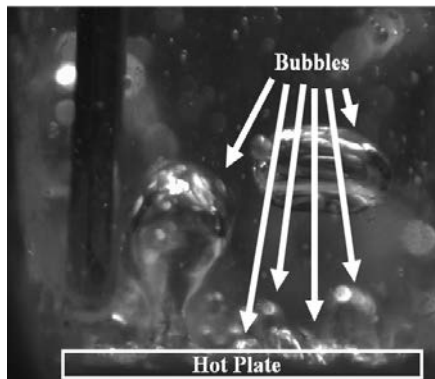


Figure 3: pHEMA coated surface

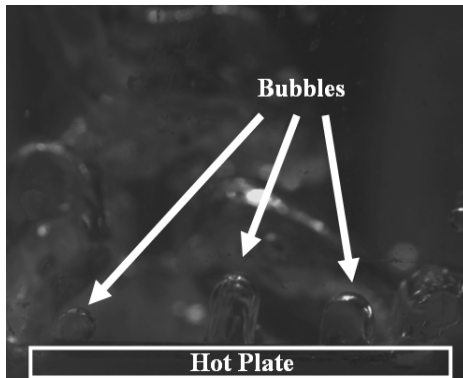


Figure 4 : Plain surface

References:

Cikim, T., Armagan, E., Ozaydin-Ince, G., and Koşar, A., "Flow Boiling Enhancement in Microtubes with Crosslinked pHEMA Coatings, Having Different Coating Thicknesses" *Journal of Heat Transfer*, 136, 081504, 2014.

Kaya, A., Demiryurek, R., Armagan, E., Ince, G., Sezen, M., and Koşar, A., "The Boiling heat transfer enhancement in mini/microtubes via polyhydroxyethylmethacrylate (pHEMA) coatings on inner microtube walls at high mass fluxes," *Journal of Micromechanics and Microengineering*, 23, 115017, 2013.

Heat Transfer Enhancement in Microtubes with Nanofluids for Energy Efficiency

Nanofluids are now a new category of fluids consisting of uniformly dispersed and suspended nanometer-sized particles in a base fluid. From literature review it is understood that possible heat transfer enhancement and/or deterioration of nanofluids is still a heated debate particularly for laminar flows. Compared to micro/mini-particle-liquid suspensions for heat transfer enhancement, nanofluids have better performance due to more heat transfer surface between solid and liquid, high dispersion stability, reduced pumping power, reduced particle clogging, and adjustable thermal properties and surface wettabilities by varying particle concentrations.

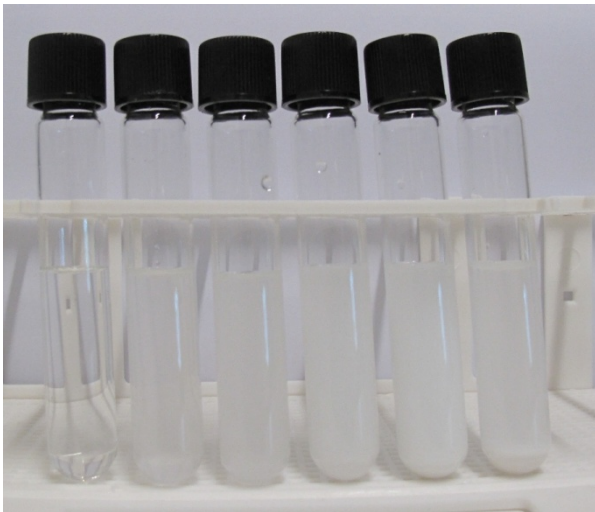


Figure 1: Al_2O_3 nanofluids, for 0.01, 0.1, 0.5, 1, 2, and 3%, weight fractions

Addition of nanoparticles affects the thermophysical properties of nanofluids. Compared to conventional solid-liquid suspensions, nanofluids possess advantages such as high specific surface area and more heat transfer surface, high dispersion stability, reduced pumping power, reduced particle clogging, improved thermal conductivity, and surface wettability. Heat and fluid in microscale is common in many applications such as microelectronic cooling of electronic chips, micro heat exchangers, bioengineering, human genome project, automobile industry, power generation systems, heating, air-conditioning, and chemical engineering.

There are a large number of studies in literature related to convective heat transfer characteristics

of nanofluids in mini/microchannels. However, the results are still contradicting to each other. Thus, the objective of this study is to characterize the nanofluids and to analyze the effect of nanoparticles on conventional fluids in industrial applications such as refrigeration systems. The need for high heat transfer rates in many engineering devices used in microelectronics, energy industry, transportation, and optoelectronic industries such as plasmonics and thermophotovoltaic cells led to the development of smart engineering designs and/or efficient and high performance heat transfer fluids.

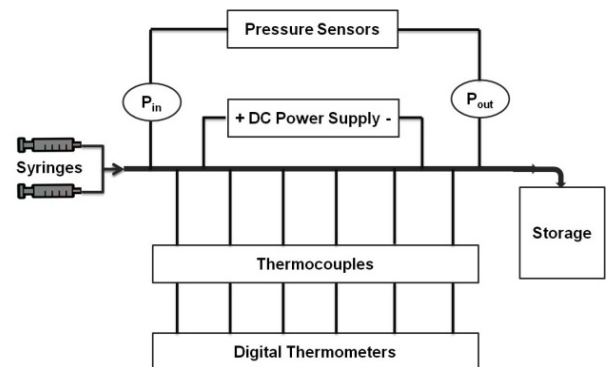


Figure 2: Experimental Setup

Pressure drop and heat transfer characteristics of water-based nanofluids with TiO_2 and Al_2O_3 nanoparticles are investigated in horizontal smooth hypodermic microtubes over a wide variety of Reynolds numbers and nanoparticle mass fractions under thermally developing flow conditions. Experimental friction factors and heat transfer coefficients could be predicted within $\pm 10\%$ and $\pm 15\%$, respectively, by considering appropriate thermophysical properties of nanofluids and using existing correlations in the literature. Experimental results show that mass fraction is not effective over heat transfer coefficient for Reynolds number less than 1200, beyond which heat transfer coefficients increase with mass fraction. As Reynolds number increases, flow starts to transition to turbulent flow, and as a result, heat transfer enhancement becomes detectable, which is due to enhanced mixing of nanoparticles at higher Reynolds numbers. While the stability of nanofluids is preserved after the experiments, a gradual agglomeration of nanoparticles in nanofluids

might occur with time and might be accelerated with their repetitive use in the experimental setup and at elevated temperatures. Therefore, methods for improving their stability should be developed so that implementation of nanofluids to commercial products such as refrigerators and heat exchangers would be possible.

oped so that implementation of nanofluids to commercial products such as refrigerators and heat exchangers would be possible.

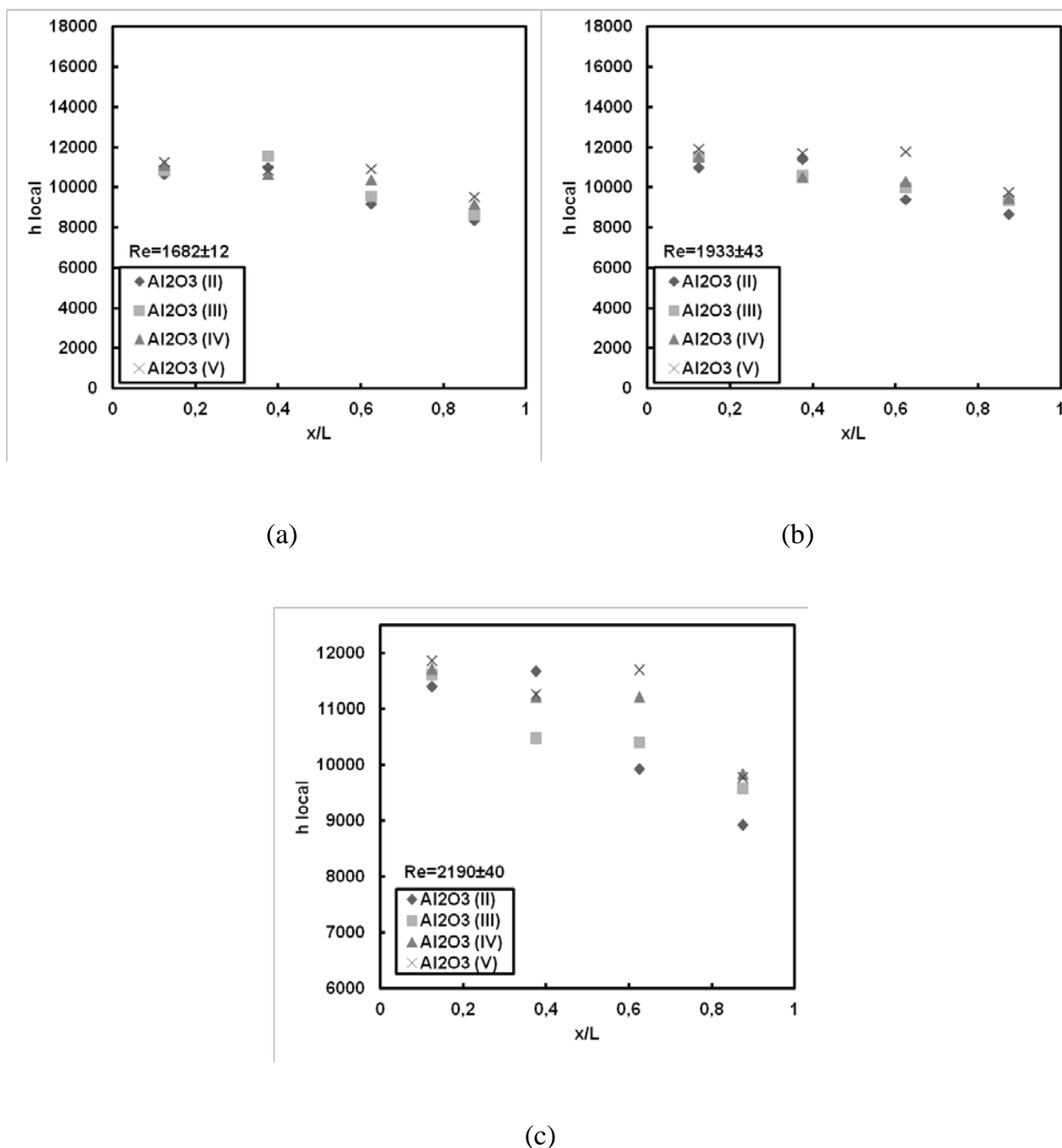


Figure 3: Results: Local heat transfer coefficients of nanofluids with Al_2O_3 nanoparticles at higher Reynolds numbers

Micro Scale Cavitation and its Energy Efficient Biomedical Applications

Hydrodynamic cavitation is mostly an undesired phenomenon in turbomachinery since it limits the performance of the fluidic system, causes catastrophic damage, flow choking and acoustic noise, and lowers the efficiency. However, it could be used for good means in small scale.

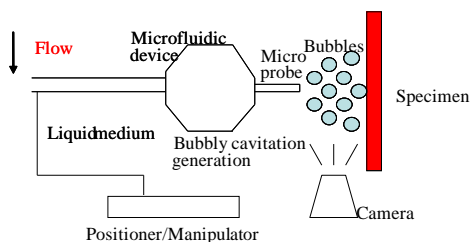


Figure 1: Concept

In this study, continuous bubbly cavitating flows with the design of a microfluidic device (bubble generator) were generated. The emerging bubbles were exposed to a small target area (kidney stones, cells in culture, human tissues). Macroscopic, microscopic and nanoscopic (e.g. molecular) changes in the target area using both biology and surface characterization methods were monitored.

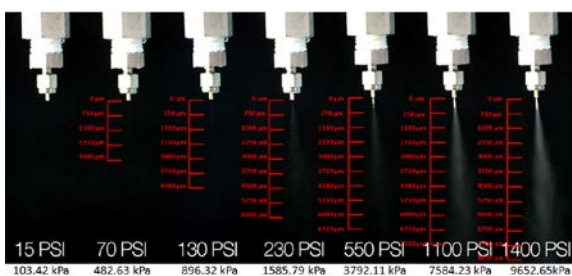


Figure 2: Bubble cloud emerging from the probe exit at different cavitation intensities

This size of micro-orifice was chosen to enable visualization of microbubbles emerging due to bubbly cavitating flow by a simple digital camera. The material involves a sheet of protection and has high resistance to corrosion thus it can be used in applications that require sensitivity.

The tests were conducted by applying different inlet pressure values at the inlet. The flow rate was controlled with a fine-metering valve. Various

inlet pressure values were applied during the tests in order to observe the result at increasing pressure differences until bubbly cavitating flow pattern is obtained.

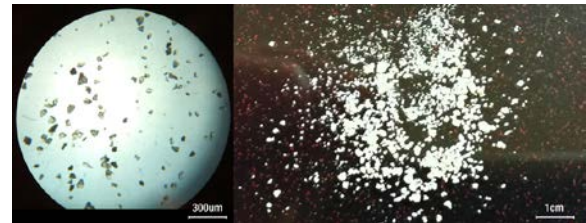


Figure 3: Kidney stone debris

It was observed in kidney stone experiments that the targeted application of the erosion with micro scale hydrodynamic cavitation causes the fracture of the kidney stones within a short time of 30 min. Moreover, micro scale bubbly cavitation caused cell death in two different cancer cell types in culture, and cell death kinetics depended on the exposure time to cavitation. In addition to cancerous cells, the destructive effect of hydrodynamic cavitation was investigated on human tissues. Hydrodynamic cavitation exposure resulted in a deep cavity on the targeted area of BPH tissue without giving any damage to the surrounding area. All these new findings support the idea of usage of hydrodynamic cavitation as a novel therapeutic method for ablating tumor tissues.

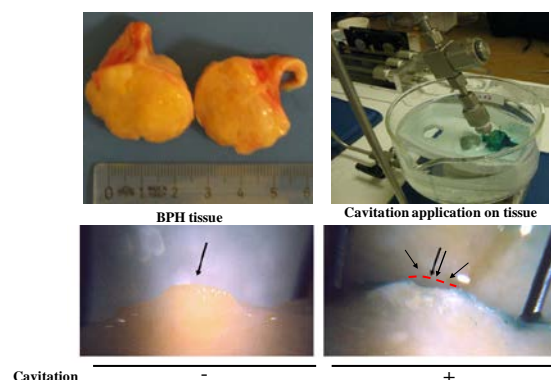


Figure 4: Cavitation on Benign Prostatic Hyperplasia

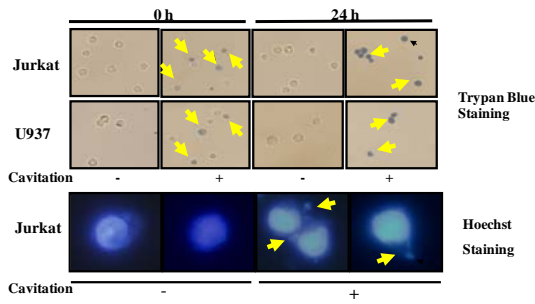


Figure 5: Cavitation leads to loss of cell membrane, possibly nuclear membrane integrity & DNA fragmentation

References:

Üzüşen, D., Perk, O.Y., Demir, E., Oral, Ö., Ekici, S., Ünel, M., Gözüaık, D., and Koşar, A., "Assessment of probe-to-specimen distance effect in kidney

stone treatment with hydrodynamic cavitation," ASME Journal of Medical Devices, Under Review.

Itah, Z., Kosar, A., Sesen, M., Ekici, I.D., Ekici, S., and Gozuacik, D., "Hydrodynamic Cavitation Kills Prostate Cells and Ablates Benign Prostatic Hyperplasia Tissues," Experimental Biology and Medicine, 238 (11), 2013.

Perk, O.Y., Şeşen, M., Gözüaık, D., and Koşar, A., "Kidney Stone Erosion by Hydrodynamic Cavitation and Consequent Kidney Stone Treatment," Annals of Biomedical Engineering, 40, pp. 1895-1902, 2012.

Koşar, A., Sesen, M., Oral, O., Itah, Z. and Gozuacik, D., "Bubbly Cavitating Flow Generation and Investigation of its Erosional Nature for Biomedical Applications", IEEE Transactions on Biomedical Engineering, 58, pp. 1337-1346, 2011.

Ferrofluid actuation for energy efficient micropumping and cooling applications

Magnetic actuation of ferrofluids with dynamic magnetic fields is one of the most important and promising research areas in biomedical and chemical analysis of microfluidics. Since, effective micropumping is a must for actuation of the sample into the microfluidics systems, magnetic actuation of the magnetic fluids can be used for this purpose. Our goal is in this project, achieving the high flow rate, portable and entegrable micropump design as well as to better understand the magnetic actuation by modeling of the system.

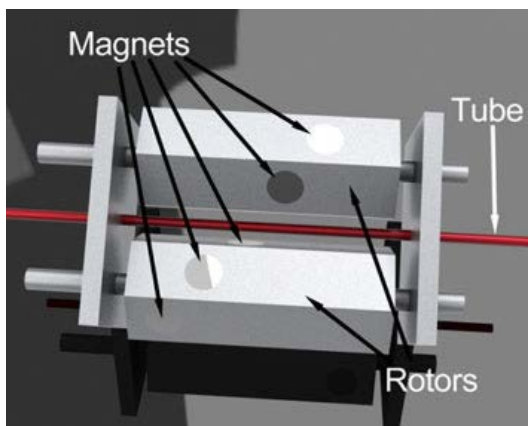


Figure 1: Design

In many actuation techniques, there are some limitations such as low flow rate, moving parts, requirement of high voltage. Additionally, most of them generates undesired effects on cell and proteins. This type of magnetic pumping technique could be used for various medical applications, including drug or hormone (e.g. insulin) infusion pumps, highly controllable intravenous liquid administration, accurate mixing of drugs.

In microsystems and lab on a chip applications, pumps are the main component of the fluidic system to deliver an assay to desired locations. But since conventional pumps are not suitable for micropumping applications, efficient micropumping technologies need to be investigated.

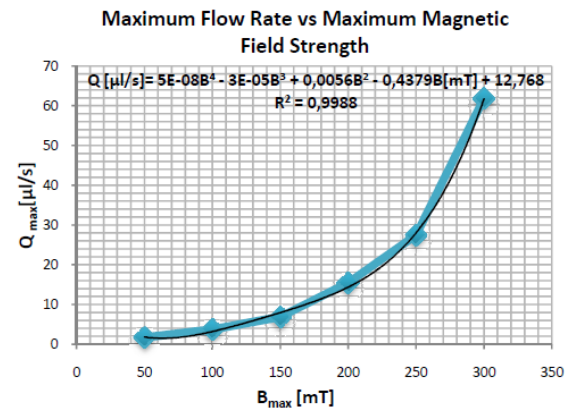


Figure 2: Flowrates

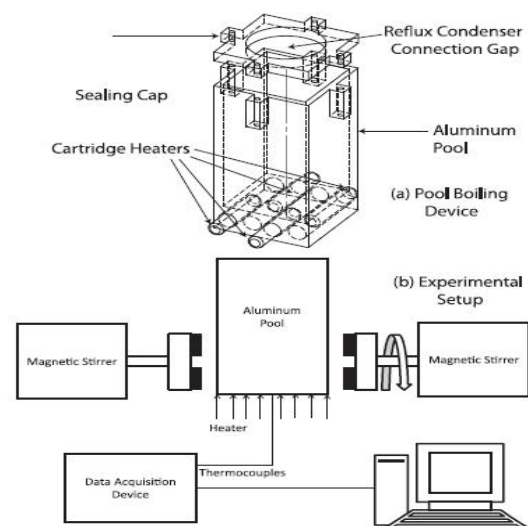


Figure 3: Heat enhancement with ferrofluids

A device producing varying magnetic field and thus actuating ferrofluids was designed and implemented. The magnet holders were placed in a frame and rigged to turn in the same direction with the same angular velocity. A plastic transparent minichannel was placed in between magnet holders, which contains the ferrofluid. With the rotation of the magnet holders, displacement of the ferrofluid was observed and the volumetric flow rate of the ferrofluid was obtained for different angular velocities of the magnet holders. Actuation was realized with a simple DC motor. The angular velocities were calculated from position data obtained from motor's encoder. Experiments were repeated for over 20 times and to

ensure the reliability of the results, the gathered data was averaged.

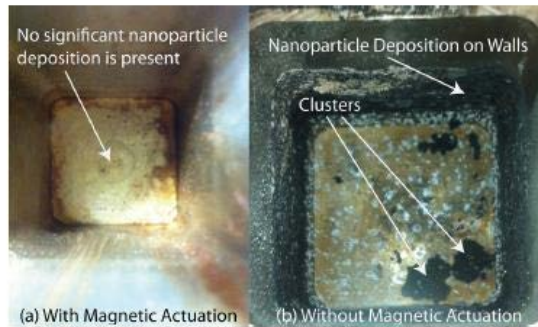


Figure 4: Surfaces with magnetic actuation

Significant flowrates could be attained using this technique so that it could be stated that this type of magnetic pumping technique can be a significant alternative for widely used techniques such as hydrodynamic, electrokinetic and piezoelectric actuation techniques.

The concept was also utilized for heat transfer enhancement with ferrofluids in a pool with varying magnetic fields. An average heat transfer coefficient enhancement of 37.5% was achieved with the magnetic actuation. Magnetic actuation could prevent clustering and sedimentation of the nanoparticles, which is undesirable in most cases.

References:

Kurtoğlu, E., Bilgin, A., Acar, H.F.Y., and Koşar, A., "Development of magnetic pumps based on ferrofluid actuation with varying magnetic fields for micropumping applications", *Microfluidics Nanofluidics*, 13, pp. 683-694, 2012.

Sesen, M., Sendur, K., Menguc, M.P., Yagci, Acar, H.F., and Koşar, A., "A Heat Removal System with the Actuation of Magnetic Nanoparticles", *Journal of Applied Physics*, 112, 064320, 2012.

Sesen, M., Teksen, Y., Şahin, B., Sendur, K., Menguc, M.P., Yagci, Acar, H.F., and Koşar, A., "Boiling Heat Transfer Enhancement of Magnetically Actuated Nanofluids", *Applied Physics Letters*, 102(16), 2013.

Kurtoğlu, M., Kaya, A., Gozuacik, D., Yagci Acar, H.F., and Koşar, A., "Experimental Study on Heat Transfer Performance of Iron oxide Based Ferrofluids to be Used as New Generation Coolants and Drug Delivery Agents", *ASME Journal of Thermal Science and Engineering Applications*, 6(3), 034501, 2014.

Effect of Nanostructure Distribution on Energy Efficiency of Thermal-Fluidic Systems

Heat and mass transfer and fluid flow in such plain microchannel systems have been extensively studied in the last decade. Although there remain still many issues with plain microchannels, the state-of-the-art knowledge in the field is such that the heat transfer community is ready to face new challenges. Moreover, there is a strong need for more sophisticated second generation microfluidic systems to have a better performance. This project addresses this lack of information about second generation microfluidic systems having microchannels with modified surfaces.

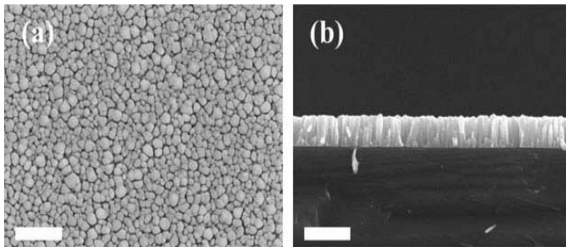


Figure 1: Nanostructures with random distribution

Different from the state-of-the-art, this study focuses on the effect of the configuration of nanostructures on the enhancement of boiling heat transfer so that their potential in performance enhancement could be exploited from a different perspective.

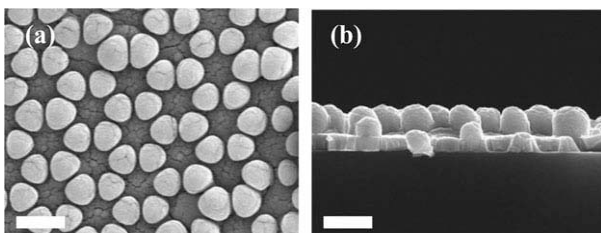


Figure 2: Nanostructures with periodic distribution

For this purpose, two configurations of nanostructured plates integrated into a rectangular channel are fabricated. The nanorod arrays are deposited utilizing glancing angle deposition (GLAD) technique on the copper thin film (~50 nm thick) coated on silicon wafer substrates. Dimensions of the test section, heat flux values, and flow rates are chosen to ensure that nanostructured plates remain intact along with their nanorods in their original shape and position, so that the nanostructured plates could be used for many experiments.

The first configuration consists of vertical Cu nanorods of length ~600 nm and average diameter ~150 nm with an average gap among the nanorods ranging from ~50 to 100 nm. These nanorods are grown in a randomly distributed manner on 50-nm-thick Cu thin film deposited on silicon substrates with a thickness of 400 μm . The second configuration has the similar Cu-film/Si substrate but involves periodic structures having ~600-nm-long copper nanorods with an average nanorod diameter of ~550 nm and a center-to-center nanorod separation of ~1 μm . It was observed that no damage and disturbance in the structural integrity of nanostructures was evident during the experiments, where maximum wall superheat was fixed at 30°C. Both nanostructure configurations of random and periodic nanorod arrays are successful to significantly enhance boiling heat transfer. A consistent increase (up to 30%) in heat transfer coefficients is observed on nanostructured plates compared to the Cu thin film, which is used as the control sample. No significant difference in the boiling heat transfer performance between the random and periodic nanorods was observed, which indicates that the distribution of nanostructures may not be very critical in achieving enhanced heat transfer. In light of the obtained promising results, channels with nanostructured surfaces are proven to be useful, particularly in applications such as cooling of small electronic devices, where conventional surface modification techniques are not applicable.

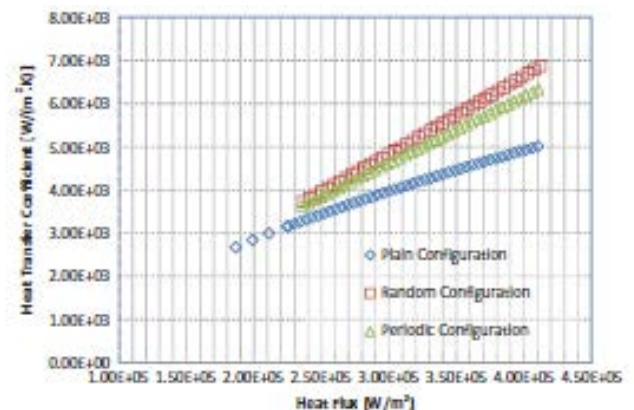


Figure 3: Boiling heat transfer coefficient

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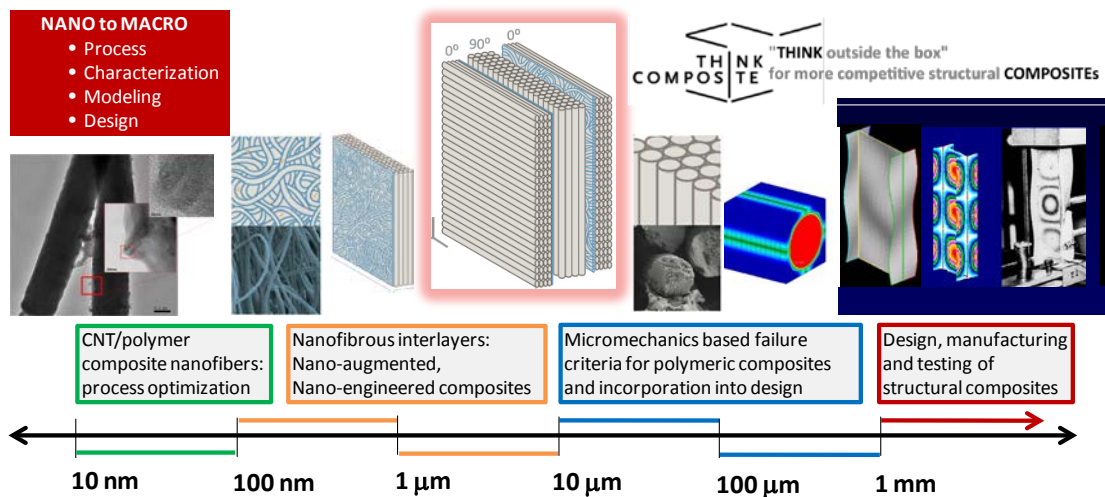
Demir, E., İzci, T., Khudhayer, W., Karabacak, T., and Koşar, A., " Subcooled Flow Boiling over Nanostructured Plates Integrated into a Rectangular Channel," Nanoscale and Microscale Thermophysical Engineering, 18, pp. 313-328, 2014. **Cover Article**

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"THINK outside the box" for structural COMPOSITES

Advanced composites have become indispensable resource in variety of fields including energy. They, for instance, have direct impact in the sector as the efficiency and performance of wind turbine based clean energy technology can be elevated by their optimal use. Nevertheless, advanced composites enable lighter structures for energy efficient vehicles of transportation without sacrificing the safety. Their undeniable potential calls engineers and scientists to push the boundaries of broad composites research and develop-

ment for making them even more competitive and promising for stringent energy needs of the society. That is, we are urged to "think outside the box" practices with advancing manufacturing and characterization techniques and software specialized on composites as opposed to traditional lay-ups, materials and production. In the context of multi-scale engineering of composites, a couple of THINKCOMPOSITE concepts that can be implemented in the design of wind turbine blades and structures of vehicles is explored.



Nano-enhanced/augmented structural composites: The concept realized by nanofibrous interlayers may find extensive use in nearly all light-weight structural applications, where advanced composites are necessary, such as in aerospace, automotive and energy. They can be easily incorporated into existing manufacturing processes and provide substantially enhanced properties, while the weight and thickness increase associated with interleaving is nearly negligible. Additionally, with the possibilities for combining the right selection of particles/fillers, the toughening

performance can be further enhanced for both in- and out-of-plane loading conditions. Moreover, their full potential is even higher with multi-functional possibilities, such as tuning of mechanical, thermal and electrical properties by the right choices of nanofiber and filler combinations and proportions. With a complete understanding of impact on properties by using the nanofibrous interlayers, the opportunities are plentiful for developing characterization and scaled-up production capabilities and integration of the nanofibrous materials into conventional composite engineering design frameworks.

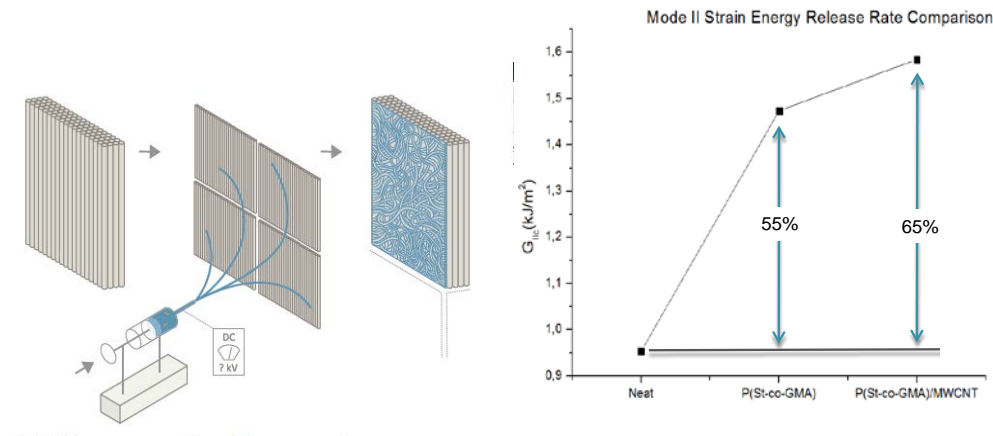


Figure: Enhanced mechanical properties by nanofibrous interlayers.

Design of and with non-crimp fabric (NCF) as building blocks for composites: New generation non-crimp fabric (NCF) offers an attractively thin and lightweight building block alternative in the design of composite materials and structures. Pre-assembly of multiple plies of parallel fibers, each laying in a different orientation would not require crimping of the fibers and would enable a one-axis lay-up that can substantially reduce the labor, scrap and manufacturing costs. A state-of-the-art tow-spreading technique enables ply thickness to be reduced to as low as one-third of the typical

commercial high quality pre-preg ply thickness. Bi-angle thin-ply NCF offers two different fiber orientations (with one being off-axis) and designing in anisotropic properties within the conventional one-axis ply thickness. In our quest for simultaneous weight and cost reduction at maximum performance of composite structures, the thin-ply bi-angle NCF building block incorporates the simultaneous design of anisotropic properties and structure, as opposed to more traditional composite designs, which typically imitate metals or materials with isotropic behavior.

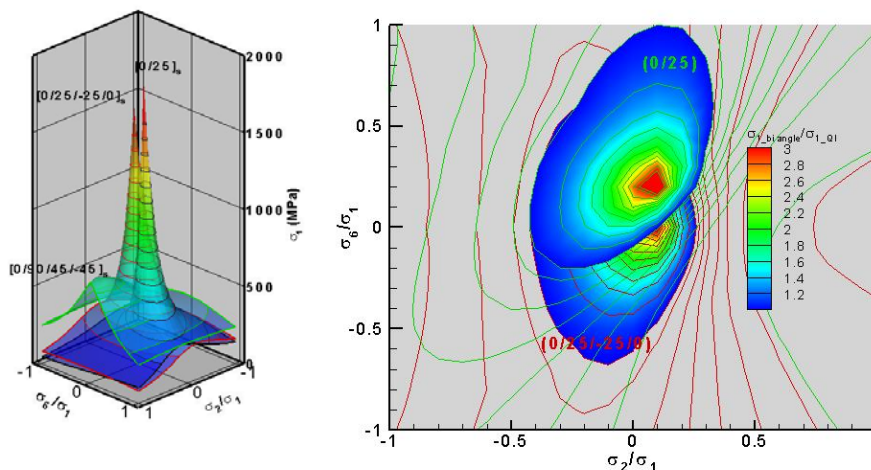


Figure: Comparison of Tsai-Wu failure surfaces for laminates of traditional (0/45/90/-45) versus shallow angle (0/±25/0) and (0/25) stacks.

Renewable & energy efficient systems

- *Linear motor design for vertical applications*
- *PEM fuel cells*
- *Vertical axis wind turbines*
- *Control of double fed electrical machine (DFIG)*
- *Hybrid renewable energy system in microgrid*

Linear Motor Design for Vertical Applications

Modern buildings are reaching ever new heights. A kilometer high building is now on the table. The difficulty with going higher is not that of structural integrity. Rather, it becomes more and more difficult to transport more people, goods, water, electricity and services to the top floors through the building base area which stays the same. Larger and larger holes area of each floor must be sacrificed for elevators, pipelines, power etc. In the extreme case, the lower floors cannot be used for anything except as a passage to higher floors, and it does not make sense to build any higher.

The most problematic is elevators. It is not uncommon for high-rise buildings to have nearly 50 elevator hoistways. One of the most promising solutions to decrease the area lost to elevators is to use the concept of multi-car elevators; running several elevator cars in each hoistway. This is not possible with conventional cable driven elevators because the cable gets in the way. However, if the cable is eliminated, and the elevator car is made self-propelled, this becomes possible.

Researchers at Sabanci university have developed linear motor propelled elevator systems where the armature of the elevator traction motor is on the elevator car and the stator is attached to the building and spans the whole hoistway. The elevator car is propelled by the magnetic field generated in the stator, completely eliminating the cable. Through this enabling technology, multi-car elevator systems become a possibility, together with the design of ever higher buildings, and also those with a curvature!

We have designed, built and tested full scale vertical linear synchronous motors for a Japanese major elevator company. Proposed new methods which drastically cut down the design time of the magnetic components of the motor (the parts that are seen as "the motor": stator and mover geometries and material, winding design etc), with respect to optimizing costs of materials, motion parameters such as speed, torque, vibration etc. We have also designed and implemented the control algorithms, the power electronics, mechanics and other components relating to the design of the complete linear motor. The design of linear motors for vertical applications is more

difficult than horizontal applications because the requirement to minimize the motor dead-weight causes the design process to be highly nonlinear.

The project has other implications exceeding



simply the design of linear motors:

Kilometer-high skyscrapers are within reach

Power Efficiency

Linear motor driven elevator systems do not have counterweights as in conventional elevator systems, and they are made to carry smaller payloads. The power required during operation is carefully balanced where elevator cars going up are partly powered by the recovered energy from those going down. Having smaller cars, the system does not need to move large dead-weights for a small number of people traveling. Overall, this means that the power required by the elevator systems can be smaller than conventional elevators.

The energy efficiency is improved because of high performance motor controllers that are distribut-

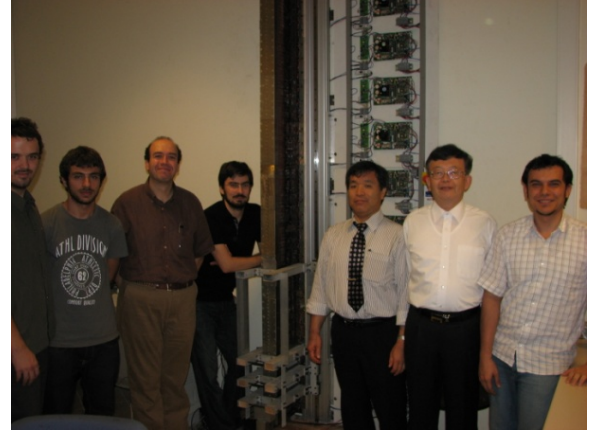
ed along the building and those which are switched on only when necessary.

Energy Storage

Since elevator cars do not have counter-weights, it is possible to store potential energy in the system by raising many of the elevator cars to higher floors using low cost electricity for example in the night, and later use the stored energy by dropping those cars in a controlled fashion in the morning rush hour to supply power to the rest of the cars.

We are also considering the possibility of using the stored potential energy in the system by using dedicated dead-weights at the top of each hoistway for an emergency such as a power outage to provide short term power to

supply the building emergency systems. We are looking for industrial partners for such applications.



Project Team

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PEM Fuel Cells

Owing to high energy efficiency and density, polymer electrolyte membrane fuel cells (PEMFC) are very attractive for transportation and stationary applications. However, commercialization of the PEMFC technology is hindered by problems such as high cost, complexity of the system, and durability of the polymer membrane, electrode and catalyst materials. As an improvement for automotive applications and to decrease the cost and the complexity of the system, in dead-ended anode (DEA) operation, the anode side is simplified by using dry hydrogen at the inlet with pressure regulators and shut by solenoid valves at the exit. However, in DEA operation, nitrogen in the air on the cathode side permeates through the thin polymer membrane and accumulates in the anode channels blanketing reaction sites and causing local hydrogen starvation, which leads severe voltage transients and the carbon corrosion in the catalyst layer on the cathode side. According to our experiments and modeling results, an ultra low flow rate in the anode does not hinder the hydrogen utilization, but is enough to release the nitrogen that accumulates in the anode, and remedies transient drops in the cell potential.

In a current project funded by TUBITAK, we are developing a PEMFC that consists of approximately 10 cells with a large active area (approximately 400 cm²), delivers about 3 kW at ultra low stoichiometric flows at the anode exit. Computational models are used to design flow and cooling channels, which are appropriate for these operating conditions and the thermal management system.

Moreover, the project includes development of alternative materials for the membrane, electrodes and the catalyst layer to address adverse effects of the targeted operating conditions and the high cost of PEMFC systems. Against the membrane dry-out, degradation and pinhole deformation, high temperature polymer membranes will be developed. Against carbon corrosion, platinum nano particles will be placed inside carbon materials such as carbon fiber, graphite and carbon aerogel in order to improve the structural and electrochemical durability of the catalyst material. In order to reduce the cost of the platinum, Pt-Cu nano particles will be used as catalysts. Materials that are developed and characterized will be tested in a small single-cell PEMFC operating at DEA and ultra-low anode stoichiometric flow conditions.

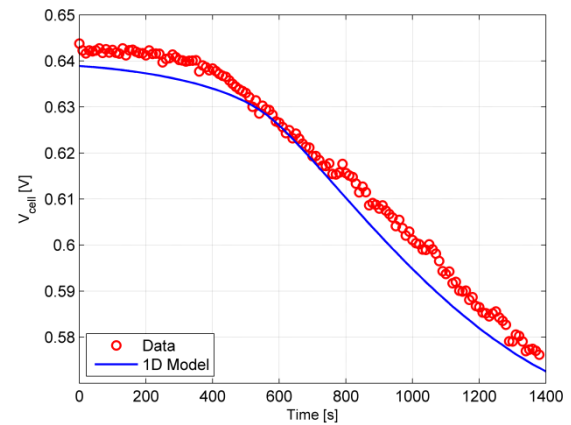


Figure 1: Model vs. experimental data for the DEA operation of an experimental single-PEM-cell.

Vertical Axis Wind Turbines

In the presence of ever visible effects of global climate change, small scale wind turbines are considered as viable renewable systems. Horizontal axis wind turbines (HAWT) are popular for grid-connected power generation. Yet there is an increasing demand for small-scale portable power generation, typically away from the grid and provided by diesel generator and small scale photovoltaic panels. Small scale vertical axis wind turbines (VAWT) can be used as power supplies for telecommunication towers, recreational and military camps away from the population. Moreover silent and aesthetic VAWT prototypes are attractive for urban use as well. Unlike HAWTs, VAWTs are omnidirectional and can obtain higher capacity factors in near-the-ground installations where the direction of the wind is more erratic than higher altitudes.

There are two types of VAWT designs: drag-based and lift-based. In the drag-based Savonius design, drag force on the blades is asymmetric and wherever the wind blows the imbalance of forces yield a net torque on the rotor. Drag-based turbines are usually very low in aerodynamic efficiency. Lift-based Darrieus-type VAWTs can have higher efficiencies up to the Betz limit in high angular velocities of the rotor, which comes in different shapes.

The VAWT design that we are working on has the following features: an efficient blade profile and the chord length obtained from CFD simulations coupled with the dynamics of the rotor; blades that are made of cheap light-weight and durable composite materials for; and a model-based controller for maximum energy generation for given

wind conditions. Generic turbulence models such as k-epsilon and k-omega are used in the time-dependent two-dimensional CFD models coupled with the dynamics and control of the rotor to obtain an optimum design. The profiles that satisfy aerodynamic efficiency requirements are built from shell-spar-foam type composite materials. Static and dynamic structural analysis of the blades and other components of the rotor such as the shaft and the arms are conducted to obtain appropriate profiles of the beams used in the design.



Installation of the experimental test-bed by research personnel in SU campus.

Control of Double Fed Electrical Machine (DFIG)

This project examines different control strategies for DFIG machine used as a generator in wind energy system. Renewable energy sources, especially wind energy conversion systems (WECS) are becoming more and more popular due to rapid consumption of fuel resources in recent years. Doubly fed induction generator based wind turbines are very advantageous because of its four quadrant active and reactive power flow capability and reduced power converter sources. For example, stator active and reactive power can be controlled with a 30% power rated rotor side converter at ± 0.25 slip variation. Robustness of

any implemented control structure can easily be lost due to nonlinearities, variations in the DFIG parameters and network voltage failures. In this project we examined the controller structures that do not need information on machine parameter dependent terms. Instead we use simple disturbance observer to evaluate compensation terms. In addition we design controller in the stator voltage frame of references what gives us simpler and more reliable structure. The laboratory setup is developed for verification of the results.

Hybrid Renewable Energy System in Microgrid

Renewable energy sources appeared as a viable alternative for environmentally hazardous sources. However, sources of renewable energy have considerably unpredictable and environmental conditions dependent power output and as such can't be directly incorporated into existing electrical grid. These sources are usually integrated to the electrical grid as part of microgrid or hybrid energy source that consists of two or more energy sources, converters and/or storage devices. In hybrid energy sources, generation and stor-

age elements complement each other to provide high quality and more reliable power delivery. The main work in this project is oriented towards defining a generalization of control problem for power electronics interfaces in hybrid energy source, the development of control for grid connected three phase switching converters and the development of a maximum power point tracking algorithm that can be easily incorporated into hybrid source control.

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Energy Economics, Policy and Markets

- *Modeling generation company interactions in power markets*
- *An integrated decision support for the energy policies of Turkey*

Modeling Generation Company Interactions in Power Markets

In this research, we focus on the strategic interaction among a number of power generation companies (generators) at a generic trading floor in an electricity market (which can be exemplified with the day-ahead market). Such a trading floor is observed in a deregulated the power industry; each generator submits bids to generate power periodically, e.g. for every hour of the following day in a day-ahead market. The Independent System Operator (ISO) collects the bids, and solves an optimization problem to determine the power to be dispatched from each generator, and the electricity prices at different locations in the power grid.

We aim to understand how the collective bidding behavior of generators evolves over time and if it particularly evolves to an undesirable outcome such as a collaborative collusion among the generators. This is an important subject of inquiry because the power dispatched from, and the profit of every generator depends on the bids of all generators in the market. Based on existing work in literature (such as Krause et al. 2004, Weidlich 2008, Bakirtzis and Tellidou 2006) we have developed an agent-based simulation model where the generators are modeled as adaptive software agents. The agent-based simulation approach offers the flexibility required to model this dynamic market, for instance, the ability to model heterogeneous generators with different production capacities, marginal costs, and behavioral parameters. Such flexibility is often not possible with traditional analytical models.

The agent-based approach also allows us to model the learning behavior of generators. The price to bid is not a trivial choice for a generator, because the best bid for a particular period of a repetitive trading floor depends on the bids of other generators in the system. The generator knows neither its competitors' bids nor their marginal costs or production capacities or financial situation. However, since the bidding floor is repeated continuously, generators may learn through experience the effect of different bids on their earnings. To this end, we use a rein-

forcement learning approach and model generators as adaptive agents who learn from past experience and adapt to environment.

Analyzing simulation data, we characterize how the generators' bids, learning model dynamics and resulting electricity prices evolve over time. We study various questions under different market, network and learning scenarios. Some generators may have advantage over others due to lower production costs or due to favorable location: Will these generators discover their advantage and benefit from it? A group of generators may increase their profits when they all place high bids: Will such groups of tacit collusion emerge among generators? Game-theoretical models of the system predict certain Nash Equilibrium in bids: Does the simulation with active agents converge to such equilibria? The Independent System Operator may choose between various market rules, such as pay-as-bid pricing versus uniform pricing. Which pricing rule leads to a more competitive market? How would the physical characteristics of the power grid, such as the transmission line constraints, or the behavioral characteristics of generators, such as their risk aversion levels, affect the results?

We plan to extend our initial model to study more realistic, hence more complicated power market settings. One extension is to consider other markets beyond the day-ahead market, such as the balancing market. Yet another extension is to include demand-side agents in the model. To approximate a real power network, we may also increase the size of the considered market.

Ultimately, our findings can help governments design more efficient power markets, leading to lower cost electricity generation and increase in public welfare. Allowing what-if scenario analyses, such simulation models can be used as a "wind tunnels" to test the effects of policy proposals on market players. They can also be employed to address greenhouse gas emissions of generators.

An integrated decision support for the energy policies of Turkey

The current account is one of the important financial indicators for the economic credibility of a country, especially for an emerging economy. The main components of the current account are visible balance (trade in goods) and invisible balance (trade in services). Investment incomes and net transfers also affect current account. Basically, a country runs current account deficit if her value of imports is greater than her value of exports, on the other hand, if the value of imports is less than the value of exports the country runs current account surplus.

In January 2014, the current account deficit of Turkey reached \$65 billion (7.8% of GDP). As current account deficit is greater than 5% of the GDP, it is expected that the current account deficit will continue to be unsustainable in the coming years. Turkey would have decreased current account deficit had she not rely on foreign energy supplies. An emerging economy needs a lot of energy and Turkey imports a major portion of the oil and the natural gas that she uses.

This research will focus on Turkey's reliance on foreign energy supplies and examine how convenient energy policies can be created to decrease the current account deficit of the country. For this purpose an integrated decision support approach will be used. Opinions of experts and related issues in the literature will be gathered and a convenient model will be proposed. As the problem on hand is a complex one and consists of several interrelated concepts affecting each other, a network model will be generated. Fuzzy cognitive mapping may be an appropriate approach for this purpose.

Causal cognitive mapping is a method that captures the diverse mental models of the experts in simple directed graphs where concepts are represented by nodes and relations between concepts are represented by an arc from the affecting concept to affected concept. The relation is positive if there is an increase at the affected concept when affecting concept increases. If there is a decrease at the affected concept when affecting concept among n concept) in each iteration to come up with an updated state vector. System reaches a

increases, the relation is negative. By interviews with experts or by examining published reports or studies, the related concepts and interrelations among them can be revealed. These beliefs and judgments are brought together to have an aggregated cognitive map. Qualitative analyses can be conducted on this map. However causal cognitive maps may have drawbacks. For instance if there are two concepts affecting a concept C, and one relation is positive and the other one is negative, it cannot be determined whether C will increase, decrease, or remain same in the long run.

To predict the overall system behavior of the concepts in the cognitive map, a formal analysis can be conducted. One potential approach may be the use of fuzzy cognitive map (FCM) which is based on Fuzzy Set Theory and the Theory of Neural Networks, improves the ability of decision makers to understand the dynamic behavior of causal cognitive maps. Instead of assigning (-1, 0, +1) for the representations of the relations as done in causal cognitive maps, a value at the interval of [-1, +1] is assigned at FCMs. They are therefore fuzzy.

FCM are regarded as a simple form of recursive neural networks, with concepts being the equivalent to neurons. However, concepts of FCMs, are not either off or on (0 or 1), but can take values in-between [0, 1]. Fuzzy concepts are non-linear functions that transform the path-weighted activations directed towards them into a value. When a concept changes its value (a neuron fires), it affects all concepts that are causally dependent upon it. Depending on the sign of the relation and the strength of it, the affected concepts subsequently may change their values as well (further concepts are activated at the network). For this purpose a simulation is conducted as follows: a given state vector with values of -1, 0, or 1 for the concepts (i.e. the value of a concept will be -1 if decision makers let it decrease and it would be 1 if it is let to increase) is multiplied with adjacency matrix (a $n \times n$ square matrix representing the fuzzy causal relations

stable state at the end. By reading the values of concepts at the final state vector, one can under-

stand to which extent which concept will increase and which one will decrease in the long run.

In this research, after making several meetings and interviews with experts and examining the written materials, a FCM will be constructed for examining how convenient energy policies can be

created to decrease the current account deficit of the country. Several scenarios can be generated to analyze how the increase or decrease at some certain concepts will affect the overall system behavior of the all concepts of the network.

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