Energy Manufacturing: Principles and Recent Advances

June 28 – July 1, 2011

Hilton Garden Inn
Evanston, IL 60201

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Jack Hu, University of Michigan	jackhu@umich.edu

COURSE SUMMARY

Energy manufacturing includes energy generation, energy storage, and energy utilization - the three key aspects of energy and sustainability. The objective of this short course is to provide attendees with a balanced review of principles and applications, as well as challenges and opportunities in manufacturing processes and systems related to energy manufacturing. Topics include surface science and engineering for reduced energy utilization in mechanical systems, battery manufacturing, membrane technologies in algae biofuel production, overview of various photovoltaic solar cell technologies and manufacturing and metrology challenges, and micro- and nano-manufacturing for texturing large surface areas with prescribed functional properties.

AGENDA

June 28, 2011 Tuesday (Surface Interface in Mechanical Systems & Algae-based Biofuel)

8:00 – 8:30	REGISTRATION
8:30 – 8:45	Welcome and Introduction – Yip-Wah Chung, Northwestern University
8:45 – 10:45	Surface Interface in Mechanical Systems – Jane Wang, Northwestern University and Ning Ren, Ashland, Inc
10:45 – 11:00	BREAK
11:00 – 12:00	Energy Storage: Battery - Jack Hu, University of Michigan
12:00 – 13:00	LUNCH
13:00 – 14:00	Energy Storage: Battery - Jack Hu, University of Michigan
14:00 – 15:00	System Analysis of Algae-based Biofuel Manufacturing - Amy Sun, Sandia (SNL)
15:00 – 15:30	BREAK
15:30 - 16:30	System Analysis of Algae-based Biofuel Manufacturing - Amy Sun, Sandia (SNL)
16:30 – 17:30	Design of Advanced Heat-transfer fluids for Concentrated Solar Power - Amy Sun, Sandia (SNL)

June 29, 2011 Wednesday (Solar Panels)

8:30 – 9:00	Introduction of Solar Energy - Steven Danyluk, Georgia Institute of Technology
9:00 – 10:00	Crystalline Silicon Photovoltaics – Overview of solar cell/module technologies, processing, manufacturing and metrology challenges (Steven Danyluk and Shreyes Melkote, Georgia Institute of Technology)
10:00 – 10:15	BREAK
10:15 – 11:45	*Continued*:
11:45 – 12:45	LUNCH
12:45 – 14:15	Organic Photovoltaics – Michael R. Wasielewski, Northwestern University
14:15 – 14:45	BREAK
14:45 – 16:15	Plastic Solar Cells with Engineered Interfaces - Tobin Marks, Northwestern University
16:15 -- 17:15	Nuclear Energy - Safety, production, research and challenges – Ken Chong, George Washington University

June 30, 2011 Thursday (Surface Engineering)

8:30 – 10:30	Coatings - Yip-Wah Chung, Northwestern University
10:30 – 10:45	BREAK
10:45 – 11:45	Lithographic Texturing at the Micro-scale – Cheng Sun, Northwestern University
11:45 – 12:45	LUNCH
12:45 – 13:45	Lithographic Texturing at the Nano-scale – Cheng Sun, Northwestern University
13:45 – 15:15	Nanomanufacturing of Nanostructured Surfaces for Energy Applications – Teri W. Odom, Northwestern University
15:15 – 15:45	BREAK
15:45 – 17:15	Laser-based Texturing – Kornel Ehmann, Northwestern University

July 1, 2011 Friday (Surface Engineering – Cont)

8:30 – 10:00	Micromachining Texturing – Shiv Kapoor, University of Illinois, Urbana-Champaign
10:00–10:30	BREAK
10:30 – 12:00	Deformation-based Texturing – Jian Cao, Northwestern University
12:00– 12:15	Closing Remarks – Jian Cao, Northwestern University
12:15 -	ADJOURN

REGISTRATION FEES

Status	Registration Fee	Deadline
Fellowship Application	Covered by NSF	March 31, 2011
Early Registration	$1,600	April 15, 2011
Registration after April 15, 2010	$2,000	

LOCATION

The course will be held at the Hilton Garden Inn - 1818 Maple Avenue, Evanston, IL.

ACCOMMODATIONS

A block of rooms has been reserved at the Hilton Garden Inn. The organizers will make hotel reservations for fellowship awardees and speakers. Other attendees can make reservations via:

(1) phone by calling the hotel directly at 847-475-6400 or through 1-877-HILTONS. Please mention “Energy Manufacturing” to receive discounted rates of $109. per night for a King or $129 per night for a Double room.
(2) online http://www.hiltongardeninn.com/en/gi/hotels/index.jhtml?ctyhocn=ORDEVGI, enter dates of stay, hit "go" and enter 'Group/Convention Code': EMF. The cut-off date is June 6, 2011.

REGISTRATION

Please register through the NSF Summer Institute website:
www.tam.northwestern.edu/summerinstitute

FELLOWSHIPS

U.S. professors, post-doctoral researchers and graduate students can apply for fellowship support through the website noted above. Fellowship applications are due March 31, 2011. Each fellowship award covers the following:

1) Full course registration
2) Up to a four-night stay at the Hilton Garden Inn based upon double occupancy
3) Lunches on Tuesday, Wednesday and Thursday.

CONTACT

Website: tam.northwestern.edu/summerinstitute
Email: summerinstitute@mail.mech.northwestern.edu

ABSTRACTS AND BRIEF-BIOS OF SPEAKERS

Tuesday, June 28, 2011
Surface Interface in Mechanical Systems & Algae-based Biofuel

Prof. Q. Jane Wang, Northwestern University, Evanston, IL
Dr. Ning Ren, Ashland, Inc. Lexington, KY 40509

Surface Interface in Mechanical Systems

ABSTRACT: Power and motion are transmitted through surface contact, and many physical functions are accomplished through surface interactions. Engineering surfaces may have complicated material, chemical, physical, and topographic properties, which give interface multidisciplinary and multiscale complexity. This session introduces the mechanics of surfaces and interfaces, influence of surface characteristics on the behavior of surface interaction. The session will also discuss our efforts on developing surfaces and interfaces for energy efficiency.

SPEAKER INFORMATION:

Dr. Jane Wang is a Professor in the Mechanical Engineering Department at Northwestern University, Evanston, IL. She served Northwestern's Mechanical Engineering as the Director of the Graduate Studies Committee during 2003-2007 and the Adviser of the ASME Student Chapter during 1998-2003. She was an elected Fellow of the American Society of Mechanical Engineers (ASME) and Fellow of Society of Tribologists and Lubrication Engineers (STLE). She is one of the receivers of the STLE Surface Engineering Committee Best Paper Award, 2011 STLE 2010 Edmond E Bisson Best Written Contribution Award, and the 1997 STLE Captain Alfred E. Hunt Best Paper Award. She received a 1997 NSF CAREER Award. Her professional society work includes the service as a Board of Director of STLE during 2008-2009, the Chairperson of the ASME/STLE International Joint Tribology Conference during 2010-2011, and the STLE Annual Meeting Program Committee during 2007-2008.

SPEAKER INFORMATION:

Dr. Ning Ren is Senior Scientist at Ashland Inc., Lexington, KY, and works on a broad range of problems in lubricant formulation and performance enhancement technology. He holds a Ph.D degree in Mechanical Engineering from Northwestern University. His research interests focus on modeling and simulation of Tribological systems.

S. Jack Hu, The University of Michigan

Introduction to Lithium Ion Battery Manufacturing

ABSTRACT: Re-chargeable batteries are a key enabling technology for renewable energy and portable applications. Portable electronic devices, such as mobile telephones, notebooks, GPS, etc., rely on batteries for their power supply. Transportation electrification requires new developments in high energy/power density batteries. Of the different battery technologies, the lithium-ion battery in particular has received great attentions since it provides the highest energy density of all available systems available today. In this talk, the manufacturing processes for such batteries will be introduced, and challenges and opportunities for research in lithium battery manufacturing will be presented. Both cell level manufacturing and pack level assembly issues will be discussed.

SPEAKER INFORMATION:

S. Jack Hu is currently Professor of Mechanical Engineering and the G. Lawton and Louise G. Johnson Professor of Engineering at the University of Michigan. He also holds a joint appointment in Industrial and Operations Engineering. He co-directs the General Motors Collaborative Research Laboratory in Advanced Vehicle Manufacturing. He is also currently the Associate Dean for Academic Affairs in the College of Engineering. Prior to this appointment, he served as Associate Dean for Research and Graduate Education, and the Director of Program in Manufacturing. Dr. Hu's teaching and research interests are in assembly, forming, manufacturing systems, and quality. He has graduated 33 Ph.D. students and a number of master students. He has published more than 130 papers in professional journals and 40 papers in conferences. He has also taught short courses on Lean Manufacturing and Statistical Process Design and Control to a number of companies around the world. He was elected a fellow of ASME in 2003 and currently serves as Editor in Chief of Journal of Manufacturing Systems.

Dr. Amy Sun, Sandia (SNL)

System Analysis of Algae-based Biofuel Manufacturing

Amy Sun is a Principal Member of Technical Staff and a Chemical Engineer from Sandia National Laboratories. She received her B.S. from UC Berkeley in 1987 and her M.S. and Ph.D. from University of Pennsylvania in 1993. Amy began her professional career working at Aspen Technology and later at Air Products and Chemicals supporting steady-state and dynamic simulations. Since joining Sandia in 1998, she has been an expert in solving interfacial transport problems using computational fluid dynamics. Since 2006, she has diversified into systems analysis of renewable energy, including hydropower, solar, and biofuels.

Proposed seminars for NSF Summer Institute Short Course on Energy Manufacturing

I. Renewable Energy Challenges: the role of systems analysis (14:00-15:00)
II. System Analysis of Algae-based Biofuel Manufacturing (15:30-16:30)
III. Design of Advanced Heat-transfer fluids for Concentration Solar Power. (16:30-17:30)

I. Renewable energy challenges: the role of systems analysis.

The US energy policy for transportation fuel and for electricity generation is mandating a greater contribution from renewable energy sources. Every potential technology pathway requires

continual discovery of science and engineering to overcome the technical barriers. Systems analysis as a discipline is broad and spans multiple length and temporal scales. How does one move from problem definition to informing the stakeholders based on systems-level approach?

II. System Analysis of Algae-based Biofuel Manufacturing
Realization of large-scale algae cultivation for biofuel production involves practical considerations of sustainable feedstock resources, scale-up economics, and operational logistics. Techno-economic assessment is a necessary component to study the economic and technical challenges to make algae an attractive feedstock for biofuels. Depending on the scope of analysis, techno-economics span multiple temporal and spatial scales. Different examples illustrate the techniques for system-level analyses and how they elucidate our understanding towards manufacturing of a new algae-based advanced biofuel.

III. Design of Advanced Heat-transfer fluids for Concentrated Solar Power
Concentrating solar power (CSP) technologies have accelerated globally as the demand for carbon neutral electricity rises. However, a critical technical bottleneck lies in the efficient storage and transfer of thermal energy using heat- transfer fluids (HTFs). Creating an optimal working fluid with desirable thermophysical or transport properties by trial and error is an intractable combinatorial problem. I will discuss the ongoing work in thermodynamic modeling and experimental testing to optimize workable heat transfer fluids that are applicable to CSP storage systems.

Wednesday, June 29, 2011
Solar Panels

Prof. Steven Danyluk, Georgia Institute of Technology

Introduction of Solar Energy

SPEAKER INFORMATION:

Steven Danyluk is the Morris M. Bryan, Jr. Chair in Mechanical Engineering for Advanced Manufacturing Systems at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology. Dr. Danyluk has also served as the Director of the Manufacturing Research Center, a multidisciplinary Center that houses 50 faculty, 120 graduate students and 35 staff from 1994 until 2010, leading multidisciplinary research in manufacturing technologies in rapid prototyping, machining, electronics, photovoltaics and aerospace. His research area has been silicon integrated circuit and photovoltaic manufacturing focusing on wafering, dicing and polishing of single and multicrystalline silicon. A consequence of this research has led him to found Qcept Technologies, Inc. in 2000. Dr. Danyluk has served as Chairman of the Board, Chief Technical Office and Board member at various stages of the life of the company. Dr. Danyluk has advised the Government of Singapore since 1996 and serves as the Chairman of the Scientific Advisory Board of SIMTech and major Research Institute developing manufacturing technologies. He received the Service Award (Friend of Singapore) Medal in 2010 at the National Day Awards. Dr. Danyluk has also held the title of Nanyang Professor from the Nanyang Technological University. Dr. Danyluk is Fellow of ASME, STLE and ASM International. He received the PhD degree in Materials Science and Engineering from Cornell University.

Professor Shreyes N. Melkote, Georgia Institute of Technology

Crystalline Silicon Photovoltaics – Overview of solar cell/module technologies, processing, manufacturing and metrology challenges

ABSTRACT: The efficient and cost effective harvesting of solar energy and conversion to electricity by photovoltaic (PV) processes is critical to the future of the U.S. This type of electricity production can be sustainable and renewable when scale-up processes and systems are developed. Crystalline silicon (c-Si) PV is the most mature process of the various other methods for energy production and c-Si promises to contribute to reducing the use of fossil fuels in the near term. Manufacturing methods will be key to making this happen. This tutorial will provide an overview of c-Si PV manufacturing with an emphasis on crystal growth technique, wafer production methods, wafer/cell handling, wafer/cell metrology, and mechanical yield issues and challenges. The presentation will conclude with a discussion of other open technical issues and challenges facing the scale-up of c-Si PV manufacturing.

SPEAKER INFORMATION:

Dr. Shreyes N. Melkote holds the Morris M. Bryan Jr. Professorship for Advanced Manufacturing Systems in the George W. Woodruff School of Mechanical Engineering at Georgia Tech. He is currently the Interim Director of the Georgia Tech Manufacturing Research Center. Dr. Melkote's research activities are focused on advanced manufacturing processes including fixturing/part handling of thin flexible materials, precision cutting processes for difficult-to-cut materials including semiconductor materials, and photovoltaic manufacturing. Dr. Melkote is a recipient of several honors including the ASME Blackall Machine Tool and Gage Award, the SME Dell K. Allen Outstanding Young Manufacturing Engineer Award and several Best Paper Awards at leading ASME and SME conferences. He is an Associate Editor of the ASME Journal of Manufacturing Science & Engineering and the Journal of Machining Science & Technology. He is a Fellow of the ASME and Chair of the Scientific Committee of the North American Manufacturing Research Institution of the SME (NAMRI/SME). Dr. Melkote obtained his B.Tech. (with Honors) degree from the Indian Institute of Technology, Kharagpur and his Ph.D. from Michigan Technological University in 1993. He did post-doctoral work at the University of Illinois at Urbana-Champaign prior to joining Georgia Tech in 1995.

Professor Michael R. Wasielewski, Northwestern University

Organic Photovoltaics

ABSTRACT: Organic photovoltaics (OPVs) (sometimes called excitonic or plastic solar cells) use organic materials comprising electron donor (D) and acceptor (A) molecules as their active light receptors and photo-induced charge separation components. The photoactive layers in many current generation OPVs include a semiconducting polymer donor blended with a fullerene electron acceptor. In optimized devices, these donor-acceptor combinations provide power conversion efficiencies (PCEs) up to ~8%. These OPV photoactive materials are solution-processed to create bulk heterojunction (BHJ) active layers having interpenetrating donor (hole transporting) and acceptor (electron transporting) networks. Such composites result in larger donor-acceptor contact areas than in simple D-A bilayers, giving OPVs that exhibit greater exciton dissociation and charge separation efficiencies, which greatly increase device PCE. Research to create OPVs with greater PCEs is also currently focused on the transparent

conductive oxide anode, the interfaces between the device layers, and the interfaces within the photoactive layer. We will discuss how OPVs work, the current state-of-the-art, the prospects for achieving economic competitiveness with traditional inorganic materials (such as silicon), and new emerging technologies that promise to boost performance significantly.

SPEAKER INFORMATION:

Prof. Michael R. Wasielewski received his Bachelor of Science (1971) and Ph.D. (1975) degrees from the University of Chicago. Following his graduate work, he was a postdoctoral fellow at Columbia University. He then moved to the Argonne National Laboratory, where he rose through the ranks to become Senior Scientist and Group Leader of the Molecular Photonics Group. In 1994, he joined the faculty of Northwestern University, where he is currently the Clare Hamilton Hall Professor of Chemistry. He served as Chair of the Chemistry Department at Northwestern from 2001-2004. He is also the Director of the Argonne-Northwestern Solar Energy Research (ANSER) Center, which is a DOE Energy Frontier Research Center. He also holds an appointment as Senior Scientist in the Center for Nanoscale Materials at Argonne. Prof. Wasielewski's research centers on light-driven charge transfer and transport in molecules and materials, photosynthesis, nanoscale materials for solar energy conversion, spin dynamics of multi-spin molecules, molecular materials for optoelectronics and spintronics, and time-resolved optical and electron paramagnetic resonance spectroscopy. His research has resulted in over 385 publications. Prof. Wasielewski was elected a Fellow of the American Association for the Advancement of Science in 1995, and has held numerous distinguished lectureships and fellowships. Among Prof. Wasielewski's recent awards are the 2008 Porter Medal for Photochemistry, the 2006 James Flack Norris Award in Physical Organic Chemistry of the American Chemical Society, and the 2004 Photochemistry Research Award of the Inter-American Photochemical Society.

Prof. Tobin Marks, Northwestern University

Plastic Solar Cells with Engineered Interfaces

ABSTRACT: The ability to fabricate molecularly tailored interfaces with nanoscale precision can selectively modulate charge transport across hard matter-soft matter interfaces, facilitating transport of the "correct charges" while blocking transport of the "incorrect charges." This interfacial tailoring can also control carrier-trapping defect densities at such interfaces and stabilize them with respect to physical/thermal decohesion. In this lecture, challenges and opportunities are illustrated for three specific and related areas of research: 1) charge transport across hard matter-soft matter interfaces in electroluminescent devices, 2) charge transport across hard matter-soft matter interfaces in organic bulk-heterojunction photovoltaic cells, 3) charge transport to unconventional electrode materials. It will be seen that rational interface engineering along with improved bulk-heterojunction polymer structures affords solar power conversion efficiencies as high as 5.6% - 7.6%, along with far greater cell durability.

SPEAKER INFORMATION:

Tobin Marks is Vladimir N. Ipatieff Professor of Chemistry and Professor of Materials Science and Engineering at Northwestern University. He received a B.S. degree in Chemistry from the University of Maryland (1966) and Ph.D. from MIT (1971) in Inorganic Chemistry. His research interests include transition metal and f-element organometallic chemistry; catalysis; vibrational spectroscopy; nuclear magnetic resonance; synthetic facsimiles of metalloprotein active sites; carcinostatic metal complexes; solid state chemistry and low-dimensional molecular metals; nonlinear optical materials; polymer chemistry; tetrahydroborate coordination chemistry; macrocycle coordination chemistry; laser-induced chemistry and isotope separation; molecular electro-optics; metal-organic chemical vapor deposition; polymerization catalysis; printed flexible electronics; solar energy; and transparent conductors. Marks has received American Chemical Society Awards in Polymeric Materials, 1983; Organometallic Chemistry, 1989; Inorganic Chemistry, 1994; Chemistry of Materials, 2001; Distinguished Service in Inorganic Chemistry, 2008; Organic Chemistry (Cope Senior Scholar), 2010. He received the 2000 ACS Cotton Medal; 2001 ACS Willard Gibbs Medal; 2001 N. American Catalysis Society Burwell Award; 2001 ACS Linus Pauling Medal; 2002 American Institute of Chemists Gold Medal; 2003 German Chemical Society Karl Ziegler Prize; 2004 Royal Society of Chemistry Frankland Medal, 2005 ACS Bailar Medal; Member, U. S. National Academy of Sciences (1993); Fellow, American Academy of Arts and Sciences (1993), Member, German National Academy of Sciences (2005); Fellow, Royal Society of Chemistry (2005); US National Medal of Science (2007); Fellow, Chemical Research Society of India (2008); Fellow, Materials Research Society (2009): Honorary Fellow, Indian Academy of Sciences (2010). He received the 2008 Spanish Principe de Asturias Prize for Scientific Research; 2009 N. American Catalysis Society Pines Award; 2009 Taylor Materials Research Award, Penn. State U.; 2009 Von Hippel Award, Materials Research Society; 2010 ACS Nichols Medal; 2010 Distinguished Affiliated Professor Award and Wilhelm Manchot Prize, Technical U. of Munich; the 2010 ACS Mosher Award; and the 2011 Schulich Prize, Technion-Israel Institute of Technology; the 2011 Dreyfus Prize in the Chemical Sciences. Marks has published over 1010 papers and holds 190 US patents.

Prof. Ken P. Chong, George Washington University

Nuclear energy: safety, production, research and challenges

ABSTRACT: As of November 2010, 29 countries worldwide are operating 441 nuclear reactors for electricity generation and 65 new nuclear plants are under construction in 15 countries. Like wind and hydro-electricity, nuclear power has the lowest carbon footprint. Nuclear power plant costs about three times more than coal power plant. However the production cost of electricity is 50% less. President Barack Obama called for "a new generation of safe, clean nuclear power plants" in his 2010 State of the Union address and pledged to triple US nuclear investment. Following the Japanese quake and tsunami in March 2011 near Sendai, the Obama administration restated its support, with spokesman Jay Carney telling reporters that nuclear "remains a part of the President's overall energy plan". In terms of energy in an earthquake, each whole number increase in the Richter Scale corresponds to an increase of about 32 times the amount of energy released. In this presentation the basics of tsunami, earthquakes, nuclear fission, and accidents at the Fukushima Dai-ichi nuclear power plants, disaster mitigation, as well as research, challenges and safety of nuclear power plants are to be presented.

SPEAKER INFORMATION:

Prof. Ken P. Chong, P.E. has been the Engineering Advisor and Director of Mechanics and Materials for the past 21 years at the National Science Foundation [NSF]. He was the NSF Interim Division Director in 2005. Currently he is associated with NIST and the George Washington University, writing a mechanics text book, editing an Elsevier and a Taylor & Francis journal, a Spon book series, doing lectures and research, serving on university advisory boards, etc. He earned his Ph.D. in Mechanics from Princeton University. He specializes in solid-mechanics/materials, nano-mechanics, and structural mechanics. At NSF in addition to managing 130 university research projects in mechanics/materials, he has been involved in the development of model-based simulation, durability and accelerated tests, life-cycle engineering, nano science and engineering, and other initiatives; and guided the establishment of the NSF Summer Institute on Nano Mechanics/Materials at Northwestern University. Prior to joining NSF, he was a senior research engineer at the National Steel Corp. for 5 years; a professor and a chair in mechanics and structures for 15 years at the U. of Wyoming. He has published 200 plus technical papers and authored several books including 2 textbooks on mechanics by Wiley. He has given more than 50 keynote lectures, received awards including the fellow of AAM, ASME, SEM, USACM and ASCE; Edmund Friedman Professional Recognition Award; Honorary Doctorate, Shanghai University; Distinguished Member, ASCE; NCKU Distinguished Alumnus Award; and the NSF highest Distinguished Service Award. He has been a visiting professor at MIT, U. of Washington – Seattle, U. of Houston; honorary professor at Hong Kong U, Shanghai University and others. He received the 2011 ASME Ted Belytschko Applied Mechanics Award for “significant contributions in the practice of engineering mechanics”.

Thursday, June 30, 2011
Surface Engineering

Prof. Yip-Wah Chung, Northwestern University

Coatings

ABSTRACT: Coatings and engineered surfaces are used in a variety of applications for enhanced mechanical, tribological, and optical properties. In this talk, we will discuss in detail how such coatings and engineered surfaces are typically made (using physical vapor deposition, chemical vapor deposition, sol gel methods, and diffusion) and characterized. Examples will be given to demonstrate how these coatings and engineered surfaces have markedly improved engineering performance.

SPEAKER INFORMATION:

Yip-Wah Chung obtained his PhD in Physics from the University of California at Berkeley in 1977. He is currently Professor of Materials Science and Engineering and Mechanical Engineering at Northwestern. He was named Fellow, ASM International; Fellow, AVS; and Fellow, Society of Tribologists and Lubrication Engineers. His other awards include the Ralph A Teetor Engineering Educator Award from SAE, Innovative Research Award and Best Paper Award from the ASME Tribology Division, Technical Achievement Award from the National Storage Industry Consortium, Bronze Bauhinia Star from the Hong Kong Special Administrative Government, and

Advisory Professor from Fudan University. Dr. Chung served two years as program officer in surface engineering and materials design at the National Science Foundation. His most recent research activities are in infrared reflecting coatings, low-friction surfaces, strong and tough coatings, and high-performance alloys.

Prof. Cheng Sun, Northwestern University

Lithographic Texturing at the Micro-/Nano-scale

ABSTRACT: This course will talk about the fundamental of micro- and nano-lithography techniques. Various state-of-the-art lithograph-based surface texturing technologies will be reviewed. Principle of light-matter interaction, micro-/nano-scale materials processing, and pattern transfer will be discussed. The course will also talk about the challenges and opportunities for potential applications of micro-/nano-scale surface texture for energy harvesting.

SPEAKER INFORMATION:

Professor Cheng Sun is Assistant Professor at Mechanical Engineering Department at Northwestern University since September 2007. He received his PhD in Industrial Engineering from Pennsylvania State University in 2002. He received his MS and BS in Physics from Nanjing University in 1993 and 1996, respectively. Prior to coming to Northwestern, he was Chief Operating Officer and Senior Scientist at the NSF Nanoscale Science and Engineering Center for Scalable and Integrated Nanomanufacturing at UC Berkeley. Dr. Sun received a CAREER Award from the National Science Foundation in 2010 and the Chao & Trigger Young Manufacturing Engineer Award from ASME in 2011. Sun's primary research interests are in the fields of Emerging applications of nano-electronics, nano-photonics, nano-electromechanical systems and nano-biomedical systems necessitate developments of viable nano-manufacturing technologies. His research group is engaged in developing novel nano-scale fabrication techniques and integrated nano-system for bio-sensing and high-efficiency energy conversion. He has published more than 50 technical papers including publications in *Science, Nature Nanotechnology, and Nature Materials*.

Prof. Teri Odom, Northwestern University

Nanomanufacturing of Nanostructured Surfaces for Energy Applications

ABSTRACT: This session will focus on the fundamental processing tools to create large-area, nanostructured surfaces that are important in energy applications. We will discuss conventional nanofabrication tools (e.g. e-beam lithography and nanoimprinting) as well as emerging, massively parallel tools (e.g. self-assembly methods, soft nanolithography and nanomolding, and multi-tipped scanning probe lithography methods). In addition, we will describe surface and pattern transfer techniques to convert these patterned nanostructures into functional, nanostructured materials (e.g. atomic layer deposition, reactive ion etching, and physical vapor deposition methods).

SPEAKER INFORMATION:

Teri W. Odom is an associate professor in the Department of Chemistry and Materials Science and Engineering at Northwestern University. Her research focuses on controlling materials at the 100-nanometer scale and investigating their size and shape-dependent properties. Odom has developed massively parallel, multi-scale nanopatterning tools to generate noble metal (plasmonic) structures that can manipulate visible light at the nanoscale. For example, plasmonic films perforated with arrays of nanoholes exhibit enhanced optical transmission and also behave as a new type of metamaterial. Micron-sized patches of nanoholes can function as an unusual class of planar lenses with exceptional focusing properties. 2D arrays of nanoholes and nanopyramid gratings can serve as ultra-sensitive sensing substrates capable of determining the kinetics of biomolecular binding events. In addition, Odom has created strongly coupled arrays of metal nanoparticles that can trap light in the plane of the array via a new type of subradiant or dark lattice plasmon. Odom has received numerous honors and awards, including a Radcliffe Institute for Advanced Study Fellowship at Harvard University; an NIH Director's Pioneer Award from the National Institutes of Health; the Materials Research Society Outstanding Young Investigator Award; the National Fresenius Award from Phi Lambda Upsilon and the American Chemical Society; the Rohm and Haas New Faculty Award; an Alfred P. Sloan Research Fellowship; a DuPont Young Investigator Grant; a National Science Foundation CAREER Award; a Dow Teacher-Scholar Award; the ExxonMobil Solid State Chemistry Faculty Fellowship; and a David and Lucile Packard Fellowship in Science and Engineering. Odom was also the first Chair of the Noble Metal Nanoparticles Gordon Research Conference, whose inaugural meeting was in 2010. In addition, Odom is an Associate Editor for Chemical Science (RSC) and is on the Editorial Advisory Boards of Chemical Physics Letters, the Journal of Physical Chemistry, ACS Nano, and Nano Letters.

Prof. Kornel Ehmann, Northwestern University

Laser-based Texturing

ABSTRACT: Following a brief account of the fundamentals of laser-based processing as applied to the creation of nano- through meso-scale features on products and components made of different engineering materials the focus will turn to the application of this class of processes to the generation of precisely controlled surfaces in terms of both their topography and physical properties. Specific subject areas to be covered include the different processing modes, process fundamentals, process capabilities and limitations, the current state of technology, typical applications and outstanding challenges.

SPEAKER INFORMATION:

Professor Ehmann received his B.S. and M.S. degrees in 1970 and 1974 from the University of Belgrade and his Ph.D. from the University of Wisconsin-Madison in 1979. He holds appointments at Northwestern, the University of Illinois, Indian Institute of Technology, Chung Yuan Christian University, and University of Belgrade. He is the Technical Editor of the ASME Journal of Manufacturing Science and Engineering. He served as the President of the North American Manufacturing Research Institution (NAMRI/SME) and Chair of the Manufacturing Engineering Division of ASME. He is a fellow of ASME and SME and the recipient of the SME gold medal.

Prof. Shiv G. Kapoor, University of Illinois, Urbana-Champaign

Micromachining Texturing

ABSTRACT: Several types of manufacturing processes exist that are suitable for producing a variety of surface patterns. Processes based on the application of thermal energy are laser scribing and micro-electrical discharge. A process based on electrochemical dissolution is micro-electrochemical machining (µ-ECM). Mechanical material removal processes include micro-endmilling, micro-fly cutting, micro-scale shaping / planing, and atomic force microscope (AFM) scribing. In this presentation, a review of these mechanical machining processes will be provided and a new micro-groove cutting process that makes use of a flexible single-point cutting tool on a 5-axis micro-machine tool (mMT) motion platform will be discussed. It will be shown how the new process is capable of achieving high cutting speeds, a large working volume, and the capability of producing curvilinear patters of grooves. The geometry of the flexible tools and the process used to fabricate them will be presented. Experimental results for machining grooves that are in close proximity to each other and when grooves intersect will be presented. These experiments demonstrate the ability to successfully cut well-formed rectangular grooves between 300 nm and 1 µm wide as well as more complex compound v-shaped grooves.. Also, the results show that one micron wide grooves can be successfully spaced as close as 1.0 µm apart. The advantages of the new process in terms of machine accuracy and resolution requirement to achieve a desired depth of cut will also 4.2 Micro-Groove Cutting Machine Tool. A micro-groove cutting process has been developed that uses a flexible single-point cutting tool to remove material via a chip formation processes. The flexible tool is shaped much like an AFM probe, i.e. a flexible cantilever that is held on one side and has a protrusion on the other side, but can have geometries more suitable for material removal in place of an AFM tip. Hence the tool is essentially a flexible micro-scale planing tool. During cutting, the cutting edge of the tool is pressed into a workpiece and the workpiece is moved underneath the tool. While this occurs, the deflection of the cantilever portion of the tool is maintained at some desired value, which maintains some desired load on the cutting edge. Cutting conditions, workpiece material, and tool geometry determine the depth of cut.

SPEAKER INFORMATION:

Dr. Shiv G. Kapoor is Grayce Wicall Gauthier Chair Professor in the Department of Mechanical Science and Engineering at the University of Illinois, Urbana-Champaign. He has been a significant contributor to the field of manufacturing engineering research and educations and a pioneer in the field of mathematical modeling and simulation of machining processes both at micro and macro-scale. He has published more than 200 technical articles in technical Journals including ASME Journal of Manufacturing Science and Engineering, Journal of Manufacturing Processes, International Journal of Machine Tool and Manufacture, International Journal of Wear, Journal of Corrosion Science, etc. A Fellow of both the American Society of Mechanical Engineers (ASME) and the Society of Manufacturing Engineers (SME), Prof. Kapoor has received ASME's Blackall Machine Tool and Gage Award for outstanding research paper for three times (1992, 1997 1nd 2008). He was given the ASME William T. Ennor Manufacturing Technology Award in 2003, SME's most coveted Education award in 2005 and NAMRI Research Implementation Award in 2010. He

currently serves as an editor-in-chief for the Journal of Manufacturing Processes and the Chair of ASME Technical committee on Publications and Communications.

Prof. Jian Cao, Northwestern University

Deformation-based Texturing

ABSTRACT: Manufacturing has enormous opportunities to make transiting and transformative contributions to energy efficiency. Methods of producing surface texturing using deformation-based processes will be presented. Recent advancements on the methodology for failure prediction and geometrical accuracy are presented.

SPEAKER INFORMATION:

Jian Cao received her Ph.D. in Mechanical Engineering from M.I.T. in 1995. She is currently a Professor of Mechanical Engineering and of Civil and Environmental Engineering at Northwestern University. Dr. Cao's major research interests include the mechanics and instability analysis of deformation processes from micro to macro scale, material characterization of metals and woven composites, and machine/process design. Her work has made fundamental contributions to the understanding of wrinkling behavior in sheet metal forming and the effects of material microstructure and material architecture on forming processes. Her research has integrated analytical and numerical simulation methods, control and sensors to advance manufacturing processes. Her contributions have been recognized by honors and awards given by her peers in the field of manufacturing, applied mechanics and control. Her work has been funded both by government agencies and industries.