NANO-DEVICES FOR ENHANCED THERMAL ENERGY STORAGE, COOLING AND SENSING

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ABSTRACT: We are developing nanotechnology enabled platforms for enhancing cooling, sensing, energy storage and safety systems (involving both experimental and computational studies). Coupling of thermal and hydro-dynamic features during phase change (boiling, condensation) causes spatio-temporal fluctuations of surface temperature at the micro/nano-scales, which are termed as "*cold-spots*" and can transmit over 60-90% of the total heat transfer. Using *Carbon-Nanotube (CNT)* **nanocoatings** - cooling was enhanced by 60~300% by leveraging cold-spots and the *"nano-fin" effect* (enhanced surface area). Using *silicon nanofins* - cooling was enhanced by ~120%. *Nano-thermocouples* and *diode* **temperature nano-sensors** integrated with the nanocoatings enabled the study of chaos/ fractal structures in boiling.

Specific heat capacity was enhanced by ~120% using **nanofluids**. This has applications in the energy technologies, such as: concentrated solar power/ CSP (thermal energy storage/ TES), nuclear, oil and gas exploration (deep drilling, reservoir engineering using *nanotracers*). Microchannel experiments using nanofluids showed that the precipitated nanoparticles behaved as nanofins (enhanced surface area) that dominate heat transfer for micro/nanoscale flows.

DPN™ (Dip Pen Nanolithography™) leverages Scanning Probe Microscopy using microfluidics. Commercial microfluidic devices called "Inkwells™" were developed earlier. The next generation microfluidic devices are being developed for DPN (e.g., Fountain Pen Nanolithography, "centiwells"). The applications are in nano-catalysis, bio-nanotechnology, maskless-lithography and *nano-sensors* for homeland security, bio-security and **explosives detection** (e.g., "*nano-nose*"/ "*nano-tongue*"). We invented a gasless process for synthesis of organic nanoparticles (e.g., graphene, CNT, etc.) under ambient conditions with synthesis temperature less than 300 °C (US Patent 8470285, awarded in 2013).

BIOGRAPHY: Dr. Banerjee received his Ph.D. in Mechanical Engineering from UCLA (with minor in MEMS). He received 3 M.S. degrees and was invited to 4 national honor societies. He attended the Indian Institute of Technology (IIT), Kharagpur for his Bachelor of Technology (Honors). Prior to TAMU, Dr. Banerjee worked as a *Manager of Advanced Research & Technology (ART)* group at *Applied Biosystems Inc. (ABI)*, CA, (currently merged into *Life Technologies*). Also as a *Hiring Manager* at *ABI* he hired ~ 30 PhDs in ~6 months and managed a group of 10~15 Ph.D. engineers / scientists. Previously in a singular capacity, he developed from concept to a commercial product at NanoInk Inc. (called "InkWells™", which are microfluidic platforms used for bio/nano-lithography of proteins, nucleic acids, etc.). **Dr. Banerjee has 10 US patents** (27 intellectual properties/IP: 10 US provisional, 5EP and 5 WO patents/applications), from his work at *ABI*, *Ciphergen Biosystems*, *NanoInk*, *Coventor Inc.* and *TAMU*. He received the "Amlan Sen *Best Mechanical Engineering Student Award (Endowment)*" at the graduation convocation at IIT and the "J.C. Bose *National Science Talent Scholarship*" from the Govt. of India. He received the "Morris Foster Fellowship (2007-2008)" from Mechanical Engineering Department; L.T. Jordan Career Development Professor and the "TEES Select Young Faculty Fellowship (2008-2009)" from the D. Look College of Engineering; and was designated as a Faculty Fellow at the Mary Kay O'Connor Process Safety Center at TAMU. He received the "2001 Best Journal Paper Award" from the ASME Heat Transfer Division (HTD), the "New Investigator Award (2005)" from the Texas Space Grants Consortium (TSGC), "3M Non-Tenured Faculty" award ('09-'12), the "ASEE/ AFOSR Summer Faculty Fellowship ('06, '07)" at AFRL, and the "ASEE/ ONR Summer Faculty Fellowship ('09)" at SPAWAR. He has supervised thesis of 11 PhD and 17 MS students.

US PATENTS: 8,470,285; 8,470,149; 8,383,062; 8,163,150; 8,147,770; 8,062,611; 7,762,638; 7,378,259; 7,034,854; 9,061,262. US PATENTS PENDING: 20140001202 A1; 20140251811; 61/916,537; 20140374259; 20150008129.

RESEARCH TOPICS: thermo-fluidics (multi-phase flows, boiling-condensation, thermal management), micro/ nanotechnology (DPN, SFIL, CNT nanosynthesis), nanofluids (complex fluids), energy-water nexus, thermal energy storage/ solar power and numerical simulations (network models, Finite Elements/ FEA, Computational Fluids: CFD/CHT, Molecular Dynamics).

SERVICE: He is an Associate Editor for the *ASME Journal of Nanotechnology in Engineering and Medicine (JNEM)*. He was invited to the advisory board of *JNEM*, *J. Nanoengineering and Nanomanufacturing*, *J. Chemical Engineering and Process Technology*; *J. Nanofluids; J. Advances in Nanoparticles*; *J. Advances in Automobile Engineering*; *Open Journal of Fluid Dynamics*. He organized international workshops in France (sponsored by ASME and CANEUS) and India. The Indo-US workshops were sponsored by NSF, AFOSR/AOARD, ONR-G (from US) as well as IUSSTF (from India).

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