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Contents

RF-MEMS Cavity-based Tunable Filters

Mahmoud Abdelfattah (Prof. Dimitrios Peroulis's group)

An all-silicon cavity-based bandpass tunable filter operating in the 60GHz band. The filter is designed to meet the specifications of the IEEE 802.11ad standard for WLAN networks. All parts of the filter are fabricated using silicon microfabrication techniques. The filter achieves high unloaded quality factor, $\mathcal{Q}_u$, in the range of 500∼600. Frequency tuning of 11% was achieved using electrostatic actuation. The RF feeding is obtained using microstrip lines and a CPW-to-Microstrip transition was designed to enable probe measurements.

The Effect of Relative Humidity on Dropwise Condensation Dynamics

Julian Castillo (Prof. Suresh V. Garimella's group)

Dropwise condensation of atmospheric water vapor is important in multiple practical engineering applications. The roles of environmental factors on the condensation dynamics need to be better understood to enable efficient water-harvesting, dehumidication, and other psychrometric processes. Experiments are performed in a facility that allows visualization of the condensation process on a vertically oriented, hydrophobic surface at a controlled relative humidity and surface subcooling temperature. The distribution and growth of water droplets are monitored across the surface at different relative humidities at a constant surface subcooling temperature. The droplet growth dynamics exhibits a strong dependency on relative humidity in the early stages during which there is a large population of small droplets on the surface and single droplet growth dominates over coalescence effects. At later stages, the dynamics of droplet growth is insensitive to relative humidity due to the dominance of coalescence effects. Low relative humidity conditions not only slow the absolute volumetric rate of condensation on the surface, but also prolong an initial transient regime over which the condensation rate remains significantly below the steady-state value. This improved understanding of the relative humidity effects on the growth of single and distributed droplets can be used to engineer condenser systems and surfaces adapted for local environmental conditions.

Buoyancy-induced on-the-spot mixing in droplets evaporating on nonwetting surfaces

Aditya Chandramohan and Susmita Dash (Prof. Suresh V. Garimella's group)

We investigate hitherto-unexplored flow characteristics inside a sessile droplet evaporating on heated hydrophobic and superhydrophobic surfaces and propose the use of evaporation-induced flow as a means to promote efficient "on-the-spot" mixing in microliter-sized droplets. Evaporative cooling at the droplet interface establishes a temperature gradient that induces buoyancy-driven convection inside the droplet. An asymmetric single-roll flow pattern is observed on the superhydrophobic substrate, in stark contrast with the axisymmetric toroidal flow pattern that develops on the hydrophobic substrate. The difference in flow patterns is attributed to the larger height-to-diameter aspect ratio of the droplet (of the same volume) on the superhydrophobic substrate, which dictates a single asymmetric vortex as the stable buoyancy-induced convection mode. A scaling analysis relates the observed velocities inside the droplet to the Rayleigh number. On account of the difference in flow patterns, Rayleigh numbers, and the reduced solid-liquid contact area, the flow velocity is an order of magnitude higher in droplets evaporating on a superhydrophobic substrate as compared to hydrophobic substrates. Flow velocities in all cases are shown to increase with substrate temperature and droplet size: The characteristic time required for mixing of a dye in an evaporating sessile droplet is reduced by $\sim$8 times on a superhydrophobic surface when the substrate temperature is increased from 40–60 °C. The mixing rate is $\sim$15 times faster on the superhydrophobic substrate compared to the hydrophobic surface maintained at the same temperature of 60 °C.

Nonlocal Transport in Plasmonic Nanostructures with Nonlocal Electronic Responses

Chen Chen (Prof. Liang Pan's group)

Heat assisted magnetic recording (HAMR) has the potential to increase the hard disk drive capacity by two orders of magnitude. It requires local temperature rises in the magnetic medium of 300 K or even higher, so thermal management is an important issue that needs to be tackled.
This work outlines the framework to study the nonlocal heat generation and transport in nanoscale plasmonic structures with considerations of nonlocal electron responses and nonlocal thermal transport. The strong nonlocality in plasmonic structures is important to understand the mechanisms of energy conversion and transport processes. This is also essential for thermal management of these structures.

Surface Dependent Fermi Velocity in Anisotropic Bismuth Telluride Nano Wires

Fan Chen (Prof. Gerhard Klimeck's group)

Introduction. Surface electrons in topological insulator (TI) based devices such as Bi_2Te_3 nanowires face no backscattering in the absence of magnetic impurities. Their surface conductance is expected to be only limited by the surface Fermi velocity. However, experimental values of the Bi2Te3 surface Fermi velocity varies more than 10%. So far, theoretical studies of TI wires assume rotational symmetry along the wire axis. In the case of Bi_2Te_3 this assumption is only true for wires grown along [001] direction. In contrast, fabricated Bi2Te3 nanowires are grown in [110] direction and often have rectangular cross sections. The facets of [110] Bi_2Te_3 nanowires show different chemical compositions: Two facets are composed of Te atoms only and the other two contain both Te and Bi atoms. Such details of the surface chemistry require atomistic representations.
In this work, atomistic $sp^3d^5s^*$ (20 band) tight binding bandstructure calculations of Bi_2Te_3 nanowires are presented. In agreement with literatures the band gap of the Bi_2Te_3 nanowires close in this work when the magnetic flux through the wire cross section agrees with half-integer flux quanta. Deviations from literature are found in the details of the surface state energies and surface Fermi velocities: Fermi velocities of chemically different surfaces differ. This creates an effective potential on the wire surface which can confine TI surface states on specific surface facets. Guided by the atomistic results, the analytical Fermi velocity model is augmented to cover the impact of the detailed wire surface chemistry.
Model. In this work, atomistic $sp^3d^5s^*$ (20 band) tight binding bandstructure calculations of Bi_2Te_3 nanowires are calculated by the multipurpose NanoElectronics Modelling Tool (NEMO5). Magnetic fields are included in terms of the Peierls phase factor in symmetric gauge. All presented atomistic calculations are numerically very intense and required typically about one million CPUs on the Blue Waters supercomputer. The surface bandstructures of these sophisticated results are very well fit with a new analytical model. This model is to include different Fermi velocities on different wire facets.
Results. The atomistic tight binding model with the Peierls phase factor of NEMO5 reproduces the band gap dependence on magnetic fields. The calculated oscillations of the magnetoconductance in these nanowires for different gate voltages agree qualitatively with experimental data. One dimensional helical states are observed in the wires. Differences in the bandstructures of rectangular Bi_2Te_3 nanowires with different ratios of pure Te and mixed atom type surfaces are observed. The surface states of these atomistic calculations are subject to confinement depending on the facets dimension and chemistry.
The surface bandstructures of the atomistic calculations serve as fitting targets for the surface Fermi velocities of the new analytical model. The analytical model can efficiently predict effective surface potentials which confine surface states on specific facets.
Conclusion. In summary, the atomistic representation of Bi_2Te_3 wires unveils chemically different wire surfaces and surface state dispersion relations. Chemically different wire surfaces host topological insulator surface states with different Fermi velocities.

Understanding the properties of twisted bilayer graphene by Raman spectroscopy

Jack Chung (Prof. Yong P. Chen's group)

Twisted bilayer graphene (tBLG) exhibits different electronic, optical, and thermal properties than regular Bernal-stacked bilayer and monolayer, originating from its lattice orientation dependent interlayer interaction and superlattice structure. Twist angle between graphene sheets therefore is an effective way to engineer properties in graphene and same idea can be applied in other 2D layered materials. By means of Raman spectroscopy which is a sensitive probe to the electronic and vibrational properties of graphene, we have found two new Raman modes below $100\,\mathrm{cm}^{-1}$ associated with the interlayer coupling in tBLG though lattice vibration. The two Raman bands are assigned to fundamental layer breathing (ZO′) and torsion modes. In addition to another ZO′ mode at $\sim 160\,\mathrm{cm}^{-1}$ reported earlier, there are two ZO′ bands in tBLG. Detailed measurements of tBLG with various twist angles reveal that the two new modes are strongly related to an enhanced electronic density of states in tBL. This also allows us to unveil two different scattering mechanisms for the ZO′modes. Furthermore, we have demonstrated that the electronic and optical properties in tBLG field effect devices with electrolyte gate can be modulated electrostatically, which would help to find applications to the material.

Film evaporation mems thruster array

Anthony Cofer and William O'Neill (Prof. Alina Alexeenko's group)

Chemical micropropulsion options for small satellite systems (i.e. cube-sats, nano-sats, pico-sats) are currently limited by feed system complexity and viscous effects which dominate low Reynolds number flows, inhibiting efficient operation at low thrust levels. Electric propulsion offers high Isp but with high power/thrust demands and require power supplies which are bulky, complex, and expensive. The proposed Film-Evaporation MEMS Tunable Array (FEMTA), exploits the small scale surface tension effect in conjunction with temperature dependent vapor pressure to realize a thermal valving system for effective propulsion in the sub-milliNewton range with a thermal management option. The local vapor pressure is increased by resistive film heating until it exceeds meniscus surface tension strength in the nozzle inducing vacuum boiling which provides a stagnation pressure equal to vapor pressure at that point which is used for propulsion. The heat of vaporization is drawn from the bulk fluid and is replaced by either an integrated heater or waste heat from the vehicle providing a thermal control capability.

Fabrication and Characterization of a Hierarchical Manifold Microchannel Heat Sink Array for Evaporative Intrachip Cooling

Kevin Drummond (Prof. Suresh V. Garimella's group)

A hierarchical manifold that feeds arrays of microchannels in a heat sink offers intrachip evaporative cooling at a low pressure drop. A thermal test vehicle, with all flow distribution components heterogeneously integrated, is fabricated to demonstrate thermal and hydraulic performance. High-aspect-ratio (AR) microchannels with constant channel widths (15 µm) and multiple heights (155 µm and 280 µm) were etched into silicon wafers and thermo-compression bonded to a silicon plenum plate. The 5 mm × 5 mm heated chip area is cooled by a 3 × 3 array of microchannel heat sinks that are fed with coolant through the plenum using a hierarchical manifold distributor. Using HFE-7100 as the working fluid, experimental results are presented for a fixed fluid mass fluxes of 1890 kg/m^{2}s and 2100 kg/m^{2}s, inlet subcooling of 7 °C, and outlet gauge pressure of 20 kPa. For 15 µm × 155 µm channels, increasing fluid mass flux from 1890 kg/m^{2}s to 2100 kg/m^{2}s lead to an increase in maximum heat flux dissipated from 275 W/cm^2 to 350 W/cm^2, a 24 % increase; at the highest heat flux condition pressure drop increased 27 % from 63 kPa to 80 kPa. Increasing channel depth from 155 µm to 255 µm provided a 100 % increase in maximum heat flux dissipated for a constant fluid mass flux and chip temperature; heat fluxes of up to 550 W/cm^2 are dissipated at less than 120 kPa pressure drop using high aspect ratio microchannels.

Lateral Force Microscopy using Nanomanipulation

Yen-Kai Hseu (Prof. Helen McNally's group)

The scanning probe microscope (SPM) is a high precision measurement research equipment that enables one to obtain images of a sample's surface topography at the nano-level using atomic force microscopy (AFM) techniques. In addition to its imaging capabilities, the SPM can also be used to obtain material characteristics such as surface electrical charges, magnetic properties, vertical/lateral force, and friction. Surface force data, represented through force curves, can be generated by different methods of SPM tip and surface interactions. The most common and well developed method of force measurement using SPM is vertical force microscopy. Force measurements in the lateral direction have also been conducted but results have mainly been qualitative. The scope of this research is to develop an SPM technique that would enable lateral forces to be quantified just like vertical forces. One motivation for this research involved incorporation of the technique with medical research. Complex structures contained within human cells are encapsulated within a lipid bi-layer known as the cell membrane. The cell membrane acts as a gateway between the internal cell structures and the external environment regulating what enters and exits the cell. Exposure of a cell to internal or external stimuli such as mutation or non-ideal physiological conditions can cause changes in the physical properties of the cell membrane. Past research in a similar area have shown that a direct correlation exists between a sample's surface vertical forces and its viscosity[1].

References

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Optical imaging with photonic hyper crystals

Andy Huang (Prof. Evgenii Narimanov's group)

We present an optical imaging system based on the recently introduced concept of photonic hyper-crystal, an artificial optical medium combining the properties of hyperbolic materials and photonic crystals. The proposed device functions as a negatively refracting (Veselago) lens with a nearly constant negative refractive index and substantially reduced image aberrations. The planar nature of this lens offers significant applications in nano-photolithography and hot-spots diagnosis in silicon- based semiconductor devices.

Spin Transfer Torque in Graphene Devices

Terry Hung (Prof. Zhihong Chen's group)

All Spin Logic (ASL) is considered an attractive post-CMOS approach for low-power operation. In our study, graphene is chosen as the channel material due to its long spin relaxation length, gate-tunable carrier densities, and high carrier mobility. In order to develop graphene based spin logic, it is essential to demonstrate spin-torque switching and decrease the critical spin-torque current in graphene devices. Two key experiments to achieve this goal are presented in this poster, injection efficiency and torque efficiency.

Challenges and solutions for 2D material tunnel transistors

Hesameddin Ilatikhameneh (Prof. Gerhard Klimeck's group)

Scaling Si MOSFETs is pushing electronic industry toward the ultra-thin channels since thin channels offer a better gate control and performance. In this regard, 2D materials have attracted a lot of attention for their promise as future transistors. Especially for Tunnel FET (TFET) applications, thin channel is of paramount importance as the tight gate control is a critical factor for high performance. TFETs are ultra-low power devices and can in principle provide subthreshold-swing (SS) less than 60 mV/dec at room temperature. Despite these benefits, TFETs usually suffer from low ON-currents compared to conventional MOSFETs. The band-to-band-tunneling (BTBT) transmission probability and consequently ON-current in TFETs depends strongly on the electric field at the tunnel junction. Since the design of the device strongly affects the electric field at the tunnel junction, it is critical to understand the impact of the device design parameters.

The tunnel junction in 2D TFETs can be realized using electrical or chemical doping of the source region. The performance of devices doped with these two methods depends on the device designs. For example, in the case of chemical doping, equivalent oxide thickness (EOT) is the major player, while in the case of electrical doping, the physical thickness of the oxide is the main factor. This work explores the effect of doping levels, oxide thickness, and EOT on the performance (ON-current and SS) of 2D TFETs.

Multi-network wireless sensors

Xiaofan Jiang (Prof. Dimitrios Peroulis's group)

In this project, a wirelessly powered sensor system with multi-wireless network protocol has been implemented. Data is transmitted via ANT 2.5GHz ISM Sensor implement of up to 5 device in a single shared channel implemented. Device has been successfully demonstrate with resolution of less than 0.01c and effective power consumption of 2.2 mW. Also, every sensor in this network should be able to upload measurement wirelessly to and controlled by one host (Android tablet). Furthermore, all sub-systems including sensor, wireless powering device, and host unit have to be energy efficient and the measurement system have to be able to work under -60–100 °C.

Mode-evolution-based polarization rotation and coupling between silicon and hybrid plasmonic waveguides

Sangsik Kim (Prof. Minghao Qi's group)

We present a mode-evolution-based polarization rotation and coupling structure that adiabatically rotates the TE mode in a silicon waveguide and couples it to the hybrid plasmonic (HP) mode in a strip silicon-dielectric-metal waveguide. Simulation shows that high coupling factors of 92 %, 78 %, 75 %, and 73 % are achievable using Ag, Au, Al, and Cu as the metal cap, respectively, at a conversion length of about 5 µm. For an extremely broad wavelength range of 1300 −1800 nm, the coupling factor is > 64 % with a Ag metal cap, and the total back-reflection power, including all the mode reflections and back-scattering, is below −40 dB, due to the adiabatic mode transition. Our device does not require high-resolution lithography and is tolerant to fabrication variations and imperfections. These attributes together make our device suitable for optical transport systems spanning all telecommunication bands.

Broadband Phase-Matched Second-Harmonic Generation via Hetero-Slot Waveguide

Sangsik Kim (Prof. Minghao Qi's group)

We present the design schemes of broadband second-harmonic phase-matching, with a hetero-slot waveguide configuration. The hetero-slot waveguide, whose waveguide arms are composed of two different dispersive materials, enables us to engineer the waveguide modal dispersions, and helps to achieve the broadband phase-matching. The second-harmonic generation with the proposed schemes also show high conversion efficiencies, with a large modal overlap between fundamental and second-harmonic modes in a highly nonlinear polymer slot area.

ENZ Al-Doped ZnO for Ultrafast Switching at Telecom: Outpacing the Amplitude-Bandwidth Trade-Off

Nate Kinsey (Prof. Alexandra Boltasseva's group)

Transparent conducting oxides (TCOs) are promising CMOS-compatible materials due to their unique optical properties, ability to achieve plasmonic properties at telecom, and dynamic tunability. However, the slow electron-hole recombination time limits the speed at which optical modulation can occur. Here, we report the optical tunability of a unique oxygen-deprived aluminum doped zinc oxide (AZO) film where 40% modulation is achieved in reflection with a speed less than 1 ps. Through modeling of the physics, critical parameters such as the carrier density and change in refractive index are extracted which will aid the development of future all-optical devices. The extracted parameters were also used to design an integrated all-optical plasmonic modulator achieving 0.4 dB/μm with an insertion loss of < 0.1 dB/μm.

Highly Directional Spaser Array for the Red Wavelength Region

Jingjing Liu (Prof. Vladimir M. Shalaev's group)

Spaser offers an opportunity to achieve coherent optical sources at nanometer scales due to the extreme confinement of optical fields. However, achievement of spasers with directional propagation in the visible wavelength region remains a challenge thus far, owing to the unique optical feedback mechanism and large dissipative losses of the metal cavity. Here, we demonstrate for the first time a spaser showing highly directional emission in the visible by using a periodic subwavelength hole array perforated in a metal film as plasmonic nanocavities and supplying optical gain with an organic laser dye. The lasing occurs in the red wavelength region and shows a single mode. It is suggested that the optical feedback for spasing is provided by the SPP-Bloch wave, which is supported by the fact that no spasing was attained in aperiodic holes as well as in periodic holes that do not support the SPP-Bloch wave at the spasing wavelength.

Observation of Current induced Optical Kerr Rotation in Topological Insulators

Nirajan Mandal (Prof. Yong P. Chen's group)

Topological insulators (TIs) are an unusual phase of quantum matter with an insulating bulk gap and gapless spin-momentum locked Dirac surface states (SS), showing exotic topological quantum properties. However, optical identification of the spin-momentum locked SS is still challenging. Here, we report room-temperature, current induced magneto-optical Kerr rotation effect observed from various TI bulk crystals grown by the Bridgman method. The Kerr rotation was measured while a square wave bias current was applied across the samples. We find that the Kerr angle increases linearly with the applied bias current and reverses its sign as the polarity of the current is reversed. Such an observation is consistent with the spin-momentum locking of the surface states.

Simultaneous Characterization of Thermal and Thermoelectric Properties

Collier Miers (Prof. Amy Marconnet's group)

Thermoelectric devices are a promising technology for reclaiming energy that would otherwise be lost as waste heat and converting it to usable electricity. A major hurdle to this goal is the limited performance of thermoelectric materials and the evaluation of new high performance materials. Determination of the constituent properties of the figure of merit ZT is generally done via separate measurements of the thermal conductivity, the electrical conductivity, and the Seebeck coefficient. Separate measurements of these properties not only slows down testing, but also allows more opportunity for error to be introduced when comparing different materials. As an alternative to separate measurement of the individual properties that comprise ZT, the properties can be simultaneously measured on the same sample. As all measurements are conducted simultaneously on the same sample, the test conditions for each property are truly identical ensuring the accuracy of the ZT characterization. Numerical simulations are used to investigate the impact of device design on measurement accuracy. Then, the device and methodology are validated using standard thermoelectric materials characterized using a high throughput testing apparatus. The testing rig is designed to allow rapid measurement of multiple samples at once. This design provides a platform for rapid, high accuracy characterization and comparison of materials.

Plasmon-Assisted Optoelectrofluidics

Justus Ndukaife (Prof. Alexandra Boltasseva's group)

It has been recently claimed that photothermal heating induced by a single plasmonic nanostructure is inefficient in controlling fluidic motion by convection. We re-examine this problem and demonstrate that by harnessing a so-called electrothermoplasmonic (ETP) flow, a significant fluid velocity at least two orders of magnitude higher than convection can be achieved. A critical phenomenon that has not been considered in the previous studies is local gradients induced in the fluid's electrical permittivity and conductivity associated with localized heating of the fluid around the plasmonic nanostructure. In the presence of such local gradients, an applied AC electric field exerts electrical body forces in the fluid producing a fast flow. The proposed device could enable rapid delivery of analytes and particles for trapping in subwavelength plasmonic hot spots, thereby overcoming the key limitation of plasmonic nanotweezers. Our approach provides a platform for elucidating the role of heat-induced fluidic motion and plasmonic field enhancement in plasmon-assisted optical trapping, which has thus far remained elusive.

Photoresponsive nanocarriers for dofetilide smart delivery

Sandra Perez-Buitrago (Prof. Rodolfo Pinal's group)

Atrial fibrillation is the most common clinically significant cardiac arrhythmia. It is also a potent risk factor for ischemic stroke, increasing the risk of stroke 5-fold and accounting for approximately 15% of all strokes nationally. Symptomatic atrial fibrillation may also reduce quality of life, functional status, and cardiac performance [1]. In addition, FA is associated with higher medical costs as well as representative side effects of drug and ablation treatments, which can cause complications such as stroke, cardiac perforation, renal and thyroid dysfunction, among others effects that increase the risks of patient health.

The antiarrhythmic agent Dofetilide may help to normalize the irregular heartbeats presented in this pathology. We are developing polymeric nanocarriers for Dofetilide biodistribution in cardiac cells. In this case, they are photosensitive nanocapsules that respond to the light stimulus and they permit a fast drug releasing at specific time and place.

This is the initial development phase of a therapy for atrial fibrillation (AF), where the electrophysiologist could select the area and study the tissue behavior before ablation, with the capacity of avoiding injuries generated by nonspecific cardiac ablation energy and toxic effects of the nonspecific drugs conventionally used.

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A sewing-enabled stitch-and-transfer method for robust, ultra-stretchable, conductive interconnects

Rahim Rahimi (Prof. Babak Ziaie's group)

Fabricating highly stretchable and robust electrical interconnects at low-cost remains an unmet challenge in stretchable electronics. Previously reported stretchable interconnects require complicated fabrication processes with resulting devices exhibiting limited stretchability, poor reliability, and large gauge factors. Here, we demonstrate a novel sew-and-transfer method for rapid fabrication of low-cost highly stretchable interconnects. Using a commercial sewing machine and double-thread stitch with one of the threads being water soluble polyvinyl alcohol (PVA), thin zigzag pattern metallic wires are sewn into a polymeric film and are subsequently transferred onto a stretchable elastomeric substrate by dissolving PVA in warm water. The resulting structures exhibit extreme stretchability (exceeding 500 % strain for a zigzag angle of 18 °) and robustness (capable of withstanding repeated stretch-and-release cycles of 15 000 at 110 % strain, 50 000 at 55 % strain, and $>$ 120 000 at 30 % strain without any noticeable change in resistance even at maximum strain levels). Using this technique, we demonstrate a stretchable inductive strain sensor for monitoring balloon expansion in a Foley urinary catheter capable of detecting the balloon diameter change from 9 mm to 38 mm with an average sensitivity of 4 nH/mm.

High performance thermophotovoltaics

Enas Sakr (Prof. Peter Bermel's group)

High-performance thermophotovoltaics (TPV), as a novel energy generation method, converts heat into electricity with a theoretical limit of 50% conversion efficiency. In our work, we propose high-performance photonic crystal selective emitters and rare-earth doped selective emitters by introducing the concept of integrated filter emitters. The proposed emitters enhances useful emission of high energy photons using quality-factor matching while reducing parasitic losses via chirping of a multilayer reflector transmitting only at short wavelengths. This allows the emissivity to approach the blackbody limit for wavelengths shorter than the photovoltaic diode bandgap, while effectively reducing the losses associated with undesirable long-wavelength emission. The proposed design can eliminate the use of expensive cold side filters such as rugate filters that were proposed to reduce parasitic emission and employ photon recycling. We obtained theoretical efficiencies of 34% for rare-earth doped ceramic emitters, and 42% for photonic crystal emitters. In order to establish the simulated work, a TPV testing experimental setup is being constructed with key components for high-performance TPV included. Using Si wafer as the emitter and GaSb cell as the PV diode, a plot of short-circuit current at different emitter temperatures is acquired, and is shown to follow the expected short-circuit current from simulation results.

Microsupercapacitor Aging Behavior by Measurement of Spatial Charge Distribution with Electroreflectance Technique

Kimberly Saviers (Prof. Timothy Fisher's group)

Supercapacitors bridge the gap between traditional capacitors and batteries in that they can achieve both high power density and high energy density in one device. Because they are new devices in the marketplace, it is imperative that their aging behavior is thoroughly understood.

In this study, microsupercapacitors were fabricated and evaluated over 4 million charge/discharge cycles using an electroreflectance method in order to understand their aging behavior. The devices were constructed of simply gold electrodes by traditional photolithography etching techniques. Eight interdigitated fingers comprise each electrode with separation 20 µm. Subsequently, an optically transparent polymer electrolyte was coated over the electrodes. Then the devices were continuously charged and discharged while capacitance and electroreflectance signals were periodically recorded.

The electroreflectance technique measures light reflected from the device during the charge/discharge cycle. Because charge accumulates in the device, the reflectivity property of the electrodes changes throughout the charge/discharge cycle. This allows for spatial resolution of the charge accumulation in the device. Here, this information is used to understand the evolution of charge accumulation behavior over millions of cycles. This is the first study which reports spatially resolved aging in a microsupercapacitor.

The results indicate a burn-in period during which the device performance increases, followed by gradually decreasing capacitance commonly associated with aging. The reflectance images show that aging in the negative electrode dominates the capacitance of the device throughout the study.

Doping of Lithium-ion Conducting Garnet Oxide Electrolytes for Safer Energy Storage Systems

Derek Schwanz (Prof. Ernesto Marinero's group)

Lithium-ion battery systems often present less than ideal
cyclability and safety, specifically related to dendritic growth and electrolyte flammability. The garnet oxide $Li_7La_3Zr_2O_{12}$ (LLZO) exhibits attractive characteristics as a potential solid state electrolyte for lithium based battery devices: high intrinsic chemical and thermal stability, even when interfaced with pure lithium metal. Ionic conductivity of LLZO achieved thus far is modest and gated by limitations of current synthetic methods to directly produce the desired cubic phase, while simultaneously manipulating the garnet's microstructure (density, stress, grain size) and incorporating dopants at site-specific locations. Here, aliovalent doping of bismuth is utilized to preferentially stabilize the desired cubic phase. Concomitant advantages of the bismuth dopant include increased control of the particle size through solution based processing as well as decreased fabrication temperature required to stabilize the fast ion-conducting LLZO cubic phase. This lower temperature fabrication will ultimately enable safer and more stable all solid-state lithium-based battery technology in the future.

Efficient broadband single-photon source based on CMOS-compatible metamaterials

Mikhail Shalaginov (Prof. Vladimir M. Shalaev's group)

The broadband enhancement of single-photon emission from nitrogen-vacancy centers in nanodiamonds coupled to a planar multilayer metamaterial with hyperbolic dispersion is studied experimentally. The metamaterial is fabricated as an epitaxial metal/dielectric superlattice consisting of CMOS-compatible ceramics: titanium nitride (TiN) and aluminum scandium nitride ($Al_xSc_{[1-x]}N$). It is demonstrated that employing the metamaterial results in significant enhancement of collected singlephoton emission and reduction of the excited-state lifetime. Our results could have an impact on future CMOS-compatible integrated quantum sources.

Comparison of Cytotoxicity of Carbon Nanomaterials in Human Lung Normal and Cancer Cell Line

Aparna Shinde (Prof. Candace Tsai's group)

Chronic Exposure of Carbon Nanomaterials induces carcinogenesis in Human Lung Cells

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Health effects associated with exposure to engineered nanomaterials (ENMs), most commonly carbon nanotubes (CNTs), have raised serious concerns because of the potential for chronic exposure to enhance the risk of carcinogenicity. Investigating the relationship between ENM exposure and established carcinogenic mechanisms is critical for scientists to gain deeper understanding of medical causation from ENM exposure and prevent associated cancer development. Our research focuses on how carbon nanoparticles (CNMs) exposure can cause cytotoxicity, including carcinogenesis in human lung cells.

Objectives: 1. Characterize carbon nanomaterials (CNMs) like multi-walled carbon nanotubes (MWCNTs) (industrial grade (IG) and research grade (RG)), graphene nano-flakes (GNF) and graphene nano-platelets (GNP) for size, elemental composition and oxidation states. 2. Perform cytotoxicity assays in human fetal lung fibroblast cells (MRC-5) and bronchi alveolar non-small lung cancer cell line (NCI-H358). 3. Compare the cytotoxicity of CNMs between normal and cancer cells with respect to time, concentration, and type of CNM.

Methodology: We characterized the CNMs for size, distribution and composition using TEM and X-ray photoelectron spectroscopy. Next, we autoclaved the CNMs and suspended them in cell media. The nanoparticle cell media stock solution (20 µg/ml) was sonicated for 10 minutes to achieve uniform dispersion of NPs in the cell media and was diluted to achieve concentrations of 1 µg/ml, 5 µg/ml and 10 µg/ml. MRC-5 and NCI-H358 cells were then incubated with different concentrations (1–20 µg/ml) of IG/RG/GNF/GNP for 24 and 48 hrs. Calcein AM assay was used to determine cellular viability. The cells were stained with Hoechst dye to study the morphology of apoptotic cells using fluorescence microscopy.

Results: The MWCNT and graphene nanoparticles studied here have a mobility diameter between 20–700 nm and 50–600 nm, respectively. XPS analysis of the two MWCNTs revealed a difference in composition, with RG MWCNTs showing the presence of MoS_2. After 24 h incubation, RG MWCNTs showed 30% less cell viability in normal cells and 10% less in cancer cells compared to IG MWCNTs. Incubation with GNP caused 40% less cell viability in normal cells and 9% less in cancer cells at 24 h compared to GNF. Those cells treated with CNMs showed markedly apoptotic cell features such as condensed and fragmented nuclei.

Conclusions: From above results, we conclude the toxicity level shown by CNM-exposed cells depends on CNM concentration, exposure time, composition, the type of CNMs and type of cells. Higher toxicity was observed for cells incubated with MWCNTs than cells exposed to graphene. RG CNTs induced higher toxicity in human lung cells than IG CNTs, which may be due to the difference in the chemical composition between IG and RG. Similarly, GNP caused higher toxicity in human lung cells than GNF which may be due to the difference in elemental composition, lateral dimensions and monolayer number between GNP and GNF. The dose and time dependent toxic effects of CNMs, irrespective of type of CNMs, is significantly higher in normal lung cells than in cancer lung cells.

The modeling of wide-bandgap GaInP Photovoltaic cells for conversion efficiency up to 16.5%

Yubo Sun (Prof. Peter Bermel's group)

III-V high quality materials are among the top candidates for Solar Cell design for many years. The state of art tandem cell with record efficiency has 1.89 eV GaInP deposited on GaAs substrate. Here we consider modeling of a single junction wide bandgap GaInP cell where the component ratio of Gallium ranges from 0.7–0.82. GaInP with compound ratio at this range could not only produce wide band-gap but also behave like pseudo-direct bandgap material that has good absorption in the effective spectrum for thin-film application. This Gallium-rich alloy was modeled using ADEPT on nanohub.org with absorption curve extrapolated from InP and $Ga_{0.5}In_{0.5}P$ absorption data. Solar simulator was calibrated to reproduce EQE and I-V characteristics, both of which were studied to explore major sources of loss

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Effect of Waveguide Surface Roughness on the Fiber Coupling Efficiency of Inverse Tapers

Min Teng (Prof. Minghao Qi's group)

Inverse silicon nanotapers have been purposed since last decade to provide a potential solution to fiber-to-chip edge coupling. Despite the perceived advantages of broadband performance and the ease of on-chip integration, inverse taper has not seen wide implementation in industry. Up to now the widely accepted idea is that inverse taper should be long enough to suppress loss during mode transition , although it has been suspected that increasing the taper length might be counterproductive when including scattering loss due to sidewall roughness Herer we provide a qualitative analysis and experimental evidence that longer tapers do not necessarily lead to better coupling efficiency due to surface roughness and insufficient tip width.
We investigate the effect of waveguide surface roughness on the coupling efficiency between silicon inverse tapers and lensed fibers. Short taper lengths of 30-50 micrometers are shown to achieve minimum coupling loss.
We have demonstrated the effect of tip width and surface roughness on the coupling efficiency of inverse silicon tapers. Without intermediate cladding stage, inverse taper should be designed to optimize tip coupling efficiency and the optimum tip width for TE and TM are 180 nm and 160 nm respectively, for a silicon thickness of 220 nm.
Contrary to conventional wisdom, longer taper does not necessarily lead to higher coupling efficiency depending on tip width even without roughness. When roughness is taken into account, coupling efficiency peaks at 30 μm for TE and 50 μm for TM, consistent with our measurement data.

Ge CMOS Devices and Circuits

Heng Wu (Prof. Peide Ye's group)

This work presents new approaches investigated for future's post-Si technology based on Germanium by both experiments and TCAD simulations.
A novel recessed S/D technique is introduced in the MOSFETs fabrication, greatly improving the n-Ge contacts. Low Rc of 0.05 and 0.23 Ω·mm are obtained for p- and n- contacts. For the first time, Ge nMOSFETs is scaled to sub-100 nm node down to 25 nm, with 4X record high Imax and gmax.
The world's first CMOS circuits on Ge are demonstrated here through a novel recessed S/D and channel process. First sub-100 nm channel length and record high voltage gain of 36 V/V on non-Silicon substrate are achieved. Logic gates such as inverters, NANDs, NORs and ring oscillators are realized. Advanced gate structures such as ET-SOI and tri-gate are further explored, showing much enhanced short channel effect immunity. First 3D FinFET CMOS circuit on Ge are also demonstrated.

Tie Chains in Polymer Thin Films: Building the Connectivity for Efficient Charge Transport

Xikang Zhao (Prof. Jianguo Mei's group)

Charge transport in polymeric thin films is a complicated process, which involves a multitude of coupled electronic events. Due to the growing appeal of semiconducting polymers in organic electronics, it makes the fundamental understanding of charge transport increasingly important.
In this study, we propose a two-step approach to reveal the nature of the connections between crystalline aggregates in polymer thin films. The first step involves the study of a crystalline semiconducting polymer with intentionally placed conjugation-break spacers along the polymer backbone. The second step brings in a fully conjugated polymer that is blended into the non-conjugated polymer matrix. The morphological characterizations and electrical measurements confirm that conjugated polymer tie chains are able to build the connectivity between crystalline aggregates, leading to efficient charge transport in the polymer blend films.
