Session J – Applied Physics

(Alphabetical)

Coupled Cavity Waveguides and Optical Bistability

Amit Alon

Mentor: Alex Scherer

The concept of photonic crystals is introduced through general analytic approach. We'll discuss a particular photonic crystal structure of coupled waveguides. This structure demonstrates optical bistability through an analytical model and simulations using meep (software that solves discretizes Maxwell's Equations using Finite Difference Time Domain method). Bistability is caused by small nonlinearities in the material which, in turn, give rise to small changes in the frequency. This change affects the dielectric constant of the material. Hence, we can switch on/off a device using only the input intensity.

Developing a Microfluidic System for On-Chip Reverse Transcription

Michael Borisov

Mentor: Michael Roukes

The field of nanobiotechnology provides a scale particularly suited to single-cell experimentation. With this project, we have developed the capability to reverse transcribe the mRNA from a single cell to cDNA and perform PCR on this resultant material to quantize the gene expression of a single cell. The microfluidic chip itself is fabricated using a 4-layer soft lithography process and is composed of a central mixing ring adjoined by five other chambers that, when connected to the main ring, can be used to mix reagents together by using a peristaltic pump to flow material around the chip. When used in conjunction with a thermocycler for precise temperature control, this device can perform the SuperScript III CellsDirect cDNA Synthesis protocol. After this is completed, qPCR mix is used to flush the cDNA into a large chamber, and qPCR is performed to quantize the presence of a certain gene. With further work, this project will be integrated into a system for single-cell protein measurements, allowing us to analyze both gene expression and translation from a single cell.

Microscale Platinum Resistors for Heating and Temperature Sensing

Samson Chen

Mentors: Axel Scherer and Aditya Rajagopal

Many microfluidic applications, such as PCR, require fast and accurate thermal control. We fabricated banks of 20 microscale and nanoscale platinum resistors on an alumina-glass substrate. Because platinum is already used in macroscale RTDs (resistance temperature detectors) for precision temperature measurements, these platinum resistors have the potential to be used as simultaneously as temperature sensors heaters (through I^2R heating). Due to their extremely small size and the lack of separation between the heater and temperature sensor, these resistors permit extremely accurate and fast thermal control. We are currently analyzing the resistor banks' static and transient thermal characteristics, and running a thermal simulation to validate the accuracy of our thermal measurements from these microstructures. We have already demonstrated the ability of these heaters to reach temperatures hot enough to emit visible light (>1000K) through blackbody radiation, effectively creating the world's smallest light bulb (100nm x 4µm x 150nm). As light bulbs, these platinum microstructures may also have potential applications in microscale spectroscopy, where a small, broadband light source may be required.

Nanostructured Electrodes for Improved Charge Carrier Collection in Conjugated Polymer Solar Cells

Arianne X. Collopy,

Mentors: Harry A. Atwater and Deirdre M. O'Carroll

Here, we investigate the use of arrays of metallic nanostructures to improve charge carrier collection efficiency in polymeric bulk-heterojunction solar cells. The cells consist of a blend of poly (3-hexylthiophene), a pi-conjugated polymer, as the active absorbing p-type semiconductor and [6-6]-phenyl-C61 butyric acid methyl ester as the n-type material. Nanostructured electrodes are fabricated via the use of ultra-thin (~ 600 nm) porous alumina templates as masks through which metal nanostructures are deposited onto metal films by thermal evaporation. The blend of p- and n-type materials is deposited directly onto the nanostructured electrode by spin coating from solution. Two strategies are employed to complete the solar cell device: The first by applying a transparent conducting polymer top electrode and the second by bonding to an transparent conducting oxide (indium tin oxide) layer on glass. A reflow step is carried out to ensure conformal coverage of the nanostructured electrode by the active material. The efficiencies of bulk-heterojunction solar cells incorporating nanostructured electrodes are compared with conventional bulk-heterojunction devices to assess the merits of our approach.

Bio–Inspired Carbon Nanotube Foams
Anna Craig
Mentor: Chiara Daraio and Abha Misra

Examination of biologically formed armors with remarkable energy-absorption properties can provide inspiration for designing new materials. In this work we create bio-inspired multilayer carbon nanotube (CNT) foams by stacking vertically aligned CNT arrays partially embedded in thin polymer films (PDMS, Polydimethylsiloxane). When compressed, these multilayer foams present a unique deformation behavior: they collapse and recover layer-by-layer, showing a sharp localization of deformation advantageous in the absorption of dynamic impacts. This response is very different than what observed in "classical" foams, generally characterized by a uniform deformation process. We studied the fundamental mechanical response of single and multilayer samples via compression tests coupled with an in-situ video acquisition system. Compression tests at various strain rates (up to 80% of sample deformation) were conducted on freestanding CNTs, CNTs anchored on a single PDMS layer, and CNTs sandwiched between two PDMS layers, as well as on several common foams as a basis for comparison. Data analysis including determination of the energy absorptions (normalized to density) and cushion factors of the samples is currently being conducted while samples of the multilayer foams are being fabricated. The data may then be applied to the fabrication of multilayer foams tuned to absorb specific impact energies.

Infrared Lensing with Plasmonic Microslits
Thomas Gwinn Jr.
Mentor: Roger Howe at Stanford University

Focusing light is one of the primary issues in optics, but refractive lenses are not always suitable for some applications, especially those requiring small size, high temperature operation, or on-wafer fabrication. We present novel planar lenses that address these issues. Our lens structure is composed of an optically thick tungsten film on a silicon substrate with hundreds of nanometers slits arranged in tens of microns scaled arrays. We design, simulate, fabricate and test these devices to work with light ranging from 2 to 10 microns. At the time of this submission, the lenses have been designed and simulated; they are currently in the process of fabrication.

Modeling Optomechanical Crystal Geometries
Michael Kaye
Mentors: Oskar Painter and Matthew Eichenfield

It has been shown recently that nanoscale periodic structures called optomechanical crystals can simultaneously localize and provide strong coupling between optical and mechanical modes. Optomechanical coupling exists in an optomechanical crystal when the mechanical vibrations of the crystal phase modulate the optical modes in direct proportion to mechanical mode amplitude. The optical modes then exert radiation pressure or gradient forces which, if of sufficient amplitude, can change the resonant frequency of and either damp or amplify the mechanical motion. The optomechanical coupling strength varies greatly depending on the geometry, so it is valuable to examine a wide variety of structures in search of those which provide the strongest coupling. We use the finite element modeling tool COMSOL to numerically solve for the optical and mechanical modes of structures and examine such properties as optical Q, mechanical Q, and degree of optomechanical coupling.

Fabrication and Characterization of Stretchable Metamaterials on Elastomeric Substrates
Yousif Kelaita
Mentors Harry Atwater, Imogen Pryce and Koray Aydin

The study of metamaterials has recently emerged as an exciting and novel way to affect the properties of electronic and optical devices. Tunable metamaterials are of particular interest because they are not limited to a single frequency of operation. This project explores using the elastomer polydimethylsiloxane (PDMS) as a substrate for arrays of split-ring resonators (SRRs). The mechanical properties of PDMS can be utilized to tune the arrays' response by changing the geometry of individual SRRs. This is accomplished by stretching the PDMS, which changes the length of the legs of the SRR and the distance between the SRR and a nanowire. This change in geometry induces a resonant frequency shift, making the metamaterial tunable. Two different approaches have been taken towards embedding Au patterns in PDMS. The first method uses electron beam lithography to write patterns directly on PDMS. The second approach is based on the transfer of functionalized Au features from a Si wafer to PDMS. We use finite-difference time-domain full field electromagnetic simulation and Fourier transform infrared spectroscopy to demonstrate the resulting frequency shift.

Growth and Characterization of Zinc Oxide for Photovoltaic Applications

Rishi D. Khanna

Mentors: Harry Atwater and Davis S. Darvish

In order for the evolution of thin-film photovoltaics to continue, new materials that are cheaper, more scalable, and less toxic need to be considered. This project focused on materials consisting of earth abundant materials, which fulfill the aforementioned requirements. In particular, zinc oxide (ZnO) and cuprous oxide (Cu_2O) were studied as potential compounds for a heterojunction. Molecular Beam Epitaxy (MBE) was used to attempt to grow single-crystalline aluminum-doped-ZnO (AZO) on single-crystalline Cu_2O, despite the fact that ZnO is naturally a Wurtzite-hexagonal crystal and Cu_2O is naturally cubic. Parameters, such as temperature and partial pressure of oxygen gas, were varied to determine optimal growth conditions, and the characterization of each sample was investigated to determine the quality of heterojunction. Processes like Reflection High Energy Electron Diffraction (RHEED), ellipsometry, and x-ray diffraction (XRD) were utilized. Additionally, Hall measurements were made to determine carrier concentration and Hall mobility. Ball-and-stick models of the molecular interface were created for further understanding, and computer simulations were conducted to model the effectiveness of such a cell. The simulations predict a cell efficiency of roughly 8.68%.

Electronic Measurements of Vapor-Liquid-Solid Grown, Ni-Catalyzed, Si Wires

Alexander M. Lapides

Mentor: Harry A. Atwater

Measurements of the electronic properties of vapor-liquid-solid (VLS) grown semiconductor wires is essential to analyzing the wires potential as solar cells. For Si wires grown by chemical vapor deposition using a Ni catalyst at 1010 °C, the resistance of the wire can be measured using a 4-pt IV analysis. This value can be used to calculate the resistivity of the Si wire, and the resistivity can then be correlated with the electrically active doping concentration, a key property for photovoltaic cells and other solid-state devices.

Designing a Ballistic Pendulum for the Caltech Spheromak Formation / Astrophysical Jet Experiment to Measure Plasma Jet Momentum

Franz Sauer

Mentors: Paul Bellan and Auna Moser

The Caltech Spheromak Formation/Astrophysical Jet experiment focuses on studying spheromaks, toroidal plasmas containing strong internal currents and internal magnetic fields. Spheromaks have applications towards fusion technology, and their physics is closely related to the physics of astrophysical jets. This project focused on designing a Ballistic Pendulum to measure the momentum of a plasma jet in a test chamber. The pendulum is placed in the path of the jet so that plasma strikes it. The plasma that strikes the pendulum transfers momentum, causing the pendulum to swing. By knowing the pendulum’s mass and length and by measuring horizontal displacement, one can determine the imparted momentum. We designed a ballistic pendulum to work without disturbing existing diagnostics on the Caltech experiment. The pendulum components were machined to the desired specifications and then assembled. At the time of writing, preliminary testing of the device showed that it is successful in being able to measure the momentum of incoming matter. The pendulum will be placed in the test chamber to measure the momentum of a plasma jet.