SEAS Undergraduate Student Affairs and Global Programs,
the Engineering Student Council, and
the Columbia Undergraduate Scholars Program present
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The Fu Foundation School of Engineering and Applied Science

1864–2014

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I. Understanding the Cosmos

Optimizing Plasma Boundary Control in Superconducting Tokamaks

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Supervising Faculty, Sponsor, and Location of Research

David A. Humphreys, Department of Energy & National Undergraduate Fellowship, General Atomics, San Diego, USA

Abstract

Plasma shape control is an important aspect of tokamak operations, but is challenging to implement in superconducting machines. A metric to quantify the quality of shape control capability was developed, enabling a comparison of DIII-D to KSTAR and other superconducting machines. Shape control is more complicated in these machines than on DIII-D because of slow power supplies and strong coupling between coils. In addition, the number of free parameters makes hand-tuning PID controller gains impractical. To move toward automated, offline tuning of the feedback loop, a linear closed-loop control simulation was created using Simulink, which allows the use of Matlab's looptune optimizer for control loops. Initial development of the tool is complete, but optimization results indicate that the problem must be simplified further to automatically converge on a solution.

Keywords

plasma physics, nuclear fusion, tokamak, superconducting, plasma control system, PID control, controllability, matlab, simulink

Space Debris: Observation, Mitigation, Remediation, & their Legal Factors

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

In 2012, a World Economic Forum panel concluded that "a day without satellites" would spell global economic collapse – GPS, communications, security, environmental data, and more are all provided via spacecraft in orbit. It might seem difficult to comprehend an apocalypse not instigated by catastrophe on the surface of the planet Earth, but, without proper protection and management of space operations, a collapse of some kind would be disastrous. Man-made space debris is arguably the most significant obstacle to the security of space, as its potential to create a "cascade effect" of collisions in orbit has reached a point of no return. Actions must be taken – but they require significant efforts in both engineering and policy.

This study asks: What is the state of debris observation (monitoring debris), mitigation (pre-launch prevention of debris creation), and remediation (removal of existing debris) efforts today? What are its deficiencies? What future methods will resolve these deficiencies? Furthermore, what is the efficacy of legal and political factors related to these debris issues? How can law/policy allow the engineering solutions to become real-world possibilities?

Through an extensive study of the academic literature in the field, the study seeks to synthesize the state of debris resolution efforts today, from both an engineering and a legal/policy point of view. The study finds that, while states and corporations across the globe have pioneered several research projects, theoretical and otherwise, in methods of debris mitigation and remediation, efforts on the whole are sparse and mostly theoretical, while domestic and international efforts in law and policy remain similarly thin and abstract. This study concludes by proposing several directions for engineers and policymakers in order to alleviate these issues.

Keywords

space debris, spaceflight, Kessler Syndrome, space policy, satellites

LOFAR-discovered Supernova remnants

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Statistical studies of supernova rates suggest that there should be considerably more galactic Supernova remnants (≥ 1000 ; *Li et al. 1991*) than we currently know of (294; *Green 2014*). We hypothesize that the remaining Supernova remnants (SNR) are very old ones whose emission has been redshifted to very low frequencies.

One defining property of SNR is that they are powerful emitters of synchrotron radiation, making them visible at radio frequencies and yielding a characteristic spectral index of $\alpha < 0$. In this study, we search for shell-like structures in low-frequency radio data from the Low Frequency Array (LOFAR) 110 MHz and VLA Galactic Plane Survey (VGPS)1.4 GHz surveys. The study has been constrained to a region of the sky ranging approximately between $38 < l < 48$, $-7 < b < 3$. Measuring the flux of the candidate SNR at two different frequencies allowed us to derive a spectral index (α) for their emission, which for a SNR typically ranges $0 > \alpha > -1$. In order to distinguish the non-thermal emission of potential SNR candidates from that of HII regions or stellar wind-blown bubbles, we compute IR/radio ratios from MIPSGAL 24μ, GLIMPSE 8μ, and MSX IR 8μ data.

This study reports 7 new SNR candidates and contributes new information to the study of four other candidates suggested by Green 2014. This means multiplying by two the number of SNRs known in this region, supporting the claim that low-frequency surveys could close the gap between the number of predicted and currently known Supernova remnants.

Keywords

supernova remnants, radio sources, synchrotron radiation, radio surveys, HII regions

Liquid Level in Dark Matter Detector

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The dark matter detector used by the XENON collaboration employs liquid Xenon as its detection medium. An essential part of the detector are several capacitive level meters which are used to measure the height of the liquid column at the liquid-gas interface. Currently the capacitance of the level meters is sent to a server using a commercially available circuit board known as UTI (Universal Transducer Interface). Since the cost of purchasing a UTI board is expensive we decided to assemble one in the lab. We would first design a prototype and then proceed on to a printed circuit board.

The first task was to obtain datasheets for each component of the board and identify their interconnections. After we devised a practical design, we successfully assembled a working circuit on a prototyping board. We then proceeded to program the microcontroller. Subsequently, we were able to attain a two way connection between our board and the server. However, upon measurement of known capacitor values we obtained inconsistent results.

We conjectured several reasons for why the board is malfunctioning. One possibility is the presence of faulty wiring between the UTI and microcontroller pins. Another reason could be use of an invalid reference capacitor values for the UTI. We also suspect that there are bugs in the microcontroller code. Our next plan of action is to debug the code and test the circuit with a scope.

Keywords

Dark Matter, Liquid Xenon, Level Meter, UTI

Probing the Big Bang: Jet Quenching in Quark Gluon Plasma

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Supervising Faculty, Sponsor, and Location of Research

Professor Brian A. Cole, CUSP Summer Enhancement Fellowship, Physics Department, Columbia University

Abstract

Quark Gluon Plasma (QGP) is a new state matter at high temperature in which the quarks and gluons—which make up the protons and neutrons that in turn make up the nuclei of atoms—become "deconfined" from their nucleonic shells. This quark gluon plasma state has not existed in our universe since a few microseconds after the big bang. Advances in particle accelerator technology, however, allow scientists to recreate the QGP in high-energy collisions between relativistic heavy ions.

Probing the QGP reveals deeper knowledge about Quantum Chromodynamics (QCD), the underlying theory of the Strong Force (one of the four fundamental forces of nature). When two high-energy particles collide they each eject a cone-shaped stream of virtual particles pulled from the vacuum. One way to proceed is to study how jet quarks lose energy as they travel through the QGP—this process is known as "Jet Quenching." We can ask questions about the fragmentation of a jet by analyzing the angular distribution of charged particles empirically.

These experiments are conducted by the ATLAS collaboration using CERN's Large Hadron Collider. The LHC occupies a tunnel 27km (17mi) in circumference and 175m (574ft) underground. The entire apparatus is cooled to superconducting temperatures (1.7K above absolute zero). In addition to being the largest physical machine ever built by mankind, the LHC also operates on the world's largest computing network, analyzing tens of petabytes (10^{16}) of data.

This summer I worked on taking measurements in 2.76 TeV proton-proton collisions as a control for lead-lead Heavy Ion collisions. I learned how to analyze CERN data files with ROOT (a Physics programming language based on C++) and also became familiar with UNIX and Python. Working from New York City, my research advisor Professor Brian Cole helped me set up a remote access account with CERN.

Keywords

quark gluon plasma, jet quenching, heavy ion collision, ATLAS collaboration, LHC

A “True” Phase Shifting Circuit for Turbulence Suppression in Plasma Physics Experiments

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Most phase shifting circuits apply a constant time delay to an incoming signal, thus achieving a greater shift for high frequency signals and a smaller shift for low frequency signals. By contrast, a “true” phase shifter induces a dynamic time delay which varies inversely with respect to an incoming signal’s frequency. By implementing this variable time delay, a circuit’s phase shift response over a selected range of frequencies can remain constant. Inside the Collisionless Terrella Experiment (CTX), located in Columbia’s Plasma Physics Laboratory, plasma oscillates between 0.1 and 20 kilohertz. To act as an intermediary between a measuring probe and an electric potential actuator that are installed at a specific angular displacement apart from one another on the experiment, a circuit had to be designed that shifted an incoming signal a fixed angle regardless of how fast or slow the plasma oscillates. To ensure effective communication between the probe and the actuator, the amplification of the shifted signal had to remain constant over the specified band of frequencies, thus this “true” phase shifter had to achieve both a flat phase shift response *and* a flat gain response in the 0.1 to 20 kilohertz band. The circuit also needed to be able to adapt to any specified angle from 0˚ to 360˚ so that the angular displacement between the actuator and measuring probe could be adjusted without impacting circuit design.

The most important component of this circuit is a digital frequency dependent resistor, which consists of a frequency-to-voltage converter, a microcontroller, and a digitally controlled resistor. The combination of these three components enables a flat phase and flat gain 90˚ shifter. By combining this 90˚ shifted signal with the original incoming signal, a “true” phase shifter that has flat gain and whose fixed phase shift can be adjusted by manipulating the amplitude of the incoming signal has been achieved. This circuit can be utilized in any number of systems where an action needs to be taken at a specific angular displacement away from a point of measurement independently of how fast the system is oscillating.

Keywords

Circuit, Plasma Physics, Electrical Engineering, Flat Phase, Flat Gain

II. Understanding the Biosphere & Human Health

Population Neural Coding of Tactile Stimulus Features in the Rodent Somatosensory

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Supervising Faculty, Sponsor, and Location of Research
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Abstract

Directional selectivity is a very important and evolutionarily advantageous feature of the tactile pathway. Complex spatiotemporal skin deformation patterns are transduced by mechanoreceptors embedded in the skin to spikes, and these spikes are subsequently transmitted to the somatosensory cortex, where sensory perception starts to form. However, while mechanoreceptors exhibit high directional selectivity, neurons in the somatosensory cortex do not show such selectivity. It remains poorly understood how the directional information of a tactile stimulus is encoded in cortical neurons. We use rat vibrissa system as a model system to investigate population neural coding of stimulus direction in the tactile pathway. Head-fixed animals were systematically trained to perform a tactile discrimination task using a go/no-go paradigm. Preliminary data suggest that the animal is able to discriminate between tactile stimuli with different directions. Our future work will aim to reveal the neural basis of tactile direction discrimination via simultaneous neural recording from populations of neurons in the somatosensory cortex.

Keywords

tactile direction discrimination, neural coding, pupillometry

Bell-shaped Dose Response Of Sodium Pyruvate On Properties Of Tissue Engineered Cartilage

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Supervising Faculty, Sponsor, and Location of Research:
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Abstract

Functional tissue engineering offers a promising solution for the replacement of damaged cartilage. Using juvenile bovine chondrocytes seeded in agarose constructs, our lab has produced engineered cartilage with near-native levels of glycosaminoglycan (GAG) and equilibrium modulus [1,2]. Studies by our team have been performed to determine the optimal supplementation of various media components to best optimize nutrient availability and cartilage construct growth [3]. The current study aims to examine the influence of sodium pyruvate supplementation to chondrogenic media on engineered cartilage properties. Sodium pyruvate is not only an intermediate energy source in glycolysis, but also aids consumption of hydrogen peroxide and prevention of metabolic acidosis and oxidative stress [4,5]. While 100 μg/mL concentration of sodium pyruvate is often used for cartilage research, including our own [2,6,7], the rationale for its adoption is not well-documented. Chondrocytes were enzymatically digested from juvenile bovine cartilage, seeded in 2% w/v agarose, and constructs, ∅4 mm × 2.34 mm, were assigned to the control (100 μg/mL) or one of three experimental groups (1, 50, or 200 μg/mL sodium pyruvate. Mechanical (equilibrium modulus, E_Y and dynamic modulus, G^*) and biochemical (GAG, DNA) properties of constructs were evaluated on days 0, 14, 28, and 42. The biochemical values were normalized to wet weight. Statistical analysis was determined with a 2-way ANOVA (α=0.05) and Fisher LSD post-hoc test, n= 6 constructs/group. The E_Y grew from ~10 kPa at day 0 to reach native levels by day 42 (50, 100 μg/mL), with significant differences across groups and a bell-shaped dose-response centered at 100 μg/mL. A similar trend was observed for G*. GAG content (expressed as percent of wet weight) was significantly higher, reaching native levels, in control and 50 μg/mL groups compared to other supplementation levels. At day 42, the results indicate that 100 μg/mL sodium pyruvate media formulation yielded the greatest overall tissue properties. Interestingly, relative to 100 μg/mL, 100-fold reduction and two-fold increase of sodium pyruvate had negative effects on tissue development. In summary, these findings provide strong support for our current practice of supplementing CM with 100 μg/mL sodium pyruvate for strategies of in vitro cartilage tissue engineering, and direct us toward the optimization of other media constituents in our CM formulation to further enhance de novo cartilage growth.

Keywords

Orthopedic, Tissue Engineering, Cartilage, Sodium Pyruvate, Dose Response

Embryonic Poly(A) Binding Protein (EPAB) is required for meiotic competence in mouse oocytes

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Embryonic Poly(A) Binding Protein (EPAB), the predominant Poly(A) Binding Protein expressed in germ cells, regulates the translation of maternal mRNAs and promotes fertility through meiotic regulation. Oocytes enter meiotic arrest following prophase I, during which they synthesize proteins necessary for development; they resume meiosis with germinal vesicle breakdown (GVBD), the breakdown of the nuclear membrane, or germinal vesicle (GV). *Epab*$^{-/-}$ mice are infertile because their oocytes do not undergo GVBD and remain arrested at Prophase I.

The goal of this project was to determine if defective Maturation promoting factor (MPF) activation is the reason for *Epab*$^{-/-}$ meiotic arrest. MPF is a protein complex integral to meiotic resumption. Meiotic arrest is maintained by high levels of cyclic-AMP (cAMP), which inhibits MPF. When cAMP is degraded, MPF is activated and the oocyte resumes meiosis.

To determine the mechanism by which *Epab*$^{-/-}$ oocytes are arrested, *Epab*$^{-/-}$ and wild type oocytes were collected and given one of three treatments. Rp-cAMP, a cAMP antagonist that promotes meiotic resumption, induced GVBD in wild type oocytes but not in *Epab*$^{-/-}$ oocytes. Oocytes were treated in Okadaic Acid, a chemical that promotes MPF by inhibiting Ppp2cb, a cAMP independent MPF inhibitor. *Epab*$^{-/-}$ oocytes were also injected with Ppp2cb siRNA, which inhibits Ppp2cb and promotes meiotic resumption. Okadaic acid induced GVBD in wild type and *Epab*$^{-/-}$ oocytes, and significantly more siRNA injected oocytes underwent GVBD than uninjected oocytes. It was also found that some cell cycle proteins were differentially expressed in wild type and *Epab*$^{-/-}$ oocytes. Because Rp-cAMP treatment did not promote GVBD in *Epab*$^{-/-}$ oocytes, but Okadaic Acid treatment and Ppp2cb siRNA injections induced significant GVBD, it can be concluded that there is a defect in *Epab*$^{-/-}$ oocyte cell cycle proteins downstream of cAMP but upstream of Maturation promoting factor. This contributes to the understanding of the mechanism through which EPAB acts and its importance in fertility.

Keywords

infertility, meiotic arrest, resumption, EPAB (Embryonic Poly(A) Binding Protein), Maturation Promoting Factor, Okadaic Acid, Rp-cAMP, Germinal Vesicle Breakdown (GVBD), Ppp2c

Investigating the neurogenetics of behavioral persistence in *Drosophila melanogaster*

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

At any given time, animals must make important decisions relating to whether they will continue their current activity or terminate it and transition into another activity. Proper allocation of time on various activities – such as eating, mating, sleeping, and avoiding danger – is essential for organismal success and survival. A major factor in making these decisions is motivation, which involves the selection, intensity, and persistence of a given activity. Motivation is known to be mediated by the neurotransmitter dopamine, whose production or release is dysregulated in several neuropsychiatric disorders, including ADHD, schizophrenia, depression, and addiction. However, the neurogenetics underlying how motivation drives behavior on a molecular level is not known.

Persistence in male flies during copulation, as measured by copulation duration, is a novel model for studying the neurogenetics of dopamine-driven motivation. At the beginning of copulation, during the first 5 minutes, male flies are persistent, mating even under harsh conditions that would normally evoke a danger avoidance response. During the 20-minute time course of copulation, male fly persistence decreases and copulating flies are easily disrupted at around 15 minutes by introducing the same harsh stimuli. Activation of dopaminergic neurons increases persistence and copulation duration, whereas activation of GABAergic neurons decreases persistence and copulation duration, implicating conserved neurotransmitter systems in motivation-driven behavior. The time-specific decrease in persistence also implies the presence of a molecular mechanism that temporally regulates neuronal activity. In order to identify genes that control behavioral persistence and its timing mechanism in copulation, we are performing an unbiased genome-wide RNAi screen using the GAL4-UAS system to knock down individual genes throughout the nervous system, focusing on genes that affect copulation duration.

Keywords

dopamine, motivation, behavioral persistence, Drosophila neurogenetics, male sexual behavior

Characterization of circadian rhythms in *Pseudomonas aeruginosa* communities

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The Gram-negative opportunistic bacterium *Pseudomonas aeruginosa* is a leading cause of hospital-acquired infections and mortality in immunocompromised and cystic fibrosis patients. We have found evidence for metabolic regulation in *P. aeruginosa* that follows a circadian rhythm. In order to develop antibiotics against this bacteria, we need to understand more about how the bacteria grows and metabolizes. When this bacterium is grown as a colony on agar, it forms morphologically distinct rings that indicate different metabolic states, visualized by the red coloration of reduced triphenyltetrazolium chloride. To explore the molecular mechanisms behind this phenomenon we screened a *P. aeruginosa* transposon mutant library for putative regulators of circadian rhythm. We identified two distinct phenotypes of altered circadian rhythmicity with shorter or longer periods. In the future, we hope to confirm the transposon insertion site by arbitrary PCR, make nonpolar deletions of the target genes, and conduct further characterization of the mutants of interest. This will include changing the time intervals of light/dark cycles, light intensity and wavelength to better understand the role of the genes in circadian rhythm regulation.

Keywords

Circadian rhythm, Pseudomonas aeruginosa

Development of fluorescent system to elucidate ABC-F protein EttA's kinetics

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Translation takes place in *Escherichia Coli* in a complex centered on the ribosome interacting with a variety of proteins known as translational factors. Herein we attempt to design a system to elucidate the mechanism of one of these recently characterized translational factors, Energy-dependent throttle A (EttA). Recent findings have shown that EttA regulates translation according to energy availability in the cell. In a high ATP/ADP ratio environment, it allows translation to occur whilst in the presence of a low ATP/ADP ratio it arrests translation at the level of the first peptide bond. We sought to develop a comprehensive model of how this occurs. We designed an EttA mutant with a maleimide fluorophore attached to the protein at the N-terminal cys_6-histag. We subjected the mutant to a fitness assay. We determined through a competitive assay, that our mutant has the same functionality as the wild-type EttA and hence can be used for the fluorescence anisotropy. We also subjected the ΔEttA and wild-type (WT) to a competitive fitness assay in various concentrations of amino acid and phosphate in MJ9 minimum media without glucose. We found that a concentration of 1.0mg/ml of amino-acid and 0.005mg/ml of phosphate strongly impaired the mutant yet concentrations above and below this level support the mutant.

Keywords

biophysics, proteins, E.coli, biochemistry, translation

Effect of Concentration of Articular Cartilage Wear Particles on Articular Chondrocytes

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Osteoarthritis (OA) is a joint disorder characterized by pain and swelling caused by wear of the hyaline cartilage on articular surfaces of bones. Due to the lack of vascularization, cartilage tissue has a very low propensity of self-repair, making OA a chronic disease. In the United States alone, OA affects 27 million people and costs more than $60 billion per year. Studies have shown that in elevating grades of OA, higher concentrations of cartilage wear particles were present in the synovial fluid of the joint capsule. Additionally, cartilage wear particles injected into lapine knee joints led to marked cartilage degradation and synovitis. Due to these findings, in this study, articular cartilage wear particles were applied to chondrocytes to better understand OA. Cartilage particles were first generated from cartilage tissue using a custom wear particle generation device. The size of these wear particles were characterized and these wear particles were coulter counted to determine concentration of particles. The particles were subsequently applied at increasing concentrations to chondrocytes in order to study chondrocyte viability at various concentrations. Finally, chondrocytes were imaged to show phagocytosis of particles. Through this process, chondrocytes were shown to have a lower viability at higher concentrations of wear particles. This work suggests that sub-10μm cartilage particles above a specific threshold may be pathological and involved in OA onset and progression. Phagocytosis of wear particles may be a potential mechanism for the role of wear particles in OA development. Future work will continue to elucidate the mechanism by which cartilage wear particles interact with cells of the synovial joint, including synovium derived stem cells and chondrocytes. Studies will also characterize the biochemical and metabolic cellular changes and expression of OA biomarkers in relation to application of wear particles.

Keywords

osteoarthritis, articular cartilage, wear particles, phagocytosis, tissue engineering

Functionalization of 6H Highly Doped Silicon Carbide Surfaces for Determining Cell Electrophysiology

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Understanding the electrical activity of biological cells and tissue is important for medical diagnostics and bioengineering. Electrophysiology is employed to measure the electrical behavior of biological materials ranging in size from single ion channel proteins to entire organs. In order to measure the electrical properties of cells, they must be attached to a surface that is conductive and biocompatible. Silicon carbide (SiC) was used in this study because in addition to having these properties, its surface can be functionalized for protein attachment, which subsequently renders the surface amiable for cell attachment. SiC was exposed to oxygen plasma to render hydroxyl (OH) groups on its silicon (Si) face. The terminal OH groups were covalently bonded to 3-aminopropyltriethoxysilane (APTES). Raman spectroscopy measurements confirmed peaks for SiC and both oxidized and APTES functionalized SiC.

Keywords

Biological Materials, BioSensors, Materials Chemistry, Silicon Carbide

III. Understanding the Anthropogenic Environment: Creating Materials & Systems

Fabrication of Diamond Microwires for Quantum Information Processing Applications

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The nitrogen-vacancy (NV) center in diamond has recently emerged as one of the potential candidates for quantum information processing applications due to its good coherence properties. However, interaction with the environment leads to decoherence – loss of quantum state. It has been reported that nanowire structures reduce interaction with the environment and increase coherence time. The purpose of this project was twofold: (1) grow and characterize diamond on silicon wafers and (2) fabricate diamond microwires using photolithography and electron-beam lithography. The hot filament chemical vapor deposition (HFCVD) system was used to grow nanocrystalline diamond on silicon wafers. Lift-off resist (LOR) 10B from MicroChem Corp. and Microposit S1818 from Shipley were used for a bilayer photoresist process followed by chrome (Cr) evaporation and liftoff process. An etch-back process was also studied to generate Cr patterns. Reactive-ion etching was used to etch diamond with an oxygen plasma with an etch rate of ~15nm/min. We achieved ~3μm sized diamond cylinders which were characterized using scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Keywords

HFCVD (Hot Filament Chemical Vapor Deposition), Quantum computing, NV-center in diamond, RIE (Reactive-Ion Etcher)

Predicting Calling Patterns Based on Location History and De-anonymizing Based on Browsing History

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Supervising Faculty, Sponsor, and Location of Research

Dr. Tony Jebara , Machine Learning Laboratory, Columbia University

Abstract

Technology is becoming increasingly prevalent in everyday life. The usage patterns of these technological devices for individuals gives an unique insight into their lives. In this project, two sets of such data were considered. Location and calling history of a population of over 2 million mobile devices were used to predict the likelihood of two devices communicating given their location history. The browsing history of computers were used to de-anonymize machines which had their identity hidden. In both scenarios, the device's location or browsing pattern was modeled as a discrete multinomial distribution. The distributions were also scaled element-wise exponentially to control the effect of differences of probability within a distribution. Both the Euclidean distance and Bhattacharyya similarity coefficient were used to measure the similarity and distance of the multinomial distributions providing information on how similar or different two device histories were.

Using an exponential scaling factor of .5 and the Euclidean distance measure, the predicting call task gave an AUC of .8823 over the random guessing AUC of .5. For the machine de-anonymization task, an exponential scaling factor of .4 with the Bhattacharyya similarity coefficient was used with a maximum bipartite matching algorithm to achieve a matching accuracy of .8398 over the random guessing accuracy of .0043.

Keywords

Bhattacharyya similarity coefficient, location/calling history, browsing history

Development and Construction of a Vapor Deposition Chamber for Lead Halide Perovskite Synthesis

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Supervising Faculty, Sponsor, and Location of Research

Dr. Xiaoyang Zhu, Department of Energy & Energy Frontier Research Center, Department of Chemistry, Columbia University

Abstract

The discovery of the photoelectric properties of the methylammonium lead halide perovskite has spurred an immense amount of attention over the past five years, piquing the interest of a wide scope of disciplines from electrical engineering to chemistry due to its relatively high solar cell efficiency from relatively low cost materials (Mitzi 2007). Although many groups investigating this material use a solution-processed synthetic method called spin coating, there is a problem in this field of research regarding variability, where different groups report a wide range of values for solar cell efficiency ranging from 1% to exceeding 17% using the same basic synthetic technique (Green et al 2014). Last year, Liu et al presented a new way to synthesize these "perovskites" by inventing a vapor deposition scheme which was not only shown to make the same material from similar starting materials, but also reporting higher efficiency statistics for their materials grown in this fashion (Liu et al 2013).

With the desire to study vapor-deposited perovskites increasing within the field, it is the goal of this project to design a deposition chamber which achieves the same synthetic success as reported by Liu et al, but constructed in such a way to be much more compact, cost-efficient, and versatile. We report some preliminary characterization methods via UV-Vis spectroscopy and comparison to known to show some evidence of perovskite formation. The structural design of the deposition chamber is also included and elaborated on. Once the parameters are identified which give the purest perovskite sample, there are myriad potential projects which could be realized, whether it is direct deposition onto a device for testing, or the modification of the synthesis process to produce more efficient perovskite solar cells.

Keywords

lead halide perovskite, vapor deposition, photovoltaics, technique development, optical spectroscopy

Molecular Clusters as Building Blocks for Solid-State Materials

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Solid-state compounds with defined cluster subunits often display interesting and useful materials properties. However, their synthesis typically relies on high-temperature reactions of atomic precursors, inhibiting the rational tuning of their structure and properties. Here, we present a strategy toward solution-phase synthesis of cluster-based solids from inorganic molecular clusters, or superatoms. By mixing electron-rich with electron-poor clusters in solution, charge transfer will occur with subsequent coulombic attraction promoting the assembly of binary solids.

In this project, the electron donors are cobalt chalcogenide octahedral clusters and the electron acceptors are iron oxide cubane clusters. Since clusters are atomically precise, we can investigate the structures of the resulting solids via single crystal X-ray diffraction (SCXRD). This confirmed that the compounds were 1:1 combinations of the parent clusters. SCXRD further revealed that by changing cluster capping ligands, we can effect subtle changes to the configuration of the clusters while maintaining the same superstructure, or force the adoption of new packing arrangements altogether. Alternatively, we can vary the elements that populate the cluster core without affecting the crystal packing. This provides independent, synthetically straightforward handles on the structural and electromagnetic properties of cluster-based solids.

Keywords

superatom, superlattice, hierarchical, redox, binary ionic solid

IV. Understanding the Anthropogenic Environment: Vehicular Improvement

Merging architectural designs with geographical information systems

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Supervising Faculty, Sponsor, and Location of Research
Dr. Charles Shen & Dr. Feniosky Peña-Mora

Abstract

Building Image Models (BIM) are graphical and computational models of buildings created by architects and designers. These representations contain detailed information about the structural and functional attributes of the building in question. BIM systems are also capable of visually rendering buildings in high detail and in multiple layers in order to plan for water, sewage, electricity and communication pathways. However, geographical information connecting buildings has been scarce. Geographical Information Systems (GIS) are designed to record, save, modify, analyze, manage and visually present geographical data. Its versatility lies in collating data about a location from seemingly unrelated sources from bathymetry, cadastral maps and other cartographical and geological data sources. This project attempted to create a prototype of a BIM-GIS Integration. The open source BIM models for this project were supplied by xBIM.org. The GIS interface selected was Google Maps. The BIM library was written in C# and the Google Maps interface is rendered in JavaScript. Two methods were employed. The first involved concurrently running C#, C++ and Java applications. The C# would fetch building data from xBIM. As C# cannot communicate with Java directly, a C++ wrapper would be used to pass the data to and invoke a Java application which embeds the building data on the map and renders it. This method failed as it was discovered that data passed from managed-memory languages (such as C++) to Java resulted in serious malfunctions. The alternative method involved using C# itself to render the building data. The second method proved to be successful and was capable of fetching building header, name and schema. The prototype is going to be expanded to completely embedding 3D visual models of BIM data onto maps.

Keywords

Computer Science, Civil Engineering, Building Image Models, Geographic Information Systems, Prototypes

Car Odor Eliminator using Chlorine Dioxide Abstract

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The goal of the study was to see whether car rental companies, used car dealerships and detailers would be interested in using a bio-degradable odor eliminator, *Odor Crush*, and how much money and time it would save them. Overall, it was important to identify where the actual market and need was for such a product that was easy to use, and had a long enough turnover time of about 1 day for the product to effectively eliminate the odor. The objective was to interview as many potential customers as possible within the duration of the internship to collect such information. In order to do so, a customer survey tailored specifically to the type of company was made, asking questions including what percentage and actual number of the cars a customer received that had an odor, what current products they used, where they felt a need had not been met, etc.

Findings indicated that the window of turnover time is a very important factor to whether a customer would adopt *Odor Crush* or not. Detailers turned out to be the least likely group of customers because they had incredibly small turnover times of only a several hours, while *Odor Crush* would need sixteen hours to operate at minimum. The same situations applies to rental car companies in that they also have variable turnover times depending on customer needs. From the surveys, it was found that rental car company’s fleet services as well as ports that exported vehicles to Asian markets would be most interested in *Odor Crush*. This is due to the fact that fleet services have long turnover times, and that in Asia, many people are adverse to the new car smell. These findings allowed the project to pivot and target specific markets to do further research into.

Keywords

Chlorine dioxide, zeolite matrix, car, odor

Investigating Catalyst Performance in the Three-Way Catalytic Converter

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The three-way catalytic converter is a device found in automobiles and is designed to facilitate the reduction of NO_x as well as the oxidation of CO and hydrocarbon emissions from the exhaust of cars. The conversion of these various emissions is made possible when the air-to-fuel ratio of the exhaust is maintained at what is referred to as the stoichiometric point. As precious metals (such as Pt, which is very expensive) are used in catalytic converters, research into more cost-effective transition metal catalysts that can perform well under testing conditions without sacrificing performance is continuing to grow in importance. Palladium on some support such as ceria-zirconia (CZO) or alumina (Al_2O_3), for instance, is such an alternative. In order to mimic the conditions in the three-way catalyst (TWC) found in cars, we made use of a furnace to carry out both the steam reforming (SR) process of hydrocarbons and the oxidation of the metal catalyst (which is reduced during SR). We repeated cycles of SR and performed several characterization tests to investigate both the conditions under which the various catalysts achieved heightened performance and the reasons why the catalyst performance may have decreased over time. These tests included Brunauer–Emmett–Teller theory (BET), Temperature-programmed reduction (TPR), and X-ray diffraction (XRD). By studying these runs, we were able to narrow down the reasons for catalyst deactivation and better understand the conditions under which oxidation and reduction of the catalyst was best performed. Our research has led to increased interest in Pd/CZO and alumina catalysts and has given us reason to believe reaction with the support is not the reason for deactivation over time.

Keywords

catalysis, three-way catalyst, emissions, oxygen storage capacity, air-to-fuel ratio

Reducing Accidents in the Lightweight Vehicle Fleet of a Large Relief Organization

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Lightweight vehicles are crucial to the operations of relief organizations, creating the final link between the organization's mission and beneficiaries. According to "Field vehicle fleet management in humanitarian operations: A case-based approach" by Pedraza-Martinez et. al. (2010) relief organizations use lightweight vehicles for the

"(1) transport of relief items in-country and to beneficiaries;
(2) transport of staff coordinating or delivering services to beneficiaries, and
(3) transport of staff and materials related to development programs (building schools, hospitals, water sanitation, etc.)" (404).

In completing objectives, the lightweight vehicles of relief organizations may be involved in accidents of ranging severity. These accidents may harm human life, the organization's operational capacity, credibility and finances. This project aims to study accident causes with the goal of reducing their frequency and severity. With vehicle data from a large relief organization, graphs were made using IBM SPSS to explore the lightweight vehicle fleet composition and the relationship between vehicle characteristics, location, and other factors with accidents.

During June and July 2014, the analysis yielded deeper insight into the context of vehicle data and the limitations of visually representing accident trends. In understanding the various conditions faced by drivers and their vehicles, the accuracy of fleet data and statistical tests can be evaluated. After completing this initial phase, additional statistical tests will be performed to quantify the effect of each factor on accidents, which may lead to the possible adjustment of fleet management policies.

Keywords

fleet management, humanitarian logistics, vehicle accidents

Columbia Engineering Young Scholars Program

The Young Scholars Program is a selective high school summer experience that provides students with integrated scientific research and engineering design experience. Both the research and design modules align with the objectives to increase

1) High school students' engagement in science and engineering,
2) Knowledge of science and engineering research practices,
3) Knowledge of engineering careers
4) Knowledge of the steps necessary to become an engineer.

The students get hands-on lab experience in Columbia Engineering research laboratories by joining an existing project, and learning a variety of laboratory techniques and technologies from principal investigators and their graduate student mentors.

Columbia Engineering Young Scholars

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Nicholas Pape

Manahil Muneeb

Principal Investigator: Dr. Sunil ~~Agarwal~~Agrawal

Naim Islam

Principal Investigator: Dr. Vijay Modi

Anthony Lewis

Principal Investigator: Dr. Abhay Pasupathy

Nafa Nafasshoev

~~*Principal Investigator*: Dr. Jeff Kysar~~

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