RLE: WHERE THE FUTURE BEGINS

The RLE 60+ Technical Gala is one of the capstone events of the Laboratory’s celebration of its 60th birthday. The Gala showcases two remarkable characteristics of RLE.

The first characteristic is the sheer diversity of research efforts in RLE. These efforts are both basic and applied, stretching across our six major themes. The Laboratory has always sought to be a nurturing environment for new ideas and intellectual directions, and the Gala demonstrates this in a wonderful way.

The second characteristic is how integral MIT students are in the way that RLE faculty and research staff conduct their investigations. The integration of education with forefront research is a hallmark of RLE history, and a fundamental component of our current identity. This interplay of fresh minds and established excellence creates unique opportunities for discoveries that help us understand nature more deeply, and allow for the development of applications that will be of profound benefit to society.

I am particularly struck by the exciting directions for the future of RLE that the Technical Gala presentations reveal. I know that you will be, too.

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## QUANTUM COMPUTATION AND COMMUNICATION

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CIRCUITS, SYSTEMS, SIGNALS AND COMMUNICATIONS
1. Advanced Telecommunications and Signal Processing

Digital Television Standard

Author(s): Jae S. Lim, et. al.

This poster shows the sequence of significant events in the digital HDTV standardization and its deployment. This is not a research paper, but an illustration of one of the accomplishments at RLE.

2. Advanced Telecommunications and Signal Processing

Reduction of Blocking Artifacts Using Side Information

Author(s): Fatih Kamisli

Block-based image and video coding systems are used extensively in practice. In low bit-rate applications, however, they suffer from blocking artifacts. In this research, we propose an approach where blocking artifacts are reduced using side information transmitted by the encoder. A major benefit of this approach is the ability to compare the processed image directly with the original undegraded image to improve the performance. We develop one particular system based on the proposed approach and compare it with a post processing type of system.

3. Digital Integrated Circuits and Systems

An Energy Efficient Pulsed UWB Transceiver

Author(s): Denis Daly, Manish Bhardwaj, Patrick Mercier, Fred Lee, Dave Wentzloff, Anantha Chandrakasan

An energy efficiency ultra-wideband (UWB) transceiver is presented that operates in the 3-5 GHz frequency band. The transceiver is designed for low data rate, highly portable applications, where weight, volume and energy must be minimized.
BILINEAR SAMPLING OF CONTINUOUS-TIME SIGNALS FOR MATCHED FILTERING APPLICATIONS

Author(s):
Archana Venkataraman

An alternative sampling method uses the bilinear transform to map the j-axis in the S-plane onto the unit circle in the Z-plane. Since the entire frequency range is mapped from one domain to the other, this representation avoids the problem of frequency aliasing. This work characterizes the tradeoffs between Nyquist sampling and the bilinear transform as it applies to inner product computation. Different sampling architectures, characterization of the resulting detection errors and simulation results are presented.

DESIGN AND IMPLEMENTATION OF DISCRETE-TIME FILTERS FOR EFFICIENT SAMPLING RATE CONVERSION

Author(s):
Thomas A. Baran, Alan V. Oppenheim

Rate-conversion systems are used in many applications, including oversampled audio and video CODECs. It is common practice for these systems to implement high-quality filters at fast sampling rates, so their designs tend to be computationally-expensive. A number of structures have been proposed to address this, including polyphase implementations and folded structures. An efficient structure which combines benefits from both classes of structures is therefore presented. Techniques are investigated for designing minimum-multiply filters for the presented structure, and a method is presented which designs filters that, for a given set of frequency domain specifications, often require fewer multipliers than a Parks-McClellan design.

FOOTSTEP DETECTION USING ACTIVE ACOUSTIC SENSORS

Author(s):
Melanie Rudoy, Jingdong Chen, Charles Rohrs

Existing footstep detection schemes rely on passive acoustic sensors to measure the sounds produced by walkers. In this research we analyze data collected using active sensors in order to determine a signature for a typical walker. In particular, we show that it is possible to extract the velocity of a person’s torso and limbs.
FREQUENCY-SHAPED RANDOMIZED SAMPLING

This poster presents discrete-time randomized sampling as a method to mitigate the effect of aliasing. In particular, colored, binary sampling processes are shown to frequency-shape the sampling error, so that it’s power is minimized in the band of interest. Optimal mean-squared error solutions are derived and results from simulation are shown.

CAN FRESHMEN LEARN BioMEMS?

We have developed a series of hands-on projects to introduce freshmen to the application of microscale engineering to problems in the life sciences. The initial offering has allowed students to do experiments with a wide variety of devices, ranging from chambers for studying diffusion to traps for observing individual cells. As final projects, they are currently designing novel, cutting-edge microfluidic devices based on their experiences in the class.

COCHLEAR MICROMECHANICS

Sensory receptor cells in the inner ear are specialized for detection of sound by an overlying gelatinous structure called the tectorial membrane. We have developed a variety of microscale methods to measure the important material properties of the tectorial membrane. Our results suggest fundamentally new ways to think about the role of the tectorial membrane in hearing.
Sound causes vibrations of millions of cellular and sub-cellular structures in the cochlea, allowing us to hear. Most types of hearing loss involve some disruption of this pattern of vibrations, but a host of challenges make it difficult to measure these vibrations even in normal ears. We have developed several techniques that are making it possible for the first time to observe the three-dimensional motions of structures throughout the cochlea.

The poster would present an overview of RSEG: current members, history, prior work, and ongoing work. The history would begin with establishment of the Radio Astronomy Group in 1961, and the prior work would highlight key RSEG accomplishments. Ongoing work includes satellite remote sensing and wireless communications.

There is growing interest in the development of efficient wireless broadcast systems. The use of a multiple-element antenna array at the transmitter can greatly increase the capacity of such systems. We develop simple and efficient quantization and scheduling strategies that approach the capacity of these broadcast systems for moderate network sizes.
Traditional solutions for secure communication require that the interested parties share a secret-key. We present our investigations of a fundamentally different approach to secure communications by considering security at the physical layer. We focus on wireless channels and show how time-variations in the channels can be exploited to enable provably secure communications. Furthermore, additional resources such as multiple-antennas and multiuser-diversity enable the system to be robust against various attacks. We will also present some practical protocols for securely distributing a common key to a set of intended receivers, which can then be used for traditional cryptographic algorithms.

Uncertainty in the sample times, or jitter, constrains the size and energy efficiency of ADCs, inhibiting the digitization of signals in miniature systems such as medical implants and remote sensors. I will describe novel nonlinear methods that leverage our digital processing capability to compensate for this jitter.

Traditional information theory deals with codes for source sequences where the order of symbols is explicitly relevant. In several applications, however, the order of source letters is irrelevant. We provide several information theoretic bounds and coding schemes that employ the order irrelevance property.
MULTISCALE BIOENGINEERING AND BIOPHYSICS
16 Analog VLSI and Biological Systems

A LOW-POWER ASYNCHRONOUS INTERLEAVED SAMPLING ALGORITHM FOR COCHLEAR IMPLANTS THAT ENCODES ENVELOPE AND PHASE INFORMATION

Author(s): J.-J. Sit, A.M. Simonson, A.J. Oxenham, M.A. Falty, R. Sarpeshkar

We demonstrate a bio-inspired asynchronous interleaved sampling (AIS) algorithm that encodes both envelope and phase information for delivery to cochlear implant (CI) users. Asynchronous firing times are generated by a “race-to-spike” among electronic neurons, which will be shown to encode highly-correlated phase information. Resulting stimulation rates are lower than those of most modern implants. Perceptual tests on normal-hearing listeners verified that melody and speech-recognition in noise were improved using AIS over envelope-vocoder simulations. Thus, our strategy could save power and improve hearing performance in CI users.

17 Analog VLSI and Biological Systems

LOW-POWER CIRCUITS FOR BRAIN-MACHINE INTERFACES

Author(s): Rahul Sarpeshkar, Woradorn Wattanapanitch, Benjamin I. Rapoport, Scott K. Arfin

Our ultra-low-power circuits for brain-machine interfaces have applications for advanced prosthetics and experimental neuroscience. The circuits presented here include a micropower neural amplifier to be implemented with adaptive power biasing for use in multi-electrode arrays; an analog linear decoding and learning architecture; radio-frequency impedance modulation for low-power data telemetry; a wireless link for efficient power transfer; mixed-signal system integration for efficiency, robustness, and programmability; and circuits for wireless stimulation of neurons. Experimental results from some of these chips are also presented.

18 Auditory Physiology, Hearing Research Center

SOUND LOCALIZATION IN REVERBERANT ENVIRONMENTS: RELATING SINGLE-UNIT NEURAL RESPONSES AND BEHAVIORAL MEASURES

Author(s): Sasha Devore, Antje Ihlefeld, Barbara Shinn-Cunningham, Bertrand Delgutte

Reverberation leads to temporal fluctuations in the interaural statistics of a stationary sound source and therefore poses a challenge to sound localization. We present results from paired neurophysiological and psychophysical studies of directional sensitivity in reverberant environments and show that a simple population-based neural decoding model qualitatively captures the trends in behavior.
21
Biological Microtechnology and BioMEMS

ISO-DIELECTRIC SEPARATION: A NEW EQUILIBRIUM METHOD FOR CONTINUOUS-FLOW CELL SORTING USING DIELECTROPHORESIS

Author(s):
Michael D. Vahey, Joel Voldman

We present a microfluidic platform for image-based sorting of mammalian cells. We combine automated fluorescence microscopy, passive cell trapping with microwell arrays, and radiation pressure to array, inspect, and release specific cells. This platform enables intuitive sorting of cells based on images, which is difficult or impossible with current technologies.

20
Biological Microtechnology and BioMEMS

INTUITIVE, IMAGE-BASED SORTING OF MAMMALIAN CELLS USING OPTOFLOWDICS

Author(s):
Joseph Kovac, Joel Voldman

We present a microfluidic platform for image-based sorting of mammalian cells. We combine automated fluorescence microscopy, passive cell trapping with microwell arrays, and radiation pressure to array, inspect, and release specific cells. This platform enables intuitive sorting of cells based on images, which is difficult or impossible with current technologies.

19
Auditory Physiology

SPATIO-TEMPORAL SENSITIVITY OF NEURONS IN THE AUDITORY NERVE AND COCHLEAR NUCLEUS

Author(s):
Grace Wang

Traditional models for pitch processing have relied on either a purely spatial or temporal representation. Recent studies from the auditory nerve suggest that the cochlear traveling wave creates robust spatio-temporal cues to pitch that better account for psychophysical observations. We are investigating whether cochlear nucleus neurons can extract these spatio-temporal cues.

1955

Joseph R. Applegate comes to MIT to join RLE's mechanical translation project. He becomes MIT's first African-American faculty member when he is appointed Assistant Professor of Modern Languages the following year.

RLE's Norbert Wiener, John Barlow, and Walter Rosenblith observe the auto-correlation function of brain waves, promoting the application of statistical communication techniques to communication biophysics.
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<td><strong>GENERATING STATISTICAL ENSEMBLES OF UNFOLDED PROTEINS</strong></td>
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<td>Author(s):</td>
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<td>Austin Huang, Collin M. Stultz</td>
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Proteins are truly fascinating in that they often exhibit relatively large conformational fluctuations during their biological lifetime. We study conformational states of a natively unfolded protein that plays an important role in neurodegenerative disorders. Our studies and results have important implications for the development of new therapies for Alzheimer’s disease.

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<td><strong>NON-INVASIVE INTERFACES FOR BRAIN CONTROLLED TELEROBOTS</strong></td>
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<td>Author(s):</td>
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<tr>
<td>David W. Schloerb, Mandayam A. Srinivasan, Seppo P. Ahlfors, Matti S. Hamalainen, Thomas Zeffiro</td>
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The MIT Touch Lab with others (Wessberg et al., Nature, 2000), first demonstrated direct control of a robotic arm by a monkey through an invasive brain-machine interface (BMI). Our current project uses non-invasive brain imaging (MEG, EEG, fMRI) to derive telerobot control signals from human subjects.

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<td><strong>THE ROLE OF SKIN MECHANICS IN TACTILE MECHANORECEPTOR RESPONSE</strong></td>
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<td>Author(s):</td>
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<tr>
<td>Siddarth Kumar, Gang Liu, Mandayam A. Srinivasan</td>
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To gain a deeper understanding of our sense of touch, we are investigating how the neural response of tactile mechanoreceptors is related to skin biomechanics. Work done includes use of novel in vivo skin imaging techniques (Videomicroscopy, High-frequency Ultrasound, and Optical Coherence Tomography), development of artificial skin and tactile sensors, and computer simulations with 2D/3D Finite Element Models of the human/primate fingertip.

---

1956

RLE’s Dudley A. Buck invents the cryotron, the first practical device exploiting superconductivity, which becomes a revolutionary component for miniaturizing the room-sized computers typical through the early 1950s.

RLE begins collaboration with the new Eaton-Peabody Laboratory at the Massachusetts Eye and Ear Infirmary, where RLE’s Nelson Y.S. Kiang is the first director.

Claude E. Shannon joins RLE’s Processing and Transmission of Information group.
We are developing a virtual reality system with 3D haptic and audio interfaces that can help blind individuals explore and become familiar with unknown real environments before actually visiting them. We have designed research protocols to directly probe the role of virtual exploration in spatial learning, in order to promote cognitive understanding of real spaces by blind individuals.

Arterial spin labeling (ASL) is an MRI technique used to measure cerebral blood flow (CBF). Cardiac gating the ASL experiment allows exploitation of CBF pulsatility to increase perfusion signal. Presented theoretical and experimental evidence suggests that by optimizing the delay between the ECG trigger and ASL module, perfusion-SNR can be maximized.

A sparsity-enforcement algorithm that optimizes the number, placement and weighting of spokes in k-space is presented. The framework extends from single- to multi-channel excitation systems and permits the design of arbitrary slice-selective excitations, trading off target profile fidelity with excitation time in a near-optimal manner.
Micro/Nanofluidic BioMEMS

ANISOTROPIC NANOFLITER ARRAY FOR SEPARATION OF PROTEINS UNDER NATIVE CONDITIONS

Author(s):
Reto B. Schoch, Jianping Fu, Jongyoon Han

Microfabricated regular sieving structures hold great promise for biology and biomedical engineering to efficiently separate biomolecules from a complex mixture. Our anisotropic two-dimensional periodic nanofluidic filter array demonstrates fast separations of DNA and proteins under native conditions. Charge- or size-based separations can be achieved, dependent on the buffer ionic strength.

Magnetic Resonance Imaging

INTERACTIVE CONTRAST AGENT FOR MRI

Author(s):
Pádraig Cantillon-Murphy

Contrast agents in magnetic resonance imaging (MRI) are a vital tool in clinical diagnosis. Critically, no mechanism currently exists whereby the induced contrast due to agents can be manipulated by active or external control. Based on theoretical derivations and numerical simulations, we propose that the complex susceptibility of magnetic nanoparticles can be modulated in the presence of a rotating magnetic field at a characteristic frequency, resulting in external contrast control.

Magnetic Resonance Imaging

SPIRAL SPECTROSCOPIC MAGNETIC RESONANCE IMAGING

Author(s):
Borjan Aleksander Gagoski

A fast spectroscopic imaging algorithm using spiral-based k-space trajectories and multiple-channel coil arrays is proposed in order to overcome the long encoding-time limitations of conventional spectroscopic imaging, while at the same time improving SNR. The spiral MRSI algorithm is implemented on various field strength systems, and appropriate results are shown.

Magnetic Resonance Imaging

INTREACTION CONTRAST AGENT FOR MRI

Author(s):
Pádraig Cantillon-Murphy

Contrast agents in magnetic resonance imaging (MRI) are a vital tool in clinical diagnosis. Critically, no mechanism currently exists whereby the induced contrast due to agents can be manipulated by active or external control. Based on theoretical derivations and numerical simulations, we propose that the complex susceptibility of magnetic nanoparticles can be modulated in the presence of a rotating magnetic field at a characteristic frequency, resulting in external contrast control.

1959

Robert N. Noyce, who had been a graduate research assistant in RLE’s Physical Electronics Group from 1949 to 1953, co-invents the integrated circuit at Fairchild Semiconductor which he co-founded in two years earlier. He later co-founds Intel in 1968.

Julius A. Stratton, RLE’s first Director, is appointed eleventh President of MIT.

RLE’s Jerome Lettvin and Walter Pitts publish their landmark neurophysiological research in the paper, “What the Frog’s Eye Tells the Frog’s Brain.”
We have developed a continuous-flow sorting scheme for isolating proteins and peptides within predetermined pI range out of complex proteomic mixtures. To enhance the sorting efficiency and resolution, an external field has been applied through the nanogap junctions. This “hybrid” sorting method can be extended to extremely basic pH ranges.

We have computationally optimized a novel microfluidic protein sorting system. Parallel laminar flows containing electrolyte are brought together in a microfluidic chip to create a liquid junction potential, which separates oppositely charged proteins. Our simulation results yielded clear maps of the protein concentration inside the channel, providing valuable information to optimize channel design.

We developed a fabrication approach to generate massively-parallel, high-aspect-ratio nanofluidic channels. We demonstrated efficient continuous-flow size-fractionation of DNA and proteins in a two-dimensional nanofilter array device. We believe that these devices could be a key to the efficient proteomic sample-preparation microsystems as well as purifying and separating bioparticles and nanoparticles.
This work describes a flexible way to enhance immuno-biosensing using an electrokinetic-based nanofluidic preconcentrator. The device integrates nanofluidic preconcentrator and standard bead-based bioassay in a chip, which can enhance the immunoassay sensitivity by more than 500 fold and increase the detection range to cover 6 orders of magnitude concentration variations.
### 37 Micro/Nanofluidic BioMEMS

**Author(s):**
Jeong Hoon Lee, Jongyoon Han

We developed a method to realize a nanofluidic preconcentrator on a PDMS based microchannel. The nanochannels were created using junction gap breakdown phenomenon between two microchannels, without any special nanochannel fabrication step. Using the device, we can achieve the concentration volume of protein as high as 70 pL, which is 120 folds larger than previous reports. From the DC current measurement, we demonstrated that the depth of trapezoidal nanochannel can be controlled by electric field.

### 38 Retinal Implant Research

**Author(s):**
John L. Wyatt, Shawn K. Kelly, William Drohan, Greg Swider, Oscar Mendoza, Douglas Shire, Marcus Gingerich, Joseph F. Rizzo

The Boston Retinal Implant Project is developing a wireless, chronically implantable retinal prosthesis to restore functional vision to the blind. We have conducted six acute human trials, built and tested a first generation prototype, and are now completing assembly of a hermetically encapsulated prosthesis, to be tested this summer.

### 39 Sensory Communication

**Author(s):**
T. M. Moallem, C. M. Reed, L. D. Braid

This research is concerned with measurements of tactual sensitivity and temporal resolution in adults with profound hearing impairment from birth. Tactual detection thresholds and temporal onset- and offset-order resolution were measured for sinusoidal vibrations presented at the left thumb and index finger. The performance of deaf subjects is compared to results obtained on age-controlled adults with normal hearing.
**40 Sensory Communication**

**THE PERCEPTION OF AUDITORY-TACTILE INTEGRATION**

Author(s):
E. Courtenay Wilson, Louis D. Braida, Charlotte M. Reed

This project explores the perceptual interactions between auditory and tactile stimuli. If the two integrate, the d-prime measure will be significantly greater than individual sensory stimuli. Preliminary data suggest the sensory stimuli integrate into a common pathway; stimuli must be synchronous; and relative tactile-auditory phase has no effect on integration.

**41 Sensory Communication**

**PREDICTING HUMAN PHONE CONFUSIONS IN NOISE**

Author(s):
David Messing

The goal of this work is to make a machine that predicts phonetic confusions made by audiometrically normal human listeners. Our approach is to build a biologically-inspired non-linear peripheral auditory model with efferent feedback and connect it to a perceptually inspired model of template matching.

**42 Speech Communication**

**ACOUSTIC CORRELATES OF STOPS AND AFFRICATES AT WORD BOUNDARIES**

Author(s):
Xuemin Chi

Unlike in written English, speakers rarely pause after each word to indicate word boundaries. How then do listeners segment a continuous speech stream into meaningful words? This study searches for boundary-related acoustic clues in stops (/b/, /d/, /g/, /p/, /t/, /k/) and affricates (/ts/, /dz/) that might help with word segmentation.
DETERMINING ACOUSTIC LANDMARK SEQUENCES IN SPEECH USING LINGUISTIC KNOWLEDGE

Author(s):
Chiyoun Park, Nancy Chen, Youngsook Jung

This research aims to determine the most likely sequences of lexically-significant acoustic events (landmarks) in American English. The primary method applies linguistic constraints which are obtained by computing maximum likelihood estimates of possible landmark transitions.

DO I SAY WHAT I HEAR MYSELF SAYING?

Author(s):
Satrajit S. Ghosh, Virgilio M. Villacorta, Frank H. Guenther, Joseph S. Perkell

To explore the relationship between speech production and speech perception, we altered subjects’ produced speech output and fed it back to them through headphones in nearly real-time. We will present data from these experiments that demonstrate the brain’s capabilities to reshape its output to compensate for such perturbations.

QUANTAL STATES IN THE SPEECH PRODUCTION/PERCEPTION SYSTEM?

Author(s):
Xuemin Chi, Youngsook Jung, Samuel J. Keyser, Steven M. Lulich, Kenneth N. Stevens

Acoustic and articulatory studies of various phonological contrasts in several languages suggest that these contrasts are grounded in quantal properties of the human speech production and perception systems. Examples are given to support this hypothesis that the articulatory/acoustic system has a relatively small number of quantal states that define a universal inventory of sound contrasts in language.
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<td><strong>DESIGN AND CHARACTERIZATION OF CNT-CMOS HYBRID SYSTEMS</strong></td>
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**Author(s):**
Taeg Sang Cho, Kyeong-Jae Lee, Tao Pan, Jing Kong, Anantha Chandrakasan

Carbon nanotubes (CNT) have found widespread interest for many electronic applications. In this poster, we study the fundamental inductance and capacitance of CNTs in order to accurately model them for circuit design and simulations. Furthermore, energy-efficient circuit architectures that interface with CNTs are explored.

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<td><strong>SUPERCONDUCTING NANOWIRE SINGLE-PHOTON DETECTORS</strong></td>
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**Author(s):**
Vikas Anant, Eric Dauler, Xiaolong Hu, Andrew J. Kerman, Kristine Rosford, Joel Yang, Karl Berggren

Superconducting nanowire single-photon detectors promise to boost the speed of both free-space optical communication and quantum key distribution 1000-fold. We will report on the nanofabrication of fast and efficient single-photon detectors, and on our work on modeling, materials growth, multi-element devices, cryogenic testing, and packaging of these nanodevices.

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<td><strong>TEMPLATED SELF-ASSEMBLY OF SUB-10NM QUANTUM DOTS</strong></td>
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**Author(s):**
Joshua Leu, Bryan Cord, Polina Anikeeva, Moungi Bawendi, Vladimir Bulovic, Karl Berggren

Patterned templates can guide the self-assembly of ordered arrays of colloidal particles. We demonstrate this technique at sub-10nm length scales through the spin-coating of solvated 8nm CdZnS quantum dots onto nanopatterned Au surface relief structures on Si substrates.
Quantum Nanostructures and Nanofabrication

QUANTUM-OPTICAL APPROACHES TO SUPERRESOLUTION IN OPTICAL LITHOGRAPHY

Author(s):
Vikas Anant, Donald Winston, Adam Chao,
Kristine Rosfjord, Karl Berggren

We present two distinct approaches that utilize the quantum-optical properties of materials to achieve superresolution in optical lithography. The first approach focuses on the quantum mechanical design of lossless, high-index immersion fluid while the second uses optically-gated photochemistry in the resist to realize sub-diffraction nanopatterning.
PHOTONIC MATERIALS, DEVICES AND SYSTEMS
50 Integrated Photonic Devices and Materials

GRADUATION INFATUATION!

Author(s):
Orit Shamir, Ta-Ming Shih

Flora Ware has set the date
Before which she must graduate.
She wants her degree from Metha-Knoll,
Which has their Commencement in the fall.

Our SEMs show her at the school:
She’s meeting the committee, as is the rule.
Come to the Gala and see her here,
Won’t you meet Flora? She’s a dear!

51 Integrated Photonic Devices and Materials

INTEGRATED PHOTONICS

Author(s):
Reginald Bryant, Orit Shamir, Ryan Williams,
Gale Petrich, Leslie Kolodziejski

Photonic integrated circuits are under investigation for applications involving optical communication. This poster highlights our work in the development of optical switches, circuits designed to demonstrate optical logic functionality, and ultra-broadband modulators, all in compound semiconductors.

52 Integrated Photonic Devices and Materials

PHOTONIC BAND GAP STRUCTURES

Author(s):
Sheila Nabanja, Natalija Z Jovanovic, Alex Grine,
Gale Petrich, Leslie Kolodziejski

Photonic band gap structures have a wide variety of applications. This poster discusses tunable broadband emitters for thermophotovoltaic applications. Nanocavity lasers implementing one-dimensional photonic crystals that can be integrated onto a chip is also discussed.
53
Integrated Photonic Devices and Materials, ab initio Physics, Optics and Quantum Electronics

SUPER-COLLIMATION OF LIGHT IN A 2D PHOTONIC CRYSTAL OF RODS

Author(s):
Ta-Ming Shih, Andre Kurs, Marcus Dahlem

Super-collimation is the propagation of light without diffraction as it is guided by the dispersion properties of a photonic crystal. We present simulation, fabrication, and measurement results from our study of super-collimation in a photonic crystal composed of a square lattice of cylindrical silicon rods, a design that is attractive for applications such as chemical sensing.

54
Laboratory of Organic Optics and Electronics

ALL INORGANIC COLLOIDAL QUANTUM DOT LEDS

Author(s):
V. Wood, J.-M. Caruge, J. E. Halpert, M. G. Bawendi, V. Bulović

We present the first all-inorganic QD-LEDs consisting of radio-frequency sputtered metal-oxide charge transport layers and a colloidal quantum dot electroluminescent region. These devices manifest a 100-fold increase in external quantum efficiency over previously reported structures.

55
Laboratory of Organic Optics and Electronics

CHARGE CARRIER AND EXCITON ENERGY DISORDER IN POLAR AMORPHOUS ORGANIC SOLIDS

Author(s):
Conor Madigan, Vladimir Bulović

The charge carrier and exciton density of states (DOS) plays a central role in controlling electronic and optoelectronic behavior in amorphous organic solids. We present novel Monte Carlo calculations of the charge carrier and exciton DOS in polar amorphous organic solids taking account of discrete molecular polarization.
56 Laboratory of Organic Optics and Electronics

INKJET ASSISTED FABRICATION OF QUANTUM-DOT LEDS

Author(s):
Jennifer Yu, Jianglong Chen, Hao Huang,
Moungi Bawendi, Vladimir Bulović

QD-LEDs are a promising technology with tunable emission wavelength, narrow emission band, and efficient luminescence. However, QD deposition is usually done via a spin-coating process which does not utilize most of the QD material. We demonstrate a method depositing QDs via inkjet printing that enables patterning and efficient material usage.

57 Laboratory of Organic Optics and Electronics

INTEGRATED ORGANIC TECHNOLOGY FOR LARGE AREA OPTOELECTRONIC APPLICATIONS

Author(s):
I.Nausieda, K. Ryu, A.I. Akinwande, V. Bulović,
C.G. Sodini

Interest in organic semiconductors is in part fueled by the promise of large area, flexible electronics. This poster will present a near room temperature process flow for fabrication of integrated organic transistors and photodetectors. Electrical & optical characterization of individual fabricated devices, and an integrated 4x4 organic active matrix imager will be presented.

58 Laboratory of Organic Optics and Electronics

LATERAL HETEROJUNCTION PHOTOCONDUCTORS FOR CHEMOSENSING

Author(s):
J. Ho, V. Bulović

The purpose of this project is to develop solid-state, organic device structures capable of efficiently converting analyte detection into an attenuation in electrical signal. The main advantage to using organic materials is that they are synthetically flexible and can be tailored to respond to specific analytes. Our proposed device structure is a heterostructure consisting of an optically active, chemosensing layer and a charge transport layer. The advantages to physically separating the sensing and transport functions in chemical sensors are 1) the ability to optimize the transduction of luminescence to device current, and 2) the development of a reusable device platform for a variety of chemosensing applications.

Photonic Materials, Devices and Systems

MIT’s Plasma Fusion Center (now the Plasma Science and Fusion Center) is formed, with a significant part of its nucleus composed of RLE’s research in experimental plasma physics and engineering.

1976 - 1978

RLE’s Henry I. Smith establishes RLE’s Submicron Structures Laboratory, now the NanoStructures Laboratory.
Molecular Jet (MoJet) printing combines the advantages of thermal evaporation with the flexibility of direct patterning to enable “flux on demand” deposition of molecular organic thin film with scalability. This technique can lead to high-quality, low-cost fabrication of organic devices in ambient with an improved version of its silicon printhead.

Large area electronics based on transparent conducting oxide thin film transistors recently emerged as a research field of intense interest. In our work we demonstrate that optically transparent semiconducting oxide films are amenable to near room-temperature processing, as needed for large-area electronic applications, maintaining charge carrier mobilities that exceed the amorphous Si state of the art electronics.

Harvesting energy directly from sunlight using photovoltaics (PV) could be efficient and cost effective if devices are printed instead of laboriously grown from silicon melt. Using solution processable organic and quantum confined semiconductors, we demonstrate a photovoltaic device where the active film is deposited via microcontact printing.
62 **Laboratory of Organic Optics and Electronics**

**WHITE LIGHT QD-LEDs WITH ELECTROLUMINESCENCE FROM A MIXED RED-GREEN-BLUE COLLOIDAL QUANTUM DOT MONOLAYER**

Author(s): P.O. Anikeeva, J.E. Halpert, M.G. Bawendi, V. Bulović

We demonstrate white-light LEDs based on electroluminescence from a monolayer of mixed red, green and blue emitting colloidal quantum dots (QDs) in a hybrid organic/inorganic structure. Our white QD LEDs exhibit external quantum efficiencies of 0.36%, CIE coordinates of (0.35, 0.41), and color rendering index (CRI) of 86 as compared to a 5500K black body reference. Independent processing of the organic charge transport layers and the mixed QD luminescent layer allows for precise tuning of the emission spectrum, by simply changing the ratio of different color QDs, without changing the device structure. The demonstrated devices suggest future use of white QD LEDs in solid-state lighting and information display applications.

63 **Millimeter-wave and Terahertz Devices**

**TERAHERTZ QUANTUM-CASCADE LASERS AND REAL-TIME THZ IMAGING**

Author(s): Qing Hu, Ben S. Williams, Sushil Kumar, Alan Lee, Qi Qin

Terahertz (1-10 THz) frequencies are among the most underdeveloped electromagnetic spectra. Following our recent breakthrough in the development of THz quantum-cascade lasers (QCLs), we have achieved several records in the performance of THz QCLs in both power levels and operating temperatures. Using these lasers, we are now able to perform THz imaging at video rate.

64 **Nanostructures and Computation**

**ROBUST OPTIMIZATION OF NANOPHOTONIC WAVEGUIDE TAPERS**

Author(s): Ardavan Farjadpour, Steven G. Johnson, Almir Mutapcic, Stephen Boyd, Yehuda Avniel

We incorporate tools of robust optimization to design waveguide tapers for coupling modes of a dielectric waveguide to a slow light mode of a photonic crystal waveguide. The robust design accounts for uncertainties in the data model and is compared with the nominal solution having no uncertainty, demonstrating that robust optimization is a valuable tool for nanophotonic device design.
FREQUENCY COMBS, OPTICAL CLOCKS AND ARBITRARY OPTICAL WAVEFORM GENERATION

Author(s):
Andrew Benedick, David Chiao, Jeff Chen, Jason Sickler, Jonathan Birge, Michelle Sander, Franz X. Kärtner, Erich. P. Ippen

High repetition rate femtosecond laser frequency combs are the basis for optical clocks and the generation of arbitrary optical waveforms. We present an approach towards such systems based on Kerr-Lens mode-locked octave-spanning Ti:Sapphire lasers and additive pulse mode-locked Erbium fiber lasers with supercontinuum generation. Its operation principles and applications are discussed.

LARGE SCALE FEMTOSECOND TIMING DISTRIBUTION

Author(s):
Jungwon Kim, Jeff Chen, Franz X. Kärtner

Large-scale, long-term stable, femtosecond-precision timing distribution and synchronization of multiple RF- and laser systems stretching over kilometer of length need to be synchronized with femtosecond precision for next generation accelerators and x-ray free electron lasers. The key-components and techniques of such a system are demonstrated: ultralow-noise mode-locked laser sources; timing stabilized fiber links; optical to optical and optical to RF-locking.

MICROPHOTONICS FOR OPTICAL COMMUNICATIONS AND ELECTRONIC PHOTONIC SIGNAL PROCESSING

Author(s):

Strong-confinement microphotonic circuits promise chip-scale, ultrahigh aggregate data-rate (Tb/s) signal routing and processing. Novel silicon- and SiN-core waveguide and microring resonator devices and architectures overcome all major challenges to their practical application: tolerant, low-loss resonators; full polarization transparency; spectrally-transparent wavelength switching and low-power tuning; high-speed signal modulation; efficient fiber-to-chip coupling.
Optical coherence tomography (OCT) has had a major impact in the field of ophthalmology where it enables visualization and measurement of retinal pathology at unprecedented resolutions. Recent advances in laser technology and detection methods enable high speed, ultrahigh resolution OCT imaging for three-dimensional visualization and rendering of the retina. These advances promise to improve the diagnosis of disease such as glaucoma, age related macular degeneration and diabetic retinopathy.

New femtosecond laser technology enables the generation high pulse energies with multiple pass cavity solid state lasers. Using nonlinear materials interactions, it is possible to write waveguide structures inside solid materials such as glass. Femtosecond laser micromachining enables the fabrication of three dimensional waveguide structures which are not possible using standard planer technologies. Devices such as couplers, interferometers, resonators, and gratings have been demonstrated.

Optical coherence tomography (OCT) generates cross sectional images in biological tissues by measuring the echo time delay of light. OCT can perform “optical biopsy” imaging pathology in situ and in real time without the need to remove and process specimens as in standard excisional biopsy and histology. Advances in laser technology enable ultrahigh resolution imaging as well as high speed, three dimensional imaging. Fiber optic endoscopes enable imaging inside the body using catheters and endoscopes. This technology has applications for guidance of biopsy in cancer detection.
Phenomena of Energy Production and Conversion

**COUPLED TWO-LEVEL SYSTEMS AND AN OSCILLATOR: EXCITATION TRANSFER AND ENERGY TRANSFER EFFECTS**

Author(s):
Peter L. Hagelstein, Irfan U. Chaudhary

We have studied models with two sets of matched two-level systems coupled to an oscillator, under conditions where the oscillator energy is small and the two-level system energy is large. Numerical solutions show an excitation transfer effect in which excitation from one set of two-level systems is transferred to the other set through indirect coupling. Numerical solutions also show coherent energy exchange between the two systems, even though the energies are incommensurate. An approximate diagonalization of the problem using a rotation helps us understand the effects. The effects are dramatically increased in the presence of oscillator loss at the two-level system energy. The rates resulting from dynamics calculations are commensurate with rates observed in cold fusion excess heat experiments.

**PHONON EXCHANGE IN NUCLEAR REACTION MATRIX ELEMENTS**

Author(s):
Irfan U. Chaudhary, Peter L. Hagelstein

We have developed a formulation for the inclusion of phonon exchange in nuclear reaction matrix elements. Correlated nuclear wavefunctions can be developed in terms of spin, isospin, and spatial parts. It is possible to extend the approach to a description of a condensed matter system, in which the nuclei are represented formally in terms of their constituent nucleons. Nuclear reactions then result in changes in lattice structure in a way that comes about naturally. Reaction matrix elements relevant to the cold fusion problem have been identified and are being evaluated.

**MULTIMATERIAL INTEGRATED FIBERS**

Author(s):
Fabien Sorin, Ayman F. Abouraddy, Nick Orf, Ofer Shapira, Jeff Viens, Jeremy Arnold, John D. Joannopoulos, Yoel Fink

To date, a barrier has existed between the processing approaches for producing electronic devices and those used for optical fibers. Our work recently enabled the combination of amorphous semiconductors, high glass transition polymers and low melting point metals into functional photodetecting fibers using conventional fiber drawing techniques. This provides us with the opportunity for the first time to realize semiconductor device functionalities at fiber-optic length scales, uniformity and cost.
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<td>74</td>
<td>Photonic Materials, Devices and Systems</td>
<td>Ofer Shapira, Ayman F. Abouraddy, Fabien Sorin, Sasha Stolyarov, Mehmet Bayindir, Nicholas D. Orf, John D. Joannopoulos, Yoel Fink</td>
<td>The development of two types of higher-functionality multimaterial device fibers is reported. First, a fiber that exhibits laser emission that is radially directed from its circumferential surface is demonstrated with a unique and controlled dipole like radiation pattern. Second, we present the use of two dimensional photodetecting fiber arrays that utilize our recently demonstrated metal-insulator-semiconductor photodetecting fibers to demonstrate lensless imaging.</td>
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<td>75</td>
<td>Physical Optics and Electronics</td>
<td>Jason Orcutt, Judy Hoyt, Vladimir Stojanović, Rajeev Ram</td>
<td>A new design for a SiGe photodiode in a standard 65-nm bulk CMOS flow for integrated photonic interconnect applications is presented. This design accommodates the highly transistor-optimized CMOS environment such as high doping levels and self-aligned process steps by leveraging its tight lithographic control in a novel layout.</td>
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<td>76</td>
<td>Physical Optics and Electronics</td>
<td>Kevin S Lee, Rajeev J Ram</td>
<td>Fluorescence detection with dense sensor arrays is realized in a multilayer large core polymer waveguide optical backplane. The multilayer backplane employs optical vias combined with frequency domain multiplexing to facilitate 4:1 multiplexing when performing localized fluorescence detection.</td>
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The monolithic integration of optical isolators has remained an unsolved problem in photonics. Our work has been on developing waveguide isolators in III-V semiconductors. We have proposed a polarization-independent isolator design and demonstrated a waveguide Faraday rotator, one of the key components of this design.

Efficient thermal tuning of 52 \( \mu \text{W/GHz} \) is analyzed for high-index-contrast silicon nitride second-order filter, with demonstration of 4.5GHz/K of tuning. Their compact size, large free-spectral range, low tuning power, low crosstalk and silicon compatibility make these resonators attractive for photonic integration.

Photo shows grad. student Shaoul “Ziggy” Ezekiel performing a “very sophisticated” experiment in Prof. Rai Weiss’ lab. in the F-wing of Building 20. The experiment demonstrated the first high-resolution optical spectrum of iodine in a molecular beam using “home-made” argon-ion laser with “home-made” almost everything else for the creation of a molecular beam stabilized laser wavelength/frequency standard.
Most organic light emitting devices (OLEDs) only emit light from molecular excited states with singlet spin. We demonstrate the ability to manipulate the fraction of singlet excited states by mixing exciton precursor states. We are thus able to triple the efficiency of a red fluorescent OLED.

We demonstrate photovoltaic devices that enhance the absorption of sunlight. With organic photovoltaics we employ a resonant 'antenna' cavity. Radiation absorbed by the antenna is transferred into the charge generating layers via surface plasmon polaritons. To concentrate sunlight on silicon photovoltaics we use a waveguide with combinations of fluorescent dyes.
PHYSICAL SCIENCES
The efficiency of thin-film crystalline silicon solar cells is limited by weak optical absorption in the near infrared. We propose and analyze an approach to alleviate this problem using photonic crystals. It is found that the relative efficiency of a 2-micron thick cell can be increased by 35% relative to a planar design.

We present a method of computing Casimir forces for arbitrary geometries, with any desired accuracy, that can directly exploit the efficiency of standard numerical-electromagnetism techniques. In particular, we examine a two-dimensional piston-like problem involving two metallic or dielectric squares sliding between two metallic walls, and demonstrate non-additive and non-monotonic lateral forces due to the walls.

Up to 400k per second isotope-selected, low-energy ions are produced by photoionization of atoms from a MOT inside a surface-electrode-based Paul trap. The speed and isotope-selectivity of this loading scheme could be useful for the loading of rare isotopes into large arrays of ion traps for future quantum computing or atomic clock applications. The spatial overlap of the ion and neutral atom traps are used to determine a cold atom-ion inelastic scattering cross section.
Using an optical resonator, we nondestructively measure atom number with sub-shot noise resolution. We plan to use such a measurement to perform spin squeezing. The resulting entangled state of the atomic ensemble would be applicable to an atomic clock approaching the fundamental Heisenberg limit of precision.

Many quantum communication and computation schemes rely upon quantized photonic excitations. We demonstrate generation, storage, and transfer of such excitations using ensembles of Cs atoms within an optical resonator as a storage medium. We achieve near-unity atomic-photonic conversion efficiency, and demonstrate entanglement of two ensembles by partial transfer of an excitation.

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There have been growing interests in the design and applications of metamaterials. Using novel design approaches, metamaterials are designed for the applications of suppression of surface waves coupling between antenna ports in a multi antenna platform and active prism through which beam steering is achieved by controlling the metamaterial.

Buried unexploded ordnance (UXO) is a serious humanitarian concern. Electromagnetic induction (EMI) detects objects but has high false alarm rate for UXO. However, all objects can be uniquely characterized by the coefficients of their EMI spheroidal response modes. Thus, these coefficients recommend themselves for use in accurate discrimination of UXO.
QUANTUM COMPUTATION AND COMMUNICATION
We study the classical information capacity of the Bosonic broadcast channel. We show that when coherent-state encoding is employed in conjunction with coherent detection, the Bosonic broadcast channel is equivalent to a classical degraded Gaussian broadcast channel. We further show that if a minimum output entropy conjecture holds true, then the ultimate capacity of the Bosonic broadcast channel can be achieved by a coherent-state encoding.

Entangled photon sources play an important role in a number of quantum information processing (QIP) tasks such as secure communication, computation and metrology. Our group's work focuses on a variety of these sources where polarization, frequency and momentum degrees of freedom can be entangled with high purity for QIP applications.

Quantum optical coherence tomography and ghost imaging are low-coherence imaging techniques employing entangled biphoton sources. Although their fundamental imaging principles have been previously ascribed to the nonclassical nature of the biphoton state, we show almost all the characteristics of these imaging schemes are due to phase-sensitive cross correlations, and hence are obtainable with classical phase-sensitive light sources.
Superconducting persistent-current qubits are quantum-coherent artificial atoms with multiple energy levels, and are promising candidates for quantum computing. We present experimental results of quantum coherence with a strongly-driven niobium persistent-current qubit. These experiments include Mach-Zehnder-type interferometry, microwave-induced cooling, and quasi-classical interference.