EEK

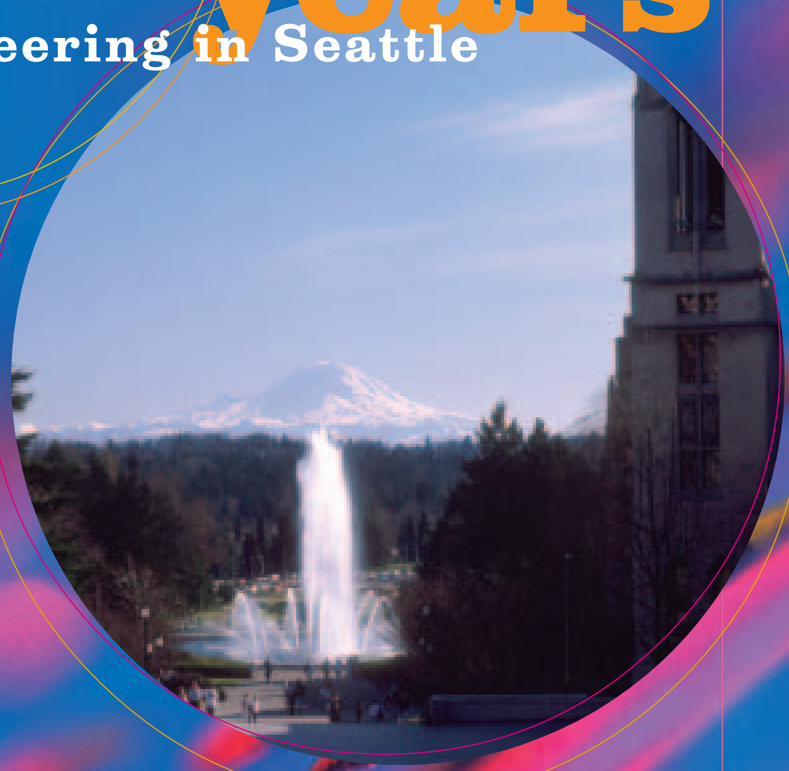
Electrical Engineering Kaleidoscope

1904-2004

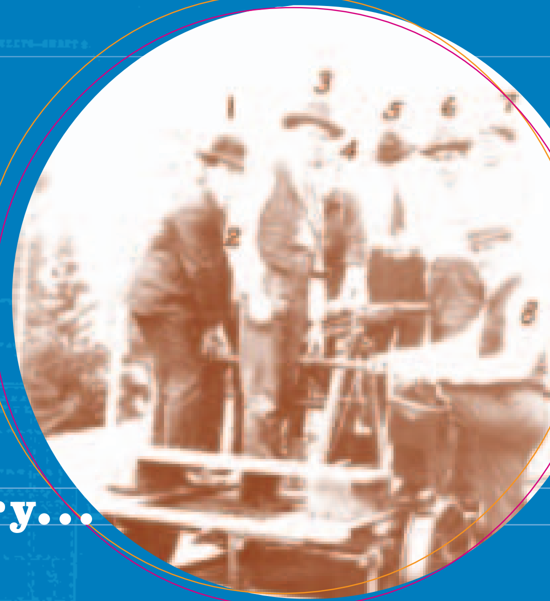
A PUBLICATION OF THE ELECTRICAL ENGINEERING DEPARTMENT UNIVERSITY OF WASHINGTON

100 years

of Electrical Engineering in Seattle



ANNUAL AND CENTENNIAL RESEARCH REVIEW



A Century of Invention and Discovery...

AT UWEE...

1901 **First faculty member appointed to UWEE** (Rudolph Ernst Heine)

1902 **First UWEE B.S. degree** (Stephen P. Rowell)

1904 **UWEE department established; Carl Magnusson appointed as the first Head of the department**

1942 **Austin Eastman becomes the second Head of the department**

1958 **First UWEE Ph.D. degree** (Professor Emeritus Akira Ishimaru)

1961 **Professor Emeritus Irene Peden became the first woman faculty member**

1968 **Daniel Dow becomes the third Head of the department**

1977 **James Meditch becomes the fourth Head of the department**

Pictured on front cover far left: U. of Wash. Libraries, Spec. Coll, Nowell x1040a; Cover left: U. of Wash. Libraries, Spec. Coll, Photo Coll 700

1901 **Hypothesis of heaviside layer** (O. Heaviside and A. Kennelly)

1902 **Air conditioner** (Willis Carrier); **neon light** (George Claude); **first successful transatlantic radiotelegraph message** (Marconi); **practical fax machine demonstrated** (Arthur Korn)

1903 **First gas-motored and manned airplane** (Wright brothers)

1904 **Vacuum tube diode** (J. Ambrose Fleming)

1905 **Photons described** and **Theory of Relativity** (Albert Einstein)

1906 **Sonar listening device** (Lewis Nixon); **electronic amplifying tube** (triode; Lee De Forest); **AM radio demonstrated allowing transmission of voice and music** (Reginald Fessenden)

1907 **Color photography** (Auguste and Louis Lumiere)

1908 **Geiger counter** (J W Geiger and W Müller)

1909 **First synthetic plastic-Bakelite-patented** (Leo Baekeland)

1910 **Thomas Edison demonstrates the first talking motion picture**

FIRST ELECTRICAL ENGINEERING FIELD TRIP – MAY 1905

A TWO-DAY TRIP TO ELECTRON, WASHINGTON TO INSPECT THE NEW HYDROELECTRIC INSTALLATION OF THE PUGET SOUND POWER AND LIGHT COMPANY ON THE PUYALLUP RIVER. 1. HENRY, H. THEDINGA, '05; 2. UICHI KUNIYASU, '05; 3. HENRY G. CORDES, '06; 4. JOHN R. KING, '06; 5. EDWARD M. BROOKS, '06; 6. ?; 7. PROFESSOR C. E. MAGNUSSON; 8. GUIDE.

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1911 **Gyrocompass** (Elmer Sperry)

1912 **Self-service store; consumer battery sizes are standardized**

1913 **Mary Phelps Jacob patents first bra**

1914 **Gas mask patented** (Garrett Morgan)

1915 **Speech first transmitted by radio across North America** (New York to San Francisco) **and the Atlantic** (Naval radio station at Arlington, Virginia to the Eiffel Tower)

1918 **Superheterodyne radio circuit** (Edwin Howard Armstrong); **binary calculating machine**

1919 **Flip-flop circuit** (W.H. Eccles and F.W. Jordan), **proton discovered**

1920 **Transmission of national election returns by broadcast radio station KDKA, Pittsburgh, Pennsylvania**

100 years...

1921 **Crystal resonator** (W. G. Cady)

1922 **First radio advertisement; 3-D movie** (using glasses with one red and one green lens)

1923 **Traffic signal light** (Garrett A. Morgan); **television** (Vladimir Zworykin)

1924 **Dynamic loudspeaker** (Rice and Kellogg); **First transatlantic radiophoto** (London to New York)

1925 **Heisenberg's first paper on quantum theory**

1926 **Liquid fueled rocket** (Robert H. Goddard)

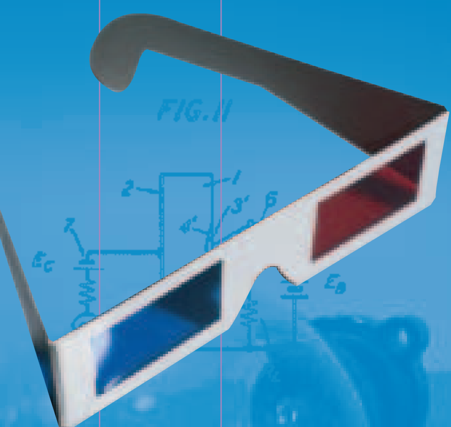
1927 **Complete electronic TV system** (Philo Taylor Farnsworth); **first picturephone conversation**

1928 **Penicillin discovered** (Alexander Fleming)

1929 **First car radio ("Motorola") invented**

1930 **Frozen food process patented** (Clarence Birdseye); **"differential analyzer"** (analog computer); **jet engine, magnetic plastic audio recording tape**

1931 **Stop-action photography** (Harold Edgerton); **electron microscope, stereo recording**



1932 **Polaroid photography** (Edwin Herbert Land), **radio telescope**

1933 **Frequency modulation (FM radio) patented** (Edwin Howard Armstrong)

1934 **Cherenkov radiation discovered** (Pavel A. Cherenkov)

1935 **First canned beer; radar patented** (Robert Watson-Watt)

1936 **Concept of Turing Machine** (Alan Mathison Turing)

1937 **Photocopier** (Chester F. Carlson)

1938 **Walkie-talkie**

1939 **Experimental FM radio stations**

1940 **First color TV broadcast**

1941 **Neutronic reactor** (Enrico Fermi); **pn-junction diode**

1942 **Electronic digital computer built** (John Atanasoff and Clifford Berry)

1943 **The slinky, silly putty and hallucinogenic properties of LSD discovered**

1944 **Kidney dialysis machine** (Willem Kolff)

1945 **Grace Murray Hopper introduces term "bug" for computer error; Vannevar Bush proposes hypertext; atomic bomb tested**

1946 **Mobile telephone service, microwave oven**

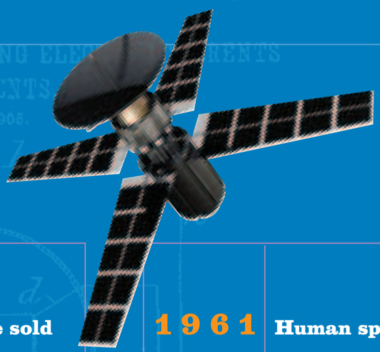
1947 **First demonstration of transistor** (Bardeen, Brattain, and Shockley); **Tupperware seal patented** (Earl Silas Tupper)

1948 **33 RPM vinyl LP records; First cable TV systems in US; Frisbee®; Velcro®**

1949 **Magnetic core memory** (Jay Forrester); **pagers; first direct-dialed long distance telephone call**

1950 **Credit card** (Diners Club)

1951 **Super glue; Power steering; videotape recorder; X-ray diffraction photographs of DNA** (Rosalind Franklin)



1952 **First transistorized device sold (hearing aid); bar code patented; first diet soft drink sold; hydrogen bomb**

1953 **Radial tires; musical synthesizer; black box - flight recorder; Transistor radio** (Texas Instruments); **DNA double helix structure recognized by Francis Crick and James Watson**

1954 **Oral contraceptives invented; nonstick pan; solar cell; Ray Kroc starts McDonalds**

1955 **Optical fiber**

1956 **Computer hard drive; transatlantic telephone cable**

1957 **Fortran (computer language); gas laser** (Gordon Gould); **Sputnik 1** (first artificial satellite) **launched; tunnel diode–the first quantum electron device** (Leo Esaki)

1958 **Modem; Hula Hoop**

1959 **Internal cardiac pacemaker** (Wilson Greatbatch); **Barbie Doll; integrated circuit patent application** (Jack Kilby and Robert Noyce)

1960 **Telephone answering machine on market; first communications satellite** (Echo); **invention of ruby laser** (T. H. Maiman)

1961 **Human spaceflight** (Yuri Gagarin one orbit flight April 12); **stereo FM radio**

1962 **Audio cassette; Spacewar** (the first computer video game); **first satellite television signal** (from Europe to Telstar satellite over North America); **GaAs laser diode**

1963 **Computer mouse patented; geosynchronous satellite** (Syncom 2) **and first satellite-relayed telephone call** (between President John F. Kennedy and Nigerian Prime minister Abubaker Balewa); **compact audio cassette, optical videodisc** (ancestor of DVD and laserdisc)

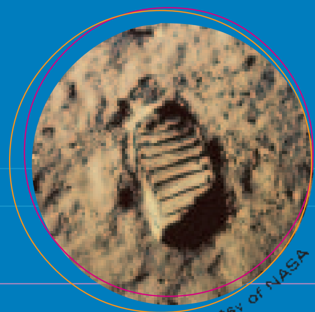
1964 **First commercial device with integrated circuit** (a hearing aid); **Quark theory**

1965 **Eight track audio players commercially available; Sony introduces first portable consumer video recorder**

1966 **Pocket calculators a[illegible] electronic watches[illegible] genetic code of[illegible] codons that[illegible] twenty a[illegible]**

1967 **Ray Dolby d[illegible] reduction system[illegible]**

1968 **Computer mouse combi[illegible] graphical user interface; computer with integrated circuits; Robert Dennard patents RAM** (random access memory)



Courtesy of NASA

1969 **Arpanet** (forerunner of internet) **operational; ATM machine; bar-code scanner; landing of humans on the moon-July 20** (Neil Armstrong and Edwin Aldrin)

1970 **F[illegible]ppy disk** (Alan Shugart)

1971 **[illegible]t-matrix printer; liquid-[illegible] di[illegible] (LCD) patented; [illegible]**

1972 [illegible] (March 2) [illegible] **[illegible]olecules pro[illegible]**

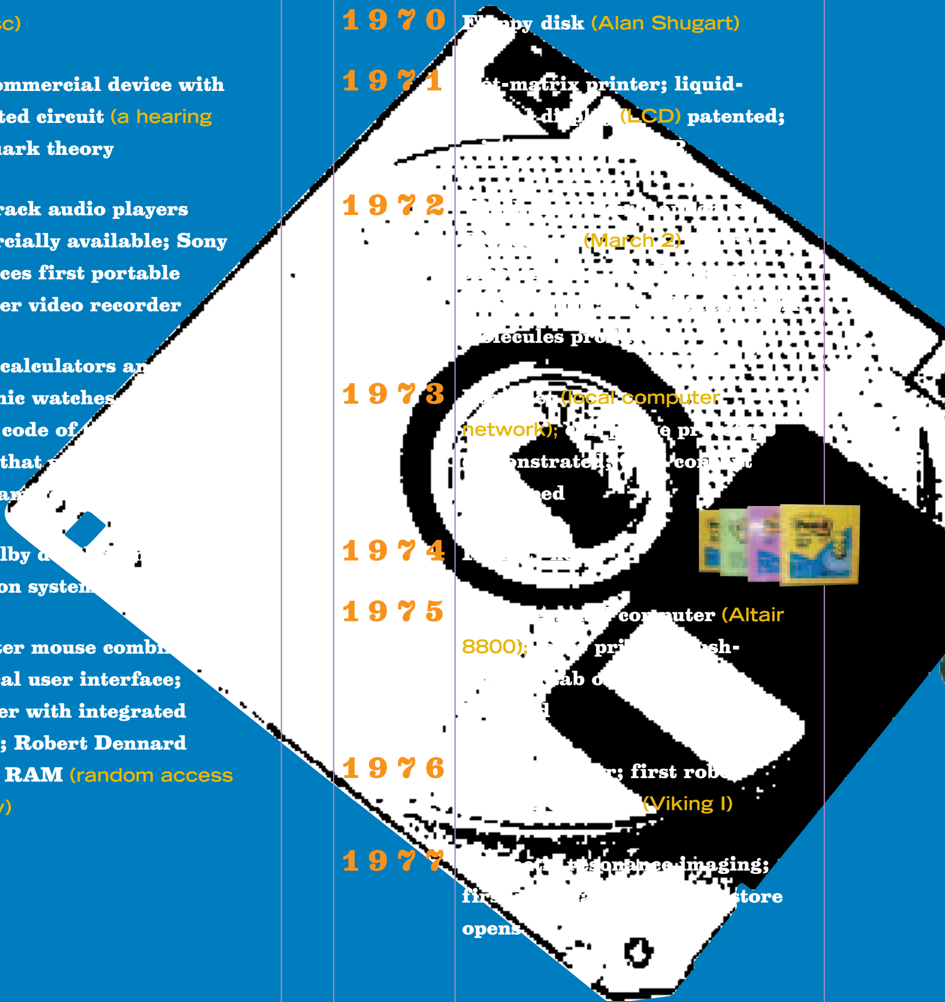
1973 [illegible] (local computer network); [illegible] **[illegible]nstrated; [illegible] co[illegible] [illegible]ed**

1974 [illegible]

1975 [illegible] **co[illegible]puter** (Altair 8800); [illegible] **pri[illegible] [illegible]sh- [illegible]ab o[illegible]**

1976 [illegible] **r; first rob[illegible]** (Viking I)

1977 [illegible] **resonance imaging; fir[illegible] store opens[illegible]**



Background photograph: U. of Wash Libraries, Spec. Coll, UW23462z

1978 Spreadsheet software (VisiCalc); first operational GPS satellite launched

1979 Personal headset audio (Sony Walkman) introduced; roller blades (in-line roller skates marketed); first proprietary online service

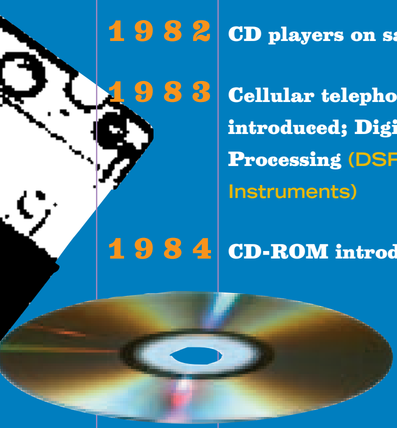
1980 Closed-captioning decoders

1981 IBM-PC using Microsoft's Disk Operating System (MS-DOS) introduced; scanning tunneling microscope invented; first computer virus in the wild (spread on Apple II floppy discs with operating system)

1982 CD players on sale in US

1983 Cellular telephone service introduced; Digital Signal Processing (DSP) chip (Texas Instruments)

1984 CD-ROM introduced



1985 Windows program (Microsoft)

1986 Scrambling of satellite-carried cable TV programming

1988 Prozac® invented; genetically engineered animal patented; quantum effect transistor; first transatlantic fiber optic cable

1989 Commercial direct broadcast satellite television (SkyTelevision in UK)

1990 World Wide Web/Internet protocol (HTTP) and WWW language (HTML) (Tim Berners-Lee); first rechargeable lithium-ion battery sold; gene replacement therapy

1991 Digital Audio tape recorders; Tequila – the first polymorphic computer virus (changing self to avoid detection)

1992 Instant language voice translator (English/Spanish) demonstrated

1993 900MHz cordless phones; PDA's (personal digital assistants); full 24 satellite GPS system in place

1994 Digital cameras commercially available

1995 DVD introduced; fifth form of matter (Bose-Einstein condensate) created

1996 Handheld computers (Palm Pilot and Windows CE-based)

1997 Quantum teleportation verified experimentally (Dik Bouwmeester); two way pagers; 56 kbps modems

1998 MP3 introduced; DSL internet access; CD-recordable systems sold; creation of element 114

1999 Cellular phone integrated with touchscreen PDA

2000 Black hole in center of Milky Way galaxy verified

2001 Satellite radio broadcasting

2002 Nanotex cloth; Metallic nanoscale logic devices

2003 Camera cell phones; completion of full Human Genome sequence; logic gate created with quantum dot; last signal received from Pioneer 10 spacecraft (23 January)

2004 Sixth form of matter (fermionic condensate) created; creation of elements 113 and 115 reported

2004 FIELD TRIP TO MANATASH RIDGE

FROM LEFT TO RIGHT: GRADUATE STUDENT ANDREW MORABITO, ASSOCIATE PROFESSOR JOHN SAHR, GRADUATE STUDENT MELISSA MEYER, ASSISTANT PROFESSOR RADHA POOVENDRAN, AND ASSOCIATE PROFESSOR RICH CHRISTIE.

EEK 1904-2004

ANNUAL AND CENTENNIAL RESEARCH REVIEW

RESEARCH

RECOGNITION

PERSPECTIVES

DEPARTMENT UPDATES

IRENE PEDEN AND AUSTIN EASTMAN.
U. of Wash. Libraries, Spec. Coll, UW23467z

Welcome

TO EEK 1904-2004

This fourth edition of EEK inaugurates the centennial of our Department of Electrical Engineering—celebrating 100 years of leadership, innovation, education, scholarship, and service at the premier university in the Pacific Northwest. Within this issue you will find a glimpse of our department's long legacy of contributions within an amazing diversity of venues. Our success in pioneering many multi-disciplinary areas and our closely coupled research and teaching programs have been, and continue to be, a hallmark that makes our department unique, fulfilling our mission of *Educational Excellence through Cutting Edge Research.*

Throughout this past year, our department has continued its rapid growth. We have added four outstanding new faculty, our annual external research funding has continued to be above $20 million per year, and we have physically expanded into the newly completed Paul Allen Center for Computer Science and Engineering and into nearly half of Sieg Hall. Of our 45 tenure track faculty, 22 of our senior faculty have now been elected IEEE Fellows, and 20 of our junior faculty have received NSF PYI/CAREER awards. Our undergraduate program has now risen to 14th and our graduate program to 19th in the national rankings for Electrical Engineering.

Our centennial is a celebration of not merely the bricks and mortar of our department, but of our most precious resource—our students, staff and faculty. I would like to acknowledge all of the above and our alumni for the continuing success of our department and the exciting fortunes that our future holds in store.

— **Robert Bruce Darling**
Professor and Acting Chair
Department of Electrical Engineering

PUBLISHER

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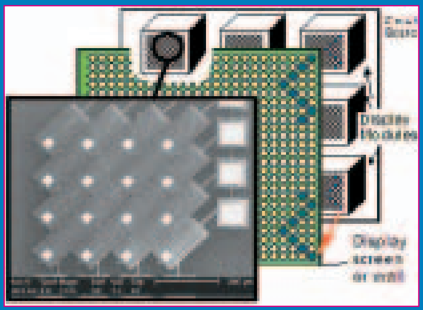
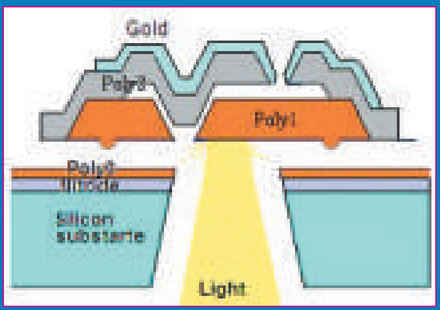
Photonics

The development history of photonics has evolved from a set of elegantly formulated theorems by physicists to multi-disciplinary interactions in the second half of the 20th century. Significant progress in opto-electronic integrated circuits (OEICs), fiber optics, optical MEMS, bio-photonics and new photonic materials and structures have resulted in substantial impacts in our life. The photonics research activities at UWEE are cross-disciplinary efforts and interact closely with many other fields such as micro-electro-mechanical systems (MEMS), bio-medicine, optical communications, nano-technology, chemistry and material science.

In collaboration with Mike Sinclair and Gary Starkweather from Microsoft Research, Associate Professor Karl Böhringer and graduate student Kerwin Wang have developed one of the world's smallest electrostatic visible light transmissive micro-optical switches (TMOS) for an integrated MEMS optical display system. Each TMOS is highly space-efficient and represents one pixel with 150µm x 150µm spacing in a display module. With a zigzag electrostatic actuator of 47µm x 160µm in size, a maximum static lateral displacement of 10µm can be achieved at 38V for the shutter function. Depending on the zigzag actuator design, these devices have a mechanical resonance frequency of up to 18.6kHz.





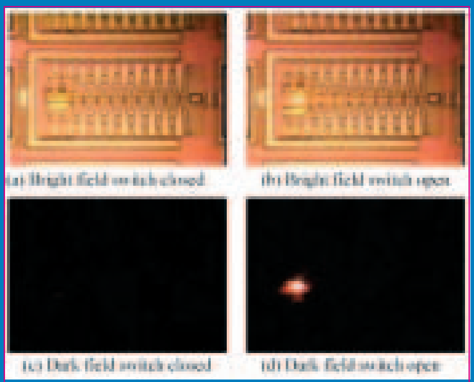
FAR LEFT THE SCANNING-ELECTRON MICROGRAPH (SEM) OF 4X4 SWITCH SHUTTERS WITH A HIGH CONTRAST, LOW POWER CONSUMPTION, AND HIGH SPACE-EFFICIENT TRANSMISSIVE OPTICAL SWITCH AT THE HEART OF THE INTEGRATED MEMS OPTICAL DISPLAY SYSTEM.

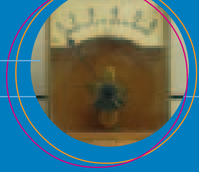
LEFT THE CROSS SECTION OF A SHUTTER MADE FROM POLY 1, POLY2, AND GOLD. THE DIMPLES WORK TOGETHER WITH PECVD CARBON FLUORIDE COATING TO REDUCE STICKING. THE CHANNEL IS DRY ETCHED BY DRIE AND RIE FOR LIGHT TRANSMISSION.

The TMOS consists of an electrostatic zigzag actuator pair, overlapping shutters, and a miniaturized optical tunnel. The dimensions of these three components mainly depend on the optical configuration. A microlens array can focus light into the aperture to minimize the optical loss. A second microlens array placed behind the TMOS array will image the light onto a display screen area or a projector lens. Assuming the light presented to the first microlens array has a nearly planar wave front, each microlens can focus its portion of the light into the aperture adjacent to the shutter.

The shutter can modulate the light by controlling its opening. A small spot size only needs a small shutter and movement to fully turn the light on and off. It also implies low driving voltage, low power consumption and higher frequency operations. The minimal spot size and the profile of the optical tunnel are constrained by the depth of focus, diffraction spot size and numerical aperture of the selected microlens system.

THE SHUTTER CAN SUCCESSFULLY SWITCH THE LIGHT ON AND OFF. OPTICAL TEST RESULTS SHOW THAT THIS TMOS CAN ACHIEVE NEAR-IDEAL CONTRAST RATIOS.





Another research project conducted by Professor Deirdre Meldrum, Director of the Genomation Laboratory, aims to develop a compact photonic system for high-throughput DNA analysis. This system consists of an array of light-emitting diodes (LEDs) as the light sources, DNA samples with fluorescent tags, and an array of lenses and fibers to collect the fluorescence signals. Also in the area of bio-photonics, Professor Sinclair Yee and Research Assistant Professor Tim Chinowsky conduct many research efforts in surface plasmon resonance (SPR) optical sensors and systems. They have been working on SPR sensor instrumentation for high-resolution refractometry and biomolecule interaction analysis, as well as novel optical configurations of SPR sensors.

Professor Bruce Darling's research focuses on developing integrated optoelectronics solutions for high-speed photodetection and image preprocessing applications. Current efforts focus on smart pixels with smart illumination (SPSI), high-speed photoconductive switching, photodetectors integrated with CMOS, and digital light processing for microscopy.

Associate Professor Lih Lin is combining the disciplines of photonics, MEMS, and nanotechnology. One of Lin's projects focuses on miniaturizing integrated photonic systems with sensing and actuation capabilities by MEMS technologies, and exploring the applications of such systems in biomedicine and advanced optical communications.

SEM OF A MEMS POLARIZATION CONTROLLER THAT CAN ACHIEVE FAST AND STABLE CONTROL WITHIN THE ACCURACY OF ONE WAVELENGTH.

The phase-modulator consists of a micro-mirror and an electrode plate in front to fine-tune the position of the micro-mirror, which adjusts the phase difference between TE and TM components of the light. These are separated by the polarization beam-splitter (PBS) and achieve polarization control. Lin also works with Assistant Professor Babak Parviz on integrated photonics systems in nanometer scales. They aim to explore new photonic structures and physical phenomena in the nano-world, design and develop theoretical models for such systems, build photonic experimental facilities that are capable of characterizing them and eventually open a new paradigm for various applications.

Professor Marty Afromowitz has developed a newly patented process for fabricating complex 3-D structures with smoothly varying elevations in thick layers of a commercially available negative photoresist called SU-8. The method may be applied to the fabrication of micro-optical, micro-mechanical and micro-fluidic structures with heights as great as 1 mm.

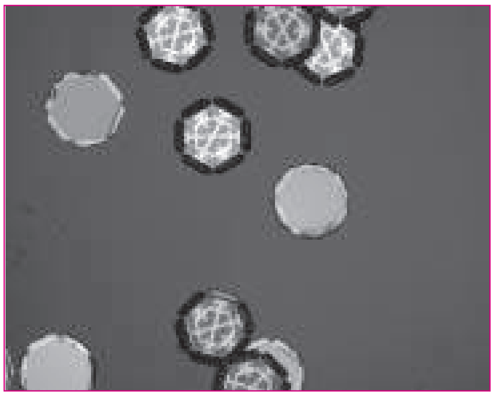
Most photoresist work is done in very thin layers (on the order of 1 µm) and patterns are almost always "binary" (that is, the photoresist is either there or not). SU-8 has been used extensively for binary masking in layers as thick as 1.2 mm. Afromowitz's work makes the fabrication of structures with smoothly varying elevations and an enormous design flexibility possible for the first time. This is accomplished through the use of grayscale illumination from the backside of a transparent wafer and a unique "hot flow" development technique. Afromowitz has also fabricated linear ramps (see below) and non-spherical lenses approximately 500 µm in height. Applications include the fabrication of molds for electroplated structures with complex shape or sidewalls with a controlled slope to enhance mold release.

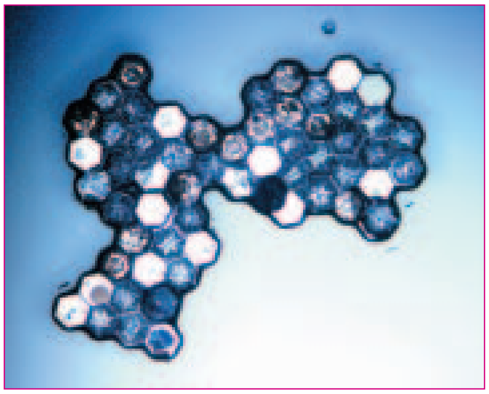
New photonic materials and study of the chemical interactions in these materials are an important foundation for photonic research. The NSF Science and Technology Center on Materials and Devices for Information Technology Research, directed by Professor Larry Dalton, focuses on development of high-performance and low-cost organic materials for next generation information technologies relevant to telecommunications, computing, defense, transportation, medicine, and entertainment.

Contributions to this story made by: Lih Lin, Marty Afromowitz, and Karl Böhringer.

Microelectromechanical Systems (MEMS) and Nanotechnology

Micro/nano electro mechanical systems (MEMS/NEMS) is a rapidly growing field of research that builds on the existing silicon processing infrastructure. However, unlike conventional integrated circuits, devices constructed at UWEE have many functions, including sensing, communication and actuation. This research aims to develop sensors, actuators, and circuits, integrating them into tiny, low-cost, low-power portable or disposable devices and to design, model, analyze, fabricate and test these systems.





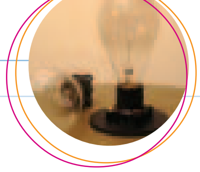
PLANAR SELF-ASSEMBLY OF SILICON COMPONENTS FORMING A NETWORK. THE 100 MICRON HEXAGONAL COMPONENTS WERE MICROFABRICATED AND THEN ALLOWED TO SELF-ASSEMBLE INTO AN ELECTRICAL NETWORK. CAPILLARY FORCES GUIDED THE SELF-ASSEMBLY PROCESS. THE NEXT STEP IS TO IMPROVE THE CONNECTIVITY OF THE COMPONENTS AND HAVE THEM SELF-ASSEMBLE IN 3-D. FAR LEFT ELEMENTS BEFORE SELF-ASSEMBLY; LEFT ELEMENTS AFTER SELF-ASSEMBLY.

Micromachined Transducers

In many cases, smaller size, cost, power, and weight are the advantages of a portable system. This can lead to an enhancement of field usability for monitoring many more points in a sensing environment than currently possible. Monitoring bioremediation sites for pollution clean up and protection of public spaces related to homeland security are an example where miniaturizing sensors and sensor infrastructure improves field sensing capacity. In other cases, enhanced performance is the advantage of micro-systems due to computationally efficient miniaturization. Portable instruments, used in monitoring small numbers or single cells in biological analysis can increase signal and decrease noise levels sufficient to meet stringent optical and non-optical detection limits.

Solid State Device Modeling

Research conducted by Professors Bruce Darling and Scott Dunham involves the modeling of fabrication and operation of integrated circuits. The transistors inside modern integrated circuits are becoming smaller and faster, but also more delicate and susceptible to damage caused by static electricity (also known as electrostatic discharge (ESD)). Static warnings on new electronic products are apparent, but how does one design an integrated circuit to survive an unpredictable ESD event? In one project, funded by the NSF Center for the Design of Analog-Digital Integrated Circuits (CDADIC), Darling and Ph.D. student Yeshwant Subramanian work on developing new software tools to analyze integrated circuit designs for ESD weaknesses. If a semiconductor device undergoes electrical breakdown due to excessive voltages or currents of an ESD event, its internal temperature can skyrocket, ultimately leading to destruction of the device and failure of the integrated circuit. The development of new device models accurately predicts these electrothermal effects, and the internal junction temperatures of the transistors can be simulated to determine if a given device will withstand and dissipate the ESD pulse energy. New algorithms have also



been developed to identify and characterize the unusual and often unexpected pathways that the current flow will take during an ESD transient. The use of these tools can analyze the layout of an integrated circuit and simulate an ESD event that may occur on any of the pins of the package. The robustness of an integrated circuit layout to specific levels of ESD can be assessed, and the weak spots re-engineered prior to fabrication, thereby avoiding a costly trial-and-error process in bringing a new chip design to market.

Manufacturing at the Micro and Nano Scale

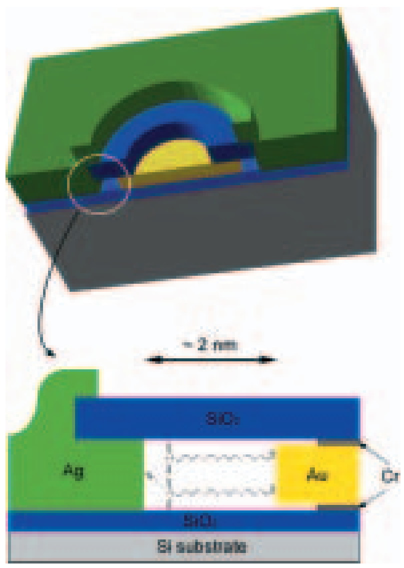
Unlike with integrated circuits, MEMS/NEMS designs may require integration of many different functions such as sensing, actuation, computation and communication into a single, complete system. This means that materials and devices from different sources may need to be combined. Often, these components cannot be fabricated in a single manufacturing process because of incompatibility between different materials and processing steps.

Researchers at UWEE are employing a technique called self-assembly – the spontaneous organization of materials and structures that happens without centralized control, such as in crystal growth, recombination of DNA, formation of snowflakes and all biological growth processes.

Can we "grow" a silicon circuit?

Fabricating three-dimensional solid-state circuits is a major area of interest to many engineers involved in microfabrication. Assistant Professor Babak Parviz is working on self-assembling networks of microfabricated silicon components. Ultimately, the goal is to design and create self-assembled three-dimensional silicon-based integrated circuits.

THE ARCHITECTURE OF A NANO-SCALE ELECTRON DEVICE.



How do we hook up molecules and make electronics components out of them?

Parviz uses self-assembled molecular monolayers to design and fabricate nano-scale integrated electron devices that incorporate organic molecules. By taking advantage of chemical self-assembly, he has fabricated 2 nm wide junctions and measured the tunneling current through the molecules in this ultra-narrow gap.

Programmable Micro Self-Assembly

While some research and commercial manufacturing have demonstrated promising work on massively parallel and self-assembling systems, Associate Professor Karl Böhringer believes that the real impact is only realized once these self-assembling systems can be programmed or reconfigured on demand (i.e., essentially in software, and without significant hardware changes). This area of research covers a broad range of issues from real-time control of surface properties, to designs that optimize binding forces between self-assembling components, to computational and algorithmic issues in the modeling of self-assembling systems.

One project involves micro self-assembly that allows multiple assembly steps to integrate different batches of micro-components. The assembly is directed by surface chemistry that can be controlled in real-time. Binding sites for self-assembly can be activated/deactivated on demand by absorbing/desorbing a hydrophobic self-assembled monolayer (SAM) on a hydrophilic background. This allows a new level of flexibility and reconfigurability in self-assembly.

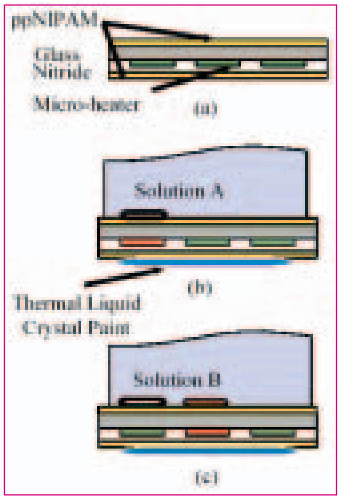
Integrating MEMS and Biology

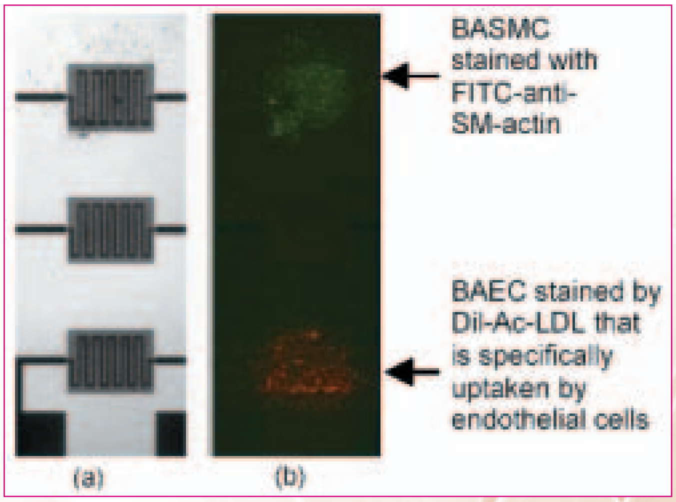
Böhringer's lab is also developing techniques for creating biomedical devices on a chip. In collaboration with the Center for Nanotechnology, he has created "rail tracks" for a molecular transport system that could one day deliver molecular cargo between microscopic factories in lab-on-a-chip applications. This project used the motor protein kinesin and is powered by ATP.

Böhringer and EE Professor and Engineering Dean, Denice Denton, work on creating bioelectrodes that can measure neural activity from the inside of an individual cell. They are building tiny silicon sensors that can be implanted into neural tissue. This is a joint effort with Computer Science and Engineering Associate Professor Chris Diorio, Bioengineering Professor Buddy Ratner, and Zoologists Thomas Daniel and Dennis Willows.

In another project, a "programmable protein chip" has been achieved by depositing a temperature sensitive polymer called ppNIPAM on to arrays of micro-fabricated metallic heaters. Activating a single heater causes a localized change in the device surface chemistry from non-fouling to fouling in an aqueous environment, which localizes immobilization of proteins and cells on such "programmable" surfaces. These experiments show, for the first time, selective cell attachments on thermally responsive polymer controlled by a micro heater array. This suggests a new approach to realize proteomic chips and cell chips.

Contributions to this story made by: Karl Böhringer, Babak Parviz, Bruce Darling, Tai-Chang Chen, Denise Wilson, and Scott Dunham.





FAR LEFT A SCHEMATIC DESCRIPTION OF ppNIPAM DEVICES. (A) DEVICES CONSIST OF MICRO-HEATERS ON A GLASS SLIDE COATED WITH ppNIPAM. (B) ACTIVE HEATER (DARK) TURNS THE SURFACE FOULING. SELECTIVE PROTEIN/CELL ADSORPTION OCCURS EXCLUSIVELY ON HEATED AREAS. TEMPERATURE SENSITIVE PAINT WAS USED TO CHARACTERIZE THE TEMPERATURE PROFILE. (C) A SECOND ADSORPTION STEP WITH DIFFERENT PROTEIN/CELL SOLUTION ON A DIFFERENT HEATER.

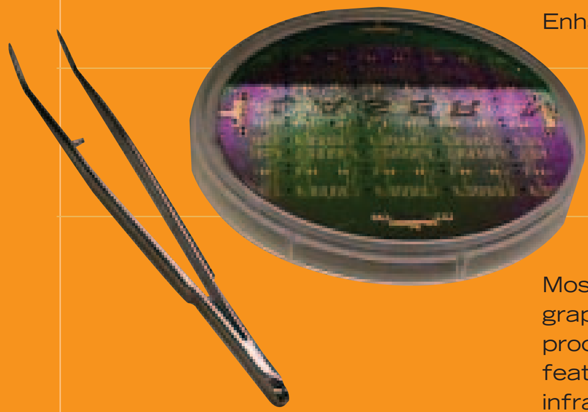
LEFT TWO STEPS OF CELL ATTACHMENTS ON THE TOP AND BOTTOM HEATER, RESPECTIVELY. (A) BRIGHT FIELD MODE AND (B) FLUORESCENCE MODE.

PICTURED IN BACKGROUND POLYIMIDE CILIA MOTION PIXEL (SEM MICROGRAPH).

Microfabrication Capabilities

Micromachining equipment in the Center for Applied Microtechnology (CAM) cleanroom at UWEE has capabilities that include lithography, thin film deposition, wet processing benches, soft lithography and micro-molding. A recently added state-of-the-art ultraviolet laser machining system adds unique capabilities for rapid prototyping and maskless micromachining. In addition, a focused ion beam system for nanoscale imaging, machining and deposition is currently being installed.

A larger cleanroom facility is located at the Washington Technology Center in Fluke Hall. This facility houses a comprehensive collection of micromachining equipment. Recent major additions to this facility provided by EE faculty include an Oxford Systems Deep Reactive Ion Enhanced (DRIE) tool, a silicon etching tool, and an Oxford Systems Plasma Enhanced Chemical Vapor Deposition (PECVD) tool for dielectric thin films.

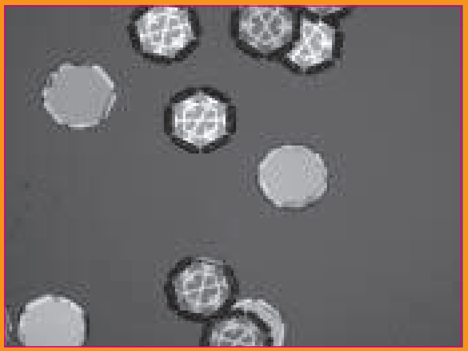


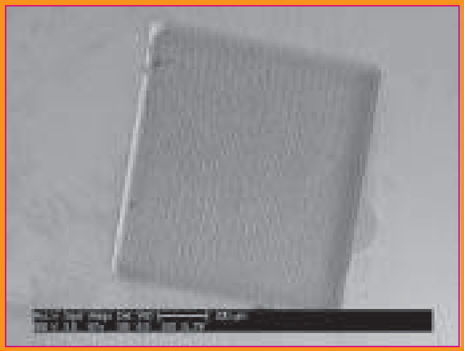
SILICON WAFER PROCESSED WITH LASER MACHINING SYSTEM.

Most microfabricated devices are batch fabricated using an expensive system of photographic masks to pattern chemically selective etches and deposition processes. Serial processing, in which a single beam spot is used to sequentially pattern and process each feature of each device, has in the past been regarded as too slow to be economical. The infrared and visible wavelength lasers used in the past for cutting and welding operate purely by rapid heating of the material, and this process has been too coarse to be applicable to microelectronic devices. Recently, Professor Bruce Darling and Research Assistant Professor Tai-Chang Chen have been investigating the use of high-speed ultraviolet lasers for direct-write micromachining. Through a grant from the Murdock Charitable Trust, a new state-of-the-art facility for laser micromachining has been established in the Center for Applied Microtechnology (CAM). The system is built around an extremely high-speed beam positioner, which allows each pulse of the laser to be accurately delivered to its desired point on the substrate. A high power pulsed ultraviolet laser is used for the micromachining. At ultraviolet wavelengths of 355 and 266 nm, the laser radiation forms a tighter focus and produces bond scission instead of purely heating the substrate. This creates a smoother and smaller cut without the melting and distortion caused by direct laser heating. This new laser micromachining system can accurately create structures to micron accuracy in materials that have traditionally been difficult to micromachine, such as sapphire, alumina, Teflon, and other ceramics, glasses, and polymers.

RIGHT DIRECT-WRITE LASER MICROMACHINING SYSTEM (FUNDED BY THE MURDOCK CHARITABLE TRUST).

FAR RIGHT SCANNING ELECTRON MICROSCOPE (SEM) IMAGE OF LASER MICROMACHINED SAPPHIRE.



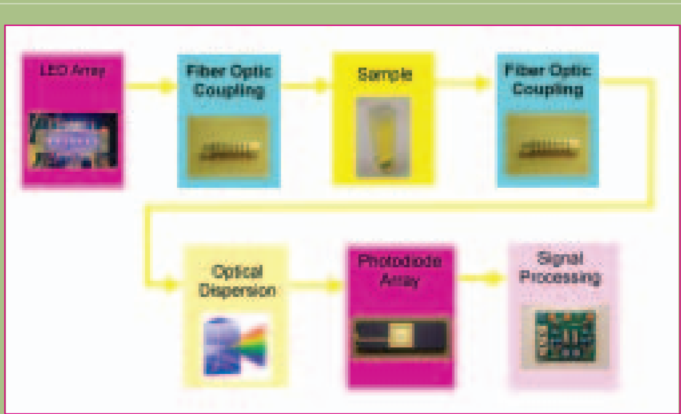


Honey, I Shrunk my Sensors!

"Smaller is better" say the swarm of researchers at UWEE and micro-sensor research is buzzing at all stages of instrumentation development. The hive of activity has demonstrated to others in the scientific community that substantial benefit is combed from shrinking sensors.

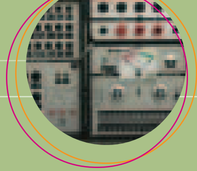
From the broad-based success of the automotive airbag sensor, smaller has increased safety for consumers across the world, dramatically reducing fatalities and proving its humanitarian value beyond any questionable doubt. Similarly, miniaturizing accelerometers has provided the stringent sensitivity and detection limits required by the automotive safety industry while bringing corresponding benefits in size, power, weight, and cost that has eased the consequence of another high technology feature on the consumer pocketbook.

But despite some commercial success, reducing sensor size through direct miniaturization of meso-scale or macro-scale structures is not always beneficial. Often the price paid for a smaller sensor is a penalty in accuracy. Most sensors, by their very nature, lose accuracy as they lose surface area. In order to reduce sensor size while retaining accuracy, new design methodologies and computing and fabrication paradigms must be developed to deliver comparable performance to meso-scale and macro-scale sensors at the micro-scale level. UWEE sensor researchers are making significant contributions to micro-sensor research by using new approaches to system-based development of sensors, sensor arrays, sensor systems, and sensor networking.



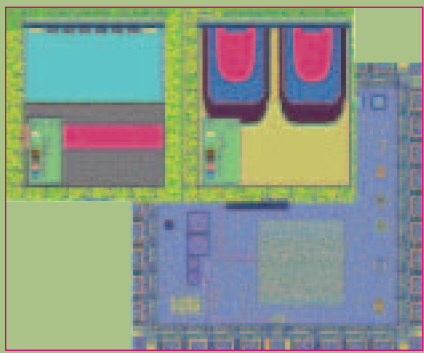
IN ORDER TO BENEFIT FROM MINIATURIZATION, FLUORESCENCE ANALYSIS SYSTEMS MUST BE CONSTRUCTED UNDER A NEW DESIGN METHODOLOGY THAT COMPENSATES FOR THE BROADER BANDWIDTH OF MINIATURIZED LIGHT SOURCES (LEDS) WITH THE FLEXIBILITY THAT COMBINING (AGGREGATING) MULTIPLE LEDS IN A DYNAMIC RECONFIGURABLE MANNER CAN PROVIDE.

A classic example of this design philosophy gone awry is the exciting development of the ion-sensitive field effective transistor (ISFET) in the 1970's, which can be loosely interpreted as a direct reduction of the Kelvin probe for monitoring ions in solution. Although a wide variety of ISFETs have been demonstrated by the research community, only a small number of ISFETs have achieved commercial viability because of limitations in accuracy, drift, aging, and lifetime that are either poorly understood or insufficiently accommodated in the miniaturization process.



To avoid reenacting the saga of the ISFET, it has become important to address both sensor fabrication and system architecture when redesigning sensors and sensor systems to a smaller footprint. Often a new paradigm of design and signal processing is required to successfully use a micro-sensor for its targeted benefits in size, power, cost or weight. Sometimes the new paradigm is driven simply by the desire to reach comparable accuracy of larger systems, albeit in a portable footprint. For example, one of the research goals of the Microscale Life Sciences Center at UW, sponsored by the NIH, is to miniaturize the size of fluorescence analysis systems so that smaller sample sizes (at a single cell level) can be analyzed at comparable accuracy to larger bench-top instrumentation. Straightforward miniaturization of the bench-top components (light source, optics, photodetection) has a devastating effect on accuracy. As a result, Professor Deirdre Meldrum, Associate Professor Denise Wilson and Research Assistant Professor Mark Holl are involved in a collaborative effort with the Department of Chemistry at UW to shift fluorescence analysis to a multiple, dynamic LED based system and specialized low-loss fiber optics and waveguides. Fluorescence is analyzed under a different design paradigm to retain accuracy while reducing overall size of the system.

The work of Professor Sinclair Yee and Research Assistant Professor Tim Chinowsky has enabled a much broader understanding of marine environments allowing organics, bacteria, metal ions and viruses to be analyzed with a single instrument. Field-portable instruments developed using surface plasmon resonance (SPR) and immunochemical-based coatings enable the uniform collection of numerous data points over time.



LEFT ALTERNATIVE PHOTOSENSOR STRUCTURES USE DOPING PROFILES, JUNCTION DEPTHS AND OTHER CHARACTERISTICS NATIVE TO THE CMOS PROCESS TO MAXIMIZE SENSITIVITY TO GREEN LIGHT. GREEN LIGHT AND NEARBY WAVELENGTHS ARE PARTICULARLY RELEVANT TO FLUORESCENCE ANALYSIS TASKS AND SUPPORT THE CONTINUED MINIATURIZATION OF SYSTEMS THAT USE FLUORESCENCE AS AN INDICATOR OF CELL BEHAVIOR AND STATE.

ABOVE LEFT YEE AND CHINOWSKY'S RESEARCH PRODUCES PORTABLE BIOSENSORS BASED ON THE "SPREETA" SPR SENSING TECHNOLOGY DEVELOPED BY TEXAS INSTRUMENTS IN COLLABORATION WITH UW. THE UNIT ON THE RIGHT IS A FULLY FUNCTIONAL SENSOR CAPABLE OF SIX SIMULTANEOUS SPR MEASUREMENTS (CHANNELS). THE BOX ON THE LEFT IS A PROTOTYPE OF THE NEXT-GENERATION SYSTEM CURRENTLY UNDER DEVELOPMENT, WHICH WILL HAVE 24 CHANNELS AND AN LCD TOUCH SCREEN INTERFACE.

Another SPR project conducted by Wilson's Distributed Microsystems Laboratory and Arizona State University monitors ground based environments such as toxic waste sites undergoing bioremediation. This research uses unique hardware architectures (integrated optical computation) as well as sensor miniaturization techniques to enable quick, efficient monitoring of both chemical and biological analytes associated with the pollution and clean up of waste sites contaminated by underground fuel tanks.

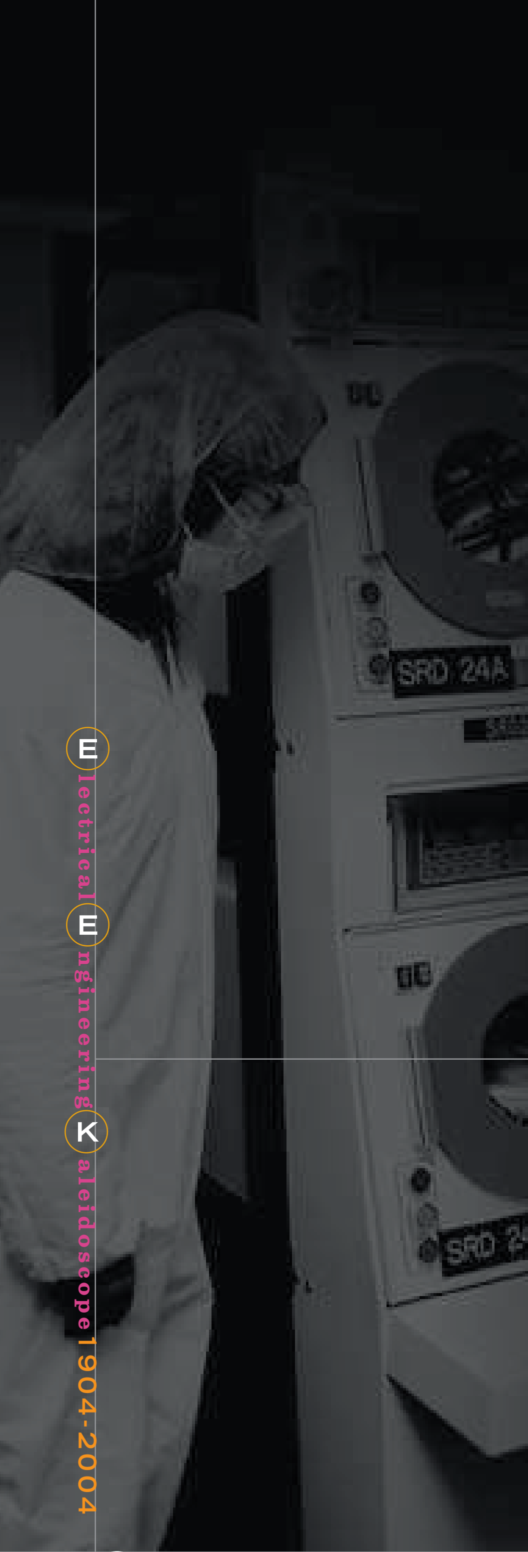
This SPR effort emphasizes collecting more points in a large sensing environment. Other sensor projects conducted by Assistant Professor Alex Mamishev focus on similar collection of distributed data points at a smaller scale using fringing field effect sensors. These sensors are used to map moisture distributions in a variety of materials for applications in preserving the integrity of power systems design and manufacturing process control (e.g. in aircraft part production).

Smaller sensors can be distributed in more places at reasonable cost and computing overhead, enabling, for perhaps the first time in history, the consistent and reliable monitoring of large public spaces. A number of researchers in UWEE are developing sensors and sensor networks at a level of highly parallel distribution, including Assistant Professor Radha Poovendran, who emphasizes the efficient wireless networking of sensors and sensor computing. Wilson focuses on the combination of multiple sensing modalities at a distributed level as well as more efficient signal processing to suit distributed sensing problems, whereas Mamishev demonstrates interests in "sensor skin" which can be loosely described as the distributed holistic monitoring of the human condition in defense and biomedical situations.

Contributions to this story made by: Denise Wilson and Tim Chinowsky.

VLSI

Five core faculty, 60 research assistants, five staff researchers, two computer support specialists and two administrators are dedicated to the research and development of Analog and Digital VLSI Design and CAD.



This effort began about 40 years ago, motivated by needs for electronic instrumentation in the department's Antarctic Project. A 21-mile dipole antenna was laid on the 8000-foot thick Antarctic ice sheet at Byrd Station. In order to use this antenna to study the lower ionosphere, faculty and graduate students built a 50 kilowatt audio amplifier to drive the antenna, a closed loop data system involving a low noise VLF receiver, a 450 MHz telemetry link, and one of the first digital data recording systems. The large computers of the time were unable to read the imperfect data on the digital tape, and thus the department obtained its first in-house computer, a DEC PDP-9, an 18 bit minicomputer with 8K of RAM that filled a room. During this time electronics were built using discrete devices and components on circuit boards.

In the early 1980's, the semi-custom integrated circuit allowed students to begin designing systems "on-chip" using a customized metal layer over standard cells. Early departmental integrated student projects included a high purity Wein bridge oscillator and a true RMS converter fabricated by Interdesign.

Around 1984, automated integrated circuit design was incorporated into the curriculum of the department. The several micron CMOS technology of this time was excellent for mixed digital analog systems. There was strong cooperation between Seattle Silicon Corporation and the department, allowing graduate students access to state-of-the-art integrated circuit design facilities. This culminated in Stewart Wu's dissertation, "Digital Process Compatible High-Drive CMOS Op-Amp with Rail-to-Rail Input and Output Ranges." Wu later formed ADHOC Technologies Inc., which was purchased by Broadcom.

In June of 1989, CDADIC (the Center for the Design of Analog and Digital Integrated Circuits) was formed in a cooperative effort with industry, NSF, Washington State University, UW, Oregon State University, and State University of New York at Stony Brook. Several UWEE researchers continue to be associated with CDADIC.

Professor Carl Sechen's research lab, along with Research Assistant Professor Larry McMurchie, is developing very low power and high-speed digital IC design, both synchronous and asynchronous. In addition to designing circuits, students develop a variety of CAD tools, including transistor sizing (for a variety of logic families) and automatic cell layout. Students are also developing a radiation-hardened, coarse-grained programmable array for digital signal processing applications. A complete set of tools for radiation-hardness by design of digital ICs using conventional fabrication processes is also being developed.

GRADUATE STUDENT TOM CHRISTIANSEN HOLDS A 6-INCH SILICON CMOS WAFER READY FOR FOCUSED ION BEAM MICROMACHINING.

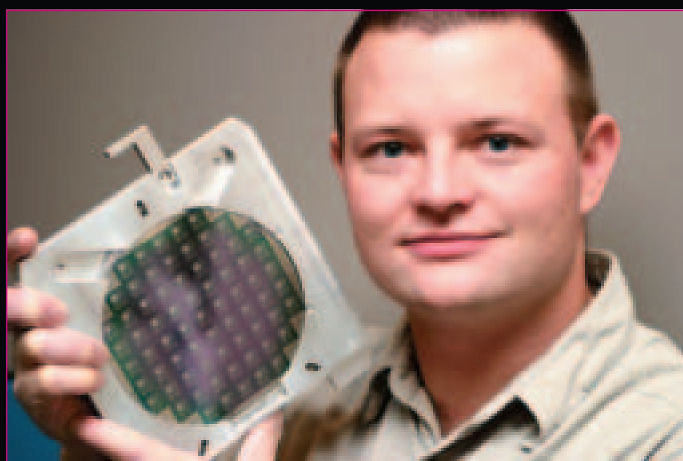
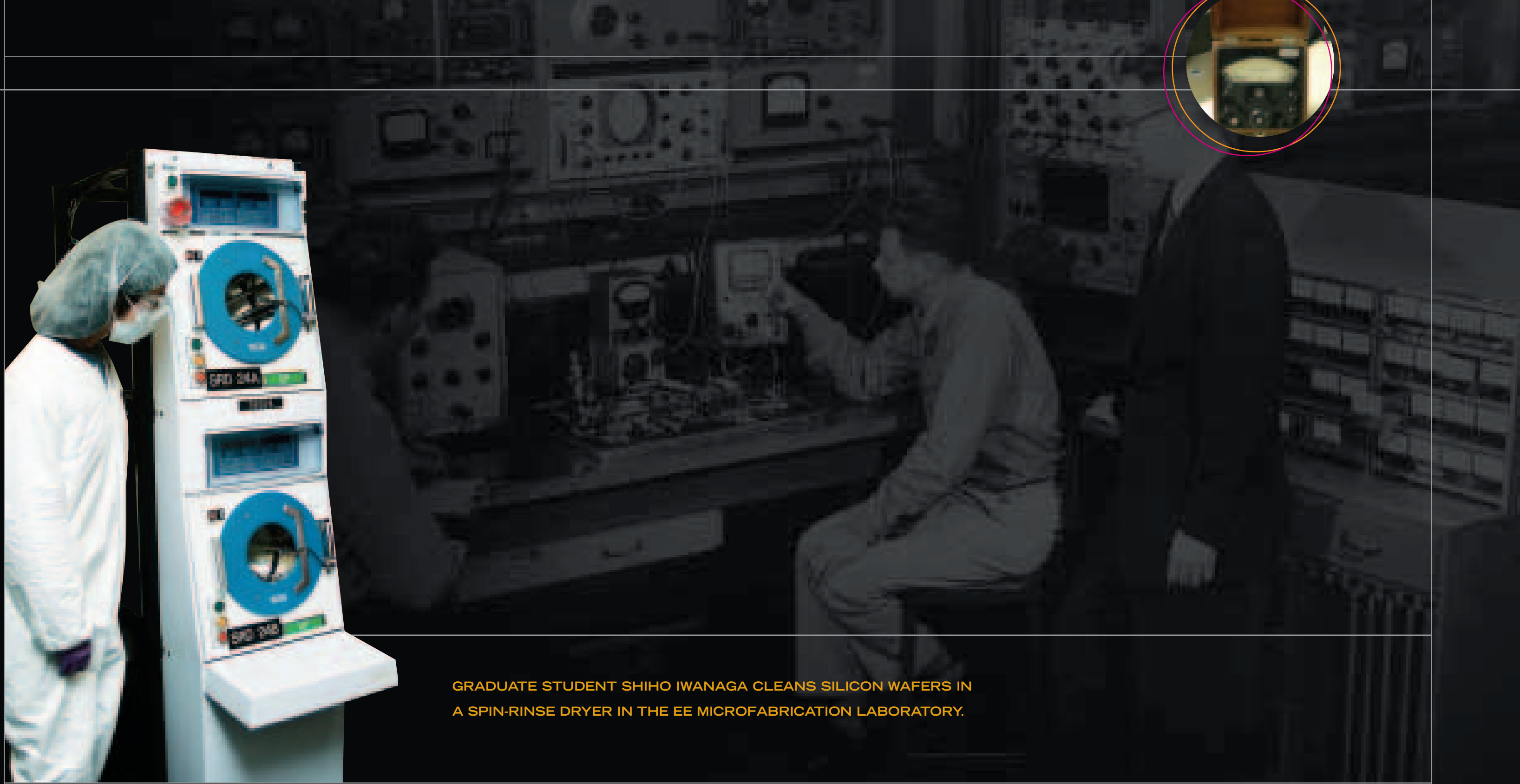


Photo by Leo Lam.



GRADUATE STUDENT SHIHO IWANAGA CLEANS SILICON WAFERS IN A SPIN-RINSE DRYER IN THE EE MICROFABRICATION LABORATORY.

Photo by Leo Lam.

Professor David Allstot and colleagues are working on the design of mixed-signal/radio-frequency (RF) system-on-chip solutions in silicon technologies, with an emphasis on multiple-antenna RF transceivers, calibration techniques for high-speed precision A/D converters and RF CAD synthesis. The demand for higher performance RF integrated systems motivates the development of low-cost single-chip phased-array communications system-on-chip solutions operating at 15 GHz and above. Concerns about coupling between transmit and receive channels are mitigated by adopting a simplex architecture including the on-chip digital command and control circuitry. In contrast to previous attempts at sub-system integration, this work aims to develop a complete single-chip solution that enables low-cost high-volume in a SiGe BiCMOS technology for chip-on-board simplex phased-array communications systems in a small physical size and low weight antenna assembly.

Associate Professor C.J. Richard Shi and students are developing computer-aided design of mixed analog-digital and RF circuits and systems, with an emphasis on modeling, simulation and layout automation techniques.

Associate Professor Scott Hauck's lab is focused on FPGAs: chips that can be programmed and reprogrammed to implement complex digital logic. His students work on VLSI layout, CAD tools, and applications of these devices to high-performance computing.

Professor Mani Soma is working on design-for-test and test methods for mixed analog-digital systems and RF systems, emphasizing on on-chip built-in test and techniques for on-chip waveform generation and measurements.

Among other topics, Professor Bruce Darling and colleagues are developing improved device models for submicron SOI MOSFETs, which include the primary effects of the space environment. The scope of the present work includes temperature effects over the range of -65°C to +200°C, the immediate effects of ionizing radiation on SOI MOSFET device characteristics, and prolonged, long-term effects of total radiation exposure doses.

These researchers are increasingly involved in interdisciplinary work involving MEMS, photonics and research on the interfaces of VLSI and biology.

Contributions to this story made by: Carl Sechen, Ward Helms, Bruce Darling, David Allstot, and Justin Clayton.

PICTURED IN BACKGROUND UWEE LAB, DATE UNKNOWN
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GEnomics and ProtEomics

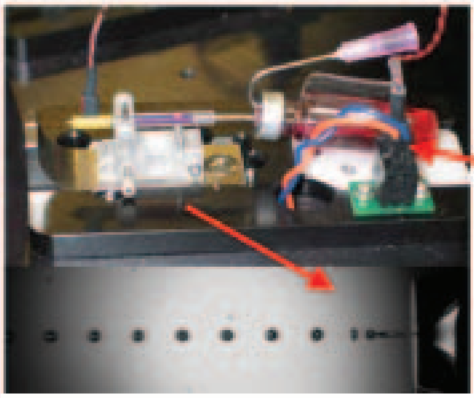
New automated instruments and core technologies are being developed at UWEE that enable biologists to push frontiers and answer new questions in biological and medical applications such as, "how does the cell work?" and "how does HIV infection in cells occur?" These applications are also driving innovations in technology development from automated fluid handling systems, to micro-scale devices, to analyzing living cells in real-time.

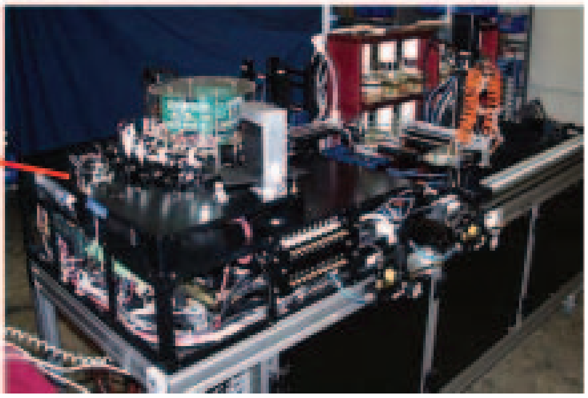
The ACAPELLA Program

Professor Deirdre R. Meldrum was an early pioneer of the Department in the development of instrumentation for genome research automation. Meldrum's Genomation Laboratory (GNL) has nurtured the development of a number of capillary-based fully automated microfluidic sample preparation systems with initial funding from the NIH and the Washington Technology Center. The flagship of these systems is the ACAPELLA-5K (A5K), which is a general-purpose chemistry preparation and analysis system that prepares 5000, 2-μL reactions in eight hours[1].

The A5K provides high-throughput processing of Polymerase Chain Reactions (PCRs) and sequencing reactions which saves significant time and cost associated with these essential genomic processes. Successful alpha-testing of A5K in the UW Genome Center (UWGC), directed by Professor Maynard Olson, is complete and the A5K is now undergoing beta-testing with the UWGC as well as Washington University Genome Sequencing Center in St. Louis, Missouri.

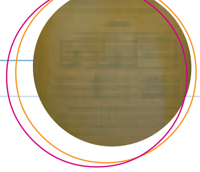
FAR RIGHT THE ACAPELLA-5K SYSTEM PREPARES 2-μL REACTION VOLUMES INSIDE GLASS CAPILLARIES. TOP RIGHT ENGINEERING ARTS PIEZOELECTRIC ACTIVE PIPETTE MOUNTED ON THE A5K. BOTTOM RIGHT 40 MICRON DROPLETS (STROBE IMAGED) PRODUCED BY THE PIEZOELECTRIC DISPENSER ARE DISPENSED INTO THE END OF EACH GLASS CAPILLARY TO PREPARE REACTIONS ON A5K. ACTIVE PIPETTES FIRE A VARIETY OF REAGENTS, SOME HAVING HIGH PROTEIN CONCENTRATIONS.





Development of the A5K involves the UW and two industry partners: Orca Photonics Systems, Inc. (Redmond, WA), and Engineering Arts (Mercer Island, WA). The core of the UW team consists of Meldrum (PI), Research Assistant Professor Mark Holl (electromechanical design), Dr. Charles Fisher (systems and testing), Dr. Mohan Saini (biochemistry), Matthew Moore (software), Tim Ren (software), and Shawn McGuire (electromechanical testing).

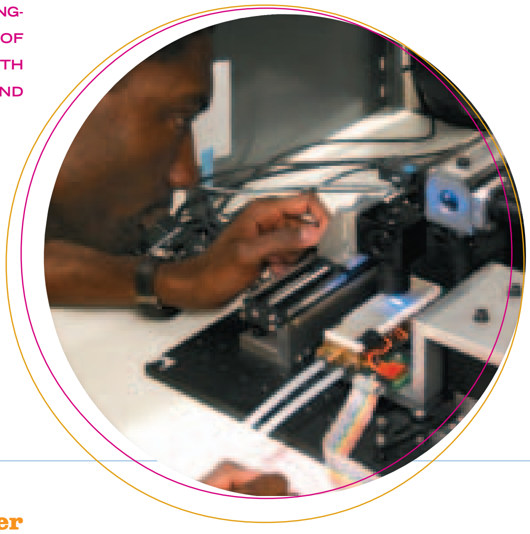
A high-throughput, real-time quantitative PCR analysis system is being developed as an add-on option to the core ACAPELLA instrument[2] for applications such as the detection of minimal residual disease for patient diagnosis and after treatment.



PCR is a technique to selectively replicate a given stretch of DNA *in vitro* to produce a larger amount of the DNA material for further analysis or to detect the existence of a defined sequence in a particular DNA sample to identify disease states. In real-time PCR, a fluorescent probe is added to the sample to enable real-time detection and quantitation of the DNA amplification process. This project is a collaborative effort between the GNL (Meldrum (PI), Fisher, Saini, Holl, Moore, and graduate students Patrick Ngatchou and Jianchun Dong), the UW Medical School Department of Laboratory Medicine (Professor Dan Sabath), and Orca Photonics Systems, Inc.

The ACAPELLA sample preparation system is also forging inroads into the field of Proteomics by providing a novel platform for preparing protein crystals for x-ray crystallography analysis[3].

This project is a joint collaboration between researchers in GNL and the Biomolecular Structure Center, directed by Professor Wim G. J. Hol in the UW Department of Biochemistry and demonstrates the ability to adapt the A5K to high throughput protein crystallography sample preparation. EE Professor Eve Riskin, EE/CSE Professor Linda Shapiro, and CSE Professor Richard Ladner are working as part of this team on image processing of samples inside glass capillaries to identify and classify protein crystals.



REAL-TIME QUANTITATIVE PCR SYSTEM FOR THE DETECTION OF MINIMAL RESIDUAL DISEASE: RIGHT EE GRADUATE STUDENT PATRICK NGATCHOU WORKS ON A LASER SCANNER PROTOTYPE; FAR RIGHT EE GRADUATE STUDENT JIANCHUN DONG MAKES ADJUSTMENTS ON HIS NO-MOVING-PARTS SCANNER SYSTEM COMPRISED OF AN ARRAY OF LIGHT-EMITTING DIODES (LEDS) AS LIGHT SOURCES. BOTH SYSTEMS HAVE YIELDED EXCELLENT SENSITIVITY AND DETECTION RESULTS.

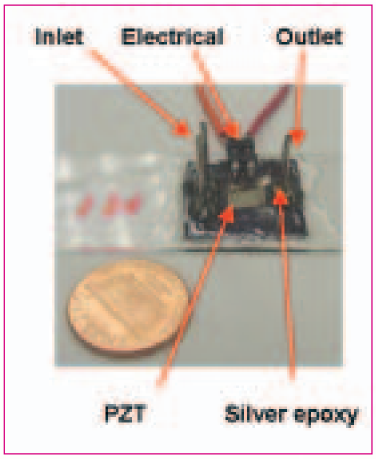
The Microscale Life Sciences Center

The Microscale Life Sciences Center (MLSC) is co-directed by Meldrum and Professor Mary E. Lidstrom of Chemical Engineering and Microbiology[4]. This NIH Center of Excellence in Genomic Science (CEGS) is focused on understanding response at the cellular level by studying functional genomics one cell at a time. The central goal is to engineer the tools needed to detect and analyze multiple parameters in individual living cells in real-time. With these tools, scientists can assess the response in cells due to biochemical, physical, infecting agent, and temporal cues. For example, how does the genome change over time? Does aging correlate with the increase in cancer in individuals? How does mechanical force regulate protein function and cell function? How does HIV infection occur in cells? The MLSC is comprised of interdisciplinary faculty, post-doctoral fellows, research scientists, graduate students, and undergraduate research assistants in seven departments at UW and the Fred Hutchinson Cancer Research Center. MLSC EE faculty members include Karl Böhringer (MEMS), Howard Chizeck (systems theory and DNA structure), Holl (microfluidics and systems design), Meldrum (PI and technology development), Denise Wilson (sensor design and fusion), and Mark Troll (detection and quantitation of small molecules).

Researchers in GNL are developing several advanced systems for single cell analysis. An advanced digital microscope incorporating modular microfluidic devices for single cell analysis is being developed by Research Associate Joseph Chao with Holl and Meldrum.

GRANTS FUNDING THIS WORK:

1. NIH NHGRI grants 1 R01 HG01497 and 1 R24 HG02215.
2. NIH NCI grant 1 R33 CA84691.
3. NIH NIGMS Grant 1 R01 GM068878.
4. NIH NHGRI grant 1 P50 HG002360.



MEMS MICROFLUIDIC VIBRATIONAL MODE HOPPING MIXER DEVELOPED IN THE PH.D. WORK OF DR. LING-SHENG JANG.

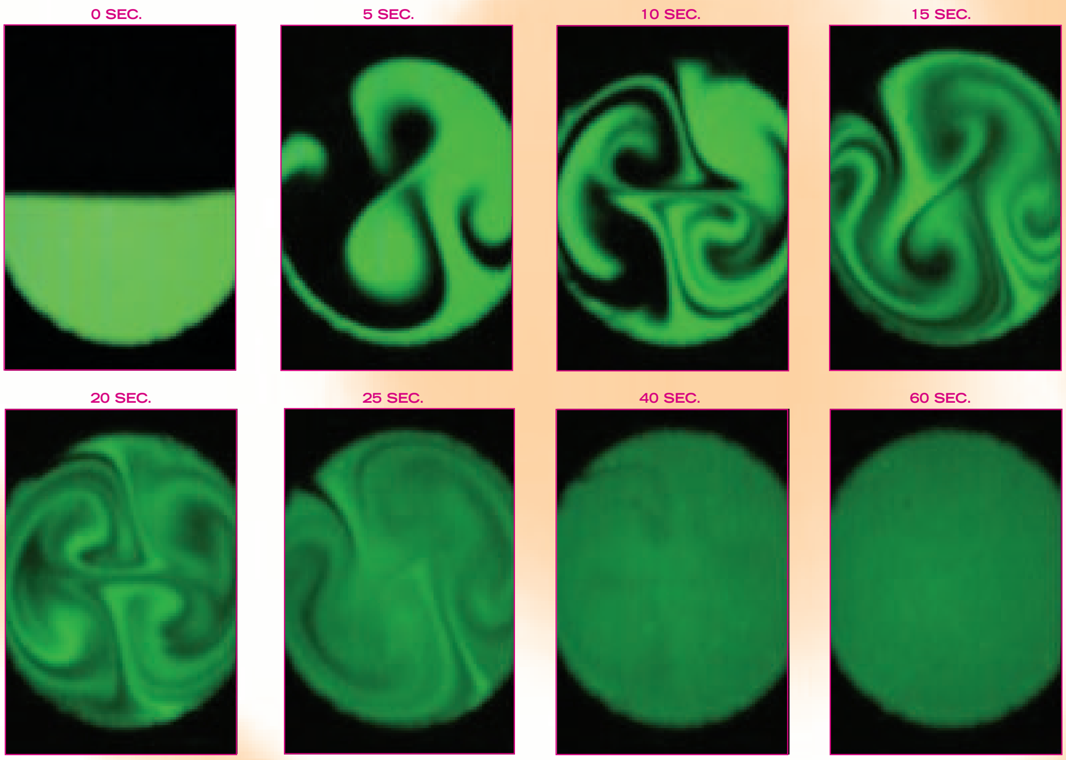
Graduate student John Koschwanez is working with Holl, Meldrum, and yeast biologists at The Fred Hutchinson Cancer Research Center (FHCRC) to build an automated microfluidic system that will perform yeast pedigree analysis. During yeast pedigree analysis, a yeast biologist will observe a single yeast cell under a microscope. When a daughter cell buds from the mother cell, normally every 90 minutes, the biologist will manually remove the daughter cell for further study. During a recent study, a biologist was forced to spend over 150 straight hours in the lab. By automating the process, they hope to eliminate the incredible labor requirements and perform yeast pedigree analysis on many cells in parallel. Yeast is being used as a model organism to study the correlation between genomic changes, aging and cancer.

Ph.D. student, Pahnit Seriburi, is working with Meldrum on a collaborative project between GNL and the UW Department of Microbiology to answer key questions relevant to the HIV infection process. Her research project involves counting the number of intact virus particles that infected host T-cells produce in real-time. This information will help to understand the dynamic relationship between the HIV virus and the host T-cell. The long-term goal is to find an effective way to treat and cure HIV infected patients. Technical challenges associated with this effort include the small virus particles size (100nm), and the need to count intact particles. Most of the data obtained in biology labs are from particulates that are not intact or are already broken down into pieces. Currently, they are investigating several electrical techniques to count these virus particles: electrical impedance spectroscopy and dielectrophoresis. If successful, an automated version of this counting process will save significant researcher time and cost.

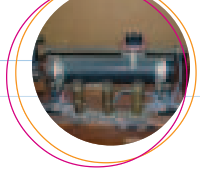
MLSC graduate student Ryan Baxter is examining optical trapping technology as a means of manipulating single cells in real-time in a minimally invasive manner. Through the use of focused laser light, particles, such as cells, can be held in place and manipulated remotely within the fluid volume of a microfluidic device. Spatial positioning of a cell or cell sensor with sub-micron resolution will enable quantitative, single-cell experiments to be performed.

A novel form of MEMS mixing technology using a microfluidic chamber and piezo-actuated vibrational mode hopping, was performed by GNL Ph.D. student Ling-Sheng Jang. This work, performed with Holl and Meldrum, is exemplified by a flow being stretched, folded, and layered. Since the diffusion length is reduced, the diffusion time dramatically decreases as the layer thickness is decreased much faster mixing of fluid volumes within the mixing chamber is achieved.

To rapidly deploy microsystem prototypes to the biologists for testing, the MLSC has been developing a modular bioanalytical tool kit with integrated sensors, microfluidics, data storage and control elements. An example of the efforts in this area is shown below.



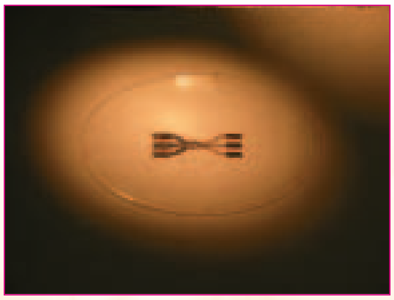
EXPERIMENTAL ILLUSTRATION OF THE NOVEL MIXING METHODS EMPLOYED BY THE MODE HOPPING MEMS MIXER TECHNOLOGY.



The need for engineers with interdisciplinary training for work in the field of Genomics, Proteomics, and related fields like Bioinformatics has created the need for new courses in the engineering curriculum. Meldrum, along with Professor Mary Lidstrom from the Department of Chemical Engineering, have created a new course to answer these needs, EE400M/EE546B, Biology and Genomics for Engineers. The course presents this intersection of fields as an opportunity to discover biology from an engineering perspective where biology is presented as an engineered system, with nature as the engineer and evolution as its design tool. Students learn about processing of biological information and circuitry in living organisms.

Exciting developments are occurring in EE in the area of Genomics and Proteomics. With the arrival of new faculty in the area of Nanotechnology (Assistant Professor Babak Parviz) and Photonics (Associate Professor Lih Lin) and the strong resident core faculty, the possibilities for novel contributions in microscale genomics and proteomics have a bright and expanding horizon.

Contributions to this story made by: Mark R. Holl and Deirdre Meldrum.



MICROFLUIDIC TOOLKIT: LEFT HOLL ILLUSTRATES A NEW PDMS (SILICONE) MOLDING KIT HE HAS DEVELOPED FOR PRODUCTION OF MICROFLUIDIC STRUCTURES; ABOVE HOLL DEMONSTRATES OPERATIONS FOR CURING OF PDMS; RIGHT NOVEL MEMS/PDMS STRUCTURES IN MULTILAYER DEVICES; AND TOP RESEARCH ENGINEER SARAH McQUAIDE EXAMINES HER WORK ON A MICROENVIRONMENTAL CHAMBER FOR METABOLIC RESEARCH AT THE SINGLE CELL LEVEL.

Supporting the Energy Backbone

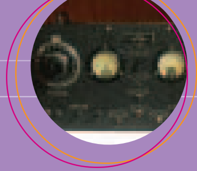
Power engineering has been a focus of the Department since its earliest days. The construction of the Bonneville Dam brought UWEE into national prominence. Stong energy conversion courses were developed by emeriti Professors Edward Guilford and Roberth Bergseth. Even now, issues of power and energy, resources and the environment remain subject to active discussion across the country. At UWEE, researchers are helping students learn about today's and tomorrow's energy challenges by teaching key topics, including renewable energy, power electronics, automated maintenance, high-performance simulation, artificial intelligence, electricity market structures and power infrastructure defense.

The 2003 blackout in the Midwest and New York demonstrated how the power electric infrastructure in the US is the support backbone of other key infrastructures, such as communications and transportation. UW faculty are researching techniques to protect the power infrastructure that is critical to the country. Professors Chen-Ching Liu, Mark Damborg, and Mohamed El-Sharkawi and students have shown that wide-area information and artificial intelligence can complement local control schemes and significantly reduce the risk of catastrophic failures. Such new technology must support efficient electricity market structures, so Associate Professor Rich Christie and his students have created market simulation methods that promote the understanding of electricity market structures.

Effective maintenance is also receiving close attention from aftermath of the 2003 blackout. Assistant Professor Alexander Mamishev and students have developed a prototype of a mobile robotic monitoring platform that travels along underground power cables and detects developing failures before they cause outages. Accessibility to the underground infrastructure is tedious and expensive so this platform is particularly significant and highly valuable.

So what does the energy system of the future look like? The Gas Research Institute predicts that distributed energy resources will capture about 30% of the energy market by 2030. One distributed energy source of key interest is wind energy conversion. While renewable and environmentally benign, wind energy conversion faces a major problem in large-scale network integration because the power generation capability directly depends on the wind speed. Similar problems of controllability exist for other renewable energy sources with intermittent output, which does not always produce power output in accordance with consumer demand.

Assistant Professor Kai Strunz and his students of the Systems, Electronics, Simulation, and Applied Mathematics for Energy (SESAME) laboratory have proposed a solution in which the unpredictable power source is coupled with diverse storage modules to overcome the stochastic nature of the source.



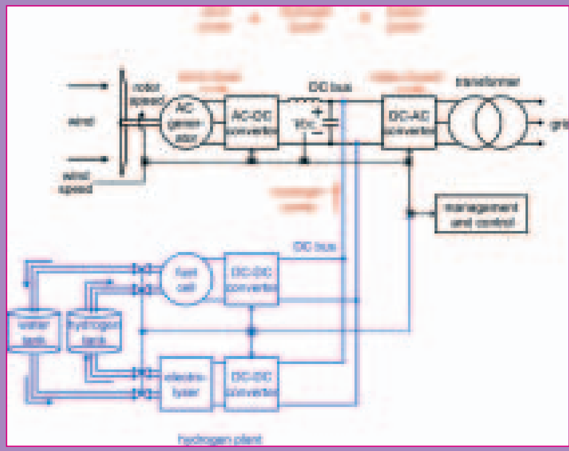
In periods of high wind speeds, the excess wind power is supplied to the hydrogen plant, where hydrogen is produced though electrolysis. This hydrogen is then available for electric power generation to complement the wind power in times of low wind speeds. As a result, the stochastic renewable energy source is transformed into a deterministic generation facility with no emissions and with controlled power output to the grid. With its high controllability, environmentally friendliness, and use of hydrogen as the major storage medium, the proposed Stochastic Energy Source Access Management fits well into the developing distributed energy systems and the hydrogen economy.

Supported through a NSF CAREER Award, Strunz and his students perform research into the computational methods needed to enable integration of such new power sources. As Convener of CIGRE Task Force C6.04.02 "Computational Tools and Techniques for Fast Transients Analysis of Distributed Generation Systems," Strunz promotes this important area of research within the technical community and beyond.

Professor Emeritus Peter Lauritzen continues to develop new circuit simulation models for power electronic switches. Many of these models were developed with former students and are public domain so Lauritzen has chosen the best of these models from the past twelve years and made them available for free download from his UWEE web page. Currently, engineers from around the world download approximately 45 models each month.

An excellent example of interdisciplinary work is evident with the NEPTUNE seafloor observatory project, in which UWEE works with researchers from the California Institute of Technology to establish a submarine network of remote, interactive laboratories along the Juan de Fuca Plate off the Pacific Northwest Coast (See EEK 2002, page 5).

Active cooperation is maintained with federal agencies such as the National Science Foundation, the Department of Defense, as well as the Electric Power Research Institute. The Department also has close ties to Pacific Northwest companies, including the Bonneville Power Administration, ESCA, Tacoma Power, and Seattle City Light. International opportunities have opened up through the Advanced Power Technologies (APT) Consortium, which includes collaborating corporations from France, Italy, Japan, Korea, and the US.



STOCHASTIC ENERGY SOURCE ACCESS MANAGEMENT ILLUSTRATED THROUGH THE COUPLING OF A WIND FARM AND A HYDROGEN PLANT.

Contributions to this story made by: Kai Strunz.

A.I.E.E. SEATTLE SECTION ON ALDER DAM, APRIL 1947.

Wireless Networking and Security

Mobile computing applications are ushering in an era of ubiquitous communications and computing. UWEE Communications and Networking researchers are striving to understand the inherent trade-offs in the design of such communication systems, including cross layer wireless communication from link layer to network layer to security.

For many years, Professors Dean Lytle and Jim Meditch personified communications research at UWEE. Lytle joined the EE department in the late 1950s. His research was in many areas of communications and signal processing. Meditch began his career in the area of Estimation and Stochastic Control, with his 1969 pioneering book "Stochastic Optimal Linear Estimation & Control." He served as the President of the IEEE Control Systems Society and his IEEE Fellowship recognized "his contributions to development and applications of estimation theory." During the late 1980s, Meditch's professional interests moved to computer communication networks. He introduced control-theoretic analysis of computer communication network models. Meditch served as Chair of the department from 1977 to 1985.

From 1994 to 2002, Professor Murat Azizoglu worked on optical networking and information theory. Along with Arun Somani, he developed dependable routing and connection management issues at wavelength- and sub-wavelength-levels in optical WDM-based networks.

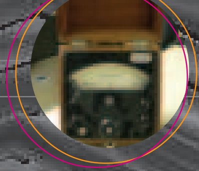
Today, Communications and Networking researchers in UWEE work on wireless networks and security. Professor Jim Ritcey is researching signal processing for communications, radar, sonar and navigation. He also investigates space-time adaptive processing, iterative decoding for coded modulation and space-time processing for underwater acoustic communication. Professor Sumit Roy's research focuses on optimizing joint physical and multi-access control (MAC) layers of wireless networks including ultra-wideband techniques for PAN networks, OFDM based LAN/MAN networks, and multi-carrier CDMA techniques. He spent 2002-2003 at Intel Labs in Hillsboro, OR as a member of the system architecture team behind Intel's 15.3a and 11n standards activities. He investigated satellite MAC protocols for a Boeing satellite gateway design and is currently engaged in performance evaluation of sensor network protocols for military applications.

Assistant Professor Radha Poovendran's current research interests involve network security and cryptography. He is developing efficient cross-layer algorithms for routing and key management in power-efficient broadcast networks. He has been working with the Army Research Laboratory (ARL) to develop secure network algorithms for ARL Blue Radio Networks.

The research of Associate Professor Hui Liu ranges from broadband wireless networks, to DSP and VLSI, to multimedia signal processing. Ongoing projects include OFDM modem, space-time coding, intelligent MAC for high-speed wireless LAN, ultra wideband (UWB), and fourth generation mobile networks. Previously, Liu was Chief Scientist at Cwill Telecomm, Inc. and one of the principal designers of TD-SCDMA 3G cellular networks. In 2000, he founded Broadstorm, Inc. and developed an OFDMA-based mobile broadband IP network. He collaborates with industrial leaders and international research organizations and is on the technical advisory board of the Chinese Academy of Broadcasting.

Assistant Professor Tara Javidi's research focuses on a cross-layer coordination between transport control protocols, such as TCP/RED, and multi-access control (MAC). She identifies these layers as two interacting "economies" of link capacity and wireless bandwidth. Using micro-economic techniques, such as non-cooperative games and public regulation/pricing, she analyzes the inherent trade-offs in the network and proposes variations in the existing MAC and transport protocols, leading to a cross-layer optimized solution.

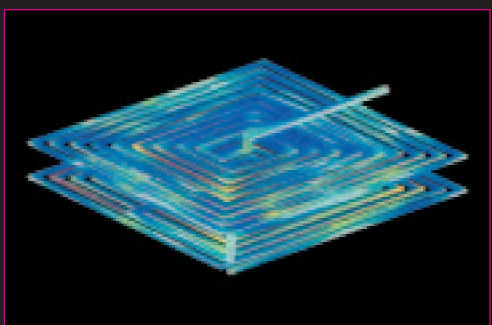
Contributions to this article made by: Radha Poovendran, Tara Javidi, Hui Liu, Sumit Roy, and Jim Ritcey.

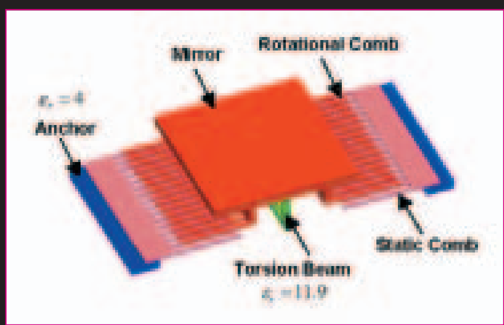


Keeping Up With Electromagnetics

For more than 50 years Electromagnetics and Remote Sensing researchers at UWEE have worked on a wide variety of topics relating to the analytical, computational and experimental aspects of electromagnetics. These laboratories have focused on research topics in the following five main areas: electromagnetics and remote sensing, applied computational electromagnetics, applied electromagnetics and optics, radar remote sensing and applied physics.

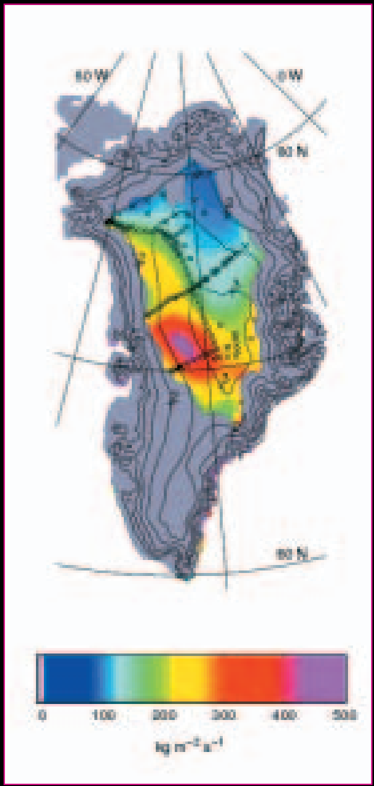
Professors Akira Ishimaru and Yasuo Kuga's Electromagnetics and Remote Sensing Lab has a long history that dates back to the 1950s when the space age promoted research on various antennas for high-speed vehicles. In the 1970s and 1980s, this lab extensively researched laser propagation in the atmosphere and remote sensing of the planetary atmosphere and solar wind. After the 1980s, the research turned to applications in medical optics and imaging, microwave imaging and photon localization. More recently, researchers have studied object detection in complex environments such as the ocean surface or terrain, probing and remote sensing of the earth atmosphere, and new metamaterials, such as negative index media.





CURRENT DENSITY SOLUTION SHOWN ON AN ON-CHIP MULTILAYERED SPIRAL INDUCTOR, AND THE ELECTROSTATIC PRESSURE AND CROSS-COUPLING EFFECTS IN A MEMS MICRO-MIRROR ARRAY. ALSO SHOWN ARE THE DETAILS OF A SINGLE ELEMENT OF THE ARRAY.

In the coming years the Electromagnetics Lab plans to continue studying the interactions of microwaves, optical waves, and acoustic waves with environments and media and finding new ways to apply object imaging and communication through complex media. The lab is particularly interested in developing new materials that have effective permittivity and permeability that are not found in existing materials. The Electromagnetics Lab recently studied excited waves on slabs of metamaterials and has developed generalized formulas for general metamaterials—formulas that will help researchers develop new materials.



MASS ACCUMULATION RATE (IN KG M-2 YR-1) ON THE PERENNIALLY FROZEN PARTS OF THE GREENLAND ICE SHEET (WITH CONTOURS OF ELEVATION OVERLAID FOR REFERENCE). THIS MAP WAS DERIVED FROM SATELLITE OBSERVATIONS OF THERMAL EMISSION OF MICROWAVES AT 4.5 CM WAVELENGTH (6.7 GHZ).

Assistant Professor Vikram Jandhyala's Applied Computational Electromagnetics (ACE) Lab develops efficient methods for electromagnetic simulation and to interface these methods with other areas, including circuits, devices, and communications. The development of these methods requires many disciplines, including applied mathematics and fast algorithms, physics formulations and methods, computer graphics, and interfaces to circuit theory and signal processing. In particular, the ACE Lab has developed fast analysis tools and methods to model scattering from large structures and novel electromagnetic materials to simulate high-speed circuits and systems, mixed-technology chips, and wireless propagation. The ACE Lab consists of 8 Ph.D. students funded by NSF, Defense Advanced Research Projects Agency (DARPA), SRC, and industrial sources.

At the UW Applied Physics Laboratory, Research Professor Dale Winebrenner studies the physics of radio wave light and the exploration of icy environments. Currently, he is researching the radar sounding of structures within and beneath frozen structures on Greenland, Antarctica, Mars, and the three Galilean moons of Jupiter; optical probing for biological molecules within ice, including the floating ice cap on the Arctic Ocean; and microwave observation of ice sheet surface temperatures and mass accumulation rates. These projects are sponsored by the NSF and NASA.

Professor Leung Tsang's Laboratory of Applications and Computations in Electromagnetics and Optics researches simulation methods for rough surface scattering, random media, and signal integrity. In particular, they have discovered that data about the land and ocean surface is essential to model weather and climate prediction. Researchers have extensively used passive microwave instruments on satellites to sense soil, ocean, and snow parameters. For many years, data from the Special Sensor Microwave Imager (SSMI) have been widely used and more missions will be flown to provide new advancements in passive microwave measurements. With these new advancements, Tsang and other researchers want to develop theoretical microwave models to predict the brightness temperatures of land and ocean surfaces and retrieve the parameters of land and ocean surfaces. Researchers also need these models to predict how wave scattering and emission from random media and rough surfaces depend on frequency, polarization, and incidence angle.

Over the past decade, the lab has rigorously and extensively studied the microwave emissivities of snow, soil, oceans, and foam-covered oceans by using non-classical analytic models and Monte Carlo simulations of exact solutions of Maxwell's equations. Students at the laboratory study and extend the microwave models, apply them to satellite data, and adapt the models so that they can be readily assimilated into microwave remote sensing and climate studies.

Associate Professor John Sahr's Radar Remote Sensing Lab has completed its second full year of nonstop operations of the Manastash Ridge Radar. During this time, Sahr, Melissa Meyer, Andrew Morabito, Hasan Mir, and Matt Grossman collected approximately 13,000 echoes from turbulence near the Aurora Borealis above northeast Washington, Idaho, British Columbia, and Alberta, Canada. The Manastash Ridge Radar listens very carefully to the echoes of commercial FM broadcasts near 100 MHz with the help of several antennas and compares the arriving signals to deduce the direction and size of the echoes. The radar also detects meteor trails and airplanes in addition to the echoes from the Aurora. The Radar Remote Sensing Laboratory is supported by the NSF, NATO, and the MIT Lincoln Laboratory (See EEK2003, page 13, and EEK2001, page 12).

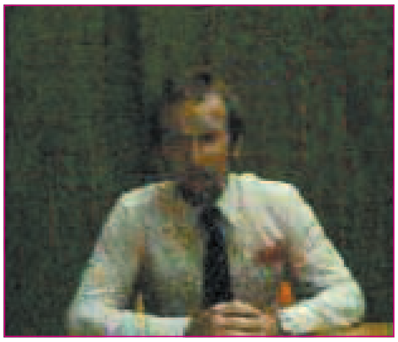
Contributions to this story were made by: Vikram Jandhyala, Akira Ishimaru, Leung Tsang, Yasuo Kuga, John Sahr, and Dale Winebrenner.

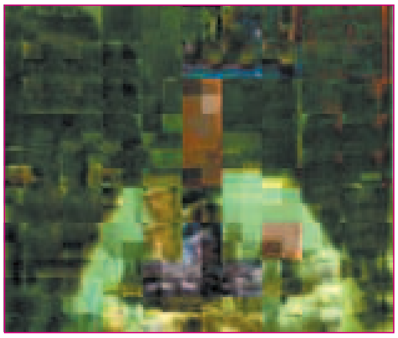
PICTURED IN BACKGROUND
FAR LEFT: DONALD REYNOLDS,
FAR RIGHT: MYRON SWARM.
U. of Wash. Libraries, Spec. Coll, UW23460z.

Signal, Speech and Image Processing

During the past half-century UWEE faculty have conducted research on a wide range of signal, speech, video and image processing topics. Included are speech recognition for human-computer dialogs and audio browsing, speech synthesis, language identification, morphological image processing, computer vision, image compression/transmission, medical image analysis, video compression, networking, segmentation and tracking, content-based retrieval and multimedia.

THE RATE CONTROL ALGORITHM USED IN THIS IMAGE ALLOCATED THE SAME NUMBER OF BITS TO EACH FRAME, CAUSING DIFFERENT LEVELS OF QUALITY TO APPEAR IN DIFFERENT FRAMES. PRECISE CONTROL OF BIT QUANTITIES IN EACH FRAME REQUIRES POLICIES ON HOW TO ALLOCATE BITS TO EACH FRAME OF THE VIDEO, BUT SOME FRAMES ARE HARDER TO CODE THAN OTHERS AND CAN CAUSE SUDDEN DEGRADATION.





CSE PH.D. STUDENT MICHAEL RINGENBURG ALTERED THE POLICY OF THE GTV RATE CONTROL ALGORITHM TO MINIMIZE THE MAXIMUM FRAME ERROR. THE IMAGE ABOVE SHOWS THE EVERY-FRAME QUALITY OF THE UW SOLUTION COMPARED TO THE SUDDEN DEGRADATION AFTER A SCENE CHANGE THAT OCCURS WITH CONSTANT RATE METHODS. THIS WORK WAS SUPPORTED BY NSF AND THE U.S. ARMY RESEARCH OFFICE.

In the 1960's, EE alum Donald Baker developed a way to turn ultrasound's formerly fuzzy images into detailed representations of what's inside a person's body by determining that pulsed, rather than continuous sound waves create the sharp images physicians needed. Last year, Baker's inventions went on display in the Smithsonian Institution's National Museum of American History to mark the 40th anniversary of ultrasound.

Over the past two decades, researchers at UW have designed better transforms for multimedia applications. For example, audio coding techniques, such as MP3, weight errors in audio frequencies less if humans are less sensitive to those frequencies. But is selective weighting in the frequency domain all we can do? Professor Les Atlas is developing, with support from the Office of Naval Research, the Army Research Office, and industry, new transforms that operate in another perceptual dimension called "modulation frequency." These transforms indeed do offer substantially more compression than MP3. Moreover, modulation frequency filtering is now being applied to a variety of other applications including hearing aids and sniper localization.

Perceptual quality can also be increased through changes in how researchers minimize distortion in video-coding. Students in the Data Compression Laboratory, directed by Professors Eve Riskin and Richard Ladner (Computer Science and Engineering (CSE) department), have developed a new video coder based on bit-plane coding called GTV. GTV outperforms the standard H.263 video coder at medium to high bit rates and provides an embedded bit stream, which means that precise numbers of bits can be allocated to each frame of the video. However sudden degradations of quality cause "flicker" that is more disturbing to viewers than small constant degradation. A "minimax" policy, developed by UW researchers, produces nearly constant quality during the video.

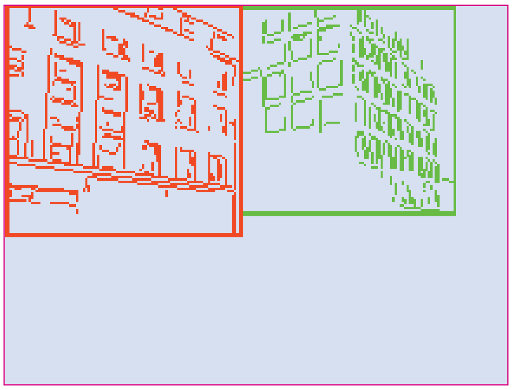
Professor Greg Zick's work involves large image and multimedia databases. Zick's work has been commercialized by a company he founded DiMeMa, Inc. — as a flexible digital collection management package that handles documents, PDFs, images, video, and audio files. Libraries, universities, government agencies, museums, corporations, historical societies and a host of other organizations to support hundreds of diverse digital collections use the fruits of his work.

Professor Yongmin Kim's Imaging Computing Systems Laboratory works on research projects that include next-generation multimedia processors, imaging and video systems, ultrasound imaging, and distributed diagnosis and home healthcare. The technologies developed in his lab are currently being used not only in medical imaging, electronic medicine and real-time microscopy, but also in digital TV, video conferencing, office equipment, telecommunications, machine vision, security and surveillance, military and aerospace, and entertainment.

Professor Jenq-Neng Hwang and students are jointly working with the Korean Electronics and Telecommunications Research Institute on the next generation VideoGIS system, in which scalable geo-referenced video and geographic information (GI) are transmitted to GPS-guided vehicles. A VideoGIS system combines geo-referenced video information with traditional geographic information to provide a more comprehensive understanding over a spatial location. Video data have been used with geographic information in some projects to facilitate a better understanding of the spatial objects of interest. The remote user can request, through mobile devices, abundant information related to the objects of interest and can systematically adapt to heterogeneous network conditions, based on an innovative bandwidth estimation technique, display area size, and CPU processing power. Data can be sent as needed, solving real-time problems instead of the one-size-fits-all data availability.

Professor Ming-Ting Sun is conducting research in image enhancement for camera systems, MPEG-2 video transcoding, video-on-demand multimedia object authoring tools and visual communication for ADSL environments, object-based video transcoding. He was actively involved in the development of H.261, MPEG-1, and MPEG-2 video coding standards.

For the problem of finding images in a database that are similar to a given image, research efforts usually try to match color, texture, or elementary shape features. Professor Linda Shapiro has taken a different approach, focusing on computer vision including the recognition of classes of objects in image and video data. This method is being applied to the recognition of insects (in a collaboration with Oregon State University sponsored by NSF) and for the recognition of tanks, trucks, and other vehicles and the patterns of their movement in video data that is acquired from unmanned aerial vehicles (for a project jointly sponsored by ARDA and Boeing).



THE RECOGNITION OF COLOR IMAGES OF OUTDOOR SCENES, SUCH AS TWO BUILDINGS IN A CITY SCENE, IS PART OF THE "OBJECT AND CONCEPT RECOGNITION FOR CONTENT-BASED IMAGE RETRIEVAL" PROJECT. THIS PROJECT IS SPONSORED BY THE NSF.

Assistant Professor Maya Gupta is interested in augmentations of normal human vision and the more general problem of "the last two inches" communications bottleneck. In one project, Gupta is investigating how to develop a cheap and reliable test for tetrachromats-hypothesized women who have and can utilize four color cones (tetrachromacy). She is also trying to optimize the visualization of data for normal color vision. In an effort to achieve better image understanding through image processing, she is working on special problems that arise in clustering and segmentation of color images and how methods developed for the particular problems raised there may be useful in other applications.

At the UW Applied Physics Lab, Professor Robert Spindel is engaged in research involving underwater acoustics and Research Professor Lawrence Crum is conducting work on advanced medical applications of ultrasound.

Assistant Professor Jeff Bilmes, Research Assistant Professor Katrin Kirchhoff and Professor Mari Ostendorf continue their work on speech recognition and synthesis. Work on these projects is featured in the EEK2003 article, "The Science of Sound: Speech Recognition Projects Conducted in EE Labs."

Contributions to this story made by: Maya Gupta, Linda Shapiro, Jenq-Neng Hwang, Eve Riskin, and Michael Ringenburg.

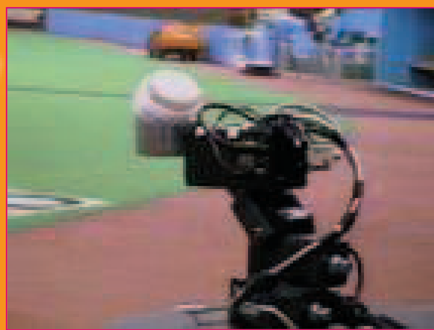
The future of signal and image processing algorithms depends on appropriately defining the problems and the solution policies. New research on human perception, more computational power, and new theoretical ideas will allow researchers to rethink traditional engineering paradigms and design algorithms that solve the "right" problems.

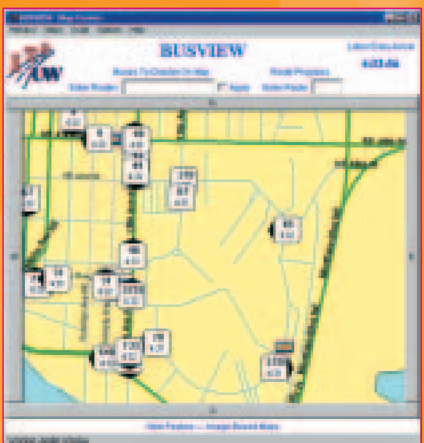
Control and Robotics

The EE Department has long recognized the fundamental role of control and robotics, starting in the 1950s and 1960s when Professors Robert N. Clark, Laurel J. Lewis, and Dean W. Lytle developed the core EE controls curriculum in conjunction with the advent of the space age and in cooperation with the Aeronautics and Astronautics (AA) and Mechanical Engineering (ME) departments.

In robotics, Professor Robert Albrecht introduced a mobile robotics research laboratory in the 1980s that was funded by the Nuclear Regulatory Commission. This work spawned several robotics courses funded by NSF, which have always been very popular amongst students since their inception. One of his robots, quite famously, even delivered the ball to "Scotty," of Star Trek fame, who threw out the first pitch at a Seattle Mariners game in the now imploded Kingdome. Others who were active in developing the Controls courses in the late 50s and early 60s were Endrik Noges, Chih-Chi Hsu, and Robert Pinter.

PROFESSOR ROBERT ALBRECHT'S ROBOT WAS USED TO CARRY OUT THE BALL TO SCOTTY, WHO THREW OUT THE FIRST PITCH DURING THE "TURN AHEAD THE CLOCK NIGHT," AT A MARINERS BASEBALL GAME. ADS FOR THE EVENT PROMISED MARINERS AND ROYALS IN FUTURISTIC UNIFORMS PLAYING IN A "BIODOME" (FORMERLY KNOWN AS THE KINGDOME), WITH LASER LIGHTS AND ROBOTS PROVIDING THE 21ST CENTURY ATMOSPHERE.



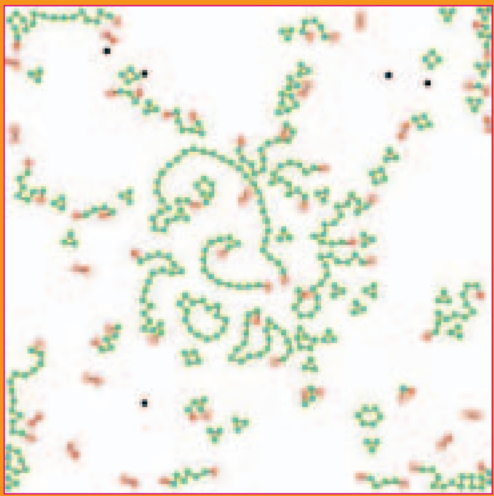


Presently, there are 11 active Robotics and Controls faculty, and several emeritus faculty in a UW Robotics, Controls, and Mechatronics (RCM) effort, which includes faculty from EE, AA, ME, and Chemical Engineering.

One of the projects from Research Professor Daniel Dailey's Intelligent Transportation Systems Lab tracks transit vehicles over a three county, 1800 square mile region. The vehicle locations can be viewed in "Busview" and are used to do the following: (1) help travelers by predicting bus departure at thousands of locations (see Mybus.org), (2) measure congestion by using the buses as probe vehicles (see http://www.its.washington.edu/transit-probes/), (3) and calibrate stochastic, predictive traffic congestion models (See EEK2001, page 5).

A MAP OF THE UW CAMPUS AND SURROUNDINGS DISPLAYING ALL THE ACTIVE BUSES NEARBY AT 4:32 PM. THE LOCATION OF ALL THE BUSES OPERATING IN KING COUNTY CAN BE DISPLAYED USING THIS APPLET: http://busview.org

Research Assistant Professor Linda Bushnell and Dr. Andy Crick continue to offer their popular LEGO-based mobile robotics courses—now in its fourth year. They recently expanded the Autonomous Robotics & Control Systems Laboratory, which consists of an impressive infrastructure of robots, camera systems, and test platforms into Sieg Hall.



A SIMULATION OF "PROGRAMMABLE PARTS" ASSEMBLED INTO STRANDS AND RINGS. THE PARTS FLOAT IN A (SIMULATED) FLUID MEDIUM. UPON RANDOM COLLISIONS, TWO PARTS MAY CHOOSE TO ATTACH TO EACH OTHER OR NOT, BASED ON THEIR PROGRAMMING.

Imagine a complex electronic device or a tiny molecular motor that puts itself together from its pieces, eliminating the need to move each part separately into place. This challenge is one of the problems studied by Assistant Professor Eric Klavins, who joined the department in Autumn 2003 from a position as a postdoctoral researcher at the California Institute of Technology. His research on multi-vehicle formation control has led him to develop algorithms that allow "programmable parts" to assemble themselves into pre-specified shapes.

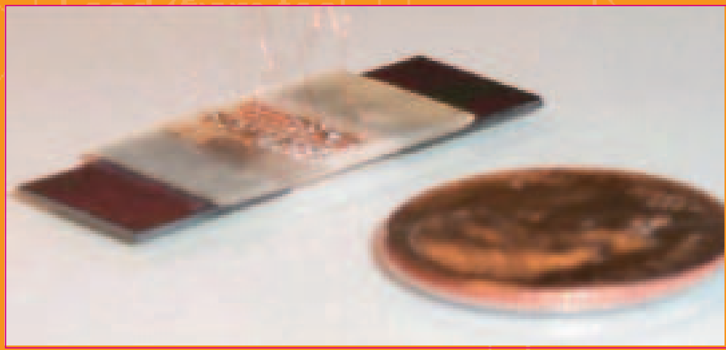
Professor Blake Hannaford, Research Assistant Professor Jacob Rosen, and the Bio-Robotics lab study robot assisted tele-surgery, which allows surgeons to operate on their patients from miles away by using robotic extensions of their hands and eyes. They want to improve minimally invasive surgery training and procedures by developing new surgical robotics, devising objective assessments of surgical performance, creating high fidelity simulations, and further understanding of the mechanics of soft tissue. Rosen is developing a robotically assisted upper limb exoskeleton (wearable robot) with a human machine interface at the neural levels proving a more natural control of the exoskeleton as intuitive extension of the operator body. The system is studied as an assisting device that may apply to rehabilitation medicine and as a force feedback haptic device that may apply to virtual reality simulations.

A PROTOTYPE OF A POWER LINE CRAWLING MICROROBOT.

EXPOSED VIEW OF UPPER LIMB POWERED EXOSKELETON WITH 7 DEGREES OF FREEDOM.

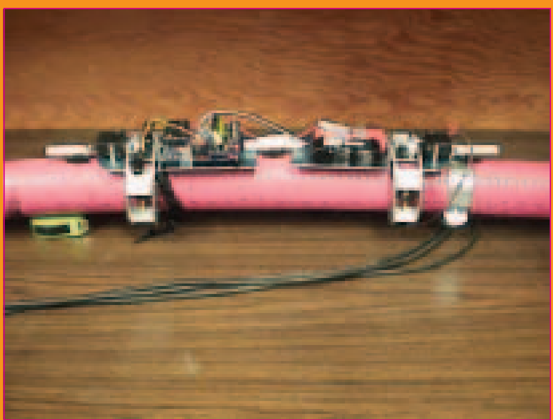
An interdisciplinary robotic activity tied to MEMS research recently created an omnidirectional mobile microrobot that moves via MEMS "cilia" actuator arrays. The microrobot consists of two rigidly connected microcilia array chips, each having an 8x8 array of "motion pixels" that are composed of four orthogonally-oriented thermal bimorph actuators. This arrangement provides the microrobot with reliable and accurate motion, a first for this type of microrobot. The microrobot is approximately 3cmx1cmx1mm and weighs less than one-half gram. Associate Professor Karl Böhringer and students are able to precisely control the velocity of the chip by varying the input power, actuation frequency, and motion gait strategy.

A WALKING MICROROBOT IN RELATION TO A US DIME - LENGTH 3CM, WIDTH 1CM, HEIGHT 1MM. TWO CILIA CHIPS WITH 256 MICROACTUATORS EACH ARE BONDED TO A TINY PCB "BACKBONE." THIS REMOTELY CONTROLLED ROBOT CAN EXECUTE MOTION IN FULL 3 DEGREES OF FREEDOM, WITH INDIVIDUAL STEPS DOWN TO ABOUT 2 MICROMETERS, AND SPEEDS OF UP TO 1 MM/SEC."



Professor Howard Chizeck is conducting research in telerobotics in the presence of communication channel properties such as noise and time delays. Also, in work supported by the MLSC, he and his students are applying algebraic systems theory to the modeling and analysis of DNA and genomic and proteomic processes. The goal is to discover and exploit underlying mathematical structures that are involved in these biological systems (See EEK2003, page15).

Assistant Professor Alex Mamishev's Sensors, Energy, and Automation Laboratory has developed a robot that crawls along an electric power cable, scanning the cable with infrared, acoustic, and dielectrometry sensors to search for developing faults and estimate cable aging. In addition to enhancing sensitivity and subsequent reliability, the use of these robotic platforms for power system maintenance could potentially have other significant advantages such as replacing human workers for dangerous and highly specialized operations.



FAR LEFT A PROTOYPE OF THE MOBILE ROBOT.

LEFT ON JULY 29-30, 2003, THE GYRE TEAM, ADVISED BY RESEARCH ASSISTANT PROFESSOR LINDA BUSHNELL, TESTED AN AUTONOMOUS SELF-ORIENTING FREE-FLYING ROBOT IN LOW GRAVITY CONDITIONS (DURING A "FREE FALL" FLIGHT).

As described in the Genomics and Proteomics article on pages 12-15, Professor Deirdre Meldrum's Genomation Laboratory is working on "ACAPELLA," a system that performs basic steps in the handling of submicroliter fluid samples, such as sample aspiration, reagent dispensing, mixing, and thermal cycling. The goal of the instrument is to process 5,000 one microliter reactions inside glass capillaries in 8 hours of unattended operation. They are currently developing automated methods for thermal cycling, real-time DNA quantitation and gel loading. The system will be used initially for PCRs, restriction digests, and sequencing reactions and will later run multiple experiments in the UW Genome Center. Meldrum is also studying applications to clinical medicine and whole-genome studies.

Contributions to this story made by: Eric Klavins, Jacob Rosen, Dan Dailey, and Robert Albrecht.

UWEE History

Electrical Engineering has been a field of study at the University of Washington for approximately one century. In the Autumn of 1901, Rudolph Ernst Heine was appointed as the university's first Assistant Professor of Electrical Engineering. The Electrical Engineering program was housed in Science Hall (renamed Parrington Hall in 1931). It was built in 1902, the year that Stephen P. Rowell received the first B.S. in Electrical Engineering. The Electrical Engineering Department separated from the Physics Department in 1904 and Dr. Carl Magnusson was appointed as its first Head.

AN ELECTRICAL ENGINEERING TEACHING LAB IN THE "OLD ENGINEERING" BUILDING (MACHINERY HALL), CIRCA 1930'S.
U. of Wash. Libraries, Spec. Coll, UW23465z

In 1910, the Department moved to Old Engineering Hall (Machinery Hall), which was built in 1908 as the Machinery Pavilion for the Alaska-Yukon-Pacific Exposition. The Department awarded its first M.S.E.E. degree in 1913 to Eric Therkelson. A corporate gift of an electric oscillograph in 1913 allowed Dr. Magnusson to teach a course on electrical transients. By 1925, the Department offered students a choice of majoring in either electric power or electronics. Courses in electronics and vacuum tubes were offered by one of the Department's graduates, Austin V. Eastman.

In the 1930s, Professor Magnusson was an advisor for the construction of Grand Coulee Dam and the design of its transmission grid. The harnessing of hydropower was pre-requisite for the development of the regional aluminum and aircraft industry. A decade later, these industries were an essential component of the American military infrastructure in World War II and they led to the development of Seattle as a major urban center.

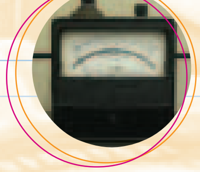
In the 1940s, the Department introduced courses in ultra-high frequencies, antennas, electromagnetic fields, communication networks and industrial control. The large growth of enrollment following World War II required the construction of a new building for EE. This structure was completed in September 1948 (it was demolished in 2001). The Department was fortunate to have 27 years of outstanding leadership from Austin Eastman, who became Head of EE in 1942 following the death of Dr. Magnusson.

In 1953, the Department was granted the authority to offer the Ph.D. degree. In 1958, the first Ph.D. in Electrical Engineering was awarded to Dr. Akira Ishimaru (currently Professor Emeritus in the Department). Also in 1958, the Department received a transmitter in West Seattle (from the Alaska Communications System). This was used to study radio wave transmission through the troposphere and ionosphere. In the 1960s, under the auspices of the NSF, a team of Department faculty, graduate students and staff conducted experiments involving the propagation of electromagnetic waves between Antarctica and receivers throughout the world. In 1964-1965 three graduate students in Antarctica installed a 21-mile antenna that crossed a 10-mile antenna at right angles, under the supervision of Professors Myron Swarm, Donald K. Reynolds, Irene Peden, Ward Helms and staff member John Schulz. Dr. Peden was the first female faculty member of the Department, joining in 1961 (See EEK2003, page 4).

In 1965, Professors Helmut Golde of Electrical Engineering, Robert Ritchie of Mathematics and Theodore Kehl of Physiology organized a "Computer Science Committee." This grew into a "Computer Science Group" that was authorized by the Board of Regents to grant the M.S. and Ph.D. degrees in 1967. Dr. Jerre Noe was appointed as the CS Group's chair.

Until the mid-1970s, the Department was focused, for the most part, on regional undergraduate educational activity. In the late 1970s and early 1980s, the research programs of the Department achieved an increasing measure of national visibility and recognition, and the graduate program grew to become a larger portion of departmental activity.

Our current EE building was put into service in February 1998. Since July 1998 the Department has experienced a period of dramatic growth and positive change.



30-Year Duisburg-Seattle Connection

In the mid-1960s Gerhard Kriechbaum, a Boeing engineer, earned his Ph.D. degree under EE Professor Endrik Noges. His dissertation concerned the sub-optimal control of nonlinear systems. Kriechbaum had a "high school" (Heidelberg Gymnasium) classmate, Paul M. Frank, who had earned his Dr.-Ing. Degree in automatic control at the Universität Karlsruhe and became a faculty member there. Noges had attended the Universität Karlsruhe in Germany at the close of World War II.

MEDALLION RECEIVED BY FORMER CHAIR, HOWARD CHIZECK, DURING A 1998 VISIT TO DUISBURG TO GIVE THE SEATTLE-DUISBURG LECTURE.

Contributions to this article were made by: Robert N. Clark.

Through this connection, Dr. Frank invited Professor Noges to spend the 1972-73 academic year as Guest Professor in Karlsruhe to cooperate in research on pulse frequency modulated control systems. As a result, Noges and Frank wrote a book, *Pulsfrequenzmodulierte Regelungssystem,* which was published in 1975 by R. Oldenbourg Verlag. This began a 30-year collaboration.

Professor Frank moved to the Universität Duisburg in 1976, and over the years several of our EE faculty members visited Duisburg on yearlong stints and for shorter trips. Duisburg faculty visited here as well. In addition, several graduate students in Engineering from Duisburg earned master degrees at the UW. In succeeding years, many exchange visits by faculty and students occurred between the two institutions. One significant result of this collaboration was in the area of fault detection. In 1977 EE Professor R.N. Clark presented a talk on his fault detection research to a group of professors and industrial research workers at an annual meeting sponsored by the Fraunhofer Gesellschaft. In this talk, he defined unexplored avenues of investigation in fault detection methods. Eventually, Professors Frank and Clark, along with Professor Ron Patton of the University of Hull in England, edited two volumes on fault detection in which the work of some 40 authors from North America, Europe, and Asia appeared. (*Fault Diagnosis in Dynamic Systems,* Prentice Hall Int., 1989 and *Issues of Fault Diagnosis for Dynamic Systems,* Springer, 2000).

In 1994, the name of the Universität Duisburg was changed to The Gerhard Mercator Universität Duisburg in honor of the geographer who lived in Duisburg during the second half of the 16th century.

In April 2001, Professor and Mrs. Clark traveled to the Gerhard Mercator Universität Duisburg and attended the retirement ceremonies for Professor Frank, who spent 25 years as head of the Institute of Automatic Control at the Universität Duisburg. The Clark's expressed their appreciation for the exchange opportunities that faculty members and students from both universities had enjoyed for 30 years.

Trans-Pacific Undergraduate Research Collaboration

Undergraduate students from UW and the Chinese University of Hong Kong (CUHK) participated in a joint research project to develop a mobile computing system for campus navigation. The collaborating students decided to focus their research on speech interfaces (mainly at CUHK), location tracking, and navigation (mainly at UW) using a Pocket PC. The students also implemented a "Campus Navigator" Pocket PC that matched user preferences in convenience, cost, and food type to eateries on campus. During Autumn Quarter 2003, they designed the user interface, purchased hardware, and implemented a prototype system—one for UW and one for CUHK.

The students, under supervision of Professors Mari Ostendorf (UW), and Helen Meng (CUHK), collaborated with each other mainly through email and learned about the culture, discipline and time zone barriers involved with collaborative efforts, as well as the technical challenges in mobile computing.

EE student participants were Shalaka Bhuskute, Brandon Smith and Eric Work. This project was sponsored by the CUHK Budding Scholars Exchange Program, the NSF, and a grant from the EE Undergraduate Research Fund. Microsoft and Intel also supported the project with software donations.

EE Faculty

Afromowitz, Marty
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NIH Career Development Award

Allstot, David
Professor
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IEEE Fellow, IEEE Circuits & Systems Society Darlington Award, IEEE W.R.G. Baker Award

Atlas, Les
Professor
Signal and Image Processing
Ph.D., 1984 Stanford University
NSF Presidential Young Investigator
IEEE Fellow

Bilmes, Jeff
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Signal and Image Processing
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Medical Ultrasound
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Ph.D., 1985 Georgia Institute of Technology

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Ph.D., 1998 University of Illinois
NSF CAREER Award

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Communication, Wireless Networks, Control
Ph.D., 2002 University of Michigan
NSF CAREER Award

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Ph.D., 1982 University of Wisconsin
IEEE Fellow, IEEE/EMBS Early Career Achievement Award

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Multilingual Speech Processing, Machine Learning
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NSF Presidential Young Investigator Award
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Lin, Lih
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Power Systems
Ph.D., 1983 UC- Berkeley
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Liu, Hui
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Ph.D., 1985 University of Texas, Austin
NSF CAREER Award, ONR Young Investigator

Mamishev, Alex
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Ph.D., 1999 MIT
NSF CAREER Award

McMurchie, Larry
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Ph.D., 1977 University of Washington

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Ostendorf, Mari
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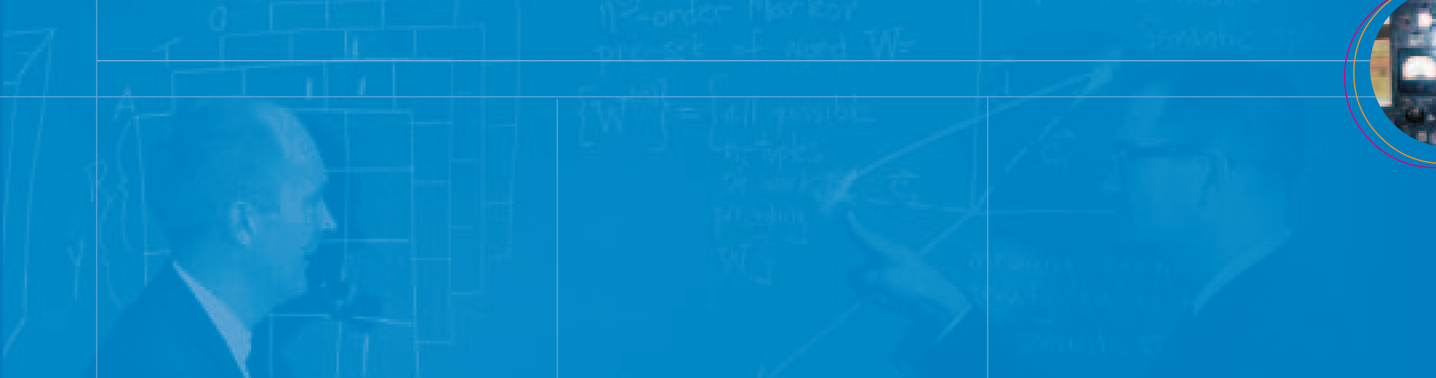
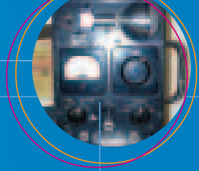
Ph.D., 1985 Stanford University

Parviz, Babak
Assistant Professor
Microelectromechanical Systems (MEMS)
Ph.D., 2001 University of Michigan





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Communications Networks and Security
Ph.D., 1999 University of Maryland
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Riskin, Eve
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IEEE Fellow, IAPR Fellow

Shi, C.J. Richard
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Spindel, Robert
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IEEE Fellow, ASA Fellow, MTS Fellow, A.B. Wood Medal, IEEE Oceanic Engineering Society Technical Achievement Award

Strunz, Kai
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Ph.D., 1983 UC-San Diego

Tsang, Leung
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Ph.D., 1976 MIT
IEEE Fellow, OSA Fellow

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Ph.D., 1995 Georgia Institute of Technology
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Winebrenner, Dale
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Ph.D., 1985 University of Washington

Yee, Sinclair
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Ph.D., 1965 UC - Berkeley
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Zick, Greg
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Ph.D., 1974 University of Michigan

EMERITI

Albrecht, Robert
Controls and Robotics
Ph.D., 1961 University of Michigan

Alexandro, Frank
Controls and Robotics
Ph.D., 1961 University of Michigan

Andersen, Jonny
Circuits and Sensors
Ph.D., 1965 MIT

Bjorkstam, John L.
Controls and Robotics
Ph.D., 1958 University of Washington

Clark, Robert N.
Ph.D., 1969 Stanford University
IEEE Fellow

Dow, Daniel G.
Ph.D., 1958 Stanford University

Guilford, Edward C.
Ph.D., 1960 UC-Berkeley

Haralick, Robert
Signal and Image Processing
Ph.D., 1969 University of Kansas
IEEE Fellow

Hsu, Chih-Chi
Ph.D., 1957 Ohio State University

Ishimaru, Akira
Electromagnetics and Waves in Random Media
Ph.D., 1958 University of Washington
IEEE Fellow, OSA Fellow, IOP Fellow, IEEE Heinrich Hertz Medal, URSI John Dillinger Medal and Member, National Academy of Engineering

Jackson, Darrell
Ph.D., 1977 California Institute of Technology

Johnson, David L.
Ph.D., 1955 Purdue University

Lauritzen, Peter O.
Ph.D., 1961 Stanford University

Lewis, Laurel
Ph.D., 1947 Stanford Unversity

Moritz, William E.
Ph.D., 1969 Stanford University

Noges, Endrik
Ph.D., 1959 Northwestern University

Peden, Irene
Ph.D., 1962 Stanford University
NSF "Engineer of the Year" Member, National Academy of Engineering, IEEE Fellow, IEEE Harden Pratt Award, U.S. Army Outstanding Civilian Service Medal

Porter, Robert B.
Ph.D., 1970 Northeastern University
ASA Fellow, OSA Fellow

Potter, William
MSEE, 1959 US Naval Postgraduate School

Redeker, Charles C.
Ph.D., 1964 University of Washington

Sigelmann, Rubens A.
Ph.D., 1963 University of Washington

Congratulations to Dan Dailey and Dale Winebrenner who were recently promoted to Research Professors, and to Karl Böhringer who was promoted to Associate Professor.

We apologize for any errors, omissions or misspellings in 2004 EEK. We would like to extend special appreciation to the faculty and staff who assisted in producing this publication and to the sponsors whose generosity made it possible.

PICTURED IN BACKGROUND AT TOP PROFESSOR EMERITUS DAVID JOHNSON AND THE LATE PROFESSOR EMERITUS DEAN LYTLE.
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New Tenure Track Faculty

Maya Gupta joined the University of Washington's Department of Electrical Engineering faculty in Autumn 2003. Her Ph.D. and M.S. in electrical engineering were completed at Stanford University in the Classification and Compression Group. Her doctoral thesis proposed innovative ideas for nonparametric classification and estimation. From 2000-2003, she was a researcher in the Color Image Processing Group of Ricoh's California Research Center where she focused on improving methods for printing color images. Prior to graduate school, she worked as an R&D engineer for Hewlett Packard's Optical Communications Division. She has also worked with Microsoft, AT&T Labs, NATO, and a now-defunct dot-com that attempted to optimize golf tee-time usage internationally.

Eric Klavins also joined UW EE as an assistant professor in Autumn 2003. He received both Ph.D. and M.S. degrees from the University of Michigan department of Computer Science and Engineering in 2001 and 1998, respectively. While a graduate student, Eric worked on control synthesis for automated manufacturing systems and on gait regulation and software systems for dynamic multi-legged robots. From 2001 to 2003, he was a postdoctoral scholar at the California Institute of Technology where he developed algorithms and models of multi-vehicle systems. In all of his research, Klavins has combined his expertise in computer science (distributed algorithms, logic, and specification) and control and robotic systems to generate novel solutions to large-scale, decentralized control problems. His current interests include self-organizing systems, cooperative control, specification and programming languages, and dynamical systems.

Babak Parviz joined the faculty of the Electrical Engineering Department in Autumn 2003. He received his graduate degrees from the University of Michigan, Ann Arbor. During his graduate studies, he developed microfabrication technologies for distributed micro-propulsion and micro-flight, high frequency distributed electrostatic micro-actuators, fluid flow in nano and micro scale, a range of problems regarding physics, scaling, and modeling of nano and micro systems. From 2000 to 2001, he worked at Nanovation Technologies, Inc., as a device designer and a product manager on MEMS-based integrated photonics systems. He joined the Department of Chemistry and Chemical Biology at Harvard University as a postdoctoral research fellow in 2001. He has been involved in a number of research projects at Harvard dealing with molecular electronics, nanofabrication, self-assembled molecular monolayers, printable organic memories, patterning of living cells on surfaces, biosensors, and self-assembling circuits.

Dr. Lih Lin Joins the Ranks of the TR100

In October 2003, Associate Professor **Lih Lin** was selected as one of the MIT Technology Review's TR100, a list of the 100 most exciting young innovators "whose work will utterly transform our world in the years to come." Recipients of this prestigious honor are selected from areas such as computing, biotechnology and medicine, the Internet, and nanotechnology. Dr. Lin was selected for her work on pivoting micromirrors, which have increased the speed of many telecommunications devices.

These miniscule mirrors can pivot and directly convert light-wave signals to electronic bits, unlike the slow and expensive method of having traditional electronic circuitry manipulate the conversion. With these micromirrors, telecommunications networks are fast becoming all-optical, which will change the face and speed of the Internet.

Dr. Lin's research has produced 16 patents and over 100 published papers so far. She "plans to apply her knowledge of photonics and micromechanics to biotechnology to devise new kinds of imaging tools that can analyze individual cells."

22 IEEE Fellows

Congratulations to our new IEEE fellows:

Les Atlas
For contributions to timevarying spectral analysis and acoustical signal processing.

Denice Denton
For leadership in engineering education and faculty mentoring.

Evan Goldstein
For contributions to optical communications.

Yasuo Kuga
For contributions to backscattering enhancement and imaging in geophysical sensing.

This brings the total of IEEE Fellows in the Department to 22.

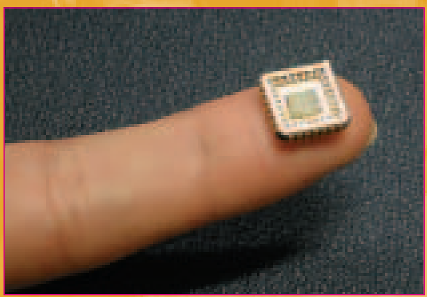
Transitions

On September 15th 2003, Professor **Howard Chizeck** stepped out of the role of department Chair and back into that of Professor. Chizeck's "contributions have been recognized both on campus and nationally as evidenced by the increase in national rankings," according to the UW College of Engineering Dean, Denice Denton. Over the past five years, the EE Department has experienced tremendous growth in research funding (from $5.0M in 1998-1999, to more than $20M in both 2001-2002 and 2002-2003), educational quality, and national stature. The number of female tenure track faculty in the department now stands at nine, which is one of the highest percentages of women faculty in the country (20%). "Thanks to everyone for your efforts, advice and support of my leadership. The achievements of the department during the past five years speak for themselves. We should be proud of what we have accomplished together," said Chizeck.

Professor **Bruce Darling** is serving as Acting Chair of the department. A national search is underway for a new department Chair.

ACTING CHAIR BRUCE DARLING (LEFT) AND FORMER CHAIR HOWARD CHIZECK (RIGHT).

Nanoscience



PACKAGED CHIP CONTAINING CONNECTED NANO-JUNCTIONS. EACH JUNCTION CARRIES A SELF-ASSEMBLED MOLECULAR MONOLAYER IN THE ACTIVE REGION.

PICTURED IN BACKGROUND PROFESSOR EMERITUS AKIRA ISHIMARU.
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The University of Washington is one of 13 major research universities comprising the National Nanotechnology Infrastructure Network, or NNIN, an integrated nationwide system that will support research and education in nanoscale science, engineering and technology. This $70 million federal grant from the National Science Foundation forms the world's largest network dedicated to studying science on the smallest of scales. The network is led by Cornell University. In addition to the UW and Cornell, members of the network are the Georgia Institute of Technology, Harvard University, Howard University, North Carolina State University, Pennsylvania State University, Stanford University, the University of California at Santa Barbara, the University of Michigan, the University of Minnesota, the University of New Mexico and the University of Texas at Austin. The network is intended to provide scientists around the country access to leading-edge tools and instruments, and help create a workforce skilled in nanotechnology and the latest laboratory techniques.

Each site involved in the network has a specific task that complements the rest of the organization. UW's key role will be to explore and build the interface between nanoscience and biomedicine. UW will receive approximately $5 million for this effort, according to Viola Vogel, director of the UW Center for Nanotechnology. Electrical Enginering faculty who are affiliated with the UW Center for Nanotechnology include Karl Böhringer, Howard Chizeck, Bruce Darling, Scott Dunham, Deirdre Meldrum and Babak Parviz. The EE Department offers a doctoral degree track resulting in a "PhD in Electrical Engineering and Nanotechnology."

STEVEN'S ROAD-BENTON LANE ENTRANCE TO THE MICROSOFT ATRIUM AND THE NEW PAUL ALLEN CENTER (LEFT) AND EE BUILDING (RIGHT). THE SECOND AND THIRD FLOOR WINDOWS AND MOST OF THE BRICKWORK ON THIS EASTERN END OF THE EE BUILDING WERE FINISHED, AS PART OF THE CONSTRUCTION. Photo by Lara Swimmer Photography.

At the Midpoint: 1904-2104

Our Department is now beginning the celebration of its centennial. It is customary at such occasions to look back profoundly at the past, to describe the present and to boldly predict the future. This issue of EEK describes some of the history of EE at UW and contains a description of many of our research activities.

THE EE LABORATORY IN THE OLD ENGINEERING HALL.

As for predicting the future—the reader is invited to first examine the listing on the inside covers of "important" events of the past century or so. The technological, scientific and commercial milestones that are listed have occurred since the first EE students began at UW. Most are of importance to EE, to technologies that have been blended into EE (such as color photography and photonics), and to fields that many believe will be of increasing importance to EE.

It is interesting to note that some innovations (fax 1902, hypertext 1945) took decades to develop to importance, while others were swiftly followed by mass distribution and commercial success. Some patterns appear. A constant theme of the last century is the development of communication and information technology. Another is the driving force of innovations for health care (for example, the first commercial transistorized and microprocessor devices were both hearing aids). A third subplot is the technological impetus of warfare. One thing is clear—it would have been very hard to predict the technological aspects of 2004 in 1904.

From 1998-2003, 25 faculty have joined our Department. Most work in research areas of perceived future innovations—including EE aspects of nanotechnology, genomics, photonics, human/machine interaction, network security and self-assembly. As a Department in a research university, our role is to help create the technological future and to prepare our students for it.

So what about 2104? Assuming that we are smart enough and lucky enough to avoid destruction from war, disease, environmental collapse or the errant asteroid, here are predictions for the next century:

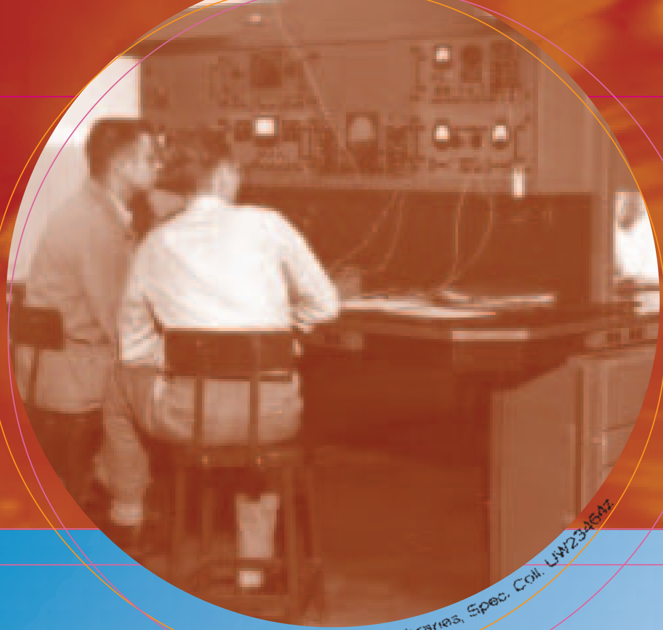
- Everything will be connected. Hardware, software and wetware will be developed so that our appliances, houses, furniture, and our brains might become part of a vast global (or larger) network—complete with instant communication, access to information, pesky advertisements and viruses. Autonomously intelligent devices will be participants in this developing culture.
- Electronics, photonics and biology will mix. This will be a consequence of the transition from nanoscience to nanoengineering, as scientific advances in biology lead to tools and mathematics for biological design engineering, and as new physics and quantum technologies develop.
- The end of disease and aging. Controlled modification and redesign of gene and protein expression will make possible the end of most forms of disease, allow for repair and regeneration from most injuries, and allow for unlimited lifespans. The availability and use of these technologies will be major social and political issues of the next few decades.

These technological changes, entwined with the political and economic realities of globalization, environmental challenges, constraints on resources, and issues related to population size will require fundamental changes in our political, economic and social structures.

To any and all who might read this a century hence—may I offer our greetings, best wishes, apologies, and hope for a bright and peaceful future.

— ***Howard Jay Chizeck***
February 2004

Photo by Leo Lam.



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