Biomimetic MicroElectronic Systems Research Center (BMES)

University of Southern California

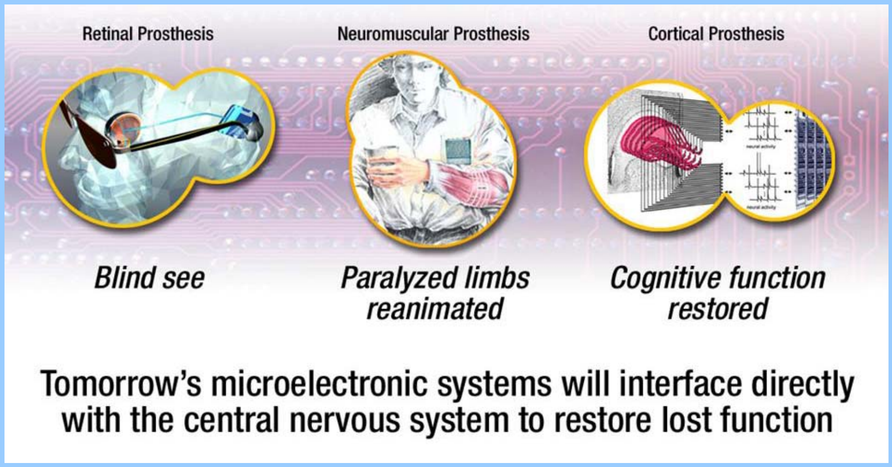
Restoring neural function through Biomimetic MicroElectronic Systems

A National Science Foundation Engineering Research Center since 2003

Partner Institutions:

- *California Institute of Technology*
- *University of California—Santa Cruz*

Our vision is to develop the science and engineering of novel biomimetic microelectronic systems (BMES) based on fundamental principles of biology. The newly developed systems allow bi-directional communication with tissue and by doing so enable implantable/portable microelectronic devices to treat presently incurable human diseases, such as blindness, paralysis, and memory loss. The Center's vision will be realized by first synthesizing engineered system specifications from medical, scientific, and engineering disciplines and then attacking the development process through an aggressive deployment of the latest microelectronic and microsystems technology. The coordinated efforts of multidisciplinary research groups at the University of Southern California, California Institute of Technology, and the University of California at Santa Cruz will yield devices for treatment of blindness, paralysis, and memory loss—areas in which the group collectively has more experience than any other consortium. The potential benefit to society comes not only from alleviating human suffering, but also through reducing the government resources now directed to assist people with disabilities. Even if only 20,000 blind patients were helped for 20 years, an estimated 4 billion federal dollars would be saved. Through community outreach and curriculum development, the BMES ERC will involve students from grade school to graduate school in a living, teaching laboratory that integrates research and education across medicine, biology, and engineering.



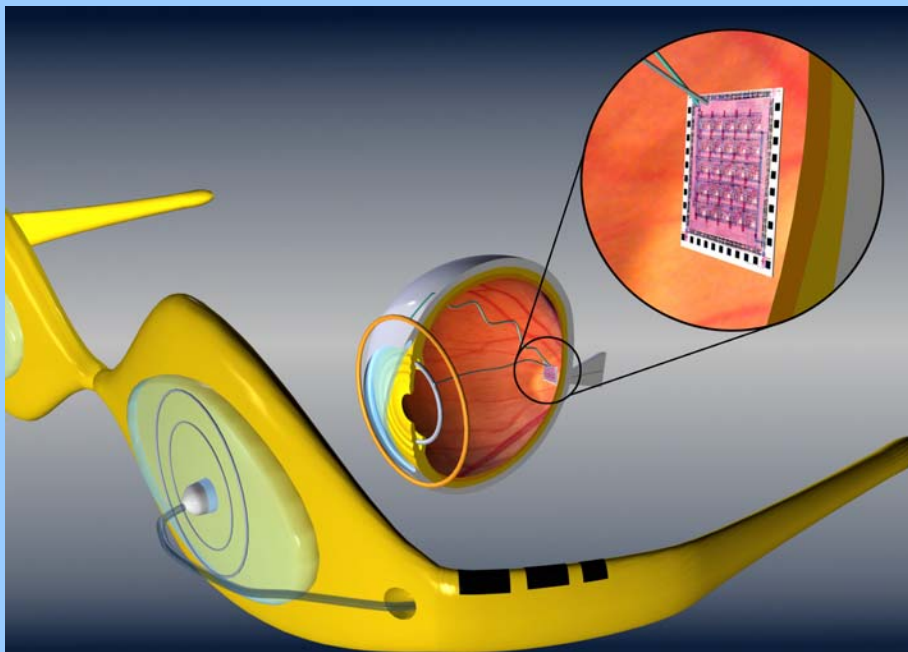
Research

One of the keys to developing and testing the engineered systems is the emphasis on multidisciplinary teams to develop system requirements. These teams are formed of faculty, students, and staff from the schools of medicine and engineering. The teams start with an assessment of the needs of patients and clinicians and the constraints imposed by biology and technology, the first steps in what the FDA mandates as a Design History process for new medical devices. This provides direction for the selection and development of technology and the design of critical scientific experiments. The educational program draws on these carefully selected ERC projects that meld medicine, engineering, biology, and industry, resulting in unique interdisciplinary training opportunities.

The BMES concentrates on three thrust areas of enabling technology that are biologically inspired and are at the core of immediate and long-term interest to the rapidly growing medical device and diagnostic industry.

Thrust #1: Mixed-Signal Systems on Chip (SoC). A new class of SoC based on the architecture of living neural systems are being developed to efficiently communicate with neurons. For example, biological signals are often lost in a sea of background noise. The fully integrated SoC will have multi-channel analog circuitry to detect and amplify weak biological signals and digital logic to rapidly process the ensemble recordings. By combining novel analog amplifier design with biologically inspired digital processing, the SoC will extract information from data with low signal-to-noise ratios characteristic of many biological signals. Similar circuits are directly applicable to the design of artificial proprioceptors for neuromuscular control. Biologically inspired image processing also will be investigated as a means to perform real-time image processing for retinal prosthesis.

Thrust #2: Power & Data Management. Efficient use of transmitted power will be achieved by implementing a dual-band hybrid power and data link and intelligent analog circuits to regulate power usage based on demand. Because biological tissue is extremely sensitive to increases in temperature, it is critical to balance the competing needs of high performance vs. low power operation. To permit high-bandwidth telemetry at low power, a two-band wireless link will be developed: a higher-frequency link to transmit large amounts of data and a lower-frequency link at which inductive coupling is more efficient to supply adequate power. A second approach will be to use biomotion and innovative thin-film Teflon electret technology to convert power from muscle and eye movement.



An intraocular retinal prosthesis is a microelectronic system that creates a sense of vision by electrically stimulating the retina. A camera/image processor in glasses captures a video, processes the video, and transmits the information in real-time to the implanted system in the eye. The implant receives the data, decodes the information, and sends a stimulus pattern to the electrode array positioned on the retina. By applying an appropriate pattern of stimulus, artificial vision can be created.

Thrust #3: Interface Technology. Micro and nano technology (e.g., microelectromechanical systems [MEMS] and nanoelectromechanical systems [NEMS]) will be used to integrate microelectronic systems to neurons. Foreign material and implants often provoke a severe inflammatory reaction followed by cell death. Surface modification techniques will be developed to substantially lengthen the viability of recording electrodes. Self-assembled, nanoscale molecular patterns on the implant surface will serve to improve integration with tissue and to sense biochemical signals. To communicate with the target neurons, penetrating ceramic electrodes for the hippocampus and non-penetrating Parylene polymer electrodes for the retina will be integrated with the engineered systems. Novel hermetic packaging schemes to produce water-tight barrier coatings will also be developed. Microns-thick coatings of pin-hole free aluminum/zirconium, as well as novel micro and nanochannel wire feed-throughs are two approaches that will be further developed.

Education

The BMES ERC goals for developing educational programs mirror the approach we are taking to realize our overall vision. By creating and implementing a collaborative system of mentoring and by integrating Science, Technology, Engineering, and Math (STEM) topics in curricula at the K-12 level, as well as through curriculum development in innovative disciplines that promote research interest at the undergraduate as well as graduate levels, we intend to have a genuine impact on new generations of students, scholars, and ultimately the future STEM workforce. Through our extensive community outreach and educational paradigm, the BMES ERC involves students from grade school to graduate school and medical school in a living teaching laboratory, integrating research and education across the many disciplines in medicine, biology, and engineering that must converge for our work to be successful. Through close collaborations with organizations and foundations we will build bridges from our institutions to our communities. One such alliance already exists between USC/Doheny Eye Institute and the Braille Institute in Los Angeles, where seminars are held for disabled patients and their relatives/friends to inform them about emerging technologies and help BMES researchers to better understand their needs. And by utilizing valuable resources such as supplemental NSF funding in the form of REUs, RETs, and the GK-12, we will commit to creating frameworks and establishing programs that will augment the impact of our mission. Our commitment to a *culture of connectivity*, which includes the multi-institutional BMES ERC, our partner institutions, K-12 schools, and communities, will, by collaborative design, reflect the diversity of our society—and, we hope, diversify the STEM workforce and shift societal mindsets in the process.

Industrial Collaboration and Technology Transfer

The BMES ERC Industrial Relations Office is forming strategic partnerships with industry, recruiting and signing a broad range of key companies as Senior and Technology Level members. This ERC will serve the rapidly growing medical device industry. We intend to foster a climate of close cooperation with our Industry Partners and BMES partner institutions, especially between ERC researchers and relevant industry representatives, which will lead to the successful transfer of intellectual property and technology commercialization. To this end we have identified directed research projects with two charter Industry Partners, with the intention that results will produce commercially valuable technologies for public benefit. Further, the A.E. Mann Institute (AMI) for Biomedical Engineering at USC provides unique resources committed to facilitating the development and commercialization of medical products from the ideas of academic researchers. These resources, such as accelerated life testing and guidance in addressing FDA regulatory issues, are critical to taking a new device from the lab to the patient. The BMES ERC will use AMI resources and expertise as necessary in transitioning technologies to many different types of industries.

Facilities

The Doheny Eye Institute at the University of Southern California is the home institute of the ERC Director and provides significant infrastructure and laboratory resources to the ERC. The ERC currently has a suite of offices (at Doheny Eye Institute) for administrative personnel and sufficient space within the existing laboratories of the investigators to accomplish the immediate research goals. In the first three years of this ERC, significant new shared lab space will be made available at all three partner institutes. At the Doheny Eye Institute, 10,000 sq. ft. of space on the first floor of the Doheny Vision Research Center will be available for ERC administrative and laboratory space. At the USC University Park Campus, the basement and fifth floor of the Tudor building will be dedicated to ERC core facilities. At Caltech, more than 7,000 sq. ft. of lab space, including the MEMS clean room (3,000 sq. ft.), electromechanical lab (500 sq. ft.), nano/micro metrology lab (500 sq. ft.), and microfluidics lab (500 sq. ft.), will be available to the Center. At UC Santa Cruz, 400 sq. ft. of laboratory space will be for optoelectronic device characterization and a 600 sq. ft. class-10K cleanroom for processing of semiconductor devices. The BMES ERC is using video conferencing between the two USC campuses, Caltech, and UCSC.

Center Configuration, Leadership, Team Structure

The three partner institutions have complementary roles and experience in the execution of the BMES vision and strategic plan. USC, as the lead institution, brings world leadership in implantable microsystems, Caltech brings unique technical expertise in interface technologies and image processing, and UCSC brings decades of expertise in microelectronic design and fabrication. The team members at all three institutions have ongoing projects and significant effort in all three testbed and thrust areas.

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