BIOGRAPHICAL SKETCH

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NAME: Kim, Eun S.

eRA COMMONS USER NAME (credential, e.g., agency login): eskim06

POSITION TITLE: Professor, Department of Electrical and Computer Engineering

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Univ. of California, Berkeley, CA	B.S.	06/1982	EECS
Univ. of California, Berkeley, CA	M.S.	05/1987	EECS
Univ. of California, Berkeley, CA	Ph.D.	12/1990	EECS

A. Personal Statement

One goal of my research is to evaluate the feasibility of developing a miniature cancer treatment system based on an ultrasonic transducer capable of producing focused-acoustic beam precisely and controllably. I have the expertise and experience to lead the research into a major success. I have actively been engaged in MEMS research and development from a few years before the major outbreak of MEMS field, and have been able to contribute to the field as an early pioneer. My research accomplishments can be highlighted as follows: (1) the integration of MEMS technology with high quality-factor film bulk-acoustic resonator (FBAR) for chembio sensing, (2) the first demonstration of an integrated microphone with CMOS circuits on a single silicon chip, and (3) the invention and implementation of micromachined Self Focusing Acoustic Transducers (SFATs) for liquid droplet-ejection, mixing, pumping and transporting. My cancer-related research builds on my prior works on SFAT-based droplet ejection and MEMS fabrication technology, and I am highly motivated to apply them to selective cytolysis for treating cancerous cells without damaging nearby benign cells. In summary, I have continuously led successful and productive research projects on MEMS technology and its applications, and my expertise and experience on SFAT related projects have well prepared me to lead the research.

<u>Ongoing Research Support</u>

NSF DBI-2129856 Kim (PI) 2/22 - 1/26
The major goal of this project is to advance the transducer technology based on focused bulk acoustic waves for cell sorting and manipulation in microfluidic systems.
Role: PI

NSF ECCS 2017926 Kim (PI) 9/20 – 8/23
The major goal of this project is to explore acoustic propulsion for microrobots in liquid and air, so that microrobots may be able to navigate to destination without mechanical engine or propeller, driven only with electrical signal and power.
Role: PI

NIH 1R01GM134352 Kim (PI) 9/19 – 8/23
The major goal of this project is to develop Fresnel-lens-based ultrasonic tweezers that can capture and manipulate living tissue in three dimensional (3D) space *on demand*, very much like optical tweezers but with several orders of magnitude stronger mechanical trapping force for a given temperature rise.
Role: PI

NIH 1R01 EB026284 Kim (PI) 7/18 – 3/22

The major goal of this project is to (1) study the underlying cellular and molecular mechanisms of ultrasound neuromodulation using a patch clamp electrophysiology technique and (2) develop a neuromodulation technology based on focused ultrasonic waves.
Role: PI

NSF ECCS-1911369 Kim (PI) 7/19 - 6/22
The major goal of this project is to explore various Microelectromechanical Systems (MEMS) approaches to efficiently generate power from vibration energy associated with human's walking motion without loading or affecting the wearer of the power generator (with a total mass and volume of <1 gram and <1 cc, respectively).
Role: PI

DoD CDMRP W81XWH-17-1-0538 Kim (PI) 9/17 - 9/22
The major goal of this project is to explore the feasibility of controlling the contractions of the bladder and external urethral sphincter muscles by stimulating the sacral spinal cord with our novel MEMS-based Self Focusing Acoustic Transducer (SFAT).
Role: PI

Completed Research Support
NIH 1R21 DC016468 Kim (PI) 5/18 – 4/21
The major goal of this project is to lay a foundation for a low-cost, low-power-consuming, active-noise-cancelling technology for hearing aids, using MEMS resonant-microphones and microspeaker, so that the wearers of the hearing aids will hear speech clearly without being hampered by undesirable sounds and noises.
Role: PI

NSF CNS-1716953 Kim (PI) 8/17 - 7/21
The major goal of this project is to explore the feasibility of a submillimeter-sized, battery-less, tamper detecting chip that can be placed inside a semiconductor package through a droplet ejector and that can be wirelessly interrogated (for any recorded tampering activity) from the outside of the semiconductor package.
Role: PI

NIH 1R21EB022932 Kim and Gross (multi-PIs) 9/16 - 7/18.
The major goal of this project is to study selective cancer treatment based on high frequency ultrasonic beam.
Role: Contact PI

B. Positions, Scientific Appointments, and Honors

Professional Appointments:

1981	College Student Engineer, IBM Research Lab., San Jose, CA.
1982 - 83	Associate Engineer-Design, NCR Corp., San Diego, CA.
1983 - 84	Teaching Assistant, University of California, Berkeley, CA.
1984	CMOS Device Engineer, Xicor, Inc., Milpitas, CA.
1984 - 90	Research Assistant, University of California, Berkeley, CA.
1991 - 95	Assistant Professor, University of Hawaii at Manoa, Honolulu, HI.
1995 - 99	Associate Professor, University of Hawaii at Manoa, Honolulu, HI.
1999 - 2006	Associate Professor, University of Southern California, Los Angeles, CA.
2009 - 2018	Chair, Department of Electrical and Computer Engineering-Electrophysics, University of Southern California, Los Angeles, CA.
2006 - Present	Professor, University of Southern California, Los Angeles, CA.

Honors/Awards:
B.S. with High Honors, 1982
Research Initiation Award from National Science Foundation, 1991
Faculty Early Career Development (CAREER) Award from National Science Foundation (NSF), 1995
Outstanding EE Faculty of the Year Award (voted by UH IEEE student chapter), 1996

IEEE Transactions on Automation Science and Engineering 2006 Best New Application Paper Award on “In-situ DNA Synthesis on Glass Substrate for Microarray Fabrication Using Self-Focusing Acoustic Transducer,” by J.W. Kwon, S. Kamal-Bahl and E.S. Kim, April 2006, pp. 152-158.

<u>Other Experience and Professional Memberships:</u>

1995 - Editorial Board for Journal of Micromechanics and Microengineering
1996 - Fellow of the Institute of Physics (IOP)
2000 - Editor for Journal of Semiconductor Technology and Science
2006 - 11 Associate Editor of IEEE Transactions on Automation Science and Engineering
2011 - Editor for IEEE/ASME Journal of Microelectromechanical Systems
2011 - Fellow of IEEE

C. Contributions to Science (through more than 250 peer-reviewed publications, 16 issued patents, a textbook entitled “Fundamentals of MEMS,” and a new course development on Wearable Technology)

My research has focused on the creative use of piezoelectric thin films and substrates for innovative acoustic devices. The challenge of using piezoelectric films is multi-faceted: ranging from the need for tight control of the deposition conditions to achieve the required film texture and orientation, to the need to couple the piezoelectric film with a micromechanical element to accomplish required transducer response. I and my students focused on this promising branch of MEMS for many years, before its recent burst of popularity. Two seminal contributions made by me can be highlighted as follows: (1) The inventions of micromachined self-focusing acoustic transducers (SFAT) and their applications to acoustic tweezing, liquid-droplet ejection, micromixing, liquid pumping and transporting, and underwater propulsion, and (2) The integration of MEMS technology with film bulk-acoustic resonators (FBAR) for high quality (Q) resonance, electrical tunability and temperature stability and for biochemical-mass sensing in vapor and liquid environments. In addition to the two contributions, I have also made major contributions to MEMS microphone and microspeaker. Each of these transducers is actuated by a piezoelectric (either in the substrate or in an adherent film), and each is inherently fast, consumes little power, and operates without heating.

1. My PhD thesis in 1990 was on ground-breaking MEMS microphone integrated with CMOS large-scale integrated circuits on a single silicon chip. Since my PhD, I have continuously contributed to acoustic MEMS including microphone and microspeaker. The first two publications below describe piezoelectric resonant microphones built on micromachined silicon diaphragms, while the next two report microspeakers microfabricated with piezoelectric thin film on silicon substrate and piezoelectric PZT (lead zirconate titanate) substrate. The largest sound pressure level obtained by a microspeaker fabricated in my group was 92 dB (when measured 2 mm away from the microspeaker in open field) for 6 $V_{peak\text{-}to\text{-}peak}$ input.
    1. H. Liu, S. Liu and E.S. Kim, “Multi-Band MEMS Resonant Microphone Array for Continuous Lung-Sound Monitoring and Classification,” The 33rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2020), Vancouver, Canada, January 18-22, 2020, pp. 857 – 860. Outstanding Student Paper Award Nominee.
    2. A. Shkel and E.S. Kim, “Continuous Health Monitoring with Resonant-Microphone-Array-Based Wearable Stethoscope,” IEEE Sensors Journal, vol. 19, no. 12, pp. 4629-4638, 2019.
    3. L. Baumgartel, A. Vafanejad, S.-J. Chen, and E.S. Kim, “Resonance Enhanced Piezoelectric Microphone Array for Broadband or Pre-filtered Acoustic Sensing,” IEEE/ASME Journal of Microelectromechanical Systems, vol. 22, pp. 107-114, 2013.
    4. S.H. Yi and E.S. Kim, "Piezoelectric Micro-speaker with Compressive Nitride Diaphragm," IEEE International Micro Electro Mechanical Systems Conference, Las Vegas, Nevada, January 20-24, 2002, pp. 260-263.

2. One of my key inventions, self-focusing acoustic transducer (SFAT), is capable of ejecting nano-liter liquid droplets in a direction oblique to the liquid surface, with the direction electrically controllable. My group integrated four SFAT-based directional ejectors as an array to target one spot (over a glass substrate) with four different liquids, without mechanical movement, for DNA synthesis and also for oil-encapsulated microreaction chambers for parallel and combinatory analysis. The directional ejections were so precise that the ejected droplets (all four of them) were shown to meet and merge in the air. This is remarkable, since with the distance of 2mm between two adjacent ejectors and the droplet sizes of 80μm in diameter, the droplets must have a same ejection speed and precise directionality, in order to meet in a three-dimensional space.

Also, my group incorporated additional features to the SFAT (1) to produce a jet steam (14 mm long and 0.4 mm in diameter) of atomized liquid droplets or (2) to generate a thrust force (with 19:1 thrust-force to weight ratio) that moved the SFAT (along with any object attached to it) in liquid. The former was for generation of directed aerosol without any volatile organic compounds, while the latter was for propulsion of a microdevice in liquid environment. Recently, we reported a study showing that highly-focused ultrasound delivered at a low intensity of 0.33 W/cm^2 at 18 MHz (Mechanical Index = 0.0055, about 50 times smaller than those used in other published studies on ultrasound's bioeffects on living cells and tissues) lysed cancerous cells at the focal point without discernable effects on normal cells. This study (performed on monolayer cells) indicated that a less organized actin cytoskeletal pattern, known to be associated with decreased cell stiffness, would correlate with changes in the acoustic-intensity threshold for cell lysis.

1. Y. Tang, L.-Y. Chen, A. Zhang, C.-P. Liao, M.E. Gross, and E.S. Kim, "In Vivo Non-Thermal, Selective Cancer Treatment with High-Frequency Medium-Intensity Focused Ultrasound," IEEE Access, vol. 9, pp. 122051-122066, 2021.
2. L. Wang, Y.-J. Li, A. Lin, Y. Choe, M.E. Gross, and E.S. Kim, "A Self Focusing Acoustic Transducer that Exploits Cytoskeletal Differences for Selective Cytolysis of Cancer Cells," IEEE/ASME Journal of Microelectromechanical Systems, vol. 22, no 3, pp. 542-552, 2013.
3. C. Lee, S. Kamal-Bahl, H. Yu, J.W. Kwon and E.S. Kim, "On-Demand DNA Synthesis on Solid Surface by Four Directional Ejectors on a Chip," IEEE/ASME Journal of Microelectromechanical Systems, vol. 16, no. 5, pp. 1130-1139, 2007.
4. D. Huang and E.S. Kim, "Micromachined Acoustic-Wave Liquid Ejector," IEEE/ASME Journal of Microelectromechanical Systems, vol. 10, pp. 442-449, September 2001.

3. My contributions are also in integrating MEMS and FBAR technologies to produce high Q, electrically tunable, temperature-compensated FBAR for GHz local oscillators. For example, my group showed electrical tuning and temperature stability by integrating an FBAR with an air-gap capacitor in series. Such an integrated FBAR was shown to have 1.5% electrical tunability and temperature stability of less than 1 ppm/ºC at 1 – 4 GHz**.** Furthermore, my group developed a high-overtone bulk-acoustic resonator with a Q of 19,000 at 3.6 GHz, used it to build a 3.6 GHz oscillator exhibiting Allan deviation of 1.5 x 10^{-9} at 1 second, while the oscillator consumes mere 3.2 mW. This kind of frequency stability had been unprecedented for such a high-frequency oscillator operating at room temperature with such low power consumption.

Also, my group pioneered FBAR-based highly sensitive, resonant mass sensing in vapor and liquid environment. My group developed the following FBAR-based sensors, for the first time, and demonstrated them to be highly sensitive and selective: a mercury sensor with gold-coated FBAR for detecting less than ppb level of mercury in drinking water, a DNA hybridization sensor with FBAR coated with single-strand DNA probes, an explosive-vapor-trace detector with FBAR coated with anti-TNT, and a neuron-firing sensor with an FBAR sensor on a 1.5mm long, 250μm wide and 15μm thick polymer probe.

1. H. Zhang, M.S. Marma, S. Kamal-Bahl, E.S. Kim, and C.E. McKenna, "Sequence Specific Label-Free DNA Sensing Using Film-Bulk-Acoustic-Resonators," IEEE Sensors Journal, vol. 7, no 12, pp. 1587-1588, 2007.
2. W. Pang, L. Yan, H. Zhang, H. Yu, E.S. Kim and W.C. Tang, "Femtogam Mass Sensing Platform Based on Lateral-extensional-mode (LEM) Piezoelectric Resonator," Applied Physics Letters, vol. 88, 243503, 2006.
3. H. Zhang and E.S. Kim, "Micromachined Acoustic Resonant Mass Sensor," IEEE/ASME Journal of Microelectromechanical Systems, vol. 14, no. 4, pp. 699-706, 2005.
4. W. Pang, H. Zhang, J.J. Kim, H. Yu and E.S. Kim, "High-Tone Bulk Acoustic Resonator Integrated with Surface Micromachined FBAR Filter on a Single Chip," Transducers '05, IEEE International Conference on Solid-State Sensors and Actuators (Seoul, Korea), June 5-9, 2005, pp. 2057-2060.

4. Recently I put together the fundamental knowledge on MEMS into a textbook entitled, "Fundamentals of Microelectromechanical Systems (MEMS)," which was published April 2021 by McGraw Hill. The textbook is intended for undergraduate seniors and graduate students in electrical, mechanical and biomedical engineering as well as professional engineers who want to learn MEMS technology. It is aimed to teach design, fabrication and testing of MEMS, and contains many questions and problems for the students' homework and exams for the sake of in-depth understanding of MEMS as well as problem-solving and/or design skills in MEMS analysis and design. Also, it covers some commercially-significant topics (such as radio-frequency [RF] front-end filters and oscillators, acoustic transducers, vibration energy harvesting, etc.)

that have not been covered in other MEMS textbooks. "Look inside" with the table of contents, preface, introduction, substantial part of Ch. 1, last five pages of Ch. 10, and index is available through the following site. https://www.amazon.com/Fundamentals-Microelectromechanical-Systems-MEMS-Eun/dp/1264257589

5. I have developed a new 4-unit graduate-level course on Wearable Technology, and have taught it in Fall 2021 with 17 students enrolled. As I developed the course, I saw that there was no formal course on wearable technology in the nation, nor any good textbook on it. Consequently, I had to spend substantial amount of time and effort over 1.5 years to develop the course to be useful and academically challenging. In the end, I have developed a total of 593 PowerPoint Slides along with 5 homework problem sets to teach wearable technology with focus on sensing, signal processing (analog and digital), RF communication, power sources, power management, energy harvesting, flexible substrate technology, and wearable algorithms. The following are the course's current weekly topics.

Week	**Topic**
1	Introduction to Wearable Technology (25 Slides)
2 – 4	Wearable Sensors for Acceleration, Angular Velocity, Ambient Pressure, Audio, Magnetic Field, Light, Infrared Imaging, Vapors, etc. (112 Slides)
5 - 6	Sensing Technologies (Capacitive, Piezoresistive, Piezoelectric, etc.), Flexible and Stretchable Substrate Technology, Lab on Skin, RF Communication, etc. (103 Slides)
7	Batteries, Energy Harvesting, and Power Management for Wearable Technology (40 Slides)
8 - 9	Wearable Hardware Platforms, Wearable Algorithms, Feature Extraction, Training and Classification, Minimum-Cost Action Coverage, Dimensionality Reduction, etc. (101 Slides)
10 - 12	Digital Signal Processing, Difference Equation, Convolution, Z Transform, DFT, FFT, Signal Modulation, Rules of Probability, Kalman Filter, Hidden Markov Model, etc. (136 Slides)
13 - 14	Wearable Technology for Healthcare: Heart Rate Sensing, Blood Oxygen Sensing, Electrocardiogram, Body Sensor Network, Algorithms to Mitigate Artifacts, etc. (76 Slides)

In summary, my contributions impact greatly many application areas such as microphone and microspeaker, ink jet printing of biochemical agents, micromixing in lab-on-a-chip and in midair, microfluidic pumping, underwater propulsion, selective cancer therapeutics, acoustic neuron stimulation, acoustic tweezing of living cells, low phase-noise local oscillator at GHz, highly selective and sensitive mass sensing, etc. Some of the applications are brand new and enabled by my contributions. For example, one of my former students is commercializing ultrasonic micromixers based on array of SFATs through a start-up company named Microsonic Systems.

URL to Full Publication List: http://mems.usc.edu