EDS Women In Engineering

Integrated Circuits, Nanoelectronics, Sensors Applications

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Background and Education

I was born in Cairo, Egypt, at a time during which the Royal family still ruled Egypt. My mother and father had obtained their Ph.D. degrees in chemistry from England and were Professors of Chemistry at Cairo University. They often took me with them, and I watched the long hours of hard work they both spent in the chemistry lab. I finished high school with above-average grades in 1960. I was accepted to Cairo University and chose to study electronics there. By the end of my undergraduate career, I met my husband (my classmate), and we were married soon after graduating. I traveled with my husband to Canada in 1968 and joined the Department of Electrical Engineering at the University of Waterloo as a Research Assistant. I continued my studies there and obtained my master's degree in Electrical Engineering in 1970. After my master's degree, I joined the School of Mathematics at the University of Waterloo to pursue a second master's degree, this one in Applied Mathematics and Computer Science. At that time, the University of Waterloo was a pioneer in studying computer science and programming language. I graduated with my second master's degree in 1971. Towards the end of my degree, I was offered an opportunity to pursue a Ph.D. with a professor of Electrical Engineering whose work focused on computer-aided design of nonlinear electronics and circuits. CAD tools such as SPICE were first introduced around that time for simulating and designing circuits. My thesis work focused on modeling circuits and electronics. The time that I spent working on my Ph.D. in the early 1970s was unique and exciting. This was the early Internet, and our Waterloo network, called WITS, was one of the first such networks in the world. I was awarded my Ph.D. in 1975.

I was the first woman to graduate with a Ph.D. from the School of Engineering at the University of Waterloo, Canada. I did not know this at the time. But in retrospect, I had noticed that I was often the only woman in attendance in most of my engineering courses. This was very different from my undergraduate experience. Many years later, I was awarded an Honorary Ph.D. degree in 2007 from the University of Waterloo. It is awarded an honorary Ph.D. degree in recognition that I was the first female graduate from their School of Engineering and my career and accomplishments in research and teaching.

Figure 1. Zaghloul with her students in her Research Laboratory at George Washington University

Move to the USA and early career

We moved to the United States in 1978. My husband was offered a position at COMSAT, Inc., a communications satellite company in the Washington, DC area. At our move, I had two young children – a four-year-old boy and a four-week-old girl. I moved to the DC area with my family and started looking for a job.

I was interested in working in academia because I had seen my mother and the example she had set. It wasn't easy, though, mainly because I was a woman. I did not know that female engineers were rare in the US. I met an individual early in my job search who told me, *"Ma'am, you are a woman, an engineer, and you are a foreigner (thinking I was French Canadian). Do you think you will find a job in this place? This is Washington, DC, the top of the nation."* Many of the recruiters I met told me that it was near impossible for a woman with a Ph.D. in engineering to find a job. My job search was more difficult because I had a husband and two small children and was limited in terms of the geographic area in which I could search for and accept a position.

I was eventually offered a job at the Computer Science Corporation; my first job involved programming using several programming languages I had studied and drew upon my experiences while writing code at Waterloo. Although my Ph.D. was focused on modeling and simulation electronics circuits, I accepted this initial position to work as a computer scientist while I continued my search for an academic job in my major area of expertise. I continued writing papers on my Ph.D. work and submitting them for publication during my free time. It wasn't easy, but after several attempts, I was finally offered a job as an Assistant Professor in the Department of Electrical Engineering and Computer Science (EECS) at George Washington University in Washington, DC. I was the first woman hired in the School of Engineering and Applied Science at GWU. This was a big change for many other faculty members, and many did not accept this change. The Chair of the EECS Department at the time was Professor Ray Pickholtz. He was well known in the field of communications, and he certainly believed in my ability to work and produce quality research. In addition, he knew that I could teach computer science courses in addition to courses in electrical engineering. His support during this early time was critical. I had experience developing Computer-Aided Design tools (CAD tools) for electrical circuits and developing simulations of circuits with active components. In addition, I was very familiar with circuit theory as a result of the courses I attended during my Ph.D. graduate courses.

I started my teaching position at GWU in 1980 by introducing several new courses on circuit theory, computer-aided tools for circuit simulation, and modelling linear and nonlinear circuits. I also taught optimization, graph theory, and programming courses in different languages. These changes were unique to the graduate curriculum at GW, and the courses attracted several students. At the time, my courses were introducing new knowledge in computer science, and the students were appreciative. My students were mainly from government agencies around the DC area attending evening classes.

In 1984, I applied for a position at the National Institute of Standards and Technology (NIST), which was called the National Bureau of Standards (NBS) at that time. I was hired by Dr. Ken Galloway, the head of the Semiconductor Electronic Technology Division. I applied for the position because I was interested in pursuing research and was trying to find better facilities than were available at GW. I was trying to create collaborations in the area. I was hired as a "faculty hire" to go to NIST one day a week in addition to my teaching job at GWU. The NIST job was an important step in my career. I was exposed to the best laboratories and the best

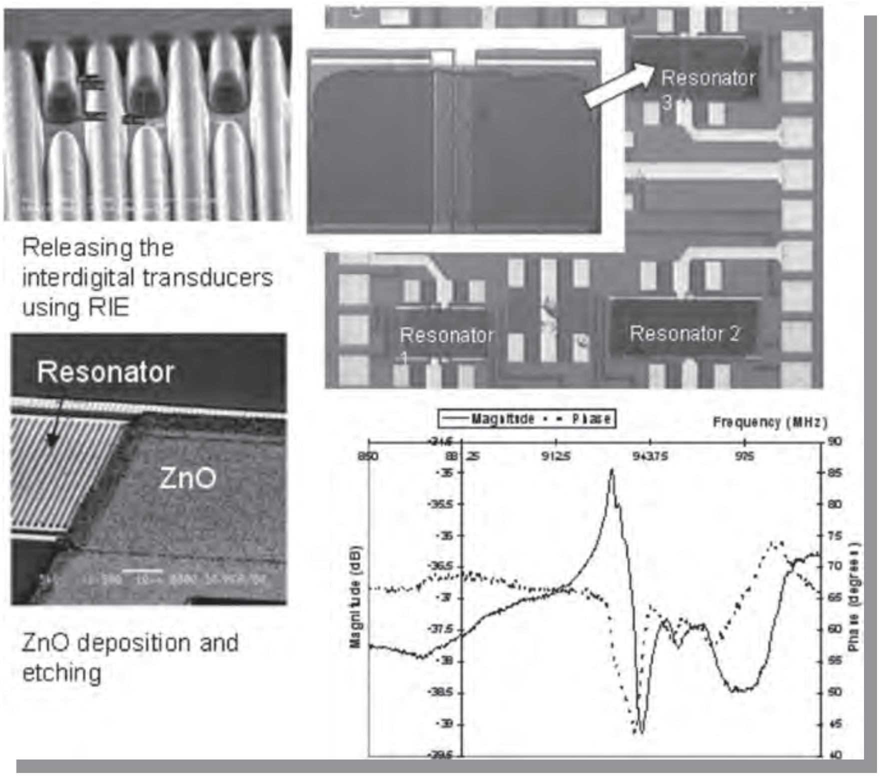

Figure 2. Surface Acoustic wave resonators which are used as Filter for Transmitter/Receiver systems. It was developed using CMOS technology with post-processing steps to obtain the resonators. Reference: Anis N. Nordin, Mona E. Zaghloul, "Modeling and fabrication of CMOS Surface Acoustic Wave Resonators"; IEEE Transactions on Microwave Theory and Techniques, Vol. 55, No.5, May 2007, pp. 992–1002.

research scientists specializing in semiconductor electronics research. I was exposed to extensive techniques for measuring and testing electronic circuits and testing electronic materials, and applying the industry standards. In addition, I learned how to fabricate devices in the cleanroom facility at NIST and the basics of chip designs. In 1984, a course was offered by MOSIS (MOS Integrated Systems was funded by the US Government) for learning the design of integrated circuit chips. The course was offered by top leading university professors at the time, and the goal of the course was to teach other university professors, and consequently their students, the art of VLSI chip design. Professor Carver Mead from the California Institute of Technology was the lead Professor. The course was offered at the MOSIS building at Marina Del Rey for two weeks. The US government set up this new initiative to motivate academic researchers to begin designing and building integrated circuit chips. I learned many things from this course. I started designing Complementary Metal Oxide Silicon (CMOS) chips for fabrication and testing. This skill was in demand in the Semiconductor Electronics Technology Division at NIST, where I worked. It was essential to design test structures to measure the performance of devices for different technologies. I collaborated with many of my colleagues in the division on these tasks. In addition, I started teaching chip design at GWU and started sending our chips to MOSIS for fabrication. We sent several students' projects using analog and digital integrated circuit designs to MOSIS for fabrication. MOSIS returned the fabricated chips to GWU, where we tested the chips and prepared testing reports for submission back to MOSIS. I added several other courses to the GWU curriculum to reflect the depth of CMOS design. I wanted to carry out several research projects and applications using CADENCE software.

I started a collaboration with University of Maryland Professor Robert Newcomb on designing Neural Networks and trying to implement the neuron with the ability to learn and process data. Several students were trained in building hardware for learning Neural networks, and as a result, several students earned their Ph.D. in this topic. Therefore, several GWU students graduated with knowledge of CMOS chip design, and my NIST knowledge of the industry standard and requirements is reflected in their courses. Many of these students are now part of a productive force in top IC design companies like Intel, Apple, Google, etc. As a result of our knowledge of the theory and design of Neural Networks, we learned about their applications to the classification of data and especially for large data (Big Data). Thus, I was asked by my NIST colleagues to develop a Machine learning approach for classifying large semiconductor data, and I was asked to write the code and verify it (that was in 1994). In 1996, I was awarded IEEE Fellow for my work on Integrated Circuits chips design and the Circuits we developed for implementing Neural Networks mimicking the firing and the learning of the neuron. In 2017, I was selected as a Fellow of the National Academy of Inventors (NAI), recognizing my patents in microelectronics and MEMS.

In 1990 the NIST team started paying attention to Microelectromechanical Systems (MEMS) design and expanding the scope of the CMOS materials to all possible other materials. I joined this effort at that time. In MEMS work, you have to be very familiar with the different layers of the material. The designer has to add and subtract new materials to construct the MEMS device. To verify

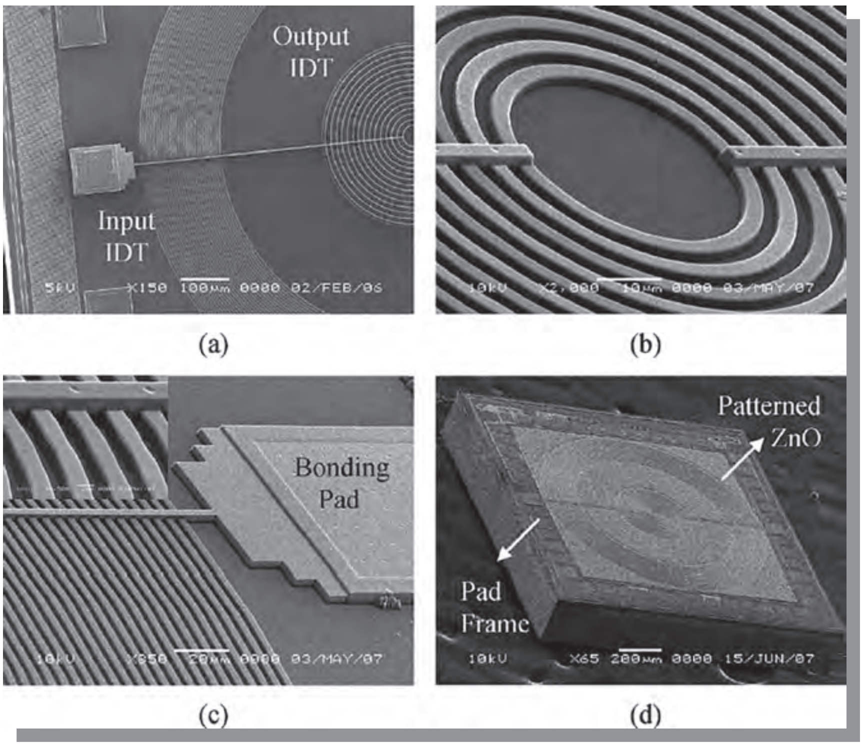

Figure 3. Novel Circular Surface Acoustic wave, which can be used as resonator or biosensor. (a) Top view SEM (Scanning Electron Microscope) of the circular SAW chip after CMOS and before postprocessing. (b) Close-up view of the inner IDT after the RIE step with 90 sidewalls. (c) Close-up view of the outer IDT with the pad after RIE. (d) Top view SEM snapshot of the device after the final step of ZnO patterning. Reference: Onur Tigli, Mona E. Zaghloul; "Design, Modeling, and Characterization of a Novel Circular Surface Acoustic Wave Devices"; IEEE Sensors Journal, Vol.8, Mo. 11, November 2008, pp 1807, 1815.

the designed and fabricated devices, the designer must have extensive knowledge of deposition and etching of different materials, material interaction, cleanroom facility equipment, and imaging equipment. I had a large team of students from GWU help me, try several recipes, and work on developing novel devices for MEMS applications. The applications chosen were to develop sensors. We used most of the available CAD tools to simulate the MEMS devices. Our team designed several novel MEMS devices. The devices were patented and were acquired by the industry. I had several Ph.D. students working with me at NIST. We used MEMS to implement varieties of novel sensors, and it was an opportunity to add the electronics on the chip to yield smart sensors.

I also used CMOS technology to build novel MEMS devices by adding to the CMOS technology other materials on the surface of the fabricated CMOS device (Surface Micromachining) or by etching layers from the standard CMOS technology (Bulk Micromachining) or possibly using both techniques at the same time. We developed several novel devices and sensors with integrated electronics. An example was developing a mechanical Surface Acoustic Wave device (SAW) for resonator applications and biosensors.

The work was acknowledged, and several students graduated using these techniques, and many joined the industry for MEMS design with the knowledge of IC design. They were hired as VLSI designers in addition to the skills of MEMS designers. Recently, I joined the material science group at NIST to synthesize 2D materials and start designing electronics circuits using 2D material. I have been working with the Material synthesis group at NIST for more than five years on 2D material. My students and I designed different transistors using different 2D materials and using 2D materials for sensors. For the design of 2D materials, the designers have to know how to build the devices in a clean room and measure the devices and use imaging equipment to have an image of the device. Several devices were fabricated and tested at the NIST laboratory and my GWU laboratory. Recently, GWU added a clean room to its new facility, which allowed our students to use it to build novel devices and use excellent imaging equipment to characterize the fabricated devices.

In 1989 I was promoted to Full Professor at the Department of Electrical and Computer Science. Again, I was the first woman to be appointed Full Professor at the George Washington University School of Engineering and Applied Science. This was a big step, and I think it opened the door for many other women to follow. Several female professors were hired at GWU School of Engineering, and a whole different era started.

The number of women engineers is still small in proportion to all engineers. For example, in the USA and Canada, it is about ~ 11%, and in Australia, it is about 9.6%. Other European countries such as Latvia, 30%, Bulgaria, 29.3%, Cyprus, 28.6%, and Sweden, 25.9%. China: the percentage of

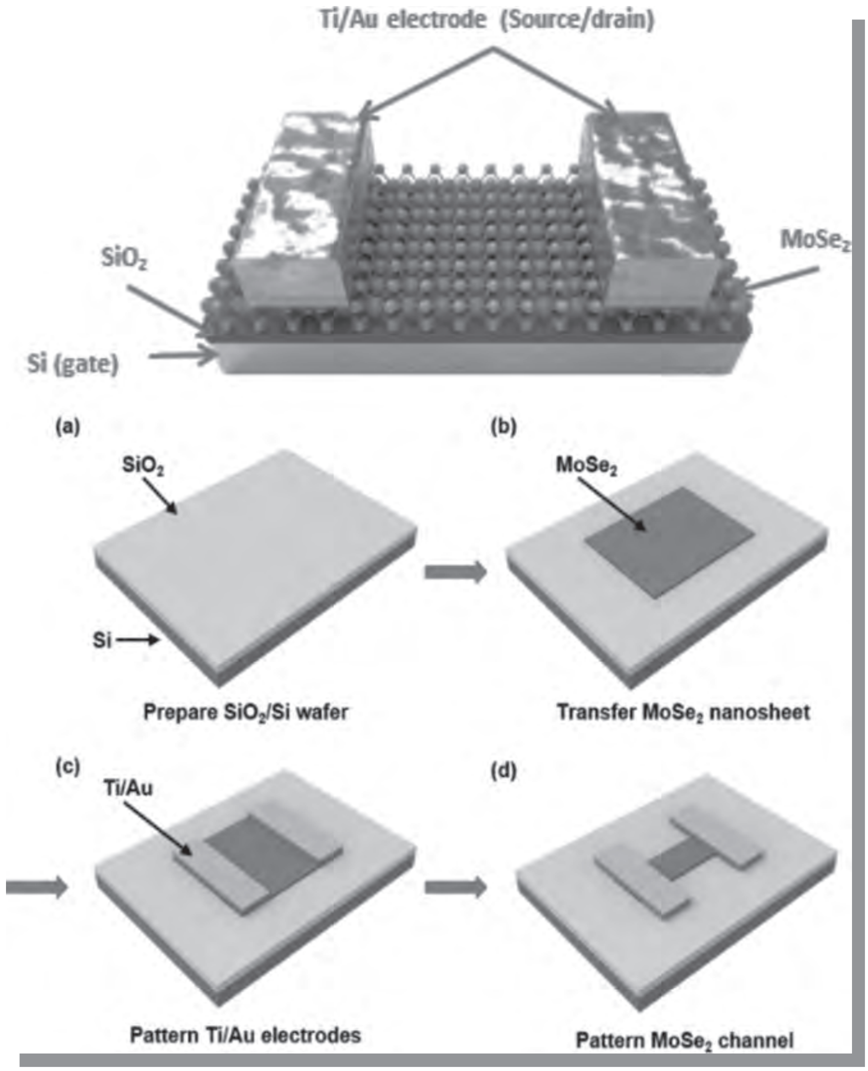

Figure 4b. Fabrication Process of transistor in the Clean Room, Reference: Shiqi Guo; "TMDS–based Soft and Wearable Bioelectronic Toward Precision Health Care"; The George Washington University, Washington, DC, PhD. Thesis, June 2019; Measurements of the transistor characteristics are shown in Figure 5.

women engineers is 40%. The IEEE, Institute of Electrical and Electronics Engineers, an International organization headquartered in New Jersey, USA, created the Women in Engineering Organization (WIE) as an affinity group in 1994. WIE celebrated its 23rd anniversary in 2017, and the estimated number of members is 24,000. WIE is very active in many regions in the US and globally: Asia, Latin America, Europe, and Africa.

Now GWU School of Engineering and Applied science undergraduate classes 2018 is about 25% female students, which is considered one of the highest in the country. Thus, several female undergraduate students are attracted to Engineering, and female engineers are now recognized and respected as productive engineers. I teach several female students in my classes, and I am proud of their accomplishments. Many professional societies recognize women in engineering and encourage women to join the profession. I have been impressed by the progress of female engineers since I started my career, and certainly, it has been a long road since 1970.

Professor experience at The George Washington University: Challenges and Successes

In the early years at GWU, I was repeatedly presented with the most challenging assignments. It seemed to me that my fellow male colleagues were eager to see whether a woman could do what was, at the time, still primarily a man's job. My only choice was to respond to their increasing challenges with increasingly hard work and the tools my education provided me. In 1994 I was elected the Chair of the Electrical and Computer Science Department. I was the First Woman to be Department Chair in the School of Engineering and Applied Science. The EECS department was a large Department with many faculties in the whole university.

I wanted to keep my research work going because I like to do research. I succeeded in managing the department, and we received accreditations from ABET with no problems for years. I hired several Assistant professors and Associate Professors and tried to increase the Department's research areas. I kept my work with NIST and was at NIST with my students, learning new technologies and directions, producing new devices, and educating my students on the latest technology directions. I was the Chair of the Electrical Engineering and Computer Science Department from 1994-1998. I ended my first period as chair. I went on sabbatical at Delft University in the Netherlands.

In 2000 the EECS department was separated into two departments, the Electrical and Computer Engineering Department and Computer Science Department.

In 2009, my colleagues elected me as Department Chair for the Department of Electrical and Computer Engineering. I worked as Chair from 2009-2014. I kept my research and maintained contact with NIST, and I was always eager to learn new technology and introduce new technology courses to my students. Thus, I spend my time learning nanotechnology and specifically nanoelectronics. I taught a new course on nanoelectronics and introduced the students to nanofabrication. Now with the new cleanroom at GWU, the course is taught with the cleanroom laboratory to teach the students nanofabrication. Currently, I am working with material scientists at NIST to synthesize 2D materials which we are using for electronics applications as flexible electronics. 2D materials are atom-thick layers of materials, and they became active research areas after the discovery of graphene.

In 2014 I was hired as Program Director at the National Science Foundation in the Division of Electrical, Communication, Cyber, Systems (ECCS). I was responsible for the Circuits, Communications, Sensors, Systems program CCSS. I worked at NSF from January 2014-December 2016. It was a very productive time, and indeed, I learned and met many new researchers in my areas of interest.

In 2017 I returned to George Washington University and concentrated on my research. Currently, I am focused on the following areas of research:

- Research on integrated circuit design as an interface for sensors, complete with fabricating and testing chips (mostly CMOS technology) with emphasis on flexible electronics components and integrating small CMOS components on a flexible substrate.
- Research on MEMS/NEMS design and fabrication to develop novel sensor devices using different materials with emphasis on biosensors for health care systems.
- Program on nanotechnology with emphasis on realizing nanodevices for electronics and sensors applications

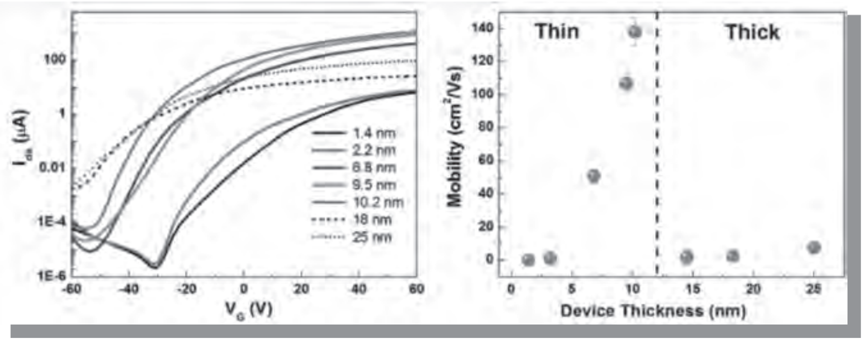

Figure 5. Measurements Characteristics of nanotransistors. Reference: Shiqi Guo; "TMDS–based Soft and Wearable Bioelectronic Toward Precision Health Care"; The George Washington University, Washington, DC, PhD. Thesis, July 2019.

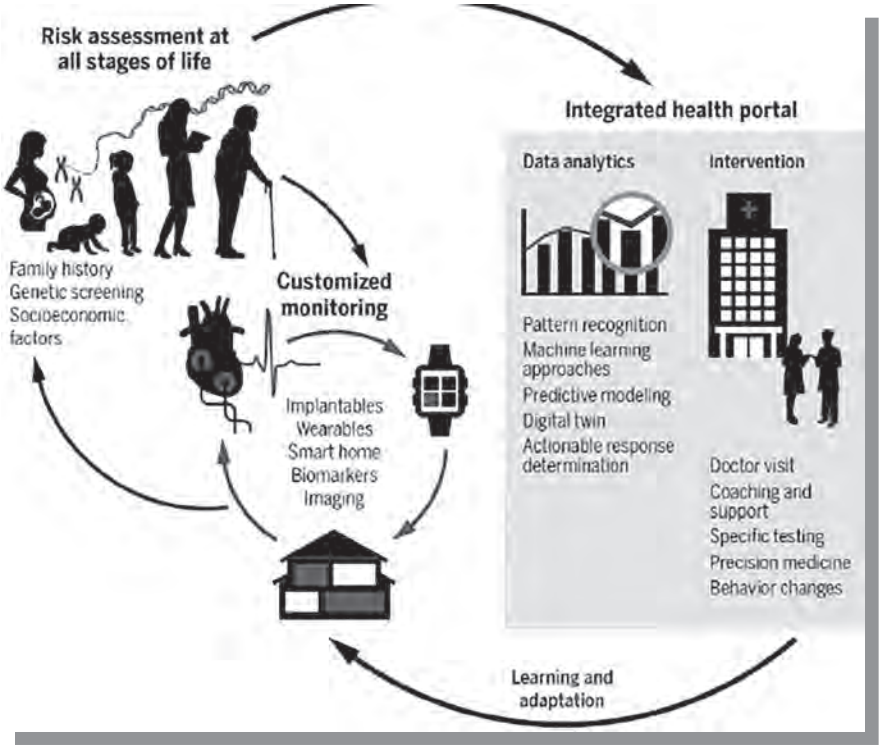

Figure 6. Precision health care overview; after S. S. Gambhir, et al., "Toward achieving precision health," Sci. Transl. Med. 10, eaao3612 (2018).

We are currently working on several projects under the above topics.

I promoted women in engineering and encouraged women undergraduates to be active in research. Over my career of 39 years at GWU, out of 38 Ph.D. dissertations completed under my supervision, 8 (21%) were female, and out of 24 Master's theses, 4 (17%) were female. All-female and male graduates are currently working in industry (Silicon Valley, etc.) and in academia (the US and abroad), with several having leading positions. At the GWU School of Engineering and Applied science SEAS, the number of undergraduate female students improved considerably, reaching 39.8% of the total number of students in 2018. For graduate students, the percentage of female students reached 26.7% of total students, above average nationwide. While this certainly leaves plenty of opportunity for growth, we must recognize and take pride in the gap narrowed in the past 40 years.

Future and Prospective

I introduced several new technical initiatives, several courses, and research areas during my career:

- Program on integrated circuit design, complete with fabricating, and testing chips (mostly CMOS technology)
- Program and Institute on MEMS/NEMS design and fabrication
- Program on nanotechnology which emphasizes realizing nanodevices for electronics and sensor applications.

There are many directions of research with an emphasis on health care; It is true that in the near future, we will have sensors attached or embedded in our body for complete monitoring of our health care. We are living in a fascinating time. New technologies are being developed around us all the time. We see tiny machines the size of one billionth of a meter. We are building with the individual atoms. This is an era of melding between man and machine. We are at a multidisciplinary time where the boundaries between electrical, mechanical, civil, chemical, and bioengineering are rapidly fading. This is truly the era of science and engineering, and it is an exciting time to be an engineer or a scientist. The possibilities to create novel things appear limitless. For young women engineers, my advice is that opportunities are endless. There are many directions, and being an engineer is an outstanding opportunity. You are the only limit to your achievements; you can achieve whatever you set your mind to with hard work and persistence. It may not have been done before, but that does not mean it can't be done. Education is essential, and it gives you the foundation and the confidence that help shape your career.

In the following, I will briefly give examples of devices developed in our laboratory. Many of the devices we micro/nanofabricated in a clean room, and most are patented.

Recently my research included nanoelectronics material for implementations of nanotransistors, examples of nanomaterial.

Currently, we are working on health care sensors. Precision health care, as shown in the following Figure 6, where sensors are implanted in the body or attached as wearable or distributed in the smart home, generate the health data. The data are analyzed, and the action response is determined.