Decades of Perspectives on Women In Microwaves

Dr. Kiki Ikossi

Sherry Hess, the Chair of IEEE Microwave Theory and Techniques Society (MTT-S) Women In Microwaves (WIM) Committee, has been asking me for years to write an article for the “Women in Microwaves” column (Fig. 1). I have been in Electrical and Electronic Engineering, both in school and working as an engineer, for nearly half a century. It is a wonderful profession, and once you are an Electrical Engineer, you can tackle anything that comes your way.

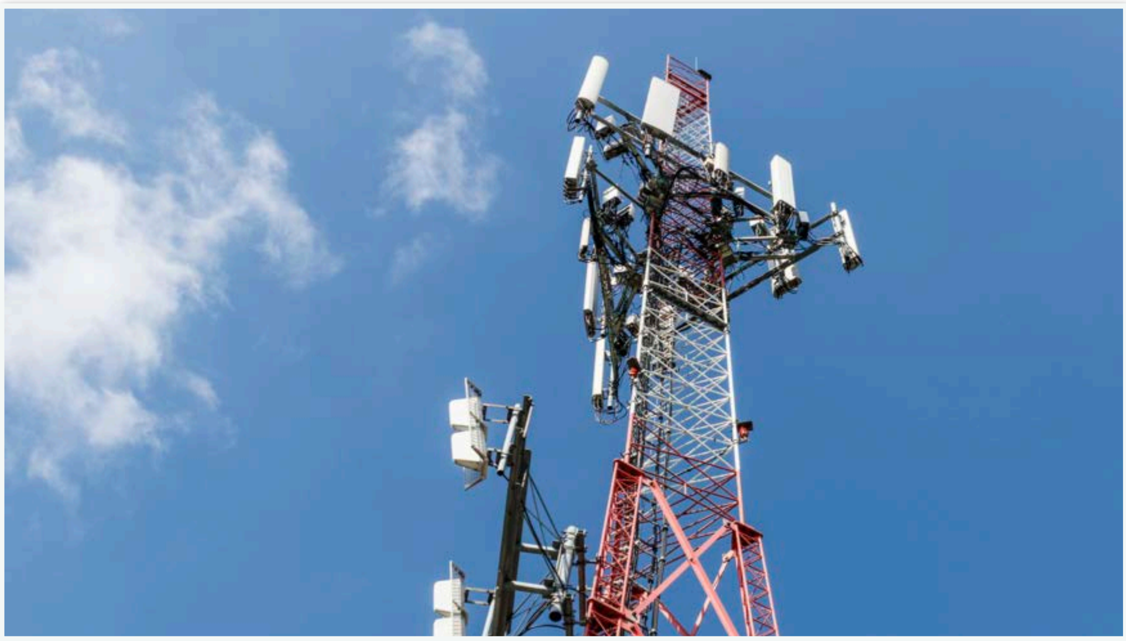

Fig. 1 Wireless Cellular Base Station Tower (Courtesy of Canva).

Where I Am Now

Currently, I am a Science and Technology Policy (STP) Fellow of the American Association for the Advancement of Science (AAAS) at the National Science Foundation (NSF). The AAAS works for programs benefiting all the scientific and engineering professional organizations in the United States (US). For the last 50 years, AAAS, using a rigorous process, selects around 160 scientists and engineers each year, as STP fellows, from all disciplines, and places them in the US Government. The STP fellows learn the way government works and form a bridge between science and government. They engage with policy decision-makers and contribute their expertise to the federal government, offering an independent scientific perspective (Fig. 2).

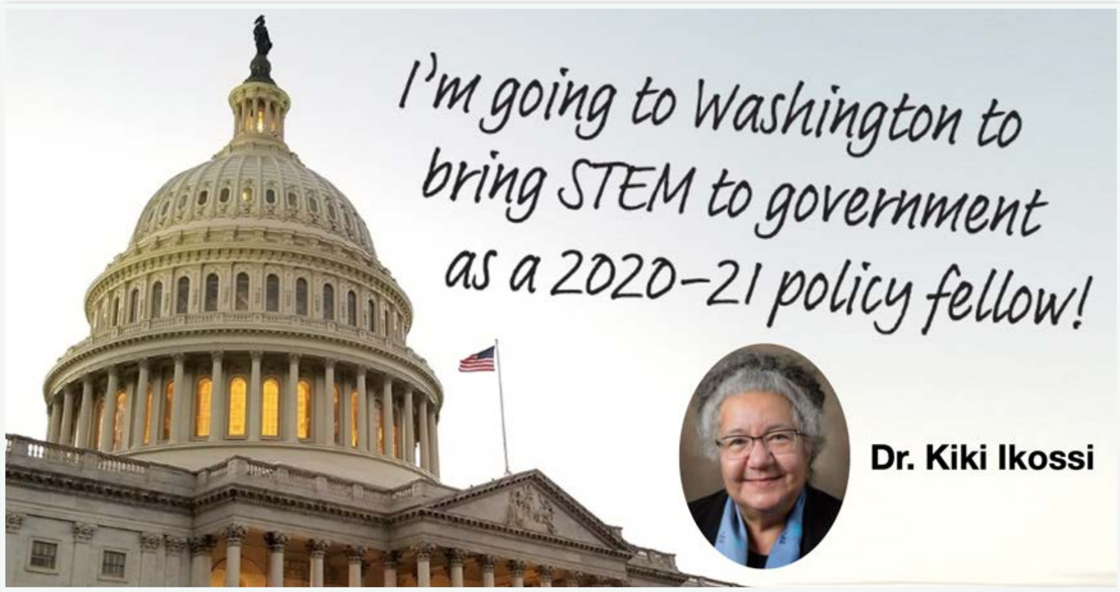

Fig. 2 AAAS Fellowship.

The NSF is an independent agency. It supports fundamental research, education, and research infrastructure, using grant mechanisms. NSF is where discoveries begin. It is a magical place. Science is everywhere, from workshops to panel meetings, and conferences. Even under the pandemic, science happens. For a science enthusiast, like me, it is a dream coming true. Learning something new every day and seeing how interdisciplinary research thrives. I work with the Electrical, Communications and Cyber Systems Division in the Engineering Directorate. There, scientific discoveries from all over the Foundation are transformed into new applications for the benefit of the citizen. The AAAS STP Fellows work across the Foundation on projects that address grand challenges and shape the future of science and engineering with an eye towards promoting not only science, but also diversity, equity, and inclusion in science, technology, engineering and math (STEM) fields.

The policy areas I am particularly interested in are emerging technologies and international collaboration. My objective is to work with policy makers in shaping policy for technology advancement and foster international collaboration for fundamental science research programs. The reasons are simple. Fundamental science is the basis of all technology and innovation that happens. Innovation fuels technology that benefits society, boosts the economy and brings prosperity. If one can understand the science behind the phenomena observed, one can control the processes and pursue applications in diverse areas. The fundamental understanding is the key, that opens the door to innovation. International collaboration and free exchange of ideas on a fundamental scientific research level can help innovation grow in multiple areas. I would very much like to help in shaping a policy where scientist will be enabled to do this. A sound science policy will help accelerate the future technology.

I expect the new experience and new knowledge that I will acquire from the AAAS S&T Policy Fellowship will allow to form strong liaisons between policy makers and scientists. I expect to be able to share my fellowship experience with my students and professional scientific organizations and assume an effective leadership role in my profession. The fellowship offers a means of using my expertise towards solving societal issues through policy. Science is the key factor shaping technology at our times. This is a unique opportunity to use policy to help shape the future of technology benefiting humanity.

How Did I Get Here?

I am a naturalized U.S. citizen, which means I was not born in the United States. My family was from a small island in the Mediterranean Sea, called Cyprus. Living in an island, the sky at night is spectacular. As a child, star gazing and dreaming were my favorite pasting time. Growing up during the space race, I was fascinated by science and saw that a girl can be anything, even a cosmonaut.

Fig. 3 Margarita and George Ikossi.

I am the fourth child in a family of five sisters. My father, George, was fluent in 6 languages and my mother, Margarita, was the brightest in her school (Fig. 3).

However, only the boy of my mother's family was sent for higher education. My mother even got a scholarship to study abroad but my grandfather did not let her go all alone to a foreign land to study. Living all her life troubled with the question "what if I went to college", my mother made sure her daughters received an education. My sisters lead the way and we all studied science - two physicists, one medical doctor (M.D.) surgeon, an engineer, and a mathematician - three with Ph.D. and one with an M.B.A. degree.

Fig. 4 Pancyprian Gymnasium, Nicosia, Cyprus.

From a young age, I embarked on a mission for science. I attended the Pancyprian Gymnasium, a very respected old high school within the medieval walls of the capital city of Nicosia, that had a science section (Fig. 4). It was an all-boys high school but would allow girls to attend the science section. My parents and sisters were very supportive, and I had great teachers. One day my science teacher took us on an excursion to a mine. He told us the ores in the mine is what is used to make transistors. He had us chip-off a piece of ore from the mine and tried to replicate Schokley's rectifying diode experiment. In retrospect that might have been a path setting experience.

EE Undergraduate

Upon completing high school, I was sure I wanted to be an electrical engineer. There were no universities in Cyprus at that time and students needed to go abroad for studies. I took the entrance exams for the Greek universities. There were blind exams. I got one of the 2 positions for engineering at the National Metsovio Polytechnic (EMP), or as it is now formally translated, the National Technical University of Athens (Fig. 5). I was also awarded a merit scholarship that made my parents very happy. Nevertheless, some in the community asked my parents to try to change my mind. They were arguing that engineering was not the right discipline for a girl, and concerned that one of the only two good engineering positions for the whole country would be "wasted on a girl". Nonetheless, my parents were very supportive, and I went to Athens to attend

Fig. 5 National Metsovio Polytechnic, Athens, Greece.

the EMP. At the Polytechnic, I was one of the two women in my class of 189 students. This led to many difficulties. However, the biggest challenge came from the political situation in Greece.

Some events are what define a generation and changes the trajectory of history. During the time I was studying in Greece, the country was run by a military junta. The democratically elected leaders were either jailed or in exile. Of course, the students at the land who invented democracy would not go along with a dictatorship. In November of my sophomore year, the students at the Polytechnic declared a general strike, locking themselves in the school complex and demanding freedom (Bread-Education-Liberty). The more senior electrical engineering students constructed an impromptu radio station and broadcasted songs of freedom all over Athens and call for support. And the people came. After 3 days of defiance, the military junta sent in tanks and crashed the gate of the Polytechnic and the students (Fig. 6).

Fig. 6 Event at Polytechnic Athens, 17 November 1973 (Courtesy of the Associated Press).

The difficulties did not stop there. In that summer, a new military junta orchestrated a failed coup in Cyprus. The neighboring Turkey, a traditional aggressor, seized the opportunity to invade Cyprus. Thousands were missing and over half of the population became refugees. Half of the island was under military occupation. These tragic events toppled the junta in Greece and democracy was restored. However, the tragedy of Cyprus still persists to this day. With the family home meters from the green-line and narrowly escaping Turkey’s ethnic cleansing, the only refuge for me was to emerge in my studies.

45 years after the events of November 17, I found myself in Athens during one of the Greek universities accreditation reviews. I was surprised to learn that the day was a national holiday. My school (EMP) became a monument to democracy and honored by the Greek people who would leave red carnations by the gate that the tanks crashed.

I could not stop thinking of that, if it was not for the electrical engineering students who turned the antenna lab into a broadcasting station and the little power amplifier who boosted the signal all over Athens, democracy may have never returned, and history would have been different.

Needless to say, that with all the events around the Polytechnic we did not have any classes for most of my sophomore year. We had to study the books and take the exams to progress. This gave me a lifetime lasting skill. Learning from the books, without a teacher or a class. I was one of the few in my EE class who managed to graduate in time. My undergraduate thesis research was in microelectronics, on multiplexing LED displays. After completing my degree, I left for graduate studies in the US.

Graduate School

I attended the University of Cincinnati (UC), in Cincinnati, Ohio, at the Electrical and Computer Engineering department in the solid state group (Fig. 7). My microelectronics professor at the Polytechnic, Dr. Halkias, recommended UC to me, as at that time UC was the only university with a clean room for teaching. At UC, I was one of the first 2 female Ph.D. graduate students in solid state electronics and the only one who was married and raising a child while in graduate school.

Fig. 7 School of Engineering, the University of Cincinnati, Ohio.

At UC at that time, a research Master of Science (MS) thesis was mandatory. By the end of the 1st year we had to have a thesis advisor and start working on our research. This was a difficult process. I had good grades because my undergraduate training was superb, and the first-year graduate classes were easy for me. However, no advisor would pick me. I was not sure exactly why. Maybe because I had a child and they thought I was not serious enough to pursue a graduate degree. One frustrating day, I just walked into the Dean's office and simply told him that I did not leave my homeland to come thousands of miles to a graduate school and not have an advisor for my research. The Dean promised to intervene, and he did. My advisor was a new professor in the department. I was one of his first graduate students and his first Ph.D. student. I am deeply grateful to Professor Kenneth Roenker. He taught me how to do research and he protected me from the department politics.

My research in graduate school was indeed very exciting. My MS thesis was in Metal Insulator Semiconductor (MIS) solar cells. The semiconductor was silicon. The insulator was a silicon oxide thermally grown and the metal was an optimized grid structure of Aluminum. The final structure was protected by an antireflection coating. Sounds simple. The oxide however for the photovoltaic effect to work to give the efficiencies we wanted had to be just 50 nm. Lower temperature dry oxide growths were exploited, and the thickness measured with ellipsometry. Ellipsometry had to be extended to extract the correct thickness for thin layers. To preserve the integrity of the ultra-thin oxide, the metal grid was deposited using a silicon shadow mask. For that, a silicon wafer was thinned, and the grid structures etched all the way through the wafer thickness using the crystallographic orientation of the Si wafer. That was one of the earliest Si micromachining and landed me my first paper [1].

Of course, years later, I saw the Si micromachining area flourish with MEMS applications [2]. I was able to follow this area and aid the Naval Research Lab (NRL), where I was working with at the time, establish a MEMS program, just from that early hands-on experience with micromachining.

Because working on solar cells and the photovoltaic effect was what Einstein earned his Nobel prize, my advisor made sure I took all the quantum physics I could. I took the “quantum solid state physics for engineers” class, but it was just not enough. I had to take a year of math physics from the physics department and a year of quantum solid state physics. With quantum mechanics, my solid-state electronics questions found their answers. I was able to comfortably say I can understand what the physics are, what the challenges are, and how to engineer solutions.

My graduate school friends were puzzled why I was still taking courses when I had finished all the required credit hours. Well, it came very handy not only for my Ph.D. but for today. With the quantum revolution of our times, I am able to follow the research and contribute. At one of my posts with the government as science and technology program manager, I initiated a quantum sensing program that won an internal competition and became the agencies R&D strategic initiative program.

For my Ph.D., I worked on deep level transient spectroscopy (DLTS). My dissertation was on capacitance transients for deep levels in epitaxial Si. The capacitance transient following an excitation was recorded over temperature. The decay time constants would give information on the energy level of the trap centers and capture cross sections. As not only one trap center might be present in the material, I adopted and refined a technique used in biology for deconvoluting multiple exponents over time [3]. For the cryogenic temperature measurements, I had to build a cryogenic wafer prob station from scratch. This was quite an experience and put my machine workshop lab, as an undergraduate in Greece, to full use. Learning how to handle humidity, vacuum, and learning how metals contract when cooled down to liquid nitrogen temperature was another challenge. Despite the challenges, the work was successful. The measurements were taken, and the analysis was made deconvoluting multiple traps. All the computer engineering classes proved helpful for this. Also, a numerical analysis class I took with the wizards of the math department proved extremely helpful. I knew they were all looking down on the engineer who was trying to learn their skills, but I got exactly what I needed out of that class and used it to its fullest in my data acquisition and analysis.

Work

Over the years, I was asked to set up a couple of cryogenic DLTS stations in different labs. I have also used them to measure the cryogenic performance of the experimental devices we were working on and analyze them [4],[5]. It is fascinating how the traps we were concerned with in graduate school are now the centers of intense studies for developing the qubits of quantum computers of the future [6].

As for nanotechnology, moving from microelectronics to nanoelectronics was a natural evolution. Besides, all the devices I had to work with were based on nano dimensions. With the 50 nm oxide of the MIS solar cells, the trapping centers in epi-Si, and the 5 nm base of the Narrow Base Heterojunction Bipolar Transistors (NBHTs,) the resonant tunneling diodes and superlattices, where pretty well “nano” before the term was adopted. Additionally, I helped develop the nanotechnology curriculum at GMU and taught two of the nano courses over the years.

Some may think that the US scientists have the best labs and opportunities to excel. The reality is that even in the US one must be creative and willing to go to extremes to do research. I was the first female faculty member at the department of electrical and computer engineering at Louisiana State University (LSU), in Baton Rouge, Louisiana; and the first female engineer to earn tenure at LSU. Needless to say, I had to fight for it. My university at the time did not have the (promised) clean room facilities I needed for my research. I was fortunate to be accepted as a summer research faculty by the American Society of Engineering Education (ASEE) at the Naval Research Lab in Washington, DC. During my first 6 weeks in DC, I made the first functioning HBTs for the lab. The management was elated, and I had an open door since. Despite the fact that my son was born while I was on my 2nd year at the university, every summer, and every break, I would pack myself and my family and travel to DC. There, I would do my research, design devices with exploratory semiconductor materials, fabricate the devices and take them back for my students to measure, study and write their thesis for their degrees. My commute from school to lab was 1,870 km one way and 1,870 km back. On my sabbatical leave, I returned to DC, where the times were exciting with exploratory research. My Ph.D. knowledge on deep traps in semiconductors helped unlock the high-speed behavior of the exploratory AlGaN/GaN HEMT devices and ease the road to their commercialization. The key paper on that work is still cited by researchers [7].

From all the areas I worked I value the most my research time in the lab using exploratory materials and novel device concepts, Nanoelectronics - the incorporation of nano sizes in electronic devices and quantum mechanical effects, for enhancing the operation of electronic and optoelectronic devices and systems. I worked with most material systems (Si, GaAs/AlGaAs, InAlAs/InGaAs/InP, AlGaSb/GaSb, AlGaN/GaN, SiC, LT-GaAs, Selective MBE) and many device types (MOS, MODFETs HEMTs, HBTs, NBHBT Optoelectronics Optical Modulators, Optical MEMS, Nanoamplifiers, ohmic contacts and solar cells). Working with government research labs, I had the opportunity to work on new semiconductors and make some of the first devices on new exploratory material [8]-[10]. There is a unique excitement and satisfaction when a theory or a speculative hint is validated and proved with an experiment.

I have seen the rise and fall of the semiconductor industry in the US. Now with the high interest in the US congress there is a new light of hope for the 21st century semiconductor era. When I graduated with my Ph.D., all of my colleagues were finding good jobs in Silicon Valley. I, however, graduated and immerge in new R&D areas in exploratory semiconductors and microelectronic devices. I worked as an electrical engineer in academia, in national labs, industry, and government.

I was fortunate to work on areas that the basic research proved the technological capabilities of the new materials for high-speed high-power devices and were adopted by the industry. These devices are in today's consumer electronics, sensors, base stations, satellite communications and high-speed internet that transformed society and our world.

IEEE Volunteering

I discovered IEEE during my first year in graduate school. An advance topics class I was taking had a special issue of IEEE journal as a text material. It was more cost effective to become an IEEE member and get the special issue, as well as the new issues of the journal every month. It was like opening a new door into an amazing world. Reading the journals became a habit that I cannot break. When doing research following the research journals is essential. I still get the IEEE journals every month. Some now are online, but equally as exciting and full of new discoveries.

My research began mainly on electronic devices, but as the devices I was working on became faster and faster with new materials and smaller dimensions, I eventually found myself in the IEEE Microwave Theory and Techniques Society (MTT-S). My first impression from going to my first International Microwave Symposium (IMS) was very positive. The people were friendly and inclusive and the technical sessions intriguing. I have been a member of MTT-S and going to IMS nearly every year.

I would urge every IEEE member to get involved with their technical society. With the local IEEE, I have served in the executive committees and as Chair of both the Washington, DC and Northern Virginia Sections. In that capacity, I ensure that the section is vibrant and active. Despite the decline in IEEE membership in our region, our local section was recognized by IEEE headquarters for increasing our membership. I believe this was possible because I ensured that we offered our members, in addition to new scientific information, development opportunities and activities beyond engineering that impact our community and society. Prime examples are a seminar series in emerging technologies like the internet of things, updates on the Fukushima tsunami/nuclear disaster, Congressional Visits and the March for Science.

Fig. 8 High Efficiency Power Amplifier Student Design Completion at IMS 2019 (Courtesy of LylePhotos).

I have been supporting the IMS for MTT-S for many years, as well as other international conferences. I find that reviewing papers from international conferences is extremely helpful for my work. Most importantly, I have the opportunity to appreciate how scientific creativity flourishes in different directions in different parts of the world.

The High Efficiency Power Amplifier Student Design Competition (HEPA-SDC) has a special place in my heart. I was one of the founding members of this competition in the MTT Microwave High-Power Techniques Committee (TC-12) and supported it for 17 years. It is an international competition open to all students around the globe. The students are asked to design and make a power amplifier and then bring it to IMS where it is measured by our industry colleagues. All must come together for success, the students, the academic advisors, the industry with the equipment to measure, and the competitive spirit. I enjoy interacting with the international students and meeting them in person - after emailing for almost a year answering questions and hearing their concerns. The HEPA-SDC became a model for IEEE conference competitions (Fig. 8).

In 2020, due to the pandemic, the IMS conference went virtual and cancelled all the Student Design Competitions. The students were disappointed. Working across the Atlantic with the MTT TC-12 Chair, Anding Zhu, we devised a hybrid virtual competition: The students had to send their Power Amplifiers (PAs) to the Microwave Research Lab of the Industry sponsor, Keysight, where the measurements took place and were live streamed on the internet. The students, the advisors, the judges, the sponsors, and the friends of the PA competition participated virtually and watched the live streamed measurements. This year again, the HEPA-SDC was in a virtual mode. Our HEPA-SDC is the only IMS related competition that found a way to continue even at the time of the pandemic. My greatest fulfilment from the HEPA-SDC came when one of our past student contestants came back as a professor with his student competing and winning again. For the HEPA-SDC, this generational continuum can be considered as achieving immortality.

Women in Microwaves

Although what is a minority or unrepresented section of the population is different from one country to another and across the 10 IEEE regions the single undisputable fact is the small number of female electrical and electronic engineers. For that, we need to work harder, encourage students to follow an EE career, mentor them throughout their career stages and help them stay in the profession. It is true that engineering gives transferable skills that can be used all over the professional world, but it takes a lot of effort to educate an engineer to lose them to other professions.

Sadly, if one is what they define as a minority in your country, school or work area, things will be a bit harder. But, after all, we are in engineering not because things are easy. We are in engineering because there are hard problems that need solutions. Engineering can help solve the most challenging problems and, as engineers, we thrive on challenges. In addition to the technological and scientific challenges, we have to deal with society and help solve societal problems as well.

With concerns of the low number of women electronic engineers, I helped find the joint Women in Engineering (WIE) group of Washington, DC, Northern Virginia and Baltimore IEEE sections. This was one of the first 3, IEEE-WIE groups founded in the world. As Chair, I ensured we welcomed as WIE members, all the electrical and electronic engineers from underrepresented sections of our population and their supporters. I am now a member of the steering committee for Women in Microwaves where again we are trying to help diversity.

In the United States, despite the stagnant and downward trend for overall enrolment in engineering, the % number of women in engineering are improving steadily. According to ASEE in 2010, the undergraduate female engineer degrees were 17.8% and by 2020 they reached 23.1%. However, in the US, the percentage of engineering bachelor's degrees awarded to women in 2020 was 23.1 % of for all disciplines. Only 15.5% for Electrical Engineering degrees and 18.8% for Electrical and Computer Engineering degrees were awarded to women [11]. Thus, there is still need for improvement and we should continue our efforts for diversity and inclusion.

The fact that fewer engineers and even fewer electrical engineers are females is not because women cannot do engineering. Rather, it is because society placed these artificial barriers that persist through the ages. Thus, our task to break these barriers with women engineers in all our ranks is paramount.

Nonetheless, times have improved with more women engineers and more opportunities now than 50 years ago. The mere fact is that, despite the difficulties, I persisted and stayed in the profession is something noteworthy. At least I feel I did my part and helped smooth the way for the next generation of women EE Engineers.

Final Thoughts

To conclude, science is a universal language. Scientist and engineers are joined by their passion for discovery, logical understanding of our world and creative solutions for society. Engineers are called to solve the most important problems and help technology and humanity move into the future. The world is interconnected and interdependent. As we see the impact technology has made on our world, we are all more demanding on engineers. A smart solution, a new cost-effective technology creating profits, is not good enough anymore. Today's engineers' responsibilities are immense. With the technical solutions engineers develop, they also need to address energy efficiency, the environment, inherit biases, social injustice, equity, and human rights. I have a good feeling that we are in good hands, and that as they carve the road to the future, the 21st century engineers will rise to the challenge.

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About the Author

Dr. Kiki Ikossi has Ph.D. and M.S. degrees in Electrical and Computer Engineering from the University of Cincinnati with emphasis in Solid State Electronics, and a B.S.E.E. from the National Technical University of Athens (EMP), Greece.

Dr. Ikossi's area of professional expertise is in advanced micro and nano electronic devices in exploratory materials. Her research interests include high frequency and high efficiency power amplifiers, nano/optoelectronics, sensors, detectors, photovoltaics, quantum effects for solid state devices, and unconventional materials for device applications. She has published over 100 scientific papers, and has numerus invention disclosures and a US patent.

Dr. Ikossi has held positions in academia, major research labs and government. She was a tenured Associate Professor at Louisiana State

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