Solar Energy as a Forum to Introduce Microelectronic and Nanofabrication Basics to the K-12 Community

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Abstract

Microelectronics and nanofabrication encompass rapidly evolving fields that open new opportunities for research and innovation. Solar energy is one such opportunity for the current group of engineering students. The challenge is attracting high school students into the STEM disciplines so that we have the workforce to develop these opportunities. This paper presents a synopsis of two outreach programs, one for teachers and the other for middle school students, that the Microelectronic Engineering faculty at Rochester Institute of Technology have developed and delivered to disseminate the opportunities to our K-12 constituents.

Background

The resources being expended in Science, Technology, Engineering, and Mathematics (STEM) initiatives are a testament to the serious challenge facing America in developing and maintaining student interest in careers in the hard sciences. A recent solicitation for program proposals from the Motorola Foundation announced a $7M budget for their 2010 Innovation Grants which will fund STEM programs for K-12 teacher training, as well as student programs including activities for underrepresented groups, inner city students, and gifted students. This serves as one example of the commitment that corporate and government agencies have made to enhancing STEM education. The Microelectronic Engineering Program at Rochester Institute of Technology (RIT) is extremely interested in STEM activities due to the unique composition of its own curriculum.

Founded in 1983, the BS in Microelectronic Engineering enhanced RIT’s reputation for career-oriented education by offering the only ABET accredited program in the nation focused on the design and fabrication of integrated circuits (IC). Accredited under electrical engineering (EE) criteria, the Microelectronic Engineering Program retained the core EE circuits, electronics, electromagnetic fields and linear systems courses. Materials science and lithography classes were added to provide the foundation of the process steps utilized in IC manufacturing. The program was completed with design and fabrication courses to build and test the actual devices. The Microelectronic Engineering Curriculum has been in a state of evolution since conception due to the relentless scaling of IC dimensions that characterizes semiconductor manufacturing. Accompanying the scaling are new processes and materials that are required to maintain functionality, and result in modifications to course content. Microelectronic Engineering is a true multidisciplinary field in a constant state of flux. Figure 1 summarizes the advances made at RIT in comparison to industry advances during the same time frame. The challenge that comes with this type of evolutionary program is not only maintaining currency in the curricular
offerings, but disseminating these advances into the K-12 community so future students are empowered to make informed evaluations of career options.

Recent discoveries and advances in nanoscience and nanotechnology, along with environmental concerns for global warming and green energy, have captured the imagination of the public, and more importantly, may affect the career choices of many entry level undergraduates considering an engineering program. The Microelectronic Engineering Program at Rochester Institute of Technology recently completed a multi-year Department Level Reform (DLR) NSF Educational Grant (EEC530575). The DLR grant provided the Microelectronic Engineering program with the resources necessary to conduct a thorough review of its curriculum, evaluate the progress and promise of nanotechnology in light of RIT’s mission to provide career-oriented education, and address the renewed interest in photovoltaics (PV), the fabrication of devices to convert solar energy into electricity. The growth of innovations that enabled integrated circuit technology to become efficient in high volume manufacturing of extremely small and complex systems on large substrates has established a sound precedence for the PV industry. However, evolving this technology to meet the cost criteria necessary for wide-spread application of PV will be a special challenge to engineers and scientists. RIT with its strength in research and education in semiconductor fields is well positioned to take on the challenges of developing these engineers...
and scientists. As a result of the DLR grant, Microelectronics at RIT has evolved its course offerings to address these challenges.

A major portion of the grant was to fund outreach initiatives disseminating the findings from the grant to our constituents. Factors driving the outreach initiative included rapidly emerging and evolving technologies and the need to inform high school students of these career paths, as well as the requirement for higher levels of education at entry level positions. As shown in Figure 2, entry level positions in the semiconductor industry that required only a high school degree in the 1980's currently require a two-year Associates Degree. Two key constituencies targeted for the outreach programs were the K-12 teachers and their students. Separate, but related, programs have been developed for the teachers and students that utilize solar cells as a vehicle for introducing the fields of microelectronics and nanofabrication.

Outreach to K-12 Teachers

Early in the grant, the decision was made to offer a program for teachers. The justification was that a successful outreach program to teachers could impact those teacher’s students for an entire year or more, as opposed to a student program in which we have a very limited amount of time, ½ a day to a week, to impact the students. A two-day forum on Microelectronics and Nanofabrication was developed and delivered seven times to over 100 teachers from New York State (NYS). The course was developed with the help of an alumnus of the Microelectronic Engineering Program, who had switched careers and was now a high school physics teacher. Having a teacher involved in the program development gave unique insight into the current high

Figure 2: Changing education requirements in the IC industry

Education

Bachelor of Science in Electronics Technology

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school curriculum and constraints faced by teachers who would like to innovate in their classroom.

The forum agenda was as follows:

**Day 1**
- **8:00 - 8:30 am**: Continental Breakfast & Course Registration
- **8:30 - 9:30 am**: History of Microelectronics and Origins of Nanotechnology
- **9:30 - 10:30 am**: Fundamentals of Semiconductor Devices
- **10:30 - 11:30 am**: Electronics Lab #1: Resistor I-V
- **11:30 - 12:30 pm**: Lunch
- **12:30 - 1:30 pm**: Overview of Lithographic Processes
- **1:30 - 3:00 pm**: Lithography Lab in cleanroom
- **3:00 - 4:00 pm**: Demonstration on vacuum fundamentals

**Day 2**
- **8:00 - 8:15 am**: Continental Breakfast & Course Registration
- **8:15 - 9:00 am**: Modern Engineering: Skill set required and economics of the industry
- **9:00 - 10:00 am**: Overview of IC fabrication process
- **10:00 - 11:30 am**: Cleanroom activity involving materials processing
- **11:30 – noon**: Lunch
- **12:30 – 2:00 pm**: Electronics Lab #2: Diode, LED, Solar Cell I-V
- **2:00 - 3:00 pm**: Synopsis of programs & projects at in Microelectronic Engineering at RIT
- **3:00 - 3:30 pm**: Open discussion on integrating forum experiences into the K-12 classroom
- **3:30 pm**: Graduation

The program content commences with an overview of the field, the origins of microelectronics in 1947 to the explosion of the modern technologies of today, including photonics, nanoelectronics, and nanotechnology. A short introduction into the physics of the semiconductor device follows, in which a qualitative approach yields Ohm’s Law and the current-voltage (I-V) response of a resistor. This session is concluded with a simple breadboard lab to build a circuit that enables the participant to acquire three or four I-V points and construct their own plot. This session may be chaotic in that the teachers possess a wide variety of skill levels when it comes to electronics. Often, any technology teachers in the group become mentors for their colleagues. Following a lunch break, the teachers are given an overview of the lithographic process, which can best be described as photography on a silicon wafer. They proceed to lab to perform the lithographic process. In order to make the experience a little more interesting, the “circuit” that is patterned is an image of the class. The silicon wafer that they process becomes a souvenir from the course. Figure 3 shows a sample wafer which becomes the teacher’s “diploma” at graduation.

On the second day, an overview of modern engineering is given highlighting the skill set needed by today’s students to succeed in tomorrow’s careers. A brief look at the economics involved in a modern IC factory reveals that a single factory may produce $20B/year in product and that a single engineering improvement may yield $75M in additional revenue. It is this set of economic conditions that drives much of technological advancement and can determine which technology transfers to manufacturing and which technology remains an academic curiosity.
An overview of the manufacturing steps then follows, with a lab to demonstrate some of the processes. Following lunch, there is an electronics lab #2 to test some basic diodes or pn junctions, which form the basic building block of the transistors and all IC’s, and to plot their I-V response. This lab culminates by entering the Microelectronic Engineering test lab and testing integrated versions of the resistors and diodes. Here the teachers see the same I-V curves that they measured by hand, being acquired automatically by test equipment requiring a microscope to find the device.

The event concludes with a quick overview of the BS degree program in Microelectronics so the teachers can see how the necessary knowledge and skill set is acquired by an undergraduate, and to see how their high school courses provide necessary background to the future engineer. At this point, the course has exposed the teachers to processes of oxidation, diffusion, photolithography, etching, and metallization used to build IC’s. The metrology tools used to check the film characteristics often take multiple measurements and report mean and standard deviation values. This illustrates the use of applied statistics in modern manufacturing. The fabrication took place in a cleanroom, which introduces concepts of design and architecture, safety issues, cleanliness criteria, and cleanroom protocol. In addition, teachers did some simple electronics testing using breadboards, resistors, and diodes to understand basic device performance.
There is then an open discussion with RIT faculty and the teachers on how to transfer some of these experiences into the high school classroom. To help the teachers, each participant receives the course notes in paper and electronic form, the souvenir wafer, their own electronics kit, a DVD narrating the IC fabrication process suitable for high school students. Costs, including printing, postage, and participant costs (anything involving the teachers) for this type of program ranges from $8-12K, depending on how much travel reimbursement is given. Faculty and staff salaries are not included as they were part of the grant.

Reaction to the program has been overwhelmingly favorable. There are points throughout the forum where individuals can feel overwhelmed because of the amount of new material to which they are exposed, but most participants would recommend it to their colleagues. While many may think that the course is geared for chemistry and physics teachers, effort are made throughout to expose the other fields needed in IC processing. Simple examples include the mathematics of plotting the I-V data and then taking the slope to find the resistance. This can serve as an example of applied mathematics. The cleanroom used to fabricate the devices requires filtering of air, temperature, humidity, and vibration control. This requires special architecture and HVAC systems. The lithography process is an extension of photography, so references can be introduced there. While there are many opportunities to connect the high school curriculum to modern IC processing, we have observed limited results. While the DVD may get played or the souvenir wafer shown, significant curricular change has not resulted from this forum. Obstacles most cited by teachers include structured curriculum geared to standardized testing which limits innovation, and lack of time and/or resources for the teacher to develop new lessons.

### Outreach to K-12 Students

Midway through the NSF DLR grant, a request for proposals was issued by NYS Department of Education offering funding for summer sessions for their Excelsior Scholars Program\(^4\) that would:

1. enhance student knowledge and understanding of the mathematics and science needed to be competitive in the global economy,
2. include hands-on, real world applications of mathematics and science,
3. provide learning experiences focused on conceptual understandings, procedural fluency, and problem solving,
4. integrate 21\textsuperscript{st} century technology into the learning experiences, and
5. result in measurable improvement in student academic achievement of the New York State learning standards as included in the core curricula for mathematics and the sciences at the commencement-level.

The Excelsior Program targeted the middle school students because a program goal was to attract these students into the STEM area during their high school careers.

The Microelectronic Outreach Office developed its summer camp to meet the criteria by expanding and simplifying the material presented to the teachers in two days, into a two week program in which a solar cell, or photovoltaic device, would be fabricated. The solar cell is a large area diode, so conceptually its operation in very simple. Since solar energy represents a viable alternative to fossil fuels, this venue provides a unique means of utilizing microelectronics
and nanofabrication technology for the betterment of humanity through green energy. The students are exposed to a plethora of topics as mentioned above in the teachers section. In order to maximize student participation, enrollment was limited to 20 students, the students were split into 2 groups, and the groups alternated between activities. This necessitated the outreach team presenting each exercise twice.

Each student made three wafers that were used to make a “diploma”. The first was an oxidized wafer that underwent sequential etching to produce a variety of colors on the wafer due to interference. The second was a lithographically produced image produced by etching the oxide using a mask that was a picture of the students. The third wafer was their solar cell. Figure 4 shows the student’s work.

The camp was quite labor intensive. In addition to the two Microelectronic Outreach people, two graduate students, two undergraduates, and a high school technology teacher were hired. For the August camp, the student instructors started in June with equipment training and process development so that they could instruct the seventh graders. The high school teacher was brought on in mid-July to learn the modules and help ensure the activities planned by the RIT staff did indeed meet NYS Learning Standards. Additional benefits realized by having a professional K-12 teacher involved were that the rest of the staff could turn to this teacher for guidance on presentation levels, dealing with bored students, and activities that could be used to fill any dead time. The students were able to review their activities for the week utilizing a technical Jeopardy Game that the teacher devised. Cost of supplies, equipment time, and personnel was in the $50-55K range.

![Figure 4: Si wafers fabricated by Excelsior Students as part of camp activity.](image-url)
The camp was assessed by the outreach staff, as well as an independent assessor. The outreach staff began and ended the camp with the same document, a short answer technical survey comprised of 30 questions on general camp themes of energy, electricity and circuits, solar cells, and mechanics of motion. Grading of the initial survey highlighted any area in which the students were weak and gave insight to the team as to where to add more effort. Post survey results showed student improvement resulting from the camp as well as any areas the team may have come up short. Through an independent evaluator, the camp was also evaluated via a process referred to as triangulation. The evaluation included four sources of data collection: the pre-test/post-test assessment of academic mastery, a survey of student attitudes and self-efficacy, observations, and archival materials. It was the judgment of the independent evaluator that the Microelectronics Program satisfied the requirements of the New York State Education Department, was administered effectively and professionally, and achieved its teaching and learning objectives.

Conclusions

The Microelectronic Engineering Outreach staff at RIT have developed and delivered two successful outreach programs, a two day course for teachers and a two week summer camp for middle school students. Both experiences utilize the current interest in solar energy as a forum to introduce the attendees to the basics of microelectronic and nanofabrication.

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Bibliography