Silicon to Silicon Carbide Electronics-50 Years of Progress

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Many people know of the iPad/iPhone and computer chips and have read that computer chips are made at Global Foundries in Malta. What makes these computer chips "tick" are metal-oxide-semiconductor-field-effect-transistors (MOSFETs) made using silicon wafers. In our digital age computer chips are everywhere: in computers, cameras, automobiles and even in some household appliances. The list is endless. But how did this technological revolution start that has had such a dramatic effect on our culture? And how did this lead GE to begin using silicon carbide wafers to make electronic devices that go into gas turbines?

As a result of GE deciding, in 1988, not to continue being a manufacturer of semiconductor devices, like Intel, few people knew or remembered that many of the inventions and technology know-how that give us all our electronic based products were made at the Schenectady GE Research Laboratory.

It must be remembered that GE had been the leading producer of transistors using germanium wafers beginning in 1950, spurred by the pioneering work of Robert N. Hall at the research lab. Bob's methods were adopted by the world's semiconductor electronic businesses. This marked the beginning of the semiconductor era. However, in the early 60s, another semiconductor material, silicon, began to be utilized. The revolutionary device that made today's computer chips feasible is the silicon MOSFET.

An Early 60s Beginning

The MOSFET is a simple device that can be fabricated on the surface of a silicon wafer, which makes it easy to connect to other MOSFETs that make today's complex computer chips possible. But, initially, in the 60s, there was a lack of scientific understanding of what controlled their properties and how they could be made to work properly. Work at GE's Corporate Research and Development Center (CRD) resolved those problems. So, in the early 60s, GE's Semiconductor Product Department

Figure 1: Dale Brown's "Old Lab Setup" to do research and development for silicon MOSFETs. Left to right: Dale Brown by the door, Richard Connery and George Charney. All the equipment was made in the research lab's machine and glass shops. The silicon wafers were about one inch in diameter at this time (1964).

(SPD) in Syracuse, N.Y., began making simple integrated circuits using MOSFETs by utilizing CRD's knowledge base. These chips were for electronic musical instruments, the first hand held calculator, and for GE's teletype machines. These were some of the first computer chips made and, even though they were simple, they represented an initial milestone on the road to the revolution that was to occur.

A small laboratory at CRD was the first silicon semiconductor device fabrication facility in the Capital District devoted to the understanding and development of MOSFETs.

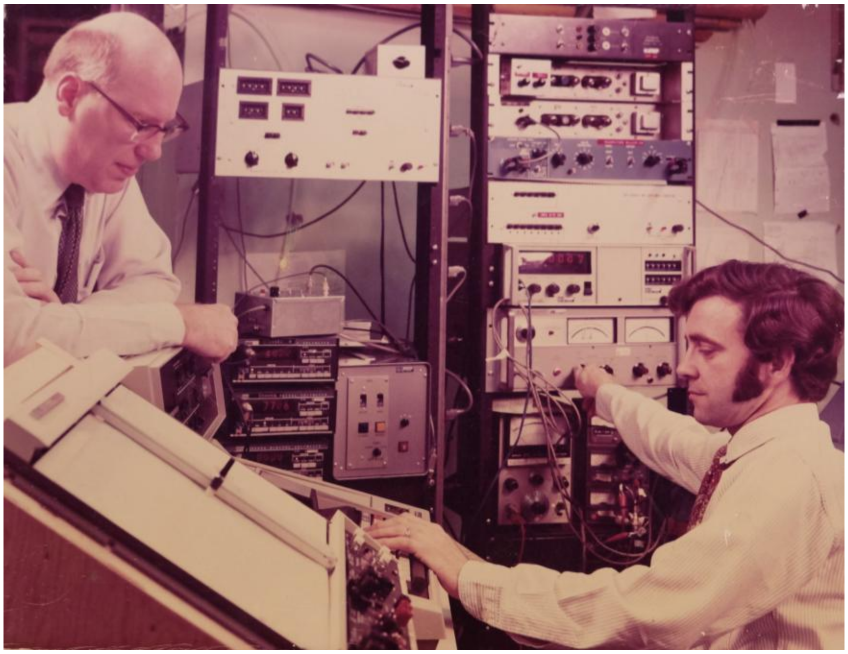

Figure 2: Making MOSFET measurements. Let to right: Dale Brown and Richard Connery (1964).

The MOSFET VHF Amplifier Chip

In the meantime, but still in the 60s, in that small GE lab, a better way to make MOSFETs was investigated. The gate on the top of a MOSFET is a narrow strip of metal. Small voltages applied to it control the current through the device. The edges of the gate must be aligned with elements in the wafer underneath it. This step was done late in the process which made the alignment difficult for narrow gates required for high frequency performance. The new method deposited the gate material and formed the gate pattern near the beginning of the process; then formed the underlying elements which automatically aligned the gate edges. This self-aligned gate method produced MOSFETs with smaller dimensions which resulted in enhanced high frequency performance.

So a really useful device (other than simple research devices) made at CRD in that small laboratory, using the advanced fabrication method, was a very high frequency (VHF) MOSFET. The electrical characteristics of this device were ideal for the first stage amplification of small signals required for all types of radio and TV receivers. CRD shipped quantities of these devices to Semiconductor Product Division (SPD) in Syracuse for customer evaluation. For example, SPD received a million unit order from GM/Delco for car radios.

The culture of the 60s and 70s encouraged publication of new scientific and technical understanding. Dr. Dale M. Brown from GE CRD gave a talk about the self-aligned gate being the best way to make MOSFETs. This was absorbed with great interest by the scientist/CEO of Intel (Andy Grove). Intel's first computer chips were not made using MOSFETs. But shortly thereafter Intel used them to become the primary developer of microprocessor computer chips, the "heart" of the desk top and lap top computers initially made by Apple, formed in 1976.

All this was helped along by the little GE MOSFET that changed the World.

The Solid State Relay

The GE Ordnance Department in Pittsfield, Mass. came to CRD explaining why the U.S. Navy needed a new type of relay that hadn't been invented yet. This was to be called the Solid State Relay. A relay is an electrical switch that can be remotely controlled by electrical signals. Mechanical relays contain an arm that moves up and down to open and close the switch. The Solid State Relay would be far different because it would not have any moving parts in contrast to mechanical relays which were not suitable for many applications in Navy ships. A concept was formed and CRD fabricated component parts for prototype testing. One component was a large power MOSFET. And relay assemblies were tested by the Navy. After passing all the qualification tests, the Ordnance Department received very large contracts over a fifteen year period to make relay assemblies for their ships.

Today Solid State Relays of various types are manufactured by a number of companies. They are used for signal switching in ships and airplanes and to turn on and off motors.

The First Digital Camera

Kodak has made the claim that they created "the World's first digital camera," a prototype built in 1975. But let's back up a bit.

At GE CRD in the early 70s, a unique way of making digital camera chips was invented. Since CRD's MOSFET technical knowhow together with recent device and processing innovations were in place in Syracuse, camera chip designs made at CRD resulted in immediate production of digital cameras by GE's Optoelectronics Systems Operations also in Syracuse. These early cameras were to be used for surveillance in stores and factories, for control of robots in industrial manufacturing applications and for missile guidance. OSO sold their first camera in 1973. And, surprisingly, Kodak bought digital camera chips from GE for their Spectra Physics Division during this early time.

At the same time this was occurring, CRD was developing an advanced second generation process and new chip designs. This enabled the production of large camera chips at high yield. It was put in place at Orbit, a silicon foundry in Silicon Valley, California and is still used by Thermo Fisher Scientific, to make digital cameras for a wide range of applications.

Several elements of CRD's previously developed MOSFET technology became part of the revolutionary large area x-ray imagers invented and manufactured by GE, now utilized in hospitals world-wide. GE is now the number one supplier of x-ray sensors used in medical imaging.

Figure 3: The upgraded Semiconductor Processing Facility (SPF) in the basement of CRD (1975). Left to right: Richard Connery, Dale Brown, Paul McConnelee, Patrica Menditto, George Charney, Bebe Spodnewski, Mario Ghezzo. Absent are: Joseph Pimbley and Paul Chow.

GE's Process for VHSIC/VLSI Integrated Circuits

In 1980 a large semiconductor processing facility to house the most up-to-date and very expensive equipment would be built at CRD. This would be the place where VHSIC/VLSI chip processing development would happen. VHSIC chips were needed by our Armed Forces. VHSIC means very high speed IC and VLSI stands for very large scale integration.

Friends and VLSI project staff. Left to right: Mario Ghezzo, Chuck Becker, Bill Cady, Dale Brown, Kirby Vosburgh, Bill Engeler, Bernard Gorowitz (1985).

In addition, a very large facility in Raleigh, N.C. was constructed to house the new process for production purposes once CRD had finished its research and development work. This production facility was named The Microelectronics Center (MEC). Numerous chip designs were fabricated at MEC for GE aircraft engine controls, sonar systems and flight simulators. Because VHSIC chips were unavailable in Silicon Valley, California, Westinghouse utilized VHSIC chips fabricated at MEC for its F16 nose cone radar system, earning GE the VHSIC Pioneer Award from the U.S. Government in 1987.

Nevertheless, in 1988 GE decided to end MOSFET production of ICs and to sell all its semiconductor patents and manufacturing operations. Shortly thereafter GE's military component manufacturing operations were also closed. This may have been a mistake, because it eliminated any opportunity to embrace future new technologically based businesses inspired by military needs and contracts. GE's past history contains several examples of this; some are described in this document.

But all of the silicon MOSFET accomplishments – the knowledge and the devices - still survive because of their uniqueness. Unfortunately, few people know of the importance of Schenectady's contributions used by all silicon chip manufacturers.

The Beginning of a New Era—Silicon Carbide Electronics

The Silicon Carbide Flame Detector for Gas Turbines

In 1990 GE Aircraft Engines in Evendale, Ohio requested that CRD work with Cree Research in Raleigh North Carolina to develop a silicon carbide photodiode for flame detectors for military jet engines.

An optical flame detector is important because, if for any reason the flame doesn't light or goes out and fuel continues to flow and floods the combustion section of the engine, ignition could blow up the plane. The old type of flame detector (a Geiger Muller tube) could not detect ("see") the presence of the flame easily. GE Power Systems in Schenectady also became interested in the possibility of replacing the "old" type of flame detector with something much better in gas turbines.

The joint program with Cree, the first US producer of silicon carbide wafers, was successful and CRD began making silicon carbide photodiodes and prototype flame detectors in the new facility in Niskayuna. These prototypes were tested at utility power plants. All tests were so successful that one utility plant operator told GE to plan to remove all the "old" type detectors and replace them with silicon carbide units. Soon, thereafter, utility plant operators were calling us at CRD for presentation material for use at gas turbine user's meetings. Such a response cleared the way for a huge retrofit market, and GE Reuter Stokes, near Cleveland Ohio, became the production facility.

The silicon carbide group. Left to right: Vikram Krishnamurthy, Mario Ghezzo, James Kretchmer, Gerry Michon, Evan Downey, Bill Hennessy, Dale Brown (1994).

CRD, now GE Global Research Center, continues to make silicon carbide photodiodes for gas turbines at the rate of about 3000 per year and has delivered more than 80,000 chips to date (2017) to Reuter Stokes for an equal number of flame detectors.

So, when people of Schenectady read about a new installation of GE gas turbines, silicon carbide photodiodes fabricated at the GE Global Research Center in Niskayuna will be used.

In Closing

The work at GE on the research and development of silicon MOSFETs formed a basis for a range of new types of silicon devices for GE which are still in production by other companies because of their uniqueness. Silicon MOSFETs have revolutionized our world in having generated many products in daily use by millions of people. Hopefully the same will occur for new silicon carbide devices developed by GE research.

At GE: Progress is Our Most Important Product

Dr. Dale M. Brown, a graduate of the University of Michigan (B.S., M.S.) and Purdue University (Ph.D.) is a GE Coolidge Fellow, Institute of Electrical and Electronics Engineers Fellow and the recipient of The 1990 Electrochemical Electronics Division Award. He has been awarded numerous patents and published three books on semiconductor technology (one of these was translated into Russian) and has written numerous articles for technical journals covering the work described in this article (most can be found on the internet). The MOS interface study papers have received more than 500 citations. He joined GE in 1961, retired in 1997, but continued to work at GRC part time until 2011.