B. Jayant Baliga

Designing The Insulated-Gate Bipolar Transistor

Although most people aren't aware of insulated gate bipolar transistors (IGBTs), they do enjoy their benefits. From air conditioners to electric cars to stereo amplifiers, the modern world relies on the power semiconductor device and its efficient fast-switching capabilities. In fact, it's hard to imagine today's mobile, energy-conscious, and gadget-driven society without the IGBT.

While there are other power-switching approaches, the IGBT earns high marks for its inherent efficiency, which allows amplifiers, motors, and other devices to run on less power and at lower cost. IGBT modules also deliver high power density in a compact form—an important attribute in a world where space is almost always a critical design factor.

B. Jayant Baliga played a major role into bringing the IGBT into reality. While working at General Electric in the late 1970s, Baliga conceived the idea of a functional integration of metal-oxide-semiconductor (MOS) technology and bipolar physics—research that directly led to the IGBT's development.

The first step toward producing an operational IGBT was taken by a Japanese researcher named Yamagami, who in a 1968 Japanese patent application proposed a MOS controlling a positive-negative-positive-negative (PNPN) semiconductor device without regenerative action.

Other researchers made additional progress over the next decade. In advanced electronics research, though, multiple individuals and/or teams often make similar discoveries virtually simultaneously. This is exactly what happened during the latter stages of the IGBT's development.

As Baliga was closing in on creating a functional IGBT, RCA engineers Hans W. Becke and Carl F. Wheatley were designing a similar device. The unintentional competition between Baliga and Wheatley/Becke led to both sides being credited with the IGBT's invention by various experts and authorities, creating a debate that continues to this day.

THE ROAD TO SUCCESS

Baliga's road to engineering fame began in Madras (now Chennai), India, where he was born on April 28, 1948. His family soon moved to Jalahalli, then a small village located on the outskirts of Bangalore. In those days, long before Bangalore became one of the world's technology powerhouses, the region was best known for its lush natural environment.

"It was like being in the jungle," Baliga recalls. He remembers playing cricket and being reluctant to follow balls that rolled into the grass. "We found a cobra probably every month, if not every other month, in our yard."

Baliga credits his father, who was one of India's first electrical engineers in the days before independence from Britain, with inspiring his career. "He was the founding president of the India branch of the Institute of Radio Engineers, which later became the IEEE in India," Baliga says. Baliga's father played pivotal roles in the founding of the Indian television and electronics industries.

While his father initially encouraged him to follow a career in mechanical engineering, Baliga enrolled at the nearby Indian Institute of Technology, where he earned his B.Tech in 1969. After deciding to continue his studies in the U.S., Baliga received his master's degree and then a PhD at the Rensselaer Polytechnic Institute in 1974.

When an opportunity to join a power devices research group at GE presented itself in 1975, Baliga got on board, but not without some reservations. "I actually didn't want to work on power devices, because it was a field that was fairly mature at the time," he says. But Baliga quickly discovered that there were still plenty of boundaries ripe for pushing. "After I joined GE, I did a lot of innovative development, which actually... completely changed the field," he says.

When an advanced air conditioning system required a highly efficient and reliable power supply, a GE executive asked Baliga to look for a solution. "Bipolar transistors were failing and giving [GE] a lot of trouble," he recalls. Baliga then began investigating a newer type of bipolar transistor, the IGBT.

"Skeptics said the IGBT had a destructive mode of failure and would never succeed," he says. Many critics also questioned whether the device could ever made to switch quickly enough to be useful.

B. JAYANT BALIGA: NOTEWORTHY ACHIEVEMENTS

- Author of 12 books and more than 500 articles
- Holder of more than 100 U.S. Patents
- One of *Scientific American*'s "Eight Heroes of the Semiconductor Revolution"
- IEEE Fellow and National Academy of Engineering Member

Baliga proved the doubters wrong on both counts. In less than two months he produced a design for an IGBT that could handle real-world applications, describing it in a paper as "a V-groove MOSFET device with the drain region replaced by a p-type Anode region." Baliga had such confidence in his concept that the technology went straight from the lab into manufacturing in less than six months without first passing through a formal tech transfer process.

WHERE CREDIT IS DUE

The final stages of the IGBT's development are intertwined in dueling patents filed by two of the largest electronics companies of the era. "IGBT was independently conceived at GE by me and at RCA by Becke and Wheatley," Baliga says, noting that both companies pursued patents that were later awarded.

"To my knowledge, Becke/Wheatley received one patent on the IGBT concept. I have received more than 20 U.S. patents on the IGBT concept and improvements," he says *(see "Hans W. Becke And Carl F. Wheatley: Discovering The IGBT," p. 68)*.

Yet Baliga notes that the matter is far more complex than simply counting the number of issued patents. "I published a paper on September 27,1979, in Electronics Letters, titled 'Enhancement and Depletion Mode Vertical Channel MOS Gated Thyristors,' in which I describe the discovery of the IGBT mode of operation."

The paper includes this statement: "This device structure can be seen to be similar to that of V-groove MOSFET devices but with the drain region of the MOSFET being replaced by a p-type anode region."

"My paper provided experimental results on fabricated devices showing reduction to practice," Baliga says. The paper has a submission date of August 28, 1979, "demonstrating that I had conceived the idea and reduced it to practice before August 1979," Baliga says.

The Becke/Wheatley patent, meanwhile, has a filing date of March 25, 1980. "Their patent fails to reference my Electronics Letter paper as prior art, even though my paper—published six months before their patent application filing date—describes their claimed invention, including its title."

Baliga alleges that this fact is sufficient to invalidate the Becke/Wheatley patent. "It is therefore difficult for me to accept credit for the invention of the IGBT being attributed to Becke/Wheatley," Baliga says.

Baliga acknowledges that after he published his paper some power device engineers were skeptical that his concept would work. Doubts were raised by the fact the structure has a four-layer thyristor region that can latch up and destroy the device. "They also felt that the device would have very limited use because of a slow switching speed," Baliga says.

Baliga says he worked on solving these issues while at GE, publishing a series of technical articles between 1980 and 1985 that showed how to overcome the obstacles. "I also championed the introduction of the first IGBT product by GE in 1982-83 and its use in numerous applications, such as appliance controls, motor drives, lighting, and robotics," Baliga says.

In contrast, Baliga notes, neither Becke nor Wheatley seems to have pursued the IGBT idea after their patent application. "Even the first and any subsequent papers by RCA on the IGBT do not include Becke and Wheatley among the authors," Baliga says. "The success of an idea is not related to just its invention, but on all the follow-up required to make it into a viable technology that has an impact on society."

The question of exactly who invented the IGBT is best left to future historians. Yet it remains undeniable that Baliga's vision and leadership played a critical role in moving the IGBT from a paper-based concept to a viable product with many practical applications. Baliga has received numerous honors from the IEEE, including the Newell Award from the Power Electronics Society, the Ebers Award from the Electron Devices Society, and the Lamme Medal from the IEEE Board of Governors. ee