Transistors: How an Electrical Component Changed the World.

05 August 2019
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The 20th century was a time of vast technological innovation that gave humanity airplanes, nuclear power, automobiles, antibiotics, televisions, microwaves, computers, and more. However, some inventions have implications that have and will continue to transform humanity forever. The transistor is such an invention, because of its versatility that has led to countless other inventions. B Fitzgerald, author of *Transistors: Types, Materials and Applications* explains that, "Transistors play a central role in many electronic circuits, where they usually function as either a switch or an amplifier" (2010). Transistors are electrical components used in circuits, and without them many electrical devices would either be significantly larger or would have never been invented. Thus, the most important invention of modern times is arguably the transistor. Without the invent of the transistor humanity would be void of cell phones, personal computers, the internet, and many other useful inventions that the people of today rely on regularly. Enter the historical events behind the electrical component that transformed the world, and why was it such a revolutionary idea.

To begin, the who and why of the transistor. The invention of the transistor is credited to three men, John Bardeen, Walter Brattain, and William Shockley as S. Begley explained in a 1997 Newsweek article titled "The transistor." These men worked for the company called Bell Telephone Laboratories. A video produced by Bell Labs titled "Genesis of the Transistor" explains their intentions for wanting to create the electrical component that is now called a transistor, "After the war, Bell Telephone Laboratories intensified the investigation of semiconductors with the hope for understanding…understanding might bring control, and control was the key to further use." (Bell Laboratories, 1965). Bell Labs was a telecommunication company, so research into new radio communication technologies would be advantageous for the company, because "vacuum tubes were too bulky, unreliable and inefficient to support what AT&T [Bell Labs] expected to be a boom in demand for telecommunications after the end of World War II" (Begley, 1997). The initial research was for a device that could efficiently amplify the quality of long-distance phone calls. In 1947, their first transistor successfully amplified an electrical signal (Bell Laboratories, 1965). Prior to their success, Shockley discovered that it should be possible to control the quantity of electrons near a semiconductor by using an electric field to move the electrons out of the semiconductor. Bardeen acknowledged that the electric field was pulling on the electrons but discovered that the electrons were trapped in the semiconductor. Brattain had a hunch that the use of electrolytes could potentially solve this problem by releasing the trapped electrons in the semiconductor materials such as germanium or silicon (Bell Laboratories, 1965). After many failed experiments, the first device to successfully amplify electrical current used a wax-insulated tungsten wire that went through a drop of water, into a piece of germanium, and another metal wire made contact directly with the water electrolytes. Voltage was applied between the waxed wire and the germanium, and another voltage was applied between the electrolytes and the germanium (Bell Laboratories,

1965). This difference in voltage caused an increase of power in the electrolytes that were about 10% higher than the input supply (Begley, 1997).

Furthermore, as development continued, water as an electrolyte raised concerns about reliability due to quick evaporation, so it was replaced with glycol borate. Researchers then determined that the electrolytes of the experiments were hindering its ability to reach maximum power amplification, so it was replaced with a piece of gold. On 16 December 1947 their final experiment became the first transistor that amplified the input power by 450 percent. (Begley, 1997). This was a level of amplification that surpassed the capabilities of vacuum tubes. Although the transistors did not have a practical application upon creation, further improvements in the transistor would change the world forever due to a better understanding of how electrons behave within atoms of a semiconductor device.

The earliest transistors were amplifiers and were not devices of practicality. They needed longevity, reliability, and affordability in production. Bell Labs first production model was the point-contact transistor (Bell Laboratories, 1965). In 1951, Shockley's concept of a junction transistor was created, and was the beginning of transistors as switches. These switches work by sandwiching a slice of semiconductor material with an excess of positively charged holes between two slices of semiconductors with an excess of negative electrons (Begley, 1997). When a certain voltage is applied to the middle layer the switch opens, and when the voltage is removed the switch closes. The terms open and closed are used metaphorically since the only moving parts are individual electrons. A few years later the low-frequency alloy transistor came to existence. Then, the high-frequency, high-speed diffused-base transistor (Bell Laboratories, 1965). These are just a few of the early transistor types, but now there exists many more. Following the widespread adoption of transistors, the vacuum tube had become obsolete. As time progressed transistor technology became more efficient and shrank in size. The earliest transistors were about the size of a one's palm and were dubbed unpractical, but today, in 2019, transistors are used in computers as switches, and each transistor is now commonly measured at a 10 nano-meters width. In the future transistors could be much smaller. Researchers at Karlsruhe Institute of Technology (KIT) are experimenting with single-atom transistors that act as quantum electrical switches (Xie, Peukert, & Obermair, 2019).

Although some transistors are used to amplify power in a circuit, most are more commonly used as electrical switches with no moving parts. Many transistors are made of silicon and injected with elements such as boron or phosphorus. These elements are added into the silicon to create the previously mentioned semiconductor sandwich in the transistor so that the current of electrons can be high or low depending on the voltage applied to the base portion of the transistor. This allows the transistor to act as a gate that either allows or prevents the flow of electrical current (Veritasium, 2013). When combined, multiple transistors can represent data using Boolean logic. Transistors have two states. They either allow electrical current or they do not; thus, transistors are binary. Their state can be represented as ones or zeros, and when the states of several transistors are combined, they lay the foundation of modern computing (TED-Ed, 2016). Transistors can be packed close together on microchips that act as the metaphorical brain of a computer. These microchips use thousands to billions of transistor switches to digitally represent complex data such as numbers, letters, words, instructions, photographs, audio, and

video in a computing system. This ability to combine billions of transistors is what makes them such an important and versatile invention.

Prior to transistors, computers relied on vacuum tubes which were large, bulky, power hungry, and unreliable (Begley, 1997). Transistors also replaced the vacuum tubes used in radios, long-distance communications, and other electrical devices. Thus, transistors reduced the size and feasibility of many electronics and computers (TED-Ed, 2016). Transistors have changed the way people live, because this one invention led to the invention of copious other inventions such as the loudspeaker, the portable hearing-aid, the microchip, the CPU, the calculator, the cell phone, the personal computer, and even more revolutionarily, the internet.

The internet has the potential to create a communication tunnel between every single human living on planet Earth. Not only does the internet connect everyone, but it allows information to be shared in the blink of an eye. No longer do people have to wait weeks for mail, nor do people have to manually search a library for information. All of this is possible because of the computers running the internet, and those computers could not have existed at the scale that it exists today without the invention of the transistor.

Overall, the transistor is a simple electrical component created by John Bardeen, Walter Brattain, and William Shockley at Bell Laboratories in 1947. Since then, the transistor has been developed into newer versions and can be used as an electrical amplifier or a switch. Its versatility has led to limitless inventions, and most modern-day electronic devices cannot exist without transistors. Looking into the future transistors will get smaller, and computers will become more powerful. In the present computers have simplified how we interact with data and with each other, but with additional advancements in computer robotics and software, artificial intelligence (A.I.) will not only sort data, but it will also analyze it as well. A.I. is not yet entirely understood, but it has the potential to change the world in the same way that the personal computer, and the internet has. Thus, the influence of the transistor has been vast, but the full potential of the transistor has yet to be fulfilled.

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