# FINFET TECHNOLOGY: A COMPREHENSIVE ANALYSIS AND LOOK INTO PROSPECTS

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***Abstract*—Transistors are the foundation for electronics and have been continually modified in design throughout the years. Each new architecture provides advancements in performance and speed, pushing the capabilities of everyday technologies used by society. This paper explores such designs and analyzes their advantages, with the focus on fin shaped field-effect-transistors or FinFETs. A background into transistors and the first designs is provided for context and comparisons. Then specific advantages in performance, power consumption, and size are explored. The innovations brought by FinFETs are built upon previous techniques, and so through historical references prospects are determined for how these transistors will continue to scale and outperform their predecessors. Designs may either continue to be iteratively modified, or new techniques like quantum computing may form and take over the field. Either way, the field is continuously advancing to support growing technologies.**

**Keywords: Transistors, architecture, FinFET, performance, power efficiency, MOSFET, BJT, quantum computing, prospects.**

## I. Introduction

Technology is everywhere. Smartphones are pouched in virtually everyone's pocket and nearly every household in America has a computer. This percentage is increasing every year [1]. From tablets to smart-watches to TVs and voice-assistants, electronics are ubiquitous. Even today's cars implement self-driving capabilities, all thanks to the powerful computer chips housed inside. Whether it be school, work, or business; almost every field incorporates and benefits from some use of electronics. There is no denying the incredible presence and functionality provided through everyday life. What is most surprising about electronics is the continued exponential growth driven from research and engineering. Since the 1960s, transistors have continued to shrink in both size and production costs. This has led to faster chips and components throughout the years, providing consistent advancements in the field. This trend is known as Moore's Law and is well often mentioned with the historical progress of technology [2].

This paper investigates the most recent transistor technology, FinFETs. This 3D multi-gate design is responsible for today's computer processors. To understand how the advances provided by this design, it is integral to analyze the previous architectures that the technology was built on. From there, specific strengths are explored, such as performance and power consumption. Lastly, prospects can be theorized based on previous designs and historical evidence.

### A. Transistor

A transistor is simply a switch. When a voltage or current is applied at its gate, the transistor allows the current to flow between its gates. Otherwise, the path is blocked, and no flow occurs. This process can be thought of like water flowing from a faucet to a drain, where the faucet knob controls the flow of water. Whereas a transistor controls the follow of electrons.

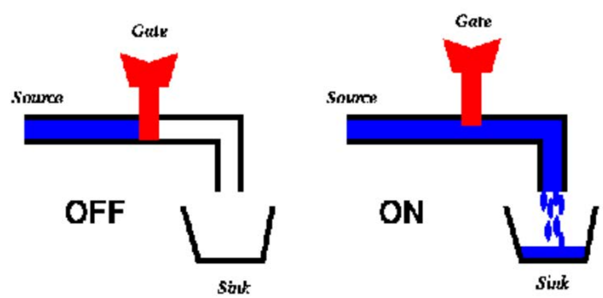


Fig. 1: Faucet analogy: The gate controls the flow of water from the source to the sink [3].

Before transistors, large vacuum tubes were used to control electric current. The first tube was created in 1904 by electrical engineer John Fleming and was used for forty years; mostly in amplifying radio technology and long-distance telephony. The problems that arose with these tubes were that they were large, fragile, and consumed a substantial amount of power. In the search for a better alternative, a few research scientists, most namely William Shockley, developed a model that achieved the same purpose but consumed less power and was much smaller [4]. Known as the point-contact transistor, it quickly evolved into the bipolar junction version or BJT. This version was not only easier to manufacture but it was more rugged, so it became the new 'vacuum tube'. And so BJTs were mass-produced and became the main source for radio technology and the first computers.

### B. BJT

As described by its name, a bipolar junction transistor operates through the two junctions that make up its structure. Figure 2 displays this structure. Combining an N-type and P-type region creates a junction, also known as a diode. These regions are created by doping a material, usually silicon, with impurities to create electron receptive areas. A diode is simply controlling the current so that it can only flow in one direction and not in reverse, usually from P-type to N-type. By combing the two diodes together, this effectively blocks the current flow within the transistor. The P-type region then acts as a gate that can control the flow. This is how it operates in its default state, it is designed to block current when there is nothing applied to the gate.

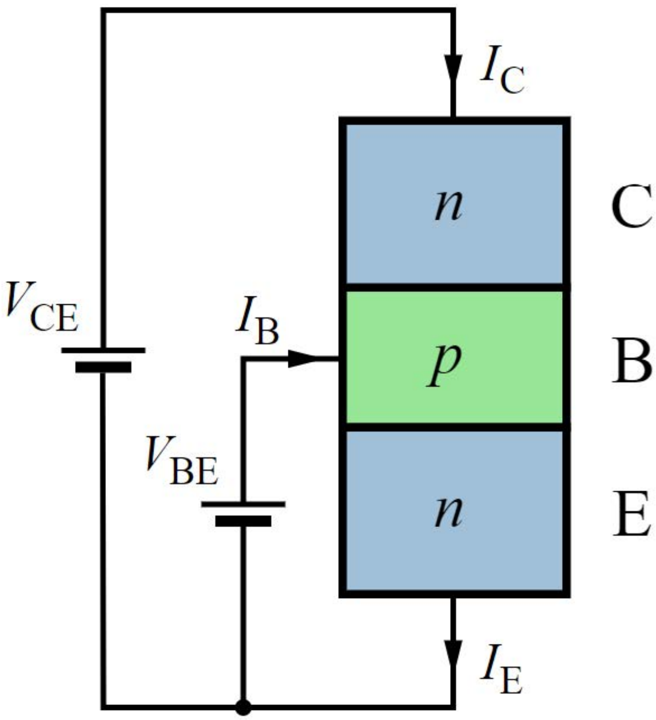


Fig. 2: NPN transistor structure [5].

When a current is applied to the base terminal (middle P-type region), it reduces the positive energy and allows the flow between the two N-type regions. Based on the figure, this can be thought of like the green region turning blue, making all three regions the same and creating a path for the current. All transistors function from this idea of bridging the gap between two sides through some gate controller.

From 1948, BJTs were found in electronics like hearing aids and telephone exchanges. The transistors improved existing technologies while also creating new ones. For instance, digital watches came around only after BJTs invention, which provided circuits to take up less space than they would have, and so fit on the wrist of a hand [6]. Not only were transistors small, but they were easily sustainable. Transistors are made from silicon, the most abundant element next to oxygen on earth [7]. Most of the silicon is found in sand, making up around 25.7% of the earth's crust. Despite having substantial resources, the BJT was still a relatively bulky device, making it difficult to produce at a large scale and thus limited its application. At that time, there were alternative designs theorized as possible replacements, like field-effect-transistors (FET), but there were issues in the design working properly. Eventually, engineer Mohamed Atalla proposed a new method for semiconductor device fabrication, resulting in the creation of the metal-oxide-semiconductor (MOSFET) and bringing in the new age. [8].

### *C. MOSFET*

The MOSFET transistor was invented in 1969 by Atalla and Dawon Kahng in the same laboratory that the junction transistor was designed [9]. Although the new design was similar, it proved longer to develop and become successful. Early in the industry, companies focused on BJTs because they worked reliably despite their bulk and difficulty to manufacture on a large scale. On the other hand, FET designs had worse issues, so many researchers had given up and switched focus to BJT technology. However, once Atalla and Kahng overcame the flaws through their unique methodology, MOS technology began to grow. The transistors were compact and as a result easier to mass-produce. Initially, they were slower and less reliable than BJTs [10], but over time they became faster and took over the industry, creating a revolution in electronic technology and fueling economic growth.

The MOSFET fundamentally works in the same fashion as BJT. There are N-type and P-type divisions, and there is a gate that controls the flow between the two ends. Rather than sending an electrical current, MOSFETs work by applying a voltage at the gate, referred to as the base in a BJT. This can be thought of as providing an electromagnetic pull, instead of some flow of electrons. This is the sole difference between the two designs. The voltage difference creates an electric field near the gate, creating a pull and bridging the gap between the two sides. Since this design does not require any external current, it uses much less power in comparison to BJTs.

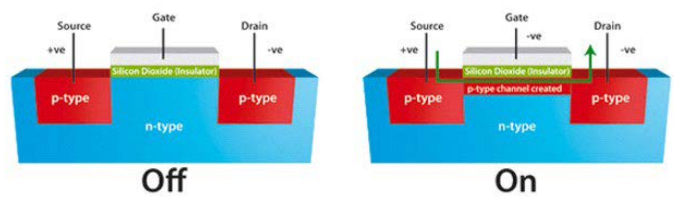


Fig. 3: MOSFET Design: On and off states [10].

Historically, MOSFETs did not catch on right away. Like with most new things, the first versions were slower and larger than later versions. BJTs had been used for such a long time, so naturally, the technology had progressed to its peak performance. Once researchers saw the potential in the new MOSFET design, they realigned their focus and quickly brought the capabilities up to speed. In 1971, the first single-chip processor, the Intel 4004, was created using this technology [11]. This increased the commercialization of electronics like radios, pocket calculators, and especially personal home computers (PCs). This was most notable with the Altair 8800. Put out into the market in 1975, this PC found the sweet spot in terms of pricing and performance [12]. From this point onward, MOSFETs were the prime choice and dominated the market.