Patent Application for "Miniaturized Electronic Circuits"

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Summary Overview

With the development, in 1947, of the transistor to replace the vacuum tube, the push for miniaturization of electronic circuits began in earnest. Many individuals, companies, and research facilities were involved in trying to build smaller, reliable circuits. Several achieved some success in developing circuits for very specific applications. During the summer of 1958, Jack Kilby envisioned a new approach to the miniaturization of electronic circuits using one wafer of germanium as the foundation for all parts of the system. By September 1958, a working prototype was demonstrated to the satisfaction of others in the Texas Instruments company. This resulted in the filing of a patent application. The difference between Kilby's circuit and others that had been created in the previous decade was that Kilby's was a general type of circuit that could be used for almost any electronic application. It ushered in the era of inexpensive electronic devices, including personal computers.

Defining Moment

The Cold War drove most scientific and technological development in the 1950s. The United States and the Soviet Union were attempting to outdo each other militarily and for bragging rights in other areas. The US defense establishment was eagerly seeking ways to make electronic systems smaller and more reliable, as a part of the arms race. American industry was also seeking more reliable systems to assist in their work. A general-purpose miniaturized integrated electronic circuit was key for either to take giant strides toward their goals. Substantial sums of money were being invested by the federal government, with limited success. With the Soviet Union launching the first satellite into orbit in October 1957, the pressure increased for American industry to create the means to once again take the technological lead in the rivalry with the Soviet Union. Jack Kilby desired to work on the problem of creating a reliable miniaturized electronic circuit, and for that reason, he left his job in Milwaukee and accepted an offer from Texas Instruments in early 1958.

Kilby was not the only person working on this problem. Nor, as it happens, was he the only one with the insight and skills to create an integrated circuit. Kilby's application (germanium and fly-wire based) beat a similar one (using silicon and with slightly different connections) filed by Robert Noyce (co-founder of Intel) by a few months, even though eventually Noyce was awarded his patent prior to Kilby. However, Kilby did create his integrated circuit prior to Noyce, and as such, he has been recognized as the first person to develop an integrated circuit. While the patents were supposed to demonstrate legal ownership of an idea, process, or product, Texas Instruments and Fairchild Semiconductor were locked in legal battles until they agreed to a settlement in 1966. Meanwhile, outside the courtroom, as a result of Kilby's work and the integrated circuit he produced, the world was transformed.

Looking back more than half a century, it is difficult for many people to understand what everyday life was like without the integrated circuit. Most of the microprocessor devices that people take for granted today were not conceivable in the 1950s; the only comparable pieces of equipment were large vacuum-tube based technologies. Thus, this simple patent application, a blend of scientific and legalist writing, heralded a major shift in everything from space missions to phone communication. Although the manufacturing process for Noyce's design was simpler than that of Kilby's, that does not take away from the contribution that Kilby made through his integrated design.

Author Biography

Jack St. Clair Kilby (1923–2005), the son of Hubert and Vina Freitag Kilby, grew up in Great Bend, Kansas, where his father ran the electric utility. Events in the 1930s led Jack to his interest in electronics, which enabled him to work as a radio technician in the Army during World War II. He graduated from the University of Illinois and then the University of Wisconsin – Milwaukee, the latter while he worked at Centralab. In 1958, he was hired by Texas Instruments, with the agreement that he could work on the problem of creating miniature electronic circuits. That summer, he began work that led to his being awarded the Nobel Prize in 2000. In addition to the integrated circuit, he was a co-inventor of the handheld calculator and thermal printers. Ultimately, he held nine patents for his research in electronics and received numerous prizes. In 1948, he married Barbara Annegers, and they had two daughters.

HISTORICAL DOCUMENT: Application for "Miniaturized Electronic Circuits"

United States Patent 3,138,743
MINIATURIZED ELECTRONIC CIRCUITS
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This invention relates to miniature electronic circuits, and more particularly to unique integrated electronic circuits fabricated from semiconductor material.

Many methods and techniques for miniaturizing electronic circuits have been proposed in the past. At first, most of the effort was spent upon reducing the size of the components and packing them more closely together. Work directed toward reducing component size is still going on but has nearly reached a limit. Other efforts have been made to reduce the size of electronic circuits such as by eliminating the protective coverings from components, by using more or less conventional techniques to form components on a single substrate, and by providing the components with a uniform size and shape to permit closer spacings in the circuit packaging therefor.

All of these methods and techniques require a very large number and variety of operations in fabricating a complete circuit. For example, of all circuit components, resistors are usually considered the most simple to form, but when adapted for miniaturization by conventional techniques, fabrication requires at least the following steps:

(a) Formation of the substrate.
(b) Preparation of the substrate.
(c) Application of terminations.
(d) Preparation of resistor material.
(e) Application of the resistor material.
(f) Heat treatment of the resistor material.
(g) Protection or stabilization of the resistor.

Capacitors, transistors, and diodes when adapted for miniaturization each require at least as many steps in the fabrication thereof. Unfortunately, many of the steps required are not compatible. A treatment that is desirable for the protection of a resistor may damage another element, such as a capacitor or transistor, and as the size of the complete circuit is reduced, such conflicting treatments, or interactions, become of increasing importance. Interactions may be minimized by forming the components separately and then assembling them into a complete package, but the very act of assembly may cause damage to the more sensitive components.

Because of the large number of operations required, control over miniaturized circuit fabrication becomes very difficult. To illustrate, many raw materials must be evaluated and controlled even though they may not be well understood. Further, many testing operations are required and, even though a high yield may be obtained for each operation, so many operations are required that the over-all yield is often quite low. In service, the reliability of a circuit produced by methods of such complexity may also be quite low due to the tremendous number of controls required. Additionally, the separate formation of individual components requires individual terminations for each component. These terminations may eventually become as small as a dot of conductive paint. However, they still account for a large fraction of the usable area or volume of the circuit and may become an additional cause of circuit failure or rejection due to misalignment.

In contrast to the approaches to miniaturization that have been made in the past, the present invention has resulted from a new and totally different concept for miniaturization. Radically departing from the teachings of the art, it is proposed by the invention that miniaturization can best be attained by use of as few materials and operations as possible. In accordance with the principles of the invention, the ultimate in circuit miniaturization is attained using only one material for all circuit elements and a limited number of compatible process steps for the production thereof.

The above is accomplished by the present invention by utilizing a body of semiconductor material exhibiting one type of conductivity, either n-type or p-type, and having formed therein a diffused region or regions of appropriate conductivity type to form a p-n junction between such region or regions and the semiconductor body or, as the case may be, between diffused regions. According to the principles of this invention, all components of an entire electronic circuit are fabricated within the body so characterized by adapting the novel techniques to be described in detail hereinafter. It is to be noted that all components of the circuit are integrated into the body of semiconductor material and constitute portions thereof.

In a more specific conception of the invention, all components of an electronic circuit are formed in or near one surface of a relatively thin semiconductor wafer characterized by a diffused p-n junction or junctions. Of importance to this invention is the concept of shaping. This shaping concept makes it possible in a circuit to obtain the necessary isolation between components and to define the components or, stated differently, to limit the area which is utilized for a given component. Shaping may be accomplished in a given circuit in one or more of several different ways. These various ways include actual removal of portions of the semiconductor material, specialized configurations of the semiconductor material such as long and narrow, L-shaped, U-shaped, etc., selective conversion of intrinsic semiconductor material by diffusion of impurities thereinto to provide low resistivity paths for current flow, and selective conversion of semiconductor material of one conductivity type to conductivity of the opposite type wherein the p-n junction thereby formed acts as a barrier to current flow. In any event, the effect of shaping is to direct and/or confine paths for current flow thus permitting the fabrication of circuits which could not otherwise be obtained in a single wafer of semiconductor material. As a result, the final circuit is arranged in essentially planar form. It is possible to shape the wafer during processing and to produce by diffusion the various circuit elements in a desired and proper relationship. Certain of the resistor and capacitor components described herein have utility and novelty in and of themselves although they are completely adaptable to and perhaps find their greatest utility as integral parts of the semiconductor electronic circuit hereof.

It is, therefore, a principal object of this invention to provide a novel miniaturized electronic circuit fabricated from a body of semiconductor material containing a diffused p-n junction wherein all components of the electronic circuit are completely integrated into the body of semiconductor material.

It is another principal object of this invention to produce desired circuits by appropriately shaping a wafer of semiconductor material to obtain the necessary isolation between components thereof and to define the areas utilized by such components.

It is a further object of this invention to provide a unique miniaturized electronic circuit fabricated as described whereby the resulting electronic circuit will be substantially smaller, more compact, and simpler than circuit packages heretofore developed using known techniques.

It is a still further object of this invention to provide novel miniaturized electronic circuits fabricated as described above which involve less processing than techniques heretofore used for this purpose.

It is a primary object of the invention to provide a miniaturized electronic circuit wherein the active and passive circuit components are integrated within a body of semiconductor material, the junctions of such components being near and/or extending to one face of the body, with components being spaced or electrically separated from one another as necessary in the circuit. These features permit a versatility in design of integrated circuits not heretofore available.

Document Analysis

The history of electronic technology in the 1950s is mainly one of incremental changes. With the development of the transistor in 1947 to replace the much larger vacuum tube, the focus of development became one of building smaller components to use with the transistors. However, by the end of the decade, it was becoming clear that there were limits in how far individual components could shrink and still be reliable. The complexity of the components and how they could be connected with one another caused constant failures in the experimental circuits. Some companies attempted to get around this by packaging electronic components together into a single unit that plugged into other components, for ease in replacing what seemed to be a continuous series of failing components. Kilby examined the problem and decided to attempt a radical change in the technology, rather than just another incremental shrinking, or repackaging, of components. He proposed and built a system that had more than one component on the same foundation material: an integrated circuit. He based his circuit on a wafer-thin slice of the semiconductor material germanium. That construction simplified the component and added reliability, in addition to causing a tremendous decrease in size.

In many ways, therefore, Kilby's contribution seemed to amount to a simplification of an existing technology. There was, however, more to it than that, including advances in understanding the electromagnetic properties of materials used in the process and improvements to the electronic components that became part of the circuit. Kilby combined his ideas and knowledge to develop a circuit that was "integrated into the body of semiconductor material and constitute portions thereof." Rather than building all of the components separately, he built them as a unit on a single wafer. His integrated circuit design would "permit a versatility in design of integrated circuits not heretofore available." Thus, it was no longer necessary to build separate circuits for each type of electronic device; integrated circuits could henceforth be used for a variety of purposes. Kilby understood that the new circuits were easier to build and would eventually be much less expensive. Everything that people had been seeking from developers working on new systems in electronics was present in this integrated circuit: it was smaller, more reliable, cheaper, and able to operate in a variety of systems.

Essential Themes

Although Kilby's description, here—part of a larger patent application package—does not contain any great philosophical insights, or visions of a digital future, it ultimately contributes to both. The world was transformed by Kilby's (and Noyce's) understanding that electrical components do not have to be separate things. If a circuit is to work in electronics, it must be a single continuum. Thus, the combined entities have a unity of purpose, and Kilby understood that, with the proper materials, there was no reason why such unity of purpose could not be achieved. In this case, Kilby built an integrated circuit having one transistor, one capacitor, and several resistors on a piece of germanium the size of a person's little finger. This might not represent a "miniaturized" integrated circuit by twenty-first-century standards, but it was a radical break from the past at the time. Kilby's work, as stated in the patent application, reflected the philosophical (and engineering) insight that diverse elements can be brought together to achieve a unity of purpose, rather than assuming that the various components must remain separate.

Because of the integrated circuit, all things that depend on the computational power of personal computers have been made possible. While most people were watching the political struggles of the 1950s to ascertain the direction in which the future might be headed, from a laboratory in Dallas came something that perhaps has equal claim to helping lay the foundation for a new world order. For better or for worse, computers of all varieties are now part of almost everyone's lives. With the integrated circuit, not only could computers be made smaller but the technology could be regarded as more reliable. The concepts contained in this 1959 patent application are now a part of the worldview of billions of people around the world, a worldview where reliability and convenience of computer technology is expected.

—Donald A. Watt, PhD

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