AUGUST 1959

APPLICATION NOTES

CLASSIFICATION OF JUNCTION TRANSISTORS

This TI Application Note classifies transistors in four major categories: grown, alloy, electrochemical, and diffusion — according to the technique used to fabricate the *emitter region*. In this classification scheme the *diffusion* category includes only one of many types of transistors made by diffusion; other types of transistors made by diffusion are listed under alloy, grown, and electrochemical categories.

CLASSICAL TECHNIQUES

The first junction transistors, in 1951, were of the *grown-junction* type.[1, 2] This type of transistor consists of a rectangular bar cut from a germanium crystal that has been grown from a melt to which suitable impurities have been added. Emitter and collector contacts then are made to each end of the bar while the base contact is made to the base region, generally located approximately midway between the two ends, as shown in Fig. 1.

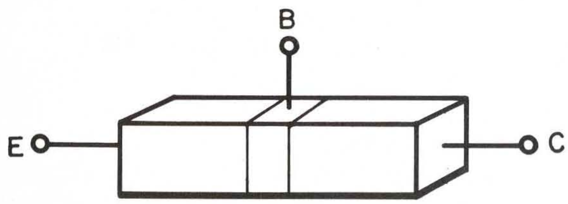

Fig. 1. Grown-Junction Transistor

Shortly after the *grown-junction* technique was introduced, the *alloy* technique[3] was developed, in which small dots of indium were fused, or alloyed, into opposite sides of a germanium wafer of suitable conductivity. (See Fig. 2.) Emitter and collector contacts then are made to each of the dots, and the base contact is made to the wafer. Silicon transistors also can be made by each of these two techniques.

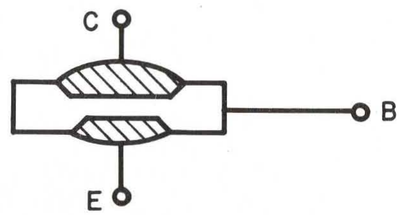

Fig. 2. Alloy-Junction Transistor

Attempts to reduce the dimensions of alloy transistors for high-frequency use led to the introduction of electrochemical etching and plating techniques and subsequently to the development of the *surface-barrier* transistor.[4] Physically the construction of this type transistor is very similar to that of the alloy transistor, except that depressions are etched into the wafer before the collector and emitter dots are added, and the latter are generally much smaller than in the conventional *alloy* transistor.

crystal is drawn from the melt. The crystal contains a predominance of p-type impurities during one stage of the growth cycle and a predominance of n-type impurities during the other stage, resulting in a crystal from which n-p-n transistors can be cut.

Melt-Back Transistors — A variation of the rate-grown transistor in which the rate growing is performed on a very small physical scale.[7] This results in a lower thermal time constant for the crystal growing system, producing thinner base regions and hence higher-frequency transistors.

Melt-Quench Transistors — Very similar to melt-back transistor described above.[8]

Grown-Diffused Transistors — A transistor made by combining diffusion techniques and the double-doped process.[9] In this case, suitable n- and p-type impurities are added simultaneously to the melt while the crystal is being grown. Subsequently, the base region is formed by diffusion during the continued growth of the crystal.

Melt-Back Diffused Transistors — A transistor made by combining diffusion techniques and the melt-back process, analogous to the combination of the grown and diffusion techniques described above for grown-diffused transistors.[10, 11, 12] In this case, however, the impurities are added to the transistor bar by the *melt-back* process, and then the transistor bar is baked to form the base region by diffusion.

ALLOY-JUNCTION TRANSISTORS (Fig. 2)

Alloy or Fused Transistors — Consists of a semiconductor wafer of p- or n-type material with two dots containing p- or n-type impurities fused or alloyed into opposite sides of the wafer to provide emitter and base junctions, while the base region comprises the original semiconductor wafer.[3, 13, 14]

DRIFT TRANSISTORS

1. In scientific literature, a *drift* transistor is a type which has a non-uniform, or graded base region that provides a better high-frequency response than a similar uniform-base structure.[15]
2. *Drift* transistor, *commercial:* A trade name for what is termed here as a diffused-alloy transistor.[16]

Diffused-Alloy Transistors — A transistor made by combining diffusion and alloy techniques. The semiconductor wafer first is subjected to a gaseous diffusion to produce the non-uniform base region, and then alloy junctions are formed as in a conventional *alloy* transistor.[16] An intrinsic region transistor *e.g.*, p-n-i-p, can be made by this technique by starting with a semiconductor wafer of essentially intrinsic conductivity.

Alloy-Diffused Transistors — Another type transistor made by combining diffusion and alloy techniques. In this case, the alloy dot material contains *both* n- and p-type impurities. Then the emitter-base junction is formed by the conventional alloy process, while the base region and collector-base junction are formed by diffusion. The collector region comprises the original semiconductor wafer.[17, 18] Alternatively, if the original wafer is of the same conductivity type as the base region, then the emitter-base junction and the base region can be formed as just described, while the collector junction can be formed by the conventional *alloy* process.[19] In this case, as in the case of the diffused-alloy transistor, an intrinsic region can be included between base and collector.

Diffused-Base Transistors (Fig. 3) — Another type transistor made by combining diffusion and alloy techniques. In this case, a non-uniform base region and the collector-base junction are formed by gaseous diffusion into a semiconductor wafer that constitutes the collector region. Then the emitter-base junction is formed by a conventional alloy junction on the base side of the diffused wafer.[20, 21, 22, 23]

ELECTROCHEMICALLY ETCHED AND PLATED TRANSISTORS (Fig. 2)

Surface-Barrier Transistors (SBT) — Consists of a wafer of semiconductor material into which depressions have been etched on opposite sides of the wafer by electrochemical techniques.[4] The emitter- and collector-base "junctions," or metal-semiconductor contacts, are then formed by electroplating a suitable metal on the semiconductor in the etched depressions, while the original wafer constitutes the base region.

Micro-Alloy Transistors (MAT) — A variation of the *surface-barrier* transistor described above in which suitable n- or p-type impurities are first plated in the etched depressions and then alloyed into the p- or n-type semiconductor wafer.[24, 25, 26]

Micro-Alloy Diffused Transistors (MADT) — A transistor made by incorporating diffusion techniques with the *micro-alloy* transistor construction described above. In this case the semiconductor wafer is subjected to gaseous diffusion to provide a non-uniform base region prior to the electrochemical plating process.[26, 27, 28]

DIFFUSION TRANSISTORS (Fig. 3)

Diffused-Emitter and -Base or Double-Diffused Transistors — Consists of a semiconductor wafer which has been subjected to gaseous diffusion of both n- and p-type impurities to form two p-n junctions in the original semiconductor material.[29, 30] An intrinsic-region transistor, *e.g.*, p-n-i-p, can be made by a variation of this process.[31]

ACKNOWLEDGMENT

The material presented herein by no means describes original work. Other semiconductor-device workers have categorized transistors in schemes similar to that described above. In particular, R. N. Hall has written an excellent survey paper[32] describing the methods used to fabricate transistors in terms of the metallurgy of p-n junctions, giving considerable more detail than has been presented. Also, P. Kaufmann and G. Freedman have recently published a paper[33] describing and categorizing various methods of transistor fabrication. The concept of the chart shown in Fig. 4 originated with Harry L. Owens.

In each of these three classical methods of fabrication the three regions of the transistor — emitter, base, and collector — generally are of uniform resistivity.

DIFFUSION TECHNIQUES

Solid-state diffusion techniques have provided a new junction-transistor-fabrication method which has a high degree of control. Moreover, with diffusion techniques it is possible to form non-uniform emitter, base, and collector regions which provide better transistor electrical characteristics than are obtainable from the classical designs of uniform-resistivity regions.

Diffusion of impurities can take place from within the crystal or through the surface from an external source; the latter process is generally termed "gaseous diffusion." It also is possible to combine diffusion techniques with one of the classical techniques described above. For example, a non-uniform base region can be obtained by diffusion, while the emitter and collector junctions can be made by the alloy technique. Alternatively, one p-n junction can be formed by diffusion and the other by one of the classical techniques, or both p-n junctions can be formed by diffusion.

As a result of this flexibility, transistors made by diffusion may assume any one of several physical appearances, some of which are identical to corresponding classical structures. On the other hand, many types of diffusion transistors are of the "mesa" construction (Fig. 3a), in which the semiconductor wafer is etched down in steps so that the base and emitter regions remain as plateaus above the collector region. Both rectangular and circular cross sections have been employed, as illustrated by Fig . 3b and 3c, respectively.

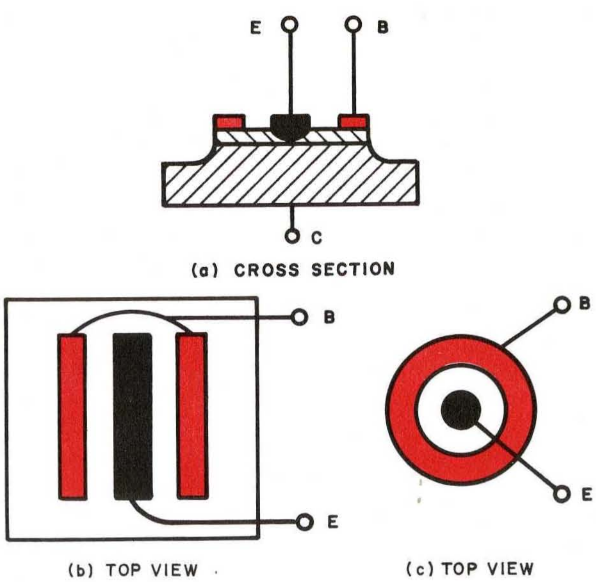

Fig. 3. Mesa-Type Diffused-Base or Double-Diffused Transistors

CLASSIFICATION SCHEME

Figure 4 illustrates how diffusion is combined with the other transistor fabrication methods to produce different types of transistor structures. Only p-n-p and n-p-n structures are discussed here; however, transistors having an intrinsic region, *i.e.*, p-n-i-p or n-p-i-n structure, also can be formed by the diffusion technique.

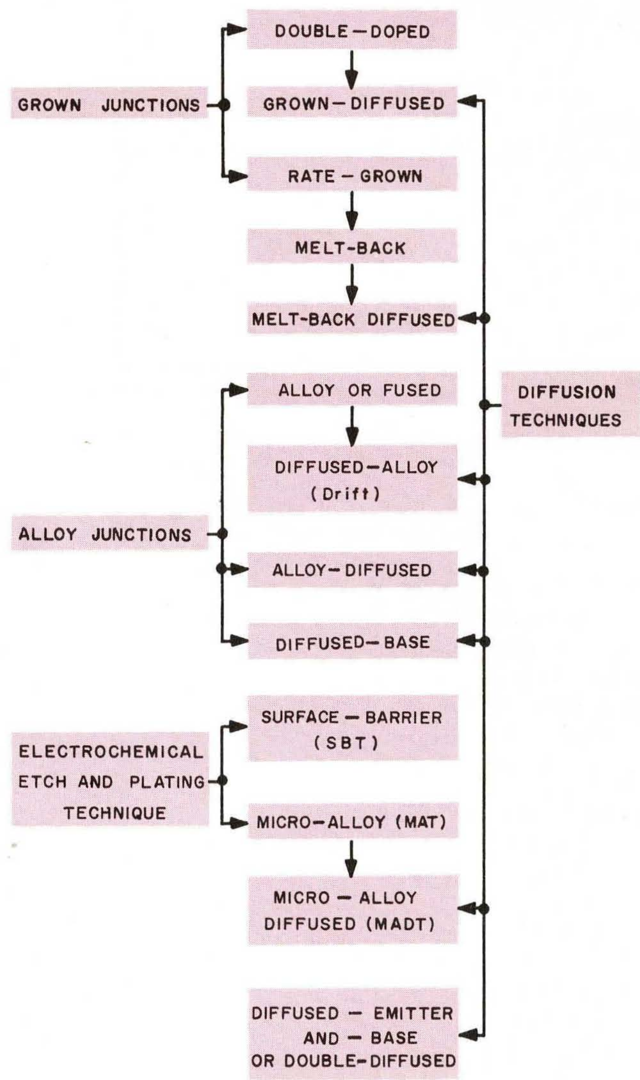

Fig. 4. Junction Transistor Classification Scheme

GROWN-JUNCTION TRANSISTORS (Fig. 1)

Double-Doped Transistors — The original grown-junction transistor, formed by growing a crystal and successively adding p- and n-type impurities to the melt while the crystal is being grown.[1]

Rate-Grown or Graded-Junction Transistors — A variation of the *double-doped* type described above, in which n- and p-type impurities are added to the melt.[5, 6] The growth rate is then varied in a periodic manner while the

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