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(54) INTEGRATED CIRCUITS

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London EC2V 8AH, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to integrated circuits.

In our co-pending Patent Application No. 23699/72 (Serial No. 1,398,862) from which the subject matter of the present Application is divided and in our co-pending Patent Applications Nos. 3618/75 (1,398,863), 3619/75 (1,398,864), 3620/75 (1,398,865), 3621/75 (1,398,866) and 3906/75 (1,398,867), which are also divided from Application No. 23699/72 (1,398,682), there are described various forms of integrated circuits each comprising a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for the electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body furthermore comprising connections for connecting the two polarities of a source for supplying bias current to one or more of the circuit elements, and the common body also comprising a current injector for supplying bias current, the said current injector being used in very close relationship with the circuit element to be biased as regards location and distance.

It is to be noted that bias currents are to include all those currents which are supplied to the circuit elements for the direct current biasing thereof. A number of these currents, usually those currents which flow through the main current path of the relevant circuit element *via* the main electrodes, for example the emitter and the collector of a transistor, also supply energy which may be used for signal amplification—the ratio between the energies of the output signal and the input signal. "Supply tracks" are to be understood to mean tracks which serve notably to supply the last mentioned bias currents.

According to a first aspect of the invention an integrated circuit comprises a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body comprising a multi-layer current injector structure for supplying bias current to one or more zones to be biased of the circuit elements, the current injector structure having at least four successive layers which are separated from each other by rectifying junctions among which layers are a first injecting layer which is separated from the circuit element or elements to be biased by at least one rectifying junction, and an adjoining second, intermediate layer of a semiconductor material, means for connecting the injecting layer and the second, intermediate layer to a source of biasing potential to polarize the rectifying junction between the injecting layer and the second, intermediate layer in the forward direction causing injection of charge carriers from the injecting layer into the second, intermediate layer and causing collection of charge carriers by the last layer of said at least four successive layers, said one or more zones to be biased belonging or being connected to said last layer.

The zone to be biased of a circuit element may belong to the main electrodes, which in a bipolar transistor are the emitter and the

collector, but it may alternatively belong to control electrodes of the circuit elements in question, for example the base of a transistor.

In one form of an integrated circuit in accordance with the first aspect of the invention the zone to be biased of one such circuit element is to collect charge carriers from a layer of the current injector which also forms a further zone of the said circuit element, the zone to be biased being directly connected to a further part of the integrated circuit, for example, the pattern of conductive tracks and/or further circuit elements.

This form is particularly suitable for the electrical biasing of control electrodes, for example the base zones of transistors.

The current injector may be constructed to be lateral, that is to say having the layers of the current injector beside each other and adjoining the said one side of the body. In this lateral form the charge carriers carrying the bias current experience a displacement in the lateral direction, thus approximately parallel to the one side of the body. In said form the zone to be biased of one such circuit element and those layers of the current injector which have the same conductivity type as the zone to be biased are surface zones of one conductivity type which extend beside each other from the said side of the body in the same region of the opposite conductivity type and are surrounded in the body by said region, and the zone to be biased forms with the region a junction bounding said zone, *via* which junction said zone collects, which charge carriers are carriers injected in the region from a layer of the current injector constituting a rectifying junction with the region and being located at the said one side of the body.

The injecting layer of the current injector can be formed, for example, by a metal layer which is separated from the semiconductor intermediate layer by a thin insulating layer, charge carriers being introduced into the intermediate layer by injection by tunneling. However, the injecting layer preferably is a semiconductor layer which forms a *p-n* junction with the intermediate layer.

It is to be noted that the collecting layer, and in general any layer of the current injector which collects charge carriers from an adjacent layer of the current injector if no external potential is impressed, will assume a potential at which the rectifying junction between the two relevant layers is polarized in the forward direction. As a result of this, injection of charge carriers will also occur across said collecting junction. If an equal amount of current flows across the collecting junction in both directions, the voltage across said junction will be maximum and substantially equal to the voltage across the injecting junction of the current injector. In all the other cases the value of the forward voltage depends upon the value of the (bias) current derived by or from the relevant collecting layer. It will be obvious that in the boundary case in which substantially no voltage exists across the relevant collecting rectifying junction, the derived current is maximum.

By means of the current injector and *via* the supply of bias current, biasing potentials for the zone to be biased can thus be obtained the value of which lies in a range which is restricted by the voltage between the two source connections of the current injector connected to a source. The bias potentials obtained by means of the current injector are maximally equal to those of the source connection with the highest potential and minimum equal to those of the source connection with the lowest potential. Furthermore, the voltage between the source connections is equal to the voltage which is necessary to operate the rectifying junction between the injecting layer and the intermediate layer in the forward direction. This voltage will generally be comparatively low. A usual value for said forward voltage for a *p-n* junction in silicon, for example, is approximately 0.6 to 0.8 Volt. It is particularly attractive that in many cases the whole circuit can be operated at the above-described low voltages as a result of which the dissipation can be extremely low. This advantage of low dissipation is also considerably realized if an important part of the circuit is operated at said low voltages beside, for example, one or more output transistors to which higher voltages are supplied so as to have a higher power available at the output(s) of the circuit.

It is to be noted in this connection that by means of the current injector, bias current can also be supplied to zones of circuit elements which are operated at voltages higher than those indicated above. In that case the potential of the zone to be biased which is connected to the current injector may lie outside the above-indicated range namely so that the rectifying junction between the zone to be biased and the adjoining layer of the current injector is polarized in the reverse direction.

The number of layers of the current injector may be both even and odd. The current injector may be a five-layer structure in which the fourth layer of the current injector adjoining the collecting third layer is a semiconductor layer of the same conductivity type as the intermediate layer, in which the third layer injects charge carriers into the fourth layer and the fifth layer collects charge carriers from the fourth layer through a rectifying junction bounding said fifth layer and thus receives a current which serves as a bias current for the zone to be biased of the one circuit element.

In this form, the intermediate layer and the fourth layer of the current injector can advantageously form a continuous region of the same conductivity type in the body.

The current injector may comprise means for controlling the bias current to be received by the zone to be biased. In this manner the bias current can be varied between zero and a value which is determined by the voltage set up at the source connections of the current injector, or be adjusted at a desirable level. In a five-layer current injector, said control or adjustment can simply be realized by means of an at least temporarily conducting connection between the collecting third layer and a layer adjoining said third layer of the current injector. Such a connection may comprise, for example, an electronic switch such as a transistor.

The bias current to be supplied by means of the current injector may be supplied, for example, to a diode. However, the circuit element to be biased may be a transistor having at least two main electrodes and at least one control electrode, for example a field effect transistor having a source and drain zone and one or more gate electrodes. When bipolar transistors are used in the circuit it is of particular advantage to supply bias current to the base zones of one or more of the transistors by means of the current injector. If the current injector is combined with the transistor, the layer of the current injector which adjoins the base zone to be biased and from which the base zone collects charge carriers may form the emitter zone or the collector zone of the transistor in question. Particularly in the first-mentioned case, circuit arrangements of a particularly simple construction can be realized. The circuit then preferably comprises a number of transistors in a common emitter arrangement in which the various base zones to be biased collect charge carriers from the same layer of the current injector, said layer forming a common emitter zone of the transistor. Thus in this manner bias current is simultaneously supplied to several circuit elements by means of one current injector. When the current injector is constructed to be vertical, the common emitter zone may form a reference potential plane for the circuit or for a part thereof, said plane separating the circuit elements from the injecting layer and the source connection connected thereto. Furthermore, multi-collector transistors may be used in the common emitter circuit, as a result of which the compactness of the circuit and the simplicity of the wiring pattern can be considerably improved.

In one form of the integrated circuit in which the base zones of several transistors are provided with bias current by means of a single injecting layer and a single intermediate layer, the collector of a first of the transistors is connected, *via* the pattern of conductive tracks, to the base of a second transistor. This cascade arrangement can extremely readily be used in circuits for low power and/or linear amplification, for example for hearing aids, or in logic circuits, such as NOR gates. In this case it is of particular importance that the bias current supplied to the base zone of the second transistor can serve, simultaneously or shifted relative to each other in time, as a base current for the second transistor and as a collector supply current for the first transistor.

Integrated circuits having such cascades can be manufactured with a strongly simplified technology while in particular logic circuits with such cascades have a considerably simplified wiring pattern because both the bias current for the control electrodes and the supply current for the main electrodes can be supplied by the current injector.

In addition, this manner of current supply makes the use of load resistors usually superfluous also as a result of which a NOR gate having several inputs may consist, for example, simply of a number of transistors having a common emitter zone the collector-emitter paths of which are connected in parallel by the interconnection of the collectors.

For example, integrated trigger circuits having cross-coupled transistors with a common emitter zone can also be obtained easily. Such trigger circuits constructed according to the invention require comparatively little semiconductive surface area and have a simple wiring pattern and a low dissipation as a result of which they are particularly attractive for use as matrix elements in large memories.

According to a second aspect of the invention an integrated circuit comprises a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, at least one of said circuit elements comprising a transistor having main electrode zones defining a main current path therethrough, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body furthermore comprising connections for connecting the two polarities of a source for supplying bias current to one or more of the circuit elements, the body also comprising a multi-layer current injector structure for supplying bias current to one of said main electrode zones of said transistor, the current injector structure having at least three successive layers which are separated from each other by rectifying junctions among which layers are a first injecting layer which is separated from the circuit elements by at least one rectifying junction, and an adjoin-

ing second, intermediate layer of a semiconductor material, the injecting layer having a connection for one polarity of the said source and the intermediate layer having a connection for the other polarity of the said source to polarize the rectifying junction between the injecting layer and the intermediate layer in the forward direction causing injection of charge carriers from the injecting layer into the intermediate layer and collection of charge carriers by said one main electrode zone, said one main electrode zone belonging to one of the layers of the current injector, said one layer being separated from the source connection for the one polarity by at least two rectifying junctions.

Embodiments of the invention will now be described in greater detail, by way of example, with reference to certain Figures of the accompanying drawings. Integrated circuits including a multi-layer current injector and forming the subject of various of the previously referred to co-pending Applications are described with reference to the Figures of the drawings together with embodiments of the present invention.

In the drawings:—

Figure 1 is a diagrammatic plan view of a part of an integrated circuit comprising a multi-layer current injector.

Figure 2 is a diagrammatic cross-sectional view taken on the line II—II of Figure 1.

Figure 3 shows an electrical circuit diagram corresponding to Figures 1 and 2.

Figure 4 shows a circuit diagram of a simple gate circuit.

Figure 5 is a diagrammatic cross-sectional view taken on the line V—V of Figure 1.

Figure 6 is a diagrammatic cross-sectional view of a part of an embodiment of an integrated circuit in accordance with the present invention.

Figure 7 is a circuit diagram of another embodiment of an integrated circuit in accordance with the present invention, of which part

Figure 8 is a diagrammatic cross-sectional view.

Figure 9 is a diagrammatic cross-sectional view of another integrated circuit comprising a multi-layer current injector forming an embodiment of the present invention, while

Figure 10 shows a circuit diagram associated with Figure 9.

Figure 11 is a circuit diagram of a linear amplifier.

Figure 12 shows diagrammatically the principle of a so-called vertical injector.

Figure 13 is a diagrammatic cross-sectional view of part of the circuit of Figure 11 when realized in an integrated circuit form employing vertical current injectors.

Figure 14 is a diagrammatic plan view of another integrated circuit comprising a multi-layer current injector, and

Figure 15 is a diagrammatic cross-sectional view taken on the line XV—XV of Figure 14.

Figure 16 is a diagrammatic plan view of a part of another integrated circuit comprising a multi-layer current injector, of which

Figure 17 is a diagrammatic cross-section view taken on the line XVII—XVII of Figure 16.

Figure 18 is a diagrammatic cross-sectional view of another integrated circuit comprising a multi-layer current injector.

Figure 19 shows a circuit diagram associated with an integrated semiconductor memory circuit including a multi-layer current injector and of a part of which

Figure 20 is a diagrammatic plan view.

Figure 21 shows a circuit diagram associated with another integrated semiconductor memory circuit including a multi-layer current injector and of a part of which

Figure 22 is a diagrammatic plan view, while

Figure 23 is a diagrammatic cross-sectional view taken on the line XXIII—XXIII of Figure 22.

This integrated circuit shown in Figures 1 and 2 comprises a plurality of circuit elements, in this case transistors, of which the base zones are denoted by reference numerals 1 to 10. These transistors are arranged beside each other on one side of a body 12 which is common to said circuit elements. The body 12 consists for the greater part of a semiconductor material and has on the side of the semiconductor surface 11 an insulating layer 13 across which extends a pattern of conductive tracks 14 which is present on said side of the body 12. The conductive tracks are connected, *via* apertures in the insulating layer 13 which in Figure 1 are denoted by broken lines, to the parts of the circuit elements emerging at the semiconductor surface in said apertures. In this manner said tracks 14 serve for the electrical connection of the transistors.

The body 12 furthermore comprises connections 15 and 16 shown diagrammatically in Figure 1 for connecting the positive and the negative polarity of a source 17 for supplying bias current to one or more of the circuit elements.

The body 12 is provided with a current injector constituted by a multilayer structure having in this case three successive layers 20, 21 and 5 separated from each other by rectifying junctions 18 and 19. In this circuit the first or injecting layer 20 is separated from the circuit elements to be biased by the junction 18. The second or intermediate layer 21 of the current injector is a semiconductor layer which constitutes the rectifying junctions 18 and 19, respectively, with the first and the third layer 20 and 5, respectively. The injecting layer 20 has a connection 15 for one

polarity of the source 17 and the intermediate layer 21 has a connection 16 for the other polarity of the source 17. By means of this source 17, the rectifying junction 18 between the injecting layer 20 and the intermediate layer 21 is polarized in the forward direction during operation so that, charge carriers are injected from the injecting layer 20 into the intermediate layer 21 and charge carriers are collected by the third layer 5 of the current injector adjoining the intermediate layer 21.

The third layer of the current injector also forms the base zone to be biased of one of the transistors, namely of the three-layer transistor 33, 5, 21. This base zone 5 to be biased is separated from the injecting layer 20, and hence also from the source connection 15 connected thereto, in this circuit by two rectifying junctions, the *p-n* junctions 18 and 19, and collects *via* the junction 19 bounding the third zone 5, charge carriers from the intermediate layer 21 of the current injector which carriers provide the desired bias current. Said zone 5 is furthermore connected to one of the tracks 14 of the conductive pattern, *via* which connection electrical signals, for example, can be supplied or can be derived.

The bias currents of the remaining base zones 1 to 4 and 6 to 10 are supplied in a corresponding manner by means of the injecting layer 20 and the intermediate layer 21. The layers 20, 21 and 10 for example, constitute a current injector for supplying bias current to the base zone 10 of the three-layer transistor 36, 10, 21. This zone 10 to be biased is also separated from the injecting layer 20 and the one source connection 15 connected thereto by two rectifying junctions, the junctions 38 and 18. Said zone 10 furthermore collects charge carriers from the intermediate layer 21 of the current injector *via* the junction 38, the intermediate layer 21 also forming a zone of the circuit element, in this case one of the outermost zones of the three-layer transistor.

The base zone 10 to be biased of the transistor 36, 10, 21 is connected to a further three-layer transistor 37, 10, 21. This connection is realized internally in the semiconductor body 12 in that the zone 10 forms a base zone which is common to both transistors. In addition, the base zone 10 is also connected to one of the conductive tracks 14, which conductive track *inter alia* leads from the base zone 10 to the three-layer transistor 33, 5, 21.

The injecting layer 20 is a semiconductor layer of the same one conductivity type as the layers 1 to 10 which each constitute a third or collecting layer of the current injector. Said layers 1 to 10 and 20 extend beside each other from one side of the body at which the conductive pattern is present in the same region 21 of the opposite conductivity type and are surrounded by said region 21 in the body 12. The zones 1 to 10 to be biased receive their bias current by collecting charge carriers from the region 21, which carriers have been injected in the region 21 from a layer of the current injector present on the said one side, namely the injecting layer 20, *via* the rectifying junction 18.

The part of the integrated circuit shown in Figures 1 and 2 constitutes a master slave flip-flop according to the electrical circuit diagram shown in Figure 3. Said flip-flop comprises 16 transistors T_{22} to T_{37} distributed over eight NOR gates having each two inputs. The collectors of said transistors T_{22} to T_{37} are referred to in Figures 1 and 2 by the corresponding reference numerals 22 to 37. The base zones of said transistors are the zones 1 to 10, the zones 1, 3, 4, 6, 7 and 10 each constituting a base zone which is common to two transistors. All the emitters of the transistors are connected together. They are constituted by the common emitter zone 21 which is also the intermediate layer of the current injector. The current injector with its collecting zones 1 to 10 to be biased is shown diagrammatically in Figure 3 by ten current sources I. The diagram of Figure 3 furthermore shows an electric input IN, an electric output Q and clockpulse connections CPM and CPS, respectively, for the master and the slave, the conductive tracks 14 corresponding thereto being denoted in the same manner in Figure 1.

It is to be noted for clarity that the transistor T_{37} in Figure 3 actually does not belong to the flip-flop. In fact, the collector of the transistor T_{34} constitutes an output of the flip-flop and transistor T_{37} belongs already to a further gate circuit connected to said output of the flip-flop. Also lacking at the input of the integrated circuit shown is the transistor T'_{37} shown in broken lines in Figure 3 which may be considered to belong to the flip-flop and which together with the transistor T_{22} constitutes a NOR input gate of the flip-flop. The reason that in the integrated form, the transistors T_{22} to T_{37} are grouped together as a structural unit is the required connection between the bases of the transistors T_{36} and T_{37}. Due to this connection, the transistor T_{37} can actually be realized simply as an extra collector zone 37 in the base zone 10 of the transistor T_{36} as a result of which a saving of required semiconductor surface area is obtained. For the same reason it is often also more favourable to provide the transistor T'_{37} in a structural unit part of the circuit immediately preceding the flip-flop, for example, a preceding flip-flop.

The use of such multi-collector transistors having a base zone which is common to two or more separate collectors results in a considerable simplification of the integrated circuit, *inter alia*, because considerably less space

at the semiconductor surface is necessary for a multi-collector transistor having, for example, three collectors than for three separate transistors. Furthermore, the number of required connections for a multi-collector transistor is considerably smaller than for an equivalent number of separate transistors as a result of which the wiring pattern is simpler with multi-collector transistors.

The flip-flop described is a particularly compact integrated circuit, *inter alia* as a result of the fact that the current injector used is very closely connected with the circuit elements to be biased. In addition to the circuit elements used, only one further zone, namely the injecting layer 20 and an extra rectifying junction, the *p-n* junction 18, is necessary for the current injector. The remaining layers of the current injector coincide with semiconductor layers necessary already for the circuit elements themselves. Furthermore, as shown in Figure 1, the connections 15 and 16 to the injecting layer 20 and the intermediate layer 21 of the current injector may be provided at the edge of the body 12. The bias currents are supplied internally *via* the body by means of the current injector. As is shown diagrammatically in Figure 2 with the connection 16', in the present example also the more readily admissible surface 39 which is situated on the oppositely located side of the body opposite to the surface 11 may be used for the connection of the intermediate layer.

An important contribution to the simplicity and the compactness of the integrated circuit originate from the fact that the current injector supplies not only the bias current for the base zones of the transistor but also the emitter-collector main currents required for said transistors. For example, the base zone 5 is connected *inter alia* to the collector zone 29 *via* a conductive track 14. The transistors T_{29} and T_{33} constitute a D.C.-coupled cascade. When transistor T_{29} is conductive, the bias current supplied to the zone 5 by the current injector flows at least for a considerable part, *via* the said conductive track, as a main and supply current through the emitter-collector path of transistor T_{29}. In this manner, all the bias currents necessary for the flip-flop are obtained with a single connected source 17.

In this connection it is furthermore to be noted that also due to the fact that the bias currents are supplied as a current by the current injector, the usual load impedances in the emitter-collector circuits of the transistors are superfluous. Generally, this also provides a considerable space saving.

Another important aspect is that a large number of transistors the emitters of which are directly connected are incorporated in the circuit. These connected emitters may be constructed as a common emitter zone 21, the double-diffused three-layer structure which in itself is usual for transistors being used in the reverse direction. The smallest zone serves as a collector which is present at the surface and which, viewed on the surface 11, lies entirely on the base zone and which in the body is surrounded by the base zone. Said base zone is a surface zone which adjoins the surface 11 around the collector and which extends from said surface in the intermediate layer 21 which also serves as an emitter. In itself, a transistor structure used in this manner has a lower current amplification factor β than the conventional non-inverted transistor. However, for many circuits said lower current amplification factor β is no objection and the use of a common emitter zone in combination with a current injector results in a very simple construction of the integrated-circuit in which *inter alia* no space is necessary for separation zones for electrical isolation of the transistors and the manufacture becomes considerably simpler. In addition, some measures to increase the current amplification factor β of the inverted transistor structure will hereinafter be described.

It was already stated that the flip-flop described is entirely operated with a single connected source 17. This means *inter alia* that during operation all the voltages in the circuit lie within the range which is given by the potential difference supplied by the source 17 to the connections 15 and 16. This potential difference is in the forward direction across the *p-n* junction 18 between the injecting layer 20 and the intermediate layer 21. The charge carriers consequently injected in the intermediate layer and which in said layer are minority charge carriers can be collected by a region of the same conductivity type as the injecting layer 20, for example the zone 5, provided that the distance between the layer 20 and the zone 5 is not too large, in practice of the order of the diffusion length of the minority charge carriers in the intermediate layer. Such a current transfer from the injecting layer 20 to the zone 5 to be biased can take place when the junction 19 between the zone 5 and the intermediate layer 21 is biased in the reverse direction which may be effected, for example, by connecting the zone 5 *via* a conductive track 14 to a point of a suitable potential. In this case a second voltage source must be used in the circuit.

As is known, a rectifying junction need not necessarily be biased in the reverse direction to be able to collect charge carriers. The collected charge carriers may result in a potential variation of the zone 5 as a result of which a voltage in the forward direction is also set up across the junction 19. Injection of charge carriers across the junction 19 will certainly occur when said forward voltage becomes large enough, as a result of which a

current flows across the junction in a direction opposite to that of the current flowing across said junction as a result of collection of charge carriers. The potential of zone 5 will adjust itself such that the difference of said two currents is equal to the base bias current necessary for operating the transistor 33, 5, 21, if desirable increased by the current which flows away *via* a connection at the zone 5. In this stationary condition, the potential of the zone 5 will generally lie between the potentials of the connections 15 and 16.

It will be obvious that in the case in which the junction 19 is operated in the reverse direction, the three-layer transistor 33, 5, 21 will be used with the zone 33 as the emitter, zone 5 as the base and layer 21 as the collector, the base bias current being supplied entirely or partly by the current injector. Also when a voltage in the forward direction is set up across the junction 19, the layer 21 may be used as the collector of the three-layer transistor 33, 5, 21, namely when the junction 40 between the zone 33 and 5 is biased far enough in the forward direction. More important, however, is that when the junction 19 is in the forward direction, the intermediate layer 21, as in the present example, can serve as the emitter of the transistor 21, 5, 33 which will be explained more fully below.

In the present example with the lateral current injector 20, 21, 5, the common body 12 is an *n*-type semiconductor body which constitutes the intermediate layer of the current injector, the intermediate layer 21 comprising a low-ohmic *n*-type substrate 21^a on which a high-ohmic *n*-type surface layer 21^b is provided. All the semiconductor zones of the circuit elements and the current injector adjoin the surface 11 of the surface layer 21^b remote from the substrate 21^a. The injecting layer 20 and the base zones 1 to 10 are provided simultaneously and with the same doping concentration as *p*-type surface zones in the surface layer 21^b which is epitaxial in this case. As a result of this comparatively simple manufacturing technology, the doping concentrations and the gradients thereof in the proximity of the *p-n* junctions 18 and 19 are substantially equal. This equality of the two junctions 18 and 19 at first may appear to preclude the use of the intermediate layer 21 as the emitter of the *n-p-n* transistor 21, 5, 33. Actually, the junction 18 constitutes the injecting junction of the current injector as a result of which the current in the forward direction at said junction must consist of holes as much as possible with a view to a reasonable efficiency, while for the same reason the current in the forward direction at the junction 19, as an emitter base junction of the transistor, must consist of electrons as much as possible. In other words, because the epitaxial layer 21^b is an intermediate layer of the current injector, the doping concentration would have to be low, while for said epitaxial layer as an emitter of the transistor just a high doping concentration is desirable.

In order to be able to use the intermediate layer 21 of the current injector as the emitter of the transistor all the same, the fact has been used that the ratio between the electron current and the hole current in an injecting junction depends not only upon the minority charge carrier concentration on either side of said junction given with the doping concentrations and the voltage across said junction, but is actually determined by the gradients of said minority charge carrier concentrations. These concentration gradients depend *inter alia* on the presence of a collecting junction such as the base-collector junction 40 and the distance from said junction 40 to the injecting junction 19. In the proximity of the collecting junction 40, the minority charge carrier concentration in the base zone 5 as a result of the collecting effect of said junction 40 is low dependent upon the biased voltage across said junction. When the distance between the junctions 40 and 19 is smaller than one or a few diffusion lengths of the minority charge carriers in the base zone 5, the collecting effect of the junction 40 results in an increase of the gradient of the minority charge carrier concentration. This effect may also be described as a shortening of the effective diffusion length of the minority charge carriers in the base zone 5. As a result of this it can be effected with the choice of the voltage across the junction 40 in comparison with that across the junction 19 and/or the distance between the junctions 19 and 40 in comparison with that between the junctions 18 and 19 that the forward current across the junction 18 consists for the greater part of holes, while the forward current across the junction 19 consists for the greater part of electrons in spite of the doping concentration of the layer 21 which is comparatively low for an emitter. The shortened effective diffusion length of the electrons in the base zone 5 must be smaller than that of the holes in the intermediate layer 21.

As already stated, the present flip-flop is constructed from a number of NOR gates which consist of a number of transistors the emitter-collector paths of which are connected in parallel. Figure 4 shows such a NOR gate which consists of two or more gate transistors T_{40}, T_{41}... The gate transistors are succeeded by a transistor T_{42}. The inputs A, B... of the gate transistors T_{40}, T_{41}... are constituted by the base electrodes of the transistors T_{40}, T_{41}, ..., while their emitter-collector paths are shunted by the emitter-base path of the transistor T_{42}. The current injector is denoted diagrammatically with current sources I_{40}, I_{41}, and I_{42} and the associated polarities between the bases and the emitters. The transistor T_{42} will conduct current only

(as a result of the current source I_{42} which is operative in the forward direction) if neither the transistor T_{40} nor the transistor T_{41} is conducting, i.e. if both at the input A and at the input B earth potential prevails or at least a voltage is present relative to the emitter which is lower than the internal base input threshold voltage of the transistors T_{40} and T_{41} respectively. The currents of the sources I_{40} and I_{41} flow to earth and since transistor T_{42} is conductive, the voltage at its collector (point D) will have dropped substantially to earth potential. If at one or more of the inputs A and B the base input threshold voltage is exceeded indeed, the current of the source I_{42} will flow via the input transistor(s) which is then conductive so that too little current remains for the base of the transistor T_{42} to cause said transistor to convey current. The current injector thus forms the indicated current source I_{42} and ensures the supply of the main current path of the transistors T_{40}, T_{41}..., while the base-emitter junction of the transistor T_{42} constitutes the load impedance of said transistors.

In many circuits more than two gate transistors T_1 and T_2 will be connected between the point C and earth with their collector-emitter paths (fan-in), while several transistors will also be connected between said points with their base-emitter path, like transistor T_{42}. The points A and B, respectively, are then connected, for example, to the outputs C' of preceding similar gate circuits, while the output C of the gate circuit shown will lead to several inputs A' or B' of subsequent similar gate circuits. The fan-out is limited by the collector-base current amplification factor β of the transistors used.

From the above it will be obvious that in addition to transistors which are conductive and the emitter-base voltage of which lies above the threshold voltage, non-conductive transistors occur in such circuits the emitter-base path of which is substantially short-circuited. This means that in an integrated circuit as shown in Figure 1 parasitic transistor action between various base zones, for example the base zones 4 and 5, can easily occur when the distance between said zones is not too large. In connection herewith a surface zone 21° belonging to the intermediate layer 21, thus also *n*-type, which is more highly doped than the base zones 4 and 5 extends between said two base zones 4 and 5 to be biased. Preferably the more highly doped zone 21° extends to at least the same depth from the surface as the base zones 4 and 5. For reasons of space saving, said more highly doped surface zone 21° directly adjoins the base zones which are to be separated electrically. However, also when said n^+ zone 21° is present at some distance from the base zones to be separated, the stray transistor action, if any, is effectively suppressed.

In the present example, the surface zone 21° is present not only between the base zones to be separated but each of the base zones 1 to 10 is substantially entirely surrounded at the surface 11 by a combination consisting of a part of the injecting layer 20 and the more highly doped zone 21°. Each of the base zones is surrounded on three sides by a U-shaped part of the zone 21°. In the cross-sectional view shown in Figure 5 it may be seen that a small aperture is still present on either side of the injecting layer 20 between the junction 18 and the n^+-n junction 44 which is not shown in Figure 1 for clarity and which is formed between the low-ohmic U-shaped parts of the zone 21° and the adjoining high-ohmic part 21^b of the intermediate layer.

With this surrounding it is achieved that each of the base zones 1 to 10 extends in, at least adjoins, a comparatively small *n*-type region which, in as far as it adjoins *n*-type material, is substantially entirely enclosed within the n^+-n junction 44 and the n^+-n junction 45 between the substrate 21^a and the epitaxial layer 21^b. These n^+-n junctions constitute a barrier for the holes present in the epitaxial layer 21^b as a result of which the holes injected in such an enclosed part by the injecting layer 20 or the base zone 5 flow away less easily to parts of the *n*-type intermediate layer 21 which are farther remote from the junctions 18 and 19. This increase of effective diffusion length of holes in the part of the epitaxial layer 21^b adjoining the base zone 5, as well as the above-mentioned shortening of the effective diffusion length of the electrons in the base zone, thus on the other side of the junction 19, results in an increase of the current amplification factor β of the three-layer transistor 21, 5, 33. In connection with the above, the *n*-type region 21^b adjoining the base zone 5 is preferably enclosed as much as possible. Furthermore, said region 21^b preferably is as small as possible so as to restrict the loss of minority charge carriers by recombination. The base zones and the injecting layer 20 preferably extend to the n^+ substrate 21^a, or at least to an n^+ layer situated below such a base zone and injecting layer. This has the additional advantage that the injection of the injecting layer 20 will take place mainly in the lateral direction parallel to the surface 11. When the thickness of said zones is smaller than that of the surface layer 21^b, the n^+ surface zone 21° preferably extends to or in the substrate 21^a. Although small apertures in the enclosure have a comparatively small adverse effect, the n^+ surface zone at the surface 11 preferably adjoins the injecting layer 20 directly. The presence of the aperture shown in Figure 5 on either side of the injecting layer is rather related to the manner of manufacturing the integrated circuit than to the effect in view of the enclosure.

Dependent upon the method of manufac-

turing, losses by surface recombination may play a more or less important part. When the properties of the semiconductor surface 11 and the junction between said surface and the insulating layer 13 are of such a nature that the surface recombination is relatively high, the current amplification factor of the transistor, when the zone to be biased is, for example, uniformly doped, for example, forms part of an epitaxial layer, may be increased by providing at least in the part of the base zone to be biased and adjoining the semiconductor surface, a gradient in the doping concentration, the concentration decreasing from the surface in a direction transverse to the semiconductor surface. The resulting drift field then keeps the minority charge carriers away from the surface. When the surface zone 21^c does not directly adjoin the base zone but when the region 21^b therebetween reaches up to the surface, a corresponding concentration gradient in the layer of the region 21^b adjoining the semiconductor surface is desirable for the same reason. Such a gradient in the region 21^b can be simply obtained, for example, simultaneously with the provision of the usually diffused collector zone 33.

The injecting layer 20 has the form of a strip-shaped surface zone along which on either side several base zones 1 to 10 to be biased and separated therefrom are juxtaposed. In this manner a large number of zones to be biased can be provided with bias current with the same injecting layer. The series resistance of such an elongate injecting layer 20 can be reduced by means of a continuous or interrupted conductive track 46.

Figure 6 is a cross-sectional view of an embodiment of an integrated circuit in accordance with the present invention. The common body 60 comprises a current injector having five successive layers 61, 62^a, 63, 62^b, 64 which are separated from each other by rectifying junctions 65, 66, 67 and 68. As already described with reference to the preceding example, by injection of charge carriers from the injecting layer 61 the third layer 63 of the current injector can assume a potential at which the junction 66 and also the junction 67 come in the forward direction. This means that the second or intermediate layer 62^a can inject charge carriers into the third layer 63, which carriers can be collected by the fourth layer 62^b, as well as that the third layer 63 in its turn can inject charge carriers into the fourth layer 62^b, which carriers can be collected therefrom, if a fifth layer 64 is present, by said fifth layer through the junction 68 adjoining and bounding said fifth layer 64. In the present example the fifth layer 64 of the current injector also constitutes the base zone to be biased of a bipolar transistor which may be constituted, for example, by the layers 69, 64 and 70.

The said layers of the current injector and of the transistor may be provided, for example, in a thin semiconductor layer which is present on an insulating substrate, the five layers of the current injector extending, for example, throughout the thickness of said semiconductor layer. In the example shown, the intermediate layer 62^a and the fourth layer 62^b constitute in the body a continuous region of the same conductivity type. The remaining parts of said region are denoted in Figure 6 by 62^e to 62^f. This region belongs at least for the greater part to an epitaxial layer 62 of one conductivity type which is provided on a semiconductor substrate 71 of the opposite conductivity type, the said region, hereinafter termed island, being separated, by means of separation zones 72 of the opposite conductivity type, from the remaining parts of the epitaxial layer 62. The island comprises a buried layer 62^f of said one conductivity type having a doping concentration which is higher than the original concentration of the epitaxial layer 62. This buried layer is present at and in the immediate proximity of the interface of the substrate and the epitaxial layer. The layers 61, 63 and 64 of the current injector are surface zones which reach from the surface 73 to the buried layer 62^f. As a result of this the diffusion voltage at said parts of the *p-n* junctions between the injecting layer 61 and the third layer 63 on the one hand and the island on the other hand which are substantially parallel to the surface 73 is larger than that of the parts 65, 66 and 67 of said junctions. In consequence of this, the injection of the charge carriers by the layers 61 and 63 will preferably take place in a lateral direction substantially parallel to the surface 73. In addition, the layers 62^a and 62^b in which said injection takes place are very small so that, as already described, comparatively few injected charge carriers are lost in the island.

In this example also, the combination of current injector and circuit element is surrounded as much as possible so as to restrict the flowing away of minority charge carriers in a lateral direction. A low-ohmic zone 62^e which belongs to the island adjoins the injecting layer. The zone 62^e serves to restrict the injection of charge carriers of the injecting layer in a lateral direction on the side of the injecting layer remote from the zone to be biased by increasing the diffusion voltage. The zone 62^e also serves as a contact zone for the connection 74 for one polarity of an external source 75 to the intermediate layer 62^a of the current injector.

The desirable enclosure of the base zone 64 to be biased has been obtained in this example by means of an insulating layer 76 which at least partly is sunken in the body 60 and which extends, from the surface 73, in the semiconductor layer 62 in which the zones to be biased are present. In this example the

insulating layer 76 extends only over a part of the thickness of the layer 62. This sunken insulating layer 76 surrounds the base zone 64 for the greater part and adjoins as much as possible the third layer 63, the injecting layer 61 or the zone 62^e, according as bias current is supplied simultaneously with the third layer 63 and/or injecting layer 61 to several juxtaposed zones to be biased, or to the base zone 64 alone.

The injecting layer 61 is provided with a connection 77 shown diagrammatically for the other polarity of the source 75. The current injector shown is furthermore provided with means for controlling or adjusting the bias current to be received by the base zone 64 to be biased. Such a control can be obtained, for example, by means of an insulated electrode to be provided on the insulating layer 78 above the intermediate layer 62^a and/or the fourth layer 62^b, the potential of said electrode influencing the recombination of the minority charge carriers at the surface of said layers. In the present example another possibility of controlling the bias current is used, namely control by withdrawing current from the third layer 63 of the current injector. For that purpose said third layer 63 is provided with a conductive connection 79. When the third layer is short-circuited, for example, *via* said connection to the fourth layer 62^b or the intermediate layer 62^a, the voltage across the junctions 66 and 67 will be so small that the third layer 63 collects but that no or substantially no injection from the third layer occurs so that no bias current is supplied to the base zone 64. Such a situation in which no bias current is supplied by the current injector to one or more circuit elements of the circuit may be permanently desirable, in which case the junction 66 and/or the junction 67 can simply be short-circuited at the surface 73 with a conductive layer. The bias current for the base zone 64, however, may also be switched on or off temporarily when, for example, an electronic switch is provided between the connections 79 and 74. Such a switch is shown diagrammatically in Figure 6 by the transistor 80 the base 81 of which, for example, can be controlled by a further part of the circuit and which can simply be integrated in the body 60. Of course, also only a part of the current flowing through the current injector and available as bias current can be withdrawn *via* the transistor 80.

The above mentioned island which comprises the layers of the current injector can form an emitter zone which is common to a number of transistors. The transistor shown in that case is a multicollector transistor having two collectors 69 and 70. The injecting layer 61, for example, is strip-shaped, several base zones which are not visible in the cross-sectional view being arranged beside each other along said strip-shaped surface zone. One or more of said base zones can form, for example, a three-layer current injector with the injecting layer 61 and the intermediate layer formed by the island, which layers are common. One or more other base zones, among which the zone 64, form part of a five-layer current injector in that the layer 63 extends between the common injecting layer 61 and the relevant base zones. The layer 63 may be common to said base zones to be biased but may also consist of separate parts which are separated from each other so that the bias current can be controlled for each individual base zone.

In addition to the island shown in which the current injector and one or more transistors are provided, the integrated circuit may comprise other islands which are isolated from each other and in which circuit elements are provided in a corresponding manner. Circuit elements may also be present in one or more islands and be provided with bias current in a usual manner and without the use of a current injector.

An important advantage of the gate circuit described is that it can be operated with very low currents and voltages, thus with low dissipation. The low value of said logic signal voltages and/or signal currents means, however, that in the case of combination in a larger assembly together with different logic circuits, for example TTL or MOST circuits an adaptation of the signal value must take place. Such an adaptation can be obtained in a particularly simple manner with an invertor or a transistor connected as an emitter follower. For example, the transistor T_{37} in Figure 3 may be an extra invertor the collector of which is connected, for example, *via* a resistor, to a point of comparatively high positive potential. The voltage variations at the output Q may then be considerably larger than those at the output proper of the flip-flop, the collector of the transistor T_{34}. The transistor T_{37} constituted by the layers 21, 10 and 37 may also be used with the surface zone 37 as emitter and the layer 21 as collector. In that case, said transistor forms an emitter follower. The emitter zone 37 may lead, for example, *via* a resistor, to a point of comparatively high negative potential. Such an emitter follower to be used at the output of the circuit is shown Figure 7 as the transistor T_{70} connected to the output terminal U. The transistor T_{71} is, for example, one of the transistors of a gate circuit or an added invertor dependent upon the desirable output signal. In this example the logic signal of low value is not directly supplied to the base of the output transistor T_{70} but *via* the emitter-collector path of a complementary transistor T_{72}, as a result of which a higher voltage is admissible and the danger of breakdown is smaller. Another possibility is that the output signal is derived

from the collector 99 of transistor T_{72}, in which case the transistor T_{70} may be omitted.

Figure 8 shows how the circuit arrangement shown in Figure 7 can be incorporated in an integrated form in accordance with the present invention. The common body has a low-ohmic *n*-type semiconductor substrate 90 with a high-ohmic *n*-type surface layer 91 in which a number of *p*-type surface zones are provided which extend up to the boundary between the substrate 90 and the surface layer 91. The body comprises a current injector having a *p*-type injecting layer 92, an *n*-type intermediate layer formed by the substrate 90 and the surface layer 91 and two *p*-type zones to be biased, namely the emitter zone 93 of transistor T_{72} and the base zone 94 of the transistor T_{71}. This current injector is denoted in Figure 7 by the two current sources I_{71} and I_{72}.

The *n*-type body simultaneously forms the emitter of transistor T_{71}, the base of transistor T_{72} and the collector of transistor T_{70}. The transistor T_{71} furthermore comprises a connection 95 on the base zone 94 and an *n*-type collector zone 96 which is connected to the emitter of transistor T_{72} *via* a conductive track 98 present on the insulating layer 97. The collector of transistor T_{72} is constituted by the *p*-type zone 99 which is also the base zone of the transistor T_{70}. Transistor T_{70} furthermore comprises an *n*-type emitter zone 100 connected to the output terminal U. Highly doped *n*-type zones 101 adjoin the *p*-type zones 94 and 99 so as to restrict the above mentioned loss of charge.

The injecting layer 92 and the intermediate layer 90, 91 of the current injector are connected to a source 102. The current injector supplies on the one hand the base bias current for the transistor T_{71} and on the other hand the main or supply current for the emitter-collector path of the transistor T_{72} *via* the body, or that for the emitter-collector path of the transistor T_{71} *via* the track 98. When transistor T_{71} is conductive, the transistors T_{72} and T_{70} are non-conductive, the latter because no base current is available due to the fact that the transistor T_{72} is non-conductive. The voltage at the terminal U is then substantially equal to $-V$. When transistor T_{71} is non-conductive, the current of current source I_{72} flows *via* the transistor T_{72} as a base current to transistor T_{70}. Transistor T_{70} is conductive and the voltage at the terminal U is substantially zero or at least small as compared with the voltage $-V$.

Figure 9 shows another embodiment of an integrated circuit in accordance with the present invention. The semiconductor body has a substrate 105 and an epitaxial layer 106. In the epitaxial layer a surface zone 107 of the opposite conductivity type is present which at the same time constitutes the base zone of a vertical transistor and the emitter of a lateral complementary transistor. The vertical transistor has an emitter 105, 106, a base 107 and a collector 108, which latter is in this case constituted by a metal-containing layer, for example an aluminium layer, which is provided on the base zone and which forms a Schottky junction with said base zone. In connection with the formation of said Schottky junction, the surface concentration of the doping in the base zone in this case is smaller than 10^{17} to 10^{18} atoms/ccm. The Schottky junction 109 is the collector-base junction of the transistor. The lateral transistor comprises an emitter zone 107, a base zone 105, 106 and a collector zone 110. The zones 107 and 110 are zones to be biased each of which together with the intermediate layer formed by the body 105, 106 and the injecting layer 11 form a three-layer current injector. The injector including the zone 110 thus supplies bias current to a main electrode zone of a transistor, namely the collector zone 110 of the lateral transistor. The layers 111 and 105, 106 are connected to a source 112 for supplying bias current. A connection 113, shown diagrammatically, is present between the collectors 108 and 110, while the zone 107 is provided with a connection *b*.

The electric equivalent circuit diagram of said integrated circuit is shown in Figure 10 in which the vertical transistor 106, 107, 108 is denoted by T_{90} and the lateral transistor 106, 107, 110 by T_{91}. In this case also the current injector is denoted by two current sources I_{90} and I_{91}.

The current supplied to the base of T_{90} by the current injector will cause said transistor to become conductive. As a result of this the current supplied to the collector zone of the transistor T_{91} *via* the body by the current injector will mainly flow from there *via* the connection 113 through the collector-emitter path of transistor T_{90}. As a result of this the voltage at the collector of transistor T_{91} falls below the voltage at the electrode *b* of the transistor T_{90} as a result of which current starts flowing across the lateral transistor T_{91} which is withdrawn from the bias current supplied to the base zone 107 by the current injector. Ultimately, a situation will be reached in which only a small fraction of the bias current supplied to the zone 107 flows as a base current through the transistor T_{90} namely such a small amount that said transistor operates in its linear operating range. With such a biasing, no more storage takes place than is just necessary to operate the transistor in its strongly conductive condition.

Other linear circuits are also simple to realize. For example, a linear amplifier of which the equivalent circuit diagram is shown in Figure 11. This comprises three transistors T_{110}, T_{111} and T_{112}. The collector *c* of the first transistor is connected to the base *b* of

the second, the collector of the second transistor to the base of the third transistor, while finally the collector of the third transistor is connected to the base of the first transistor *via* a circuit which permits direct current flow and which comprises a loudspeaker or telephone L and a microphone M. The capacitor C serves to suppress alternating current negative feedback coupling. As a result of the direct current negative feedback coupling *via* the said direct current-transmitting circuit, only so much base current will again be available for each of the transistors as described with reference to Figures 9 and 10 (the rest of the current of the sources I_{110}, I_{111} and I_{112} flowing via the collector-emitter circuit of the preceding transistor in the cascade) that said transistors are adjusted in their linear operating range. In this manner an extremely simple amplifier is obtained, for example, for hearing aids.

In the integrated circuit, the base zones of the transistors T_{110}, T_{111} and T_{112} can be provided beside each other along a strip-shaped injecting layer in a manner similar to that described with reference to Figure 1. Another possibility is to use a current injector in a vertical construction instead of a lateral current injector.

The principle of such a construction is shown in Figure 12. The integrated circuit has a semiconductor layer 180, for example an *n*-type layer, which may form, for example part of a substrate of the circuit. An injecting contact in the form of the *p*-type layer 181 is present on one side of said layer. Between the layer 180 and the injecting contact 181 a source 182 is connected with which the rectifying junction between the layer and the contact is biased in the forward direction. The charge carriers, in this case holes, injected as a result in the layer 180 can reach the *p*-type layer 183 present on the other side of the layer 180 opposite to the injecting contact, provided the layer 180 is not too thick, for example not thicker than a diffusion length. As a result of this the layer 183 assumes a positive potential relative to the *n*-type layer 180. In this manner an energy source is obtained on the oppositely located side of the layer 180 which can supply current and which can be connected to one or more circuit elements, for example the circuit element 184. This connection can be obtained *via* a conductor 185 or also *via* an internal connection present in the semiconductor body.

If further a connection is provided between the circuit element 184 and the layer 180, the current of the current injector may flow through the circuit element, for example as a supply current. Such a connection can be obtained again *via* a conductor or, for example, also in that the layer 180 itself forms part of the circuit element 184. The circuit element is, for example, a transistor the emitter of which is formed by the layer 180. The transistor furthermore has the diagrammatically shown base zone 186 and collector zone 187. The layer 180 may also be an emitter zone which is common to a number of transistors in grounded emitter arrangement.

By providing, opposite to the base zone 186, a second injecting contact 188 shown in the Figure in broken lines, a second vertical current injector 188, 180, 186 is obtained which can supply the required base bias current. In this manner, all the bias current for the transistor is supplied by means of the same external source 182 *via* current injectors, substantially no wiring being necessary for said current supply on the side of the layer where the circuit elements are present. Moreover, the layer 180 may be grounded, the bias current being supplied transversely through the grounded layer 180 to the circuit element.

Also with reference to a few of the following examples, the principle shown in Figure 12 will be described and explained in detail.

As already stated, a vertical current injector may be used upon integration of the circuit shown in Figure 11. The integrated circuit in that case may have the form as is shown in Figure 13.

In this case also, the transistors are arranged beside each other on one side 120 of a common body 121. Semiconductor zones of said transistors are connected to a pattern of conductive tracks 122, 123 and 124. This pattern has an input for electrical signals, namely the track 122 along which the input signals originating from the microphone M are supplied to the base 125 of the first transistor. The pattern furthermore has an output, namely the track 124 along which the amplified output signals of the third transistor are supplied into the loudspeaker L. The tracks 123 connect a collector zone 126 to the base zone 125 of the subsequent transistor.

The transistors furthermore have a common emitter zone formed by an epitaxial layer 127 of one conductivity type which is provided on a substrate 128 of the opposite conductivity type.

The body 121 has a current injector of which the injecting layer which is formed by the substrate 128 adjoins the side 129 of the body situated opposite to the side 120 and of which a layer 125 separated from the injecting layer 128 and the source connection 132 of the source 133 connected thereto by two rectifying junctions 130 and 131 extends opposite to the injecting layer 128 on the side 120, said oppositely located layer 125 collecting charge carriers from an adjacent layer 127 of the current injector *via* a junction 131 bounding said layer and thus receiving current which serves as a bias current for the base of the transistor and possibly for the collector of the preceding transistor connected thereto. The epitaxial layer 127 which at the same time

forms the common emitter zone of the transistors and the intermediate layer of the current injector comprises a source connection 134 for the other polarity of the source 133.

In this integrated circuit the intermediate layer 127 of the current injector is constructed as a reference potential plane for the amplifier circuit. This plane to which may be applied a reference potential, for example earth, separates all the zones 125 of the transistors present on the side 120 and to be provided with bias current by means of the current injector from the injecting layer 128 present on the oppositely located side 129. In this manner an electrical screening is obtained in which the required bias current is supplied, transversely through the usually grounded layer 127, directly to the relevant zone to be biased.

The intermediate layer 127 has more highly doped sub-zones of the same conductivity type constituted by a buried layer 135 and an upright wall 136 which extends from the surface 120 down to the buried layer 135. This upright wall 136 may also fully or partly be constituted by a sunken insulating layer.

These sub-zones and notably the parts 136 serve to suppress parasitic transistor action between the juxtaposed base zones 125. Moreover, said parts 136 may in this case be used to bound the separate base zones 125 which are each constituted by parts of an epitaxial layer 137 of the opposite conductivity type separated from each other by parts 136 which are provided on the epitaxial layer 127 of the one conductivity type. Furthermore, the parts 136 together with the buried layers 135 constitute an enclosure of the zones 125 to be biased so as to confine as much as possible the minority charge carriers injected from said zones 125 into the intermediate layer 127 in the high-ohmic regions of the intermediate layer 127 and thus to obtain the desired increase of the effective diffusion length of said charge carriers. In this manner, the sub-zones 135, 136 separate the transistors from each other and from the substrate 128. Although not necessary, small apertures are preferably present in said separating sub-zones, in the example at the area of the parts 130^a and 130^b of the junction 130. These parts 130^a and 130^b of the junction 130 then have a lower diffusion voltage than the remaining part of the junction 130 so that the injection of charge carriers from the injecting layer 128 into the intermediate layer 127 takes place mainly *via* said parts 130^a and 130^b, the injection in the reverse direction from the intermediate layer 127 into the injecting layer 128 being comparatively small due to the comparatively low doping of the intermediate layer at that area.

The ratio between the bias currents supplied to the various base zones 125 can be influenced with the size of the area of the parts 130^a and 130^b of the junction 130. In this example the surface area of the part 130^a is larger than that of the parts 130^b, as a result of which the current source I_{110} in Figure 11 which ensures the supply current for the output transistor T_{112} supplies more current than the sources I_{111} and I_{112}.

A simple method for (if desirable automatic) gain control can be obtained by using, for example, two collectors as in the transistor shown in Figure 6. If one of these collectors is connected to ground *via* a controllable resistance (for example the internal resistance of a transistor) the signal current to the other collector will become dependent on said resistor so that it can easily be controlled, if desirable automatically.

In the integrated circuit shown in Figures 14 and 15 the injecting layer has the form of a grid-shaped surface zone 140 which adjoins the side 141 of the body 142. In the parts 143^a of the region 143 of the opposite conductivity type surrounded at the surface 141 by the grid-shaped surface zone 140 of one conductivity type, the zones 144 to be biased are present which constitute the base zones of three-layer transistors 143, 144, 145.

The region 143 which constitutes the intermediate layer of the current injector has a low-ohmic substrate and a high-ohmic surface layer which is subdivided into parts 143^a and 143^c. This subdivision is obtained with the grid-shaped injecting layer 140 which extends from the surface 141 up to or in the substrate 143^b. As is shown, transistors or also other circuit elements may be provided in the high-ohmic parts 143^a and 143^c. Furthermore, said parts may be different in size and several circuit elements can be provided beside each other in one or more parts.

One of the advantages of the use of a grid-shaped surface zone 140 as an injecting layer of the current injector is that the series resistance in such a zone may be low. For the same reason a large depth of penetration and/or a higher doping concentration may be used for the injecting layer than for the base zones 144. The maximum admissible doping concentration of the base zones 144 is restricted as a matter of fact, *inter alia* since in said zones, zones 145 of the opposite conductivity type have usually to be provided.

A direct current source 146 may be connected between the injecting layer 140 and the intermediate layer 143 of the current injector. Both for this and the other examples it holds that such a source can be shunted, if desirable with a capacitor 147 to short-circuit the connections 148 and 149 for alternating voltage.

A further integrated circuit having a multi-layer current injector comprises one or

more three-layer transistors 150, 151, 152[a,b] as shown in Figures 16 and 17. In addition to the *n*-type emitter or collector zone 150 an *n*-type zone 153 extends in the base zone 151 which is, for example, *p*-type, said *n*-type zone 153 in turn surrounding a further *p*-type surface zone 154. Said zones 153 and 154 constitute the intermediate layer and the injecting layer, respectively, of the current injector. Shown in broken lines in Figure 16 are furthermore apertures in the insulating layer 158 present on the semiconductor surface *via* which the zones 150, 151, 153 and 154 are connected to conductive tracks for electrical connection. The injecting layer 154 and the intermediate layer 153 of the current injector are provided with the connections 155 and 156, respectively, shown diagrammatically in Figure 17, for connection of a source 157. The present embodiment is particularly suitable if only one or a few of the circuit elements of a circuit need be provided with bias current by means of a current injector. The intermediate layer 153 may also be connected directly to the region 152[a,b] of the transistor, for example in that the intermediate layer 153 at the semiconductor surface extends to or in the low-ohmic zone 152[a]. As a result of this, space is saved while in addition the connection 156 may be provided, if desirable, on the lower side on the substrate 152[b].

In another integrated circuit the circuit elements are provided at a surface 167 of a common body which is constituted by a low-ohmic *n*-type substrate 160 on which a lower-doped *n*-type epitaxial layer 161 is provided (Figure 18). In the epitaxial layer a number of circuit elements which are isolated from each other are provided in a manner known in semiconductor technology by means of *p*-type regions 162; for simplicity, only one of the elements is shown in the drawing, namely the *n-p-n* transistors 163, 164, 165.

The *n*-type body 160, 161 which constitutes a ground plane for the integrated circuit, also is the injecting layer of a current injector which furthermore comprises the *p*-type intermediate layer 166 and the *n*-type third layer 168 adjoining the surface 167.

The injecting layer 160, 161 and the intermediate layer 166 are provided with connections 169 and 170, respectively, for connection of the source 171. Furthermore, the injecting layer 160, 161 adjoins the side 172 of the body located opposite to the side 167, and the third layer 168 of the current injector which is separated from the injecting layer by two *p-n* junctions 173 and 174 is situated on the side 167 and opposite to the injecting layer 160, 161. The oppositely located third layer 168 of the current injector collects, *via* the junction 173, charge carriers from the adjacent intermediate layer 166 of the current injector and thus receives current which serves as a bias current for the emitter 163 of the transistor 163, 164, 165 which is connected, *via* a conductive track 175, to the oppositely located layer 168 of the current injector. It will be obvious that *via* the conductive track 175 several zones to be biased of circuit elements can also be connected simply to the same oppositely located layer 168 of the current injector.

Via a connection 176, electrical signals can be supplied to or derived from the base 164 of the transistor, while the collector 165 may be connected to a point of positive voltage +V *via* a connection 177, for example, *via* an impedance 178.

The last-described integrated circuit is particularly suitable for applications in which bias current has to be supplied to one or a few circuit elements which are situated, for example, in the centre of a large integrated circuit. The required bias current can locally be brought from the ground plane of the circuit to the surface by means of a current injector which occupies little extra area, and be conducted, *via* the pattern of conductive tracks, to the adjacent zones to be biased of the circuit elements in question. For this supply of bias current no resistors are necessary while nevertheless no fixed potential is impressed upon the zones to be biased so that said zones can convey, for example, electric signal current or signal voltage.

Figure 19 shows the circuit diagram of a trigger circuit of a group of trigger circuits constructed in a corresponding manner which, according to a matrix pattern, together constitute a memory circuit.

The trigger circuit comprises the transistors $T_{101} \ldots T_{107}$ whose emitters are all connected to ground potential. The trigger circuit proper is constituted by the transistors T_{101} and T_{102} whose collectors are connected crosswise to the base of the other transistor. Furthermore the base of transistor T_{101} is connected to the collector of transistor T_{103} whose base in turn is connected to the collector of transistor T_{105}. In the same manner the base of transistor T_{102} is connected to the collector of transistor T_{104} whose base is connected to the collector of transistor T_{106}. Furthermore the base electrodes of the transistors T_{105} and T_{106} are connected to the write conductors R and S which are common to a column of trigger circuits. In order to enable reading out, the transistor T_{101} comprises an extra collector which is connected to the base of the transistor T_{107} whose collector is connected to the read conductor O which is common to a column of trigger circuits.

Let it be assumed that the base electrodes of the transistors T_{101}, T_{102}, T_{105} and T_{106} are connected, *via* current sources I_{101}, I_{102}, I_{105} and I_{106} with the polarity indicated, to the supply line V which is common to each row

of trigger circuits and the base electrodes of the transistor T_{103}, T_{104} and T_{107} are connected, via similar current sources I_{103}, I_{104} and I_{107}, to the selection line SE which is common to a row of trigger circuits. It is assumed that the current sources are of such a type that they supply current only if the relevant supply of selection line conveys a positive voltage.

The supply line V always has a positive voltage so that the current sources I_{101}, I_{102}, I_{105} and I_{106} are always operative. During the rest condition, that is to say if no selection has taken place of the row of trigger circuits to which the circuit shown belongs, the selection line SE is at ground potential or lower so that the current sources I_{103}, I_{104} and I_{107} are not operative. The result of this is that in the rest condition the transistors T_{103}, T_{104}, T_{105}, T_{106} and T_{107} will convey no current and consequently the dissipation will be low.

In the rest condition of the trigger circuits, one of the transistors T_{101} and T_{102} will be conductive. Let it be assumed that transistor T_{101} is conductive; the voltage at the base of transistor T_{101} will be equal to $+V_j$, where V_j is the "junction" voltage between the base and emitter of a saturated transistor. The voltage at the base of transistor T_{102} is equal to V_k, V_k representing the voltage between the collector and the base of an overdriven transistor. In the case of silicon transistors a usual value for V_j is 0.7 V and V_k usually is between 0 and 0.4 V. This means that the voltage at the base of transistor T_{102} is lower than the voltage at the base of transistor T_{101}, namely lower than the junction voltage V_j so that transistor T_{102} is cut off. The collector current for transistor T_{101} thus is supplied by the current source I_{102}, while its base current is supplied by the current source I_{101}.

If the information has to be read from the trigger circuit or new information has to be written, a positive pulse is supplied to the selection line so that the current sources I_{103}, I_{104} and I_{107} become operative. If writing is desirable, one of the write conductors R and S is brought at ground potential. Let it be assumed, for example, that the write conductor R is brought at ground potential. The current which is supplied by the current source I_{105} flows to ground so that transistor T_{105} is cut off. The current which is supplied by the current source I_{103} serves as a base current for transistor T_{103} so that said transistor is conductive. So this transistor draws current from the current source I_{101} so that the transistor T_{101} is cut off. Starting from the write conductor S, which is floating, it is found in a corresponding manner that transistor T_{102} is conductive. The collector current for said transistor T_{102} is supplied by the current source I_{101}. So this current source I_{101} supplies both the collector current for transistor T_{102} and for transistor T_{103}. After termination of the selection pulse on the selection line SE, the transistor T_{102} remains conductive and transistor T_{101} remains cut off so that the information is stored in the trigger circuit.

It is to be noted that a writing pulse on one of the write conductors R or S has no influence on non-selected trigger circuits. If no selection pulse is present on the selection line SE, the current sources I_{103} and I_{104} actually are not operative so that the transistors T_{103} and T_{104} remain cut off and hence no information can be transmitted from the write conductors to the transistors T_{101} and T_{102}.

Upon reading out, the write conductors R and S are floating so that in the presence of the selection pulse the transistors T_{105} and T_{106} are conductive. As a result of this the transistors T_{103} and T_{104} are cut off so that the information in the trigger circuit is not attacked. Dependent upon the condition in which the trigger circuit is, transistor T_{107} will be conductive or non-conductive. Let it be assumed again that transistor T_{101} is cut off and transistor T_{102} is conductive, then the current which is supplied by the current source I_{107} which actually is operative as a result of the selection pulse, will serve as a base current for the transistor T_{107} so that said transistor is conductive. The state of said transistor T_{107} is read *via* the read conductor O. Although only one read conductor is shown it will be obvious that a second read conductor may be present as such and be connected in a manner identical to the first-mentioned conductor to an extra collector electrode of transistor T_{102}.

Figure 20 shows a part of the integrated memory circuit in which for clarity only one of the trigger circuits is shown while of the remaining identical trigger circuits of the matrix only two of the adjacent matrix elements are shown diagrammatically.

A number of *p*-type base zones of the transistors T_{101} to T_{107} of the trigger circuits are provided in a surface layer of an *n*-type semiconductor body. Each of the said base zones surrounds in the body one, or in the case of the transistor T_{103}, two *n*-type collector zones, while the body constitutes an emitter zone which is common to all transistors. The transistors are connected, by means of a pattern of conductive tracks 192, to trigger circuits according to the diagram shown in Figure 19 in which each of the trigger circuits of the matrix is connected to conductive tracks R, S and O.

The current sources I_{101} to I_{107} shown in Figure 19 are realized in the integrated circuit with current injectors. A strip-shaped *p*-type surface zone V which serves as a supply line and on either side of which the base zones 190 of the transistors T_{102}, T_{103}, T_{105} and T_{106} are arranged, adjoins the semicon-

ductor surface. The surface zone V constitutes the injecting layer of a current injector in which the semiconductor body serves as an intermediate layer and the last-mentioned base zones are zones to be biased to which bias current is supplied in the above-described manner. In a corresponding manner the *p*-type surface zone SE which serves as a selection line also constitutes a current injector, together with the semiconductor body and the base zones 190 of the transistors T_{103}, T_{104} and T_{107}. The semiconductor body furthermore comprises two parallel *n*-type surface zones which extend parallel to the two injecting layers V and SE and which have a higher doping concentration than the adjoining part of the *n*-type semiconductor body. One of the said zones, the zone 193, adjoins one of the long sides of the zone SE as a result of which the injection of charge carriers from the zone SE takes place mainly in the direction of the transistors T_{103}, T_{104} and T_{107} and not in the direction of the transistors T_{101} and T_{105} of adjacent trigger circuits. The other *n*-type zone 194 extends between the base zones of the transistors T_{103}, T_{104} and T_{107} on the one hand and the base zones of the transistors T_{102} and T_{106} on the other hand and prevents parasitic transistor action between the base zones situated on oppositely located sides of the zone 194. If desirable, further *n*-zones may be provided between the trigger circuits of adjacent columns, which zones extend parallel to the tracks R and S between the injecting layers V and SE. As in the previously described embodiments, all the base zones may also be surrounded separately for the greater part by n^+ surface zones, or sunken insulating layers may be used instead of more highly doped *n*-zones.

In the integrated circuit described, the presence of the transistors T_{105} and T_{106} is necessary so as to be able to select the separate memory elements for writing. Because in this circuit the emitters of all the transistors are connected together, the selection of a memory element can be obtained only *via* base connections. As a result of this, separate transistors are necessary for the selection of rows and columns.

Figure 21 shows a second memory circuit which may be used in a matrix formed by a number of identical memory circuits arranged in rows and columns This memory circuit comprises two transistors T_{201} and T_{202} of the *n-p-n*-type whose emitters are connected to a point of fixed potential, for example earth potential. In order to obtain a bistable element, the base of each of the said transistors is connected to the collector of the other transistor. The supply current for the memory circuit is supplied *via* the current sources I_{201} and I_{202} connected to the base electrodes of the transistors T_{201} and T_{202}.

The writing and reading of information takes place by means of the transistors T_{203} and T_{204} of the *p-n-p*-type. Via the main current path of the said transistors T_{203} and T_{204}, respectively, a connection is produced between the base of transistors T_{201} and T_{202}, respectively, and the read and write conductors S and R, respectively, which are common to a column of memory circuits. The said transistors T_{203} and T_{204} preferably have a symmetric construction because they are operated in both directions in order to fulfil both a reading and a writing function. This capability is represented in Figure 21 by the presence of two emitter symbols in each of the transistors T_{203} and T_{204}.

Selection of the desirable memory circuit takes place by selection of the relevant row by means of a selection line which is common to a row of memory elements and which is connected to the base electrodes of the transistors T_{203} and T_{204} and by selection of the relevant column by means of the read and write conductors S and R. It will be obvious that both in the selected and in the non-selected condition a suitable value should be chosen for the voltage level of the selection line and the read and write lines. For example, the selection line in the non-selected condition will have to convey such a voltage that the transistors T_{203} and T_{204} are cut off independently of the presence or absence of a write pulse on one of the conductors S or R. In the selected condition, the voltage at the selection line will have to have a value which lies between the voltage values at the base electrodes of the transistors T_{201} and T_{202} occurring in the two stable conditions of the memory circuit. In their non-selected condition, the read and write conductors S and R, can, for example, be made floating as a result of which no information can be lost independently of the selected or non-selected condition of the row belonging to the relevant memory element. Upon writing information, the write pulse will have to be sufficiently positive relative to the voltage level of the selected selection line to bring the associated transistor T_{203} or T_{204} in the conductive condition, while for reading information the voltage level of the read conductor will preferably be smaller than the voltage level of the selected selection line.

In order to keep the dissipation of the memory circuit as small as possible and nevertheless to realize a large reading speed, it may be ensured that the supply level of the memory circuit during the stationary condition is low and during reading is switched to a higher level by controlling the currents to be supplied by the current sources I_{201} and I_{202}.

The circuit arrangement shown in Figure 21 is particularly suitable for integration in a semiconductor body. In that case the *p-n-p*-transistors T_{203} and T_{204} may be constructed

as lateral transistors in which in connection with the use in two directions it is of importance that in particular of lateral transistors the electrical properties in both directions can be substantially equal. Furthermore, the two current sources I_{201} and I_{202} are realized with a current injector as a result of which also for the integrated construction a comparatively small semiconductor surface area is necessary.

Figures 22 and 23 shows a part of such an integrated construction of a memory matrix having a current injector and reference is invited to co-pending Application No. 3618/75, (Serial No. 1398863. The part of said integrated circuit present within the broken line 223 in Figure 22 comprises a matrix element according to the diagram of Figure 21. The semiconductor body 200 has a semiconductor substrate 201 which in this case is of *p*-type conductivity. This *p*-type substrate 201 comprises an *n*-type epitaxial layer 202 which is subdivided into islands in a usual manner by means of *p*-type separation zones 203. All the *n-p-n* transistors T_{201} and T_{202} of a row of matrix elements are provided in an elongate island 204 which may be connected at the edge of the semiconductor body, for example, to ground by means of a connection 205 which is shown diagrammatically. The island 204 constitutes a common emitter zone for the said *n-p-n*-transistors. A number of injecting layers is present in said island 204 and only one of them is shown in the Figures, said layers being constituted by *p*-type surface zones 206. On either side of each injecting layer 206, four *n-p-n*-transistors are present having a *p*-type base zone 207 and an *n*-type collector zone 208. The base zones 207 are surrounded at the surface 209 on three sides by a low-ohmic *n*-type surface zone 210 which extends from the surface 209 in the epitaxial layer and adjoins an *n*-type buried layer 211 which is present at the boundary of the substrate 201 and the epitaxial layer 202. The zone 210, 211 belonging to the intermediate layer 204 constitutes a low-ohmic assembly having a number of cavities in which current injectors constituted by an injecting layer 206, a high-ohmic part 212 of the intermediate layer 204 and base zones 207 to be biased are present. Moreover, the zone 210, 211 and notably the buried layer 211 serves to reduce the series resistance in the island 204 as a result of which said island during operation is substantially an equipotential plane.

A likewise elongate island 221 in which the lateral *p-n-p*-transistors T_{203} and T_{204} of the matrix elements are present extends on either side of the elongate islands 204. The islands 221 also have a low-ohmic *n*-type zone constituted by a surface zone 213 and a buried layer 214 to reduce the series resistance. Actually, these islands 221 constitute a common base zone for the *p-n-p*-transistors of a row of matrix elements and serve as selection lines SEL. Furthermore, the *p-n-p*-transistors each have a *p*-type zone 215 which, upon reading information, serves as an emitter zone and, upon writing information, serves as a collector zone and a *p*-zone 216 which serves as a collector zone and an emitter zone, respectively. These *p-n-p* transistors are each surrounded by a cup-shaped part of the low-ohmic zone 213, 214 as a result of which substantially no parasitic transistor action can occur between the zones of adjacent *p-n-p* transistors.

On the surface 209 of the semiconductor body 200 is present an insulating layer 217 on which conductive tracks 218 extend which constitute the internal connections of the matrix elements and which are connected to semiconductor zones of the circuit elements *via* apertures in the insulating layer which are denoted in broken lines in Figure 22. The injecting layers 206 are furthermore connected to a conductive track 219 which is provided with a connection 220, while the zones 216 of the transistor T_{203} of a column of matrix elements are connected to a conductive track S and the zones 216 of the transistors T_{204} of a column of matrix elements are connected to a conductive track R.

A source 222 may be connected between the connections 205 and 220 to bias the *p-n* junctions between the injecting layers 206 and the islands, at the same time intermediate layers 204, in the forward direction. This source 222 may, for example, be controllable so as to be able to provide the *n-p-n* transistors of the matrix elements with more bias current during the reading of information than in the rest condition and during writing. Such a control of the bias current can also be incorporated per conductive track 209 so that the bias currents can be controlled individually for each two adjacent columns of matrix elements.

The integrated construction described with reference to Figures 22 and 23 is particularly compact. A further reduction of the required semiconductor surface area can still be obtained by replacing the n^+ zones 210 and 213 by sunken insulating layers which extend from the surface 209 down to the boundary between the epitaxial layer 202 and the substrate 201. In that case, actually the *p*-type separation zone 203 and the parts of the *n*-type zones 210 and 213 present on either side beside it may be replaced by a single sunken insulating layer as a result of which the distance between the *n-p-n* transistors and the *p-n-p*-transistors in a column and between the *p-n-p*-transistors of adjacent columns may become smaller.

In many cases it is sufficient during the manufacture to use only five masks. Furthermore, a high packing density of the active elements is obtained while resistors are substantially entirely superfluous. The emitters

of the transistors used are often connected together directly so that the pattern of conductive tracks is comparatively simple, the collectors being moreover separated from each other automatically. Furthermore, multi-collector transistors can simply be used as a result of which much area and a number of conductive tracks are saved. During operation it is of particular advantage that all the bias currents supplied by means of the current injector vary in the same manner with the voltage across the injecting junction as a result of which the functioning of the integrated circuit is substantially independent of the current level so that a high noise margin is obtained.

It will be obvious that in the circuits described notably those currents are supplied in particular by means of the current injector which have to be present in order that any information containing analogue or digital signal currents or voltages can be handled and, if applicable, written information can be stored. These currents, which might be called preparatory currents, comprise, in components such as logical configurations, trigger circuits and memory elements, all those currents which in the static or in the dynamic condition of the component must be present to cause the component to be ready, that is to say when information is presented at the input, if necessary in combination with a selection signal, to be able to pick up said information, to be able to store written information and/or to be able to inform said information to the output, if desirable after selection.

All the integrated circuits described, including the embodiments of the present invention can be entirely manufactured by means of methods conventionally used in semiconductor technology, for example epitaxial methods, the provision of buried layers, the local doping with diffusion and/or ion implantation, the provision of patterned insulating, masking and conducting layers, and so on. Furthermore, the integrated circuits described can be assembled in the usual manner in conventional envelopes. For further illustration, the manufacture of the flip-flop shown in Figures 1 to 5, will now be described briefly hereinafter.

Starting material is a silicon substrate 21^a (Figure 2), for example of *n*-type conductivity and a resistivity between 0.005 and 0.015 ohm cm. On said substrate is provided an *n*-type epitaxial silicon layer 21^b having a resistivity of, for example, between 0.2 and 0.6 ohm cm and a thickness of, for example, approximately 5 μm. In this connection it is to be noted that the current amplification factor β of the inverted transistor structure used also depends upon the resistivity of the epitaxial layer. When said factor β is approximately 20 with a resistivity of approximately 0.1 ohm cm, the factor β is approximately 10 with the same *p* and *n*-type diffusions and a resistivity of approximately 0.6 ohm cm, in which it may be noted that with a view to a reliable operation of the circuit in practice a value of 3 or higher is desirable for the factor β.

A diffusion treatment is then carried out while using a masking layer of, for example, silicon dioxide and with phosphorus as an inpurity to obtain the low-ohmic *n*-type parts 21°. The surface concentration in said parts is, for example, 10^{21} atoms/ccm. The apertures through which said phosphorus doping is provided in the semiconductor body have a number of parallel extensions in such manner that between two adjacent extensions always sufficient area is present to be able to provide therein a base zone of the desirable size in a subsequent operation. Furthermore, two of those apertures are used in which the extensions of said apertures face each other and are in alignment with each other. The distance between the ends of oppositely located extensions is chosen to be equal to or slightly smaller than the distance which is ultimately desirable between the oppositely located base zones, for example, the zones 5 and 10. The base zones 1 to 10 and the injecting layer 20 may then be provided simultaneously in the conventional manner by diffusion *via* apertures of the desirable size in a masking layer. In the present example the masking pattern consists of two parallel strips which extend in a direction transverse to the n^+ extensions obtained in the meantime and which are present for the greater part in the intermediate space between the oppositely located extensions and each slightly overlap on one side the ends of said extensions or at least touch them. The width of said strips corresponds to the desirable distance between each of the base zones and the injecting layer. Boron, for example, is then indiffused throughout the free surface, for example to a depth of 2.5 μm, the resistance per square being, for example, approximately 150 ohm. Between the two masking strips the injecting layer results while furthermore the base zones 1 to 10 separated from each other are obtained because the surface concentration of said diffusion treatment is insufficient to change the conductivity type of the already present n^+ parts 21°. In this manner the base zones automatically adjoin the n^+ subzones 21° directly, they being each enclosed on three sides by a U-shaped n^+-type region.

The collector zones 22 to 37 are provided in the usual manner, for example, by local diffusion of phosphorus to a depth of approximately 1.5 μm and having a resistance per square of approximately 5 ohm, contact holes being then etched in the insulating layer and the pattern of conductive tracks 14 being provided, for example, by vapour-depositing and then etching a layer of aluminium.

The width of the injecting layer 20 is,

for example, approximately 20 μm. The distance from the injecting layer 20 to each of the base zones is approximately 8 μm. The dimensions of base zone 5 are, for example, approximately 50 μm$\times$80 μm, while those of the collector zone 33 are 20 μm$\times$20 μm. The width of the n^+ extensions between adjacent base zones may be, for example 10 μm.

If a sunken insulating layer is used entirely or partly instead of the ohmic subzones 21°, said layer can be obtained, for example, by local oxidation while using a masking layer which may consist, for example, of silicon nitride.

When buried layers are used, as denoted, for example, in Figures 6 and 13, these may be, for example, doped with arsenic with a surface concentration of approximately 10^{19} atoms/ccm and a resistance per square of approximately 20 ohm. For example, the buried layers 135 in Figure 13 may also be more highly doped than the base zones 125 to be biased which may be particularly advantageous if said buried layers form part of the emitter zone of the relevant transistor.

Other semiconductor materials such as germanium and $A^{III}B^{V}$ compounds or combinations of semiconductor materials in which, for example, the substrate consists of a semiconductor material other than the surface layer in which the circuit elements are present may be used. Instead of starting from an n^+ substrate 21^a (Figure 2) on which a lower doped layer 21^b is provided epitaxially, the starting material may also be a low-ohmic substrate which is then provided by outdiffusion of impurities with a lower doped surface layer. Furthermore, the conductivity types in the integrated circuits described may also be interchanged, in which the polarities of the voltages also have to be interchanged. The integrated circuit may also be provided, for example, with one or more electromagnetic radiation signal inputs and/or signal outputs. For example, an incoming radiation signal can be converted into an electric signal by means of a photodiode or phototransistor incorporated in the circuit, which electric signal may then serve as an input signal for a further part of the circuit.

As an injecting layer may also be used, for example, a layer which is separated from the intermediate layer of the current injector by a thin layer of insulating material. By using tunnel injection charge carriers can reach the intermediate layer of the current injector as minority charge carriers from the conductive layer through the thin insulating layer.

The current injector may have an even number of layers, although a current injector having an odd number of layers may be preferred. Also in the case of current injectors having four or more layers, it may be preferred that apart from the zone to be biased at most one further zone of the relevant circuit element coincides with a layer of the current injector.

In the integrated circuits described the common body consists substantially entirely of a semiconductor material. However the common body alternatively may consist mainly of insulating material, one or more semiconductor regions being provided on or embedded in the insulating material. Usually the semiconductor material is monocrystalline. In, and in certain cases also entirely or partly on, such semiconductor bodies, all kinds of circuit elements such as diodes, transistors, resistors and capacitors may be provided with semiconductor regions having different electrical properties, *p-n* junctions, Schottky junctions, insulating and conductive layers, and so on, which elements are connected to form a circuit by means of a pattern of conductive tracks.

Furthermore, in a current injector having, for example, seven layers, the third and the fifth layer may be used independently of each other for controlling the bias current to be supplied to the zone to be biased. The third and fifth layer of the current injector may then be considered, for example, as the two inputs of an AND gate of which the zone to be biased forms an output.

Zones of circuit elements other than the bipolar transistors shown, for example, zones of diodes and field effect transistors, can also be provided with bias current by means of the current injector in a corresponding manner. Moreover, for example, gate electrodes of field effect transistors, in particular of field effect transistors having a low threshold voltage, can be controlled by means of the current injector.

When using a lateral current injector as in Figure 1, the ratio between the bias currents supplied to various zones to be biased is proportional to the ratio between the lengths of the parts facing the injecting layer 20 of the *p-n* junctions between the relevant base zones to be biased and the intermediate layer 21. In the example shown the available bias current is equally large for each base zone. Other ratios can simply be realized by means of differences in length in the structure. In this way, for instance, the first transistor on the chip of an integrated circuit and/or the last one may be given a relatively large bias current to increase the noise margin at the input(s) and/or the output(s) of the chip. Another measure to increase the noise margin where necessary is to use a higher value of the current gain β. Such higher circuit gain may be obtained by giving the transistor(s) in question a relative large area collector region. Such relatively large collector region may have dimensions of, for example, 40 μm$\times$20 μm instead of 20 μm$\times$20 μm as used in the embodiment of Figure 1. This enlarged collector region may be nested in a relatively broad base region of 70 μm instead

of the 50 μm mentioned with reference to Figure 1.

Another method to set up different bias currents at different zones to be biased is to use different distances between the relevant injecting rectifying junction of the current injector and the different zones to be biased. The greater this distance the smaller is the number of charge carriers collected by the zone to be biased and the greater is the effective diffusion length in the region adjoining said zone to be biased.

Furthermore, instead of by doping, one or more of the layers of the current injector can be induced in the semiconductor body, for example, with surface states and/or charges in the insulating layer and/or by means of an electrode layer present on the insulating layer. In the five-layer current injector described, for example, the third layer may be formed by an induced inversion layer. One or more layers of the current injector may also consist of a combination of a part obtained by doping and an induced part cohering therewith. For example, when the distance between an injecting junction in the current injector obtained by doping and a collecting junction in the current injector obtained by doping is comparatively large so that in said part of the current injector no or a small current transfer takes place, said distance can be reduced by extending one or both layers at the surface on a side facing the other layer by an inversion layer.

When the described induced inverted layers are used, and in particular if they are obtained by means of an insulating electrode layer, the bias current to be supplied to the zone to be biased may also be controlled by the voltage on the electrode layer.

It will be apparent that in some of the integrated circuits described one characteristic feature is the presence of a semiconductor region of one conductivity type which adjoins a surface and in which an elongate strip-shaped surface zone of the opposite conductivity type extends which forms part, for example, of a system of channels or of a grid and which forms a *p-n* junction with the adjoining region, several juxtaposed surface zones of the opposite conductivity type which are separated from each other and from the strip-shaped zone adjoining the surface on at least one of the long sides of said strip-shaped zone, said surface zones constituting zones to be biased of circuit elements of the circuit and in particular base zones to be biased of bipolar transistors, the region and the strip-shaped surface zone being each provided with a connection to bias the said *p-n* junction in the forward direction to inject minority charge carriers into the region, the zones to be biased receiving bias current by collection of minority charge carriers from the region *via* the *p-n* junctions which said region forms with the zones to be biased.

WHAT WE CLAIM IS:—

1. An integrated circuit comprising a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body comprising a multi-layer current injector structure for supplying bias current to one or more zones to be biased of the circuit elements, the current injector structure having at least four successive layers which are separated from each other by rectifying junctions among which layers are a first injecting layer which is separated from the circuit element or elements to be biased by at least one rectifying junction, and an adjoining second, intermediate layer of a semiconductor material, means for connecting the injecting layer and the second, intermediate layer to a source of biasing potential to polarize the rectifying junction between the injecting layer and the second, intermediate layer in the forward direction causing injection of charge carriers from the injecting layer into the second, intermediate layer and causing collection of charge carrier by the last layer of said at least four successive layers, said one or more zones to be biased belonging or being connected to said last layer.

2. An integrated circuit as claimed in Claim 1, wherein the zone to be biased of at least one such circuit element is to collect charge carriers from a layer of the current injector which also forms a further zone of the said circuit element, the zone to be biased being directly connected to a further part of the integrated circuit.

3. An integrated circuit as claimed in Claim 1 or Claim 2, wherein the zone to be biased of one such circuit element and those layers of the current injector which have the same conductivity type as the zone to be biased are surface zones of one conductivity type which extend beside each other from the said side of the body in the same region of the opposite conductivity type and are surrounded in the body by said region, and the zone to be biased forms with the region a junction bounding said zone, *via* which junction said zone is to collect charge carriers from the region, which charge carriers are carriers injected in the region from a layer of the current injector constituting a rectifying junction with the region and being located at the said one side of the body.

4. An integrated circuit as claimed in any

of the 50 μm mentioned with reference to Figure 1.

Another method to set up different bias currents at different zones to be biased is to use different distances between the relevant injecting rectifying junction of the current injector and the different zones to be biased. The greater this distance the smaller is the number of charge carriers collected by the zone to be biased and the greater is the effective diffusion length in the region adjoining said zone to be biased.

Furthermore, instead of by doping, one or more of the layers of the current injector can be induced in the semiconductor body, for example, with surface states and/or charges in the insulating layer and/or by means of an electrode layer present on the insulating layer. In the five-layer current injector described, for example, the third layer may be formed by an induced inversion layer. One or more layers of the current injector may also consist of a combination of a part obtained by doping and an induced part cohering therewith. For example, when the distance between an injecting junction in the current injector obtained by doping and a collecting junction in the current injector obtained by doping is comparatively large so that in said part of the current injector no or a small current transfer takes place, said distance can be reduced by extending one or both layers at the surface on a side facing the other layer by an inversion layer.

When the described induced inverted layers are used, and in particular if they are obtained by means of an insulating electrode layer, the bias current to be supplied to the zone to be biased may also be controlled by the voltage on the electrode layer.

It will be apparent that in some of the integrated circuits described one characteristic feature is the presence of a semiconductor region of one conductivity type which adjoins a surface and in which an elongate strip-shaped surface zone of the opposite conductivity type extends which forms part, for example, of a system of channels or of a grid and which forms a *p-n* junction with the adjoining region, several juxtaposed surface zones of the opposite conductivity type which are separated from each other and from the strip-shaped zone adjoining the surface on at least one of the long sides of said strip-shaped zone, said surface zones constituting zones to be biased of circuit elements of the circuit and in particular base zones to be biased of bipolar transistors, the region and the strip-shaped surface zone being each provided with a connection to bias the said *p-n* junction in the forward direction to inject minority charge carriers into the region, the zones to be biased receiving bias current by collection of minority charge carriers from the region *via* the *p-n* junctions which said region forms with the zones to be biased.

WHAT WE CLAIM IS:—

1. An integrated circuit comprising a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body comprising a multi-layer current injector structure for supplying bias current to one or more zones to be biased of the circuit elements, the current injector structure having at least four successive layers which are separated from each other by rectifying junctions among which layers are a first injecting layer which is separated from the circuit element or elements to be biased by at least one rectifying junction, and an adjoining second, intermediate layer of a semiconductor material, means for connecting the injecting layer and the second, intermediate layer to a source of biasing potential to polarize the rectifying junction between the injecting layer and the second, intermediate layer in the forward direction causing injection of charge carriers from the injecting layer into the second, intermediate layer and causing collection of charge carrier by the last layer of said at least four successive layers, said one or more zones to be biased belonging or being connected to said last layer.

2. An integrated circuit as claimed in Claim 1, wherein the zone to be biased of at least one such circuit element is to collect charge carriers from a layer of the current injector which also forms a further zone of the said circuit element, the zone to be biased being directly connected to a further part of the integrated circuit.

3. An integrated circuit as claimed in Claim 1 or Claim 2, wherein the zone to be biased of one such circuit element and those layers of the current injector which have the same conductivity type as the zone to be biased are surface zones of one conductivity type which extend beside each other from the said side of the body in the same region of the opposite conductivity type and are surrounded in the body by said region, and the zone to be biased forms with the region a junction bounding said zone, *via* which junction said zone is to collect charge carriers from the region, which charge carriers are carriers injected in the region from a layer of the current injector constituting a rectifying junction with the region and being located at the said one side of the body.

4. An integrated circuit as claimed in any

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of Claims 1 to 3, wherein the current injector is a five-layer structure.

5. An integrated circuit as claimed in Claim 4, wherein the intermediate layer and the fourth layer of the current injector in the body constitute a continuous region of the same conductivity type.

6. An integrated circuit as claimed in any of the preceding Claims, wherein the current injector comprises means for controlling the bias current to be received by the zone to be biased.

7. An integrated circuit as claimed in any of Claims 4 to 6, wherein at least temporarily conducting connection is present between the collecting third layer and an adjoining layer of the current injector to control the bias current to be received by the zone to be biased.

8. An integrated circuit as claimed in any of the preceding Claims, wherein at least one such zone to be biased forms part of a transistor having at least two main electrodes and at least one control electrode.

9. An integrated circuit as claimed in Claim 8, wherein the transistor is a bipolar transistor, said zone to be biased being the base zone of the transistor.

10. An integrated circuit as claimed in Claim 9, wherein the layer of the current injector adjoining the base zone of the transistor constitutes the emitter zone of the transistor.

11. An integrated circuit as claimed in any of the preceding Claims, wherein at least two such circuit elements are present each having a zone to be biased which is to receive bias current by collection of charge carriers *via* a rectifying junction bounding said zone, said zones to be biased adjoining the same layer of the current injector.

12. An integrated circuit as claimed in Claim 10, or Claim 11 where appendant to Claim 10, wherein the base zones of a group of transistors are to receive their bias current by collection of charge carriers from the same layer which belongs to the current injector and which constitutes an emitter zone which is common to the transistors of the group.

13. An integrated circuit as claimed in Claim 12, wherein a collector of a first transistor of the group is connected, *via* the pattern of conductive tracks, to the base of a second transistor of the group as a result of which said two D.C. coupled transistors are arranged in cascade.

14. An integrated circuit as claimed in Claim 13, wherein of at least a further transistor of the group the emitter-collector path is connected parallel to the emitter-collector path of the said first transistor, the collectors of the further transistor and the first transistor being connected together *via* the pattern of conductive tracks.

15. An integrated circuit as claimed in any of Claims 12 to 14, wherein with one or more transistors belonging to the group a linear amplifier circuit is formed which comprises two or more direct current coupled transistors, the base zone of a first of the transistors of the group also constituting one of the main electrodes of a lateral complementary transistor, a direct current coupling being provided which derives a direct current from the collector of the first transistor, said current being supplied to the other main electrode of the lateral transistor.

16. An integrated circuit as claimed in any of the preceding Claims, wherein one or more collectors of the transistors are formed by a metal-containing layer which forms a Schottky junction with the adjoining base zone.

17. An integrated circuit as claimed in Claim 12, or in any of Claims 13 to 16 where appendant to Claim 12, wherein at least a direct current coupling is present between a collector of one transistor of the group and the base zone of a further transistor, of which further transistor the one main electrode is constituted by the common emitter zone of the group of transistors, the other main electrode being connected to a connection point for a comparatively large potential lying outside the voltage of the current injector.

18. An integrated circuit as claimed in Claim 17, wherein the one main electrode of the further transistor is the collector and the other main electrode is the emitter.

19. An integrated circuit as claimed in any of Claims 6 to 13, wherein the current injector is a five-layer structure of which the fifth layer belongs to the base zone of a transistor, means being present for causing a variation in the bias current supplied to said base zone by withdrawal of injected charge carriers from the third layer of the current injector.

20. An integrated circuit comprising a plurality of circuit elements which are arranged beside each other at one side of a body which is common to said circuit elements, at least one of said circuit elements comprising a transistor having main electrode zones defining a main current path therethrough, semiconductor zones of said circuit elements being connected to a pattern of conductive tracks present at the said one side of the body for electrical connection of the said circuit elements, said pattern having at least one input and at least one output for electrical signals, the body furthermore comprising connections for connecting the two polarities of a source for supplying bias current to one or more of the circuit elements, the body also comprising a multi-layer current injector structure for supplying bias current to one of said main electrode zones of said transistor, the current injector structure having at least three suc-

cessive layers which are separated from each other by rectifying junctions among which layers are a first injecting layer which is separated from the circuit elements by at least one rectifying junction, and an adjoining second, intermediate layer of a semiconductor material, the injecting layer having a connection for one polarity of the said source and the intermediate layer having a connection for the other polarity of the said source to polarize the rectifying junction between the injecting layer and the intermediate layer in the forward direction causing injection of charge carriers from the injecting layer into the intermediate layer and collection of charge carriers by said one main electrode zone, said one main electrode zone belonging to one of the layers of the current injector, said one layer being separated from the source connection for the one polarity by at least two rectifying junctions.

21. An integrated circuit as claimed in Claim 20, wherein the other main electrode zone of said transistor is connected to means for applying a comparatively large potential lying outside the voltage range of the current injector, said transistor having a base zone belonging to the intermediate layer of the current injector.

22. An integrated circuit as claimed in Claim 1 or Claim 20, wherein means are present whereby at least two layers of the current injector situated between the first injecting layer and the last layer of the current injector serve independently of each other for the control of bias current to be supplied to the zone to be biased.

23. An integrated circuit as claimed in Claim 22, wherein said at least two layers of the current injector are alternately situated layers.

24. An integrated circuit substantially as herein described with reference to Figures 7 and 8 of the accompanying drawings.

25. An integrated circuit substantially as herein described with reference to Figure 9 and 10 of the accompanying drawings.

C. A. CLARK,
Chartered Patent Agent,
Century House,
Shaftesbury Avenue,
London WC2H 8AS.
Agent for the Applicants.

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