istic resembles that of a tetrode valve having a negative resistance region at about 0.15 volts. This negative resistance can be used to obtain oscillations.

Integrated Circuits

By extending the planar technique many transistors and other components can be diffused into a single silicon die with dimensions typically $1.5 \times 1.5 \times 0.3$mm. In an integrated circuit these components are connected together in some desired circuit configuration by a network of metal interconnections on the surface of the die. Fig 42 illustrates a tiny piece of a junction type integrated circuit which contains a resistor and a transistor. The n-type epitaxial layer, into which the components are diffused, is grown on a substrate of p-type silicon. The n^+ buried layer underneath the transistor helps to reduce the saturation voltage by reducing the lateral resistance of the collector.

The first diffusion after the epitaxial layer has been grown and its surface oxidised is that of the isolation regions (the curved vertical columns); trivalent material is diffused through windows in the oxide, the diffusion being allowed to continue until the p-type region so produced meets the underlying substrate (the epitaxial layer is typically about 10μm deep). Isolation between the individual components on the die is achieved by reverse biasing the p-n junctions formed between the isolation regions and the epitaxial layer. In this

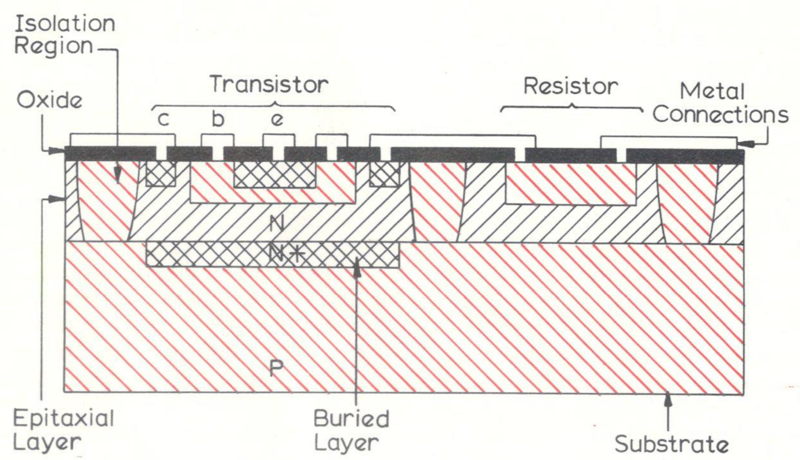

Fig. 42 Tiny Piece of Integrated Circuit

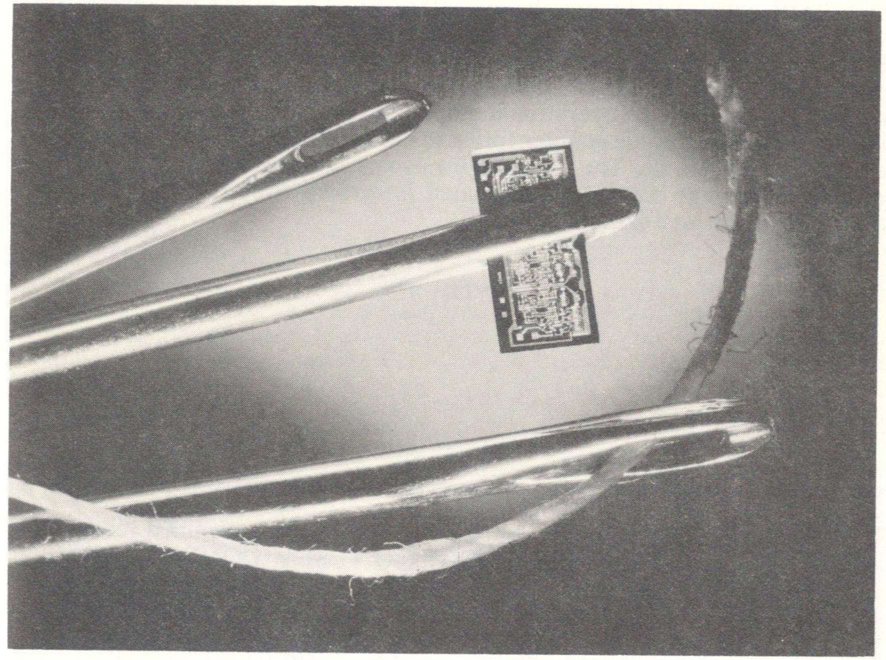

Fig. 43 Typical Integrated Circuit

type of integrated circuit resistors are simply layers of p-type silicon. The p-type transistor bases and resistors are diffused simultaneously, the value of the resistor being determined by its surface area. The parts of the manufacturing process not described here are the same as for planar transistors (see section 4).

Where diodes are required the emitter diffusion can be omitted but it is more usual to employ a transistor whose emitter and collector are short-circuited. Small capacitors are provided by reverse-biased diodes which exhibit a few pF of capacitance dependent on the degree of reverse bias. Larger capacitors and inductors are added externally i.e. outside the integrated circuit encapsulation.

A far greater degree of miniaturisation can be achieved using MOST techniques. Their high input resistance and simpler construction make it possible to diffuse thousands of devices on a small silicon die.

The number of applications for integrated circuits is almost limitless. Devices are available that can replace all the basic computer circuits such as NAND

and NOR gates, J-K binary stages, binary counters employing several J-K stages and so on. There are also integrated circuits for single and multiple linear amplifier stages, for example the I.F. and audio driver sections of an A.M. radio receiver can be included on one die. Other examples are pre-amplifying circuits and operational amplifiers. Fig 43 is a photograph of an integrated circuit decade counter (prior to encapsulation) passing through the eye of a No. 5 needle. The die contains over 120 components. The 'rope' is ordinary 40 gauge cotton. Encapsulated integrated circuits are included in the frontispiece photograph.

The material used in this book is available in programmed form in A PROGRAMMED BOOK ON SEMICONDUCTOR DEVICES and also as a filmstrip SEMICONDUCTOR DEVICES (reference number E136). Details of these and other teaching materials are available from the Mullard Educational Service, Mullard House, Torrington Place, WC1E 7HD.

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