AN INTRODUCTION TO

THICK FILM HYBRID CIRCUIT TECHNOLOGY

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INTRODUCTION

The development of microelectronic technology has led to the emergence of three methods of manufacture, namely thick film, thin film and monolithic semiconductor technologies. Of these, thick film has emerged as the main workhorse as it is flexible, low cost and can produce an electronic assembly which is reliable in the most demanding environments.

Thick film hybrids are produced by screen printing conductive and resistive inks onto a ceramic substrate and then firing at a high temperature. Monolithic semiconductors can then be attached in either their unpackaged or encapsulated state, along with other passive components available in a microminiature form, with plastic, ceramic or metal encapsulation.

The main advantages of hybrids are:

- a considerable reduction in size for use where conventional printed circuit boards will not fit;
- efficient and reduced interconnection between electronic subassemblies;
- the ability to calibrate the module to system requirements where needed;
- relatively low development costs, compared with silicon.

PRINTING AND FIRING

The printing process used in hybrid production has been developed from silk screen processes used in the textile industry *(figure 1).* The base substrate, commonly an 800 microns thickness alumina compound, is available in industry standard sizes, of which 50 and 75 mm square are typical.

The printing sequence involves a screen being placed over the substrate and then a squeegee passes over the screen, depositing a layer of ink onto the substrate. This process is repeated for each layer of conductor, resistors or dielectric. Conductor inks are usually gold or silver based and multilayer circuits can be built up by sandwiching a dielectric layer between each layer of conductor *(figure 2).*

It is quite normal for six or seven screens to be used for each type of circuit and where the hybrid is small in relation to substrate, several are printed on the same substrate.

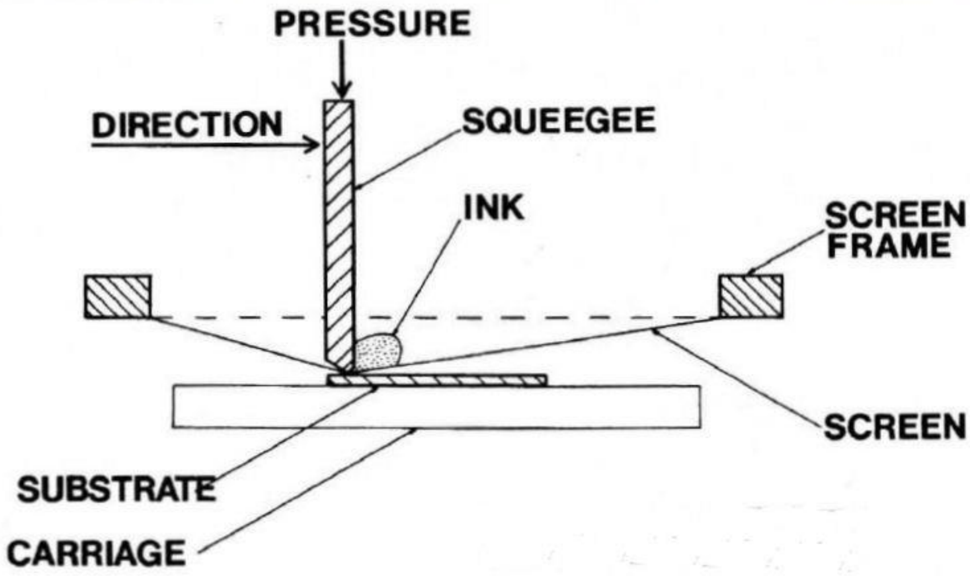

Figure 1: Screen printing onto alumina substrate

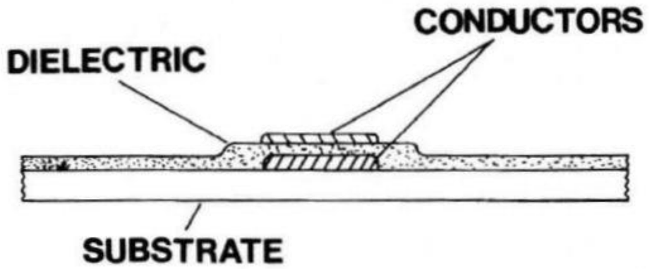

Figure 2: Multilayer circuit

Having been printed, the substrates are dried at a temperature of 70-150°C. This is to remove the more volatile ink components. Once drying is complete the substrates must be fired.

Firing consists of two stages which take place consecutively in the same furnace. Primarily, solvents and organic binding materials used in the inks are removed in an oxidising atmosphere at around 450°C. The substrates are then passed into a temperature zone of 850°C, at which point the glass elements in the ink melt to form a vitreous medium which consolidates the printed layer and allows adhesion to the ceramic substrate. As the substrates are very gradually cooled down, the molten glass solidifies to form a coherent thick film. The two most important variables in the firing process are time and temperature. Any deviation from those specified for the ink and substrates being used may result in the deformation of the conductive patterns, resistors and their Temperature Coefficient of Resistance (TCR) ratings. The peak temperature may last for any period between one and fifteen minutes.

Substrate firing usually takes place using a slow-moving belt which passes through a furnace with several closely controlled temperature zones *(figure 3).* An airflow passes over the belt which removes volatiles from the firing substrates and maintains temperatures throughout the furnace.

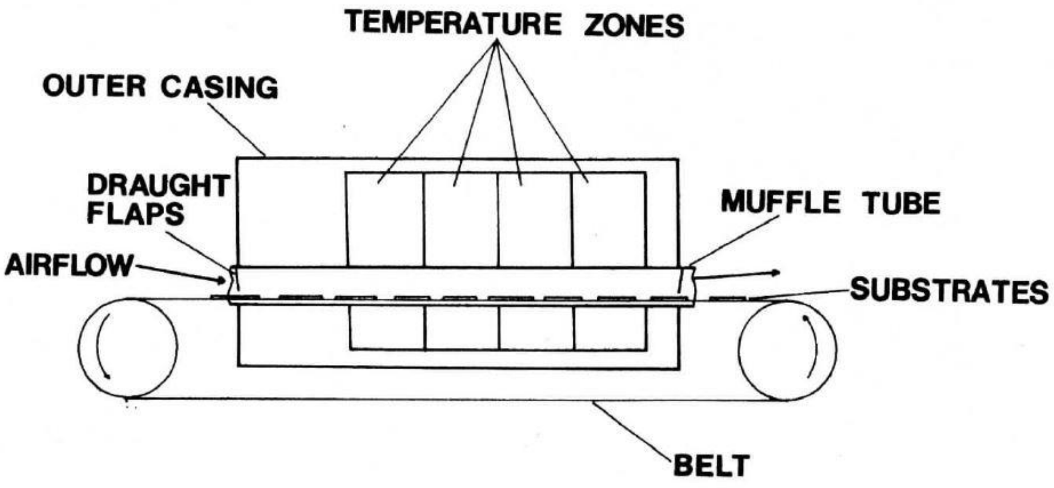

Figure 3: Substrate furnace

RESISTORS

The ink material for resistors is normally changed between decades. This means that resistors of high values can occupy the same area as smaller values, the resistance obtained being dependent on aspect ratio and sheet resistivity.

Where resistor tolerances are critical, it is usual to print at a value below that required. Increasing values to their required level is achieved by trimming the resistors on completion of firing. At this stage an industrial laser bean is employed. The substrate is placed under the optics of the laser and a ring of probes descends onto it, with each pair of probes positioned so that they are effectively measuring the resistance across a particular resistor. The layout of the circuit includes small pads within the conductors which enable a good connection with the probes to be made.

By using the laser beam to vapourise a section of the material of each resistor, the impedance against electron flow is increased and the effective resistance is thus enlarged *(figure 4).* When this process is automated, the laser beam cuts off when the required quantity has been reached and then passes to the next resistor to be trimmed. In a computer-controlled production suite, even large circuits can have resistor trimming complete in a few seconds.

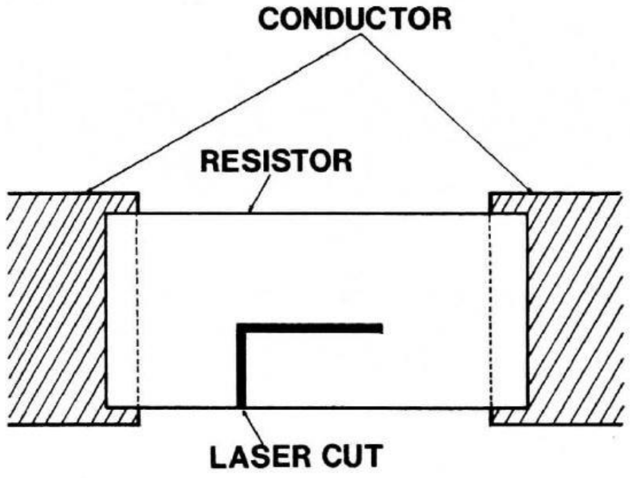

Figure 4: Resistor trimming

One of the advantages of thick film resistors on hybrid circuits is that they can be manufactured to any value required, thus eliminating the dilemma faced by many designers when they have to meet a specified resistance by using standard value resistors in series or parallel. This alone means that the resistor itself is space efficient and avoids the cumulative tolerances that may otherwise be encountered. The process of trimming resistors under their quiescent state is called a *passive trim*.

COMPONENT ASSEMBLY

At the assembly stage, discrete components, both active and passive, are attached to the ceramic substrate. Where semiconductor devices are to be used, there are two catagories of non-packaged and packaged components.

The first category - which is the most space-efficient - involves the attachment and interconnection of naked semiconductors to the circuit. These devices, referred to as dice, are bonded to the circuit with either an electrically conductive or non-conductive thixotropic epoxy resin paste. The conductive type is commonly filled with a gold or silver powder, particularly useful where a transistor or diode has an active substrate connection. The non-conductive material contains aluminium or asbestos, aiding thermal conductivity and lowering the coefficient of thermal expansion of the adhesive. A metered amount of this compound is dispensed onto a pad of the conductor material and the die is then positioned on the surface of the resin *(figure 5).* The assembly is then cured at room or an increased temperature, depending on the materials used.

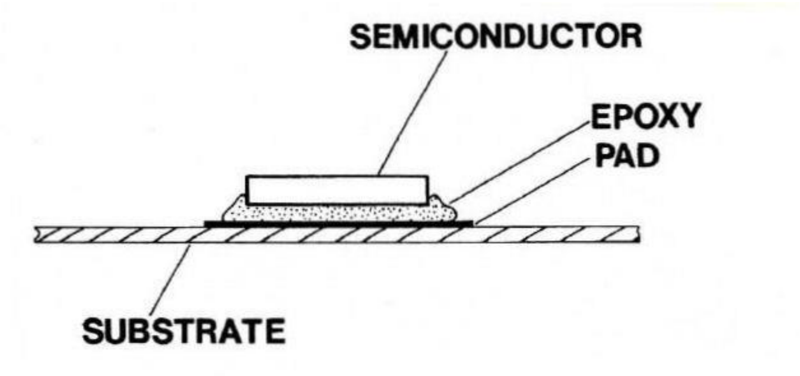

Figure 5: Die attachment

Connections to the surface of the semiconductor are made using a thermosonic or thermocompression wire bonding technique. In this process, gold or aluminium wire is passed through a capilliary on a bonding bead, with permanent contact to the die and substrate made by a simultaneous application of heat, vibration or pressure *(figure 6).*

This is repeated for each of the pinouts on the active device and since the same wire bonds are to be made on each specified circuit, the process is often automated at high volumes.

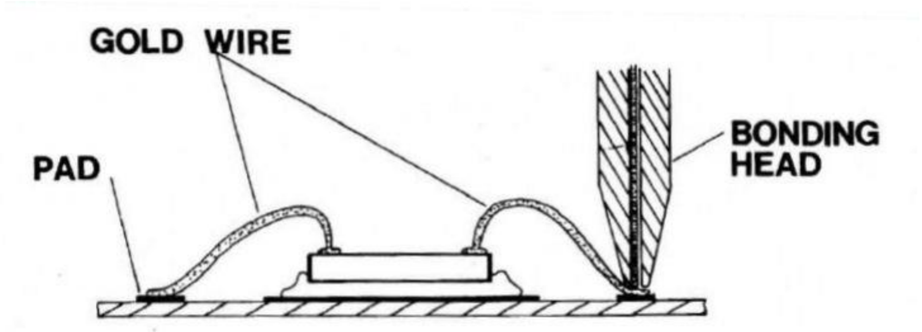

Figure 6: Wire bonding of die

The second method of attachment employs surface mounted microminiature packages in either leadless chip carrier or small outline configurations. These are re-flow soldered to the circuit and are generally used where size and/or environmental criteria are not intrinsically critical. In both methods of assembly, chip capacitors, miniature inductors and other passive components will be mounted, their method of attachment being either resin or solder orientated, depending on that used for the semiconductor devices.

It is possible to combine both die-and-wire bond and reflow solder methods on the same circuit for a variety of reasons, such as having to use encapsulated leadless chip carriers on a circuit that is mainly die for size reasons. It is not uncommon to have up to twenty integrated circuits on a 25mm square substrate employing die and wirebond technology, emphasising the considerable size reduction that can be achieved.

ACTIVE TRIMMING

In some applications, the construction of the hybrid lends itself to calibration of the circuit under test conditions. One popular application of hybrid technology is the design and implementation of RF filters, where the frequency response characteristics can be calibrated during manufacture. This is done by returning the assembled units to the laser trimmer and, by setting up the hybrid under its operating conditions, adjusting parameters such as gain, bandwidth and offset voltages by increasing the value of certain resistors, using laser trimming. Such resistors normally occupy a larger area than the passive resistors to allow a further cut to be made where active calibration is required.

This process also lends itself to automation, provided that a suitable algorithm is used, coupled with an effective interface between the test equipment and the laser control apparatus *(figure 7).*

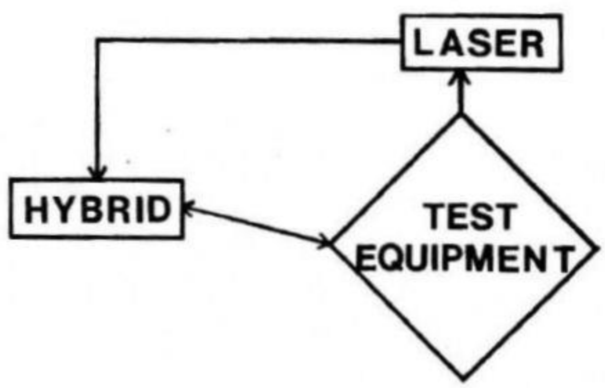

Figure 7: Active trimming to calibrate a hybrid under test conditions

ENCAPSULATION

The final stage of hybrid fabrication is the encapsulation and packaging, providing environmental protection as well as safeguarding from mechanical damage and wear and tear. There are three methods that are widely used, depending on the application and assembly technique employed.

The most flexible method in terms of size and pinout configuration is conformal coating *(figure 8).* In this process, a relatively thin layer of protective resin covers the circuit, resulting in an external profile similar to the bare circuit with its components. Where die-and-wire bond technology has been used, a local resin encapsulation covers the semiconductor and wire-bonded regions to provide initial protection. Final coating is achieved by dipping the assembled units into a bath of resin that is subsequently cured. Circuits employing pins for connection have these attached by solder prior to dipping. This method is most used for single in line circuits, although dual in line circuits may be encapsulated in the same way. Conformal coating is not normally acceptable in high specification environments, although it does provide rugged protection and a degree of commercial security for industrial and telecommunications applications.

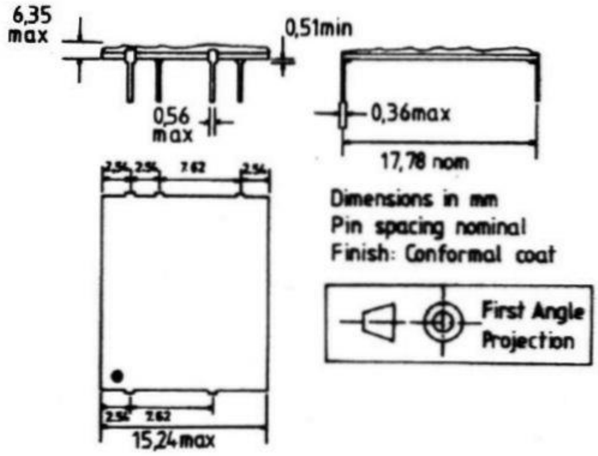

Figure 8: Typical hybrid circuit with conformal coated resin finish

Secondly, a ceramic lid may be attached to the circuit *(figure 9)*, which may be either dual in line or single in line configuration. A military temperature range, high integrity and the ability to mix construction technologies make ceramic encapsulation increasingly popular.

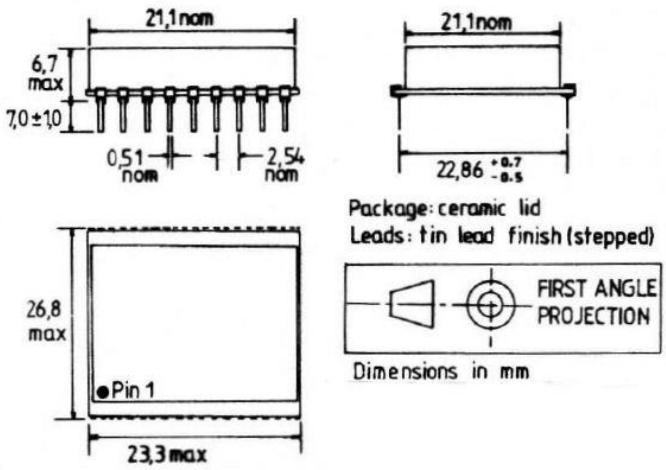

Figure 9: Typical hybrid circuit with ceramic lid encapsulation

Finally, where hermeticity is an important consideration, the hybrid circuit is sealed inside a welded metal can. Metal packages, either plug-ins or flatpacks come in a wide variety of outlines and sizes. The substrate is glued to the base of the package, with connections to the outside world made by wire-bonding the conductive tracks to glass sealed lead-outs.

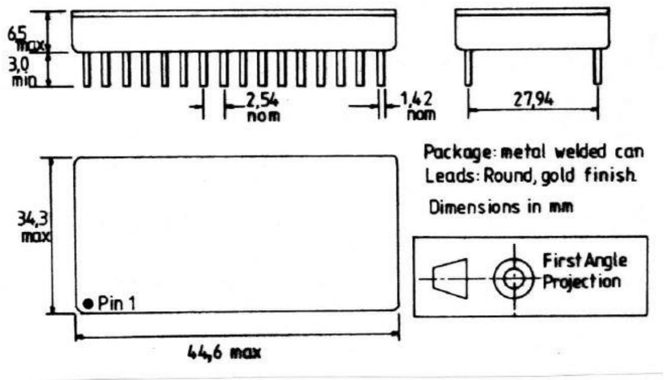

Figure 10: Typical hybrid circuit encapsulated in a hermetically-sealed package

Hermetic sealing can be carried out by projection and parallel seam resistance welding, generally taking place in an enclosed chamber filled with an inert dry gas. In both methods, the lid is sealed to the base by applying a high current pulse between two electrodes in contact with the base and lid, which provides sufficient heat to make a contact weld.

In the case of projection welding, a single pulse is made through two electrodes tooled to simultaneously touch all of the weld area, whereas seam welding involves two rolling electrodes being moved around the package surface emitting a series of high frequency current pulses to each other and causing a resistive weld to be made. Ceramic and metal packages are only effective where die and wirebond assembly techniques have been used due to the internal size constraints. Some passive components are also limited in use, particularly high value chip capacitors, for the same reasons.

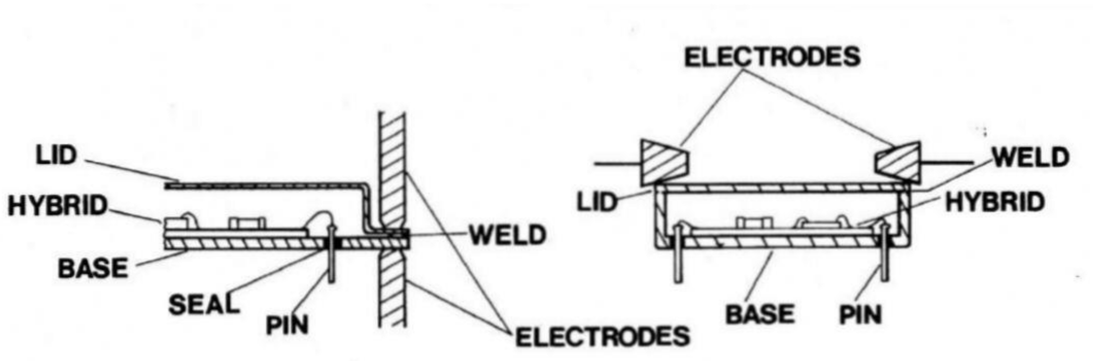

Figure 11: Projection and seam welding of hermetically-sealed packages

RECENT DEVELOPMENTS

As size reduction and efficient interconnection have become an important feature of microelectronic assemblies in the 1980's, hybrid circuits have played an increasing role. In applications where a hybrid may contain several monolithic circuits of the same technology, these can be replaced by a single die using custom and semi-custom integrated circuits. Semi-custom VLSI is now regularly specified and is regarded as a natural complement to the thick film process
.
It is also possible for substrates to be configured to any shape using some imaginative computer aided laser scribing techniques. These are then printed and assembled in the same way as conventional hybrids, although many, by virtue of their outline utilise a special method of interconnection. Where several hybrids are to be mounted on the same board, manufacturers have come up with some innovative advances of which using flexible printed circuit boards as an interconnection method between a number of thick film circuits.

CONCLUSION

In conclusion, it can be said that whilst some electronic assembly techniques have waxed and waned in relevance and popularity, thick film technology has been an important consideration in microelectronic system realisation in the 1970s and 80s. Despite the progressive trend towards monolithic solutions, thick film circuits will continue to be an attractive option to design engineers well into the 21st century.