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The following two papers were not presented at the Symposium, but are included in the proceedings since the information would be of significant value for the people in this field.

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Thick Film Production Techniques

by

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Thick Film Production Techniques

Introduction

The user of our engineering designs is expecting and receiving more product sophistication and system complexity than ever before. Electronics plays a role which ranges from dimming the living room lights to docking space-craft in orbit, and the pressures of economics and reliability challenge us incessantly. One significant response has been the widespread application of microelectronics in volume production as our skills with this useful tool have matured. Consequently, rapid growth in production and packaging of microcircuits has marked a large segment of industry.

Thick film circuits have grown increasingly in volume with the general growth in microelectronics as a reliable, low cost means of interconnecting active devices. The thick film technology makes it possible to mix monolithic circuits and discrete components for any circuit function at the lowest possible cost. Additional advantages include power rating, thermal tracking, high circuit density, fewer discrete components and fewer interconnections.

Flat pack active devices are shown mounted to the substrates. Chips, lids, (Leadless Inverted Devices), and hermetic ceramic microtransistors can also be used. Other circuits with attached plastic transistors and standard hermetically sealed TO-5 and TO-18 transistors have been manufactured in quantity. Substrates have been produced in sizes small enough to fit in a TO-5 can and up to several square inches in size. Circuits combining monolithic integrated circuit chips and passive interface components are in production.

The article describes processing of thick-film networks from raw materials through package assembly into finished circuits.

Part I: Thick Film Passive Networks

Fabrication of Thick Film Networks

The fabrication steps in manufacturing thick film circuits are listed in the flow diagram (Fig. 1). The first steps, starting with the schematic and progressing through the photographic processes yielding masks, are common to many associated technologies. Therefore, detailed discussion of the subsequent steps is more appropriate.

The Substrate

The most commonly used substrate material is a high-alumina porcelain containing from 4 to 6% glass. The selection of this material is based on a compromise of thermal, electrical, and mechanical properties together with economic considerations. Substrates are generally used in the "as-fired" state, and are obtainable from a number of suppliers in a wide variety of sizes and shapes with standard 1% dimensional tolerances. Holes frequently simplify layout, assembly, and interconnection of the circuits, often amply justifying the cost and time delay of special tooling for substrate production. Their use should be carefully engineered in consideration of substrate thickness and location in order to anticipate potential stress-cracking problems in substrate processing and packaging.

Screening

All pastes, whether they are conductive, resistive, or dielectric, possess certain general properties. They consist of very fine particles suspended in organic vehicles. The weight fraction of solids usually ranges from 50 to 80%, depending on the specific gravity and film thickness desired. Useful values of viscosity range from 20,000 to 250,000 centipoise, with the higher values required for conductors and resistors and lower values for dielectrics. Thorough mixing of high viscosity pastes is necessary to maintain homogeneity. Vehicles should not have excessive vapor pressures and must provide lubrication for the squeegee during screening. A moderate degree of thixotropy is most desirable, otherwise the paste is apt to lose screening definition. Highly thixotropic pastes tend not to heal, however, leaving the imprint of the screen mesh.

A variety of hand, semiautomatic and automatic machines has been developed for deposition by screen printing. Each has idiosyncrasies in setup and work handling, but the dynamics of the printing process are similar. The squeegee is driven across the screen at a constant rate and deforms the screen to the point where it contacts the substrate, forcing the paste through the mask. The machine's allowance for control of squeegee rate and pressure, and its ability to maintain these settings, is an important factor in achieving economy and uniformity in the product since material deposition must be controlled in three dimensions.

Firing

Continuous conveyor furnaces are preferable for the production of thick film components. When very high temperatures are required, as in the production of high value capacitors, pusher type furnaces with boats are used.

The sequence of screenings and firings for R-C networks consists of a high temperature conductor, dielectric, capacitor top conductor, resistor(s), and glass encapsulation. The temperature profiles in the furnaces depend on the materials selected.

The temperature schedules for conductors are functions of the percentage, composition, and softening point of glass fluxes. Schedules are optimized by pull and peel tests for solderable conductors. Conditions for gold conductors are determined by inspecting alloying with silicon chips and the force required to remove attached chips under a shear stress.

The optimum temperature profiles for dielectrics are determined by satisfactory dielectric properties and vitrification. One family of dielectric pastes developed and extensively used at Microtek is fired for thirty minutes in the 800 - 900°C range. High "K" materials require much higher temperature.

The resistor furnace profiles are determined by the desired resistivity and related properties. The firing of resistor materials is complex even with the most commonly used systems such as the Dupont 8000 Series. At present a peak temperature around 685°C is recommended for these materials. These pastes consist of mixtures of organics, a relatively low melting glass, and silver and palladium metals. The proportions of glass and metal determine the specified sheet resistivities. During the firing process organics are oxidized and vaporized. Then alloying of the metals, oxidation of palladium, softening of the glass all take place, resulting in a very complex heterogeneous microstructure. Such kinetic processes as alloying and oxidation are diffusion controlled, and wetting rates are determined by interfacial energies and controlled by the viscosity of the glass. Diffusion coefficients and viscous flow of glasses generally display exponential temperature dependencies. The result is that both the heating rate and time at peak temperature strongly influence sheet resistivity, long term stability, temperature coefficient and current noise characteristics of resistors.

Subsequently, a low melting glaze is fired at temperatures below 600°C, at a temperature where the resistor may be heated without changing in value. This glaze provides a protective seal for resistors and capacitors and serves as an insulation for conductors.

Trimming

Resistors are trimmed to value by an airbrasive process. A stream of abrasive alumina particles impinges on the film resistor, selectively removing resistor material from the substrate. Material is removed in such a way as to increase the effective number of squares of material, thus increasing the resistor value. During trimming, the value is monitored on an electrical bridge which compares the trimmed value to a preset standard value of resistance. When the trimmed resistor reaches the target value, the bridge becomes balanced, and a signal is sent to the abrasive unit to shut off the stream of particles. The automatic shut-off feature is sensitive enough to allow many shapes of resistors to be corrected to tolerances as low as ±0.1%.

Similar mechanical methods can be adapted to trim capacitors. A laser beam has been used to remove material from the top conductor area without damaging the dielectric.

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Properties of Thick Film Components

Conductors

All the conductor materials have very low sheet resistivities, less than .05 ohms/sq. This can be further reduced by soldering when necessary. Palladium-silver conductors are generally used for solderable leads although platinum-gold and palladium gold find frequent use. Pure gold is most satisfactory for chip and wire bonding.

The most important conductor property is adhesion to the substrate. In use, stress which is applied generally comes from the flexing of leads, and peel strength tests are more meaningful than axial pull tests. The peel strength is determined by soldering a ribbon lead to a pad on a tangent to the substrate, then pulling it off at constant force perpendicular to the substrates. The force required divided by the pad width indicates the peel strength and is generally of the order of 100 lb./in. for palladium-silver.

Capacitors

The design versatility of the thick film capacitors is
Sheet capacitances are available in the 1,250 - 100,000 pf/in.^{2} range. The temperature and voltage characteristics vary depending on the dielectric material. Composition 001G004 is used primarily in the fabrication of crossovers and small capacitors in the 1-25 pf range. Crossover capacitance is generally between 0.1 - 1 pf and capacitors in the 1-25 pf range can easily be screened and fired to tolerances $\pm 10\%$ of design value. These capacitors have excellent stability and can pass a 500 volt breakdown test.

The glass based dielectrics have low temperature coefficients in the $-50^{o}C$ to $+150^{o}C$ range Capacitors can possess Q's greater than 500 at frequencies up to 100 megacycles per second. There is a small variation of capacitance over a wide frequency range. The glass based dielectric formulations have only a small voltage coefficient of capacitance.
Dissipation factors remain relatively unaffected by increased voltages.

Resistors

Available resistivities range from 100 ohms/sq. to 200,000 ohms/sq., so that most useful resistance values are easily attainable. The distribuiton of values of any particular resistor after firing even with careful control is usually about $\pm 10\%$. Therefore, when close tolerances are required, resistors are designed for about 80% of the desired value, and then trimmed to value.

Part II: Thick Film Hybrid Microcircuits

In Part I the fabrication and properties of thick film passive networks were discussed. The resistors, capacitors, and conductor patterns achieved by the thick film process on an insulated substrate constitute a network component. In most practical circuits, a marriage with active devices and other component types is necessary before a passive network can do anything useful to a product or system. Device selection, assembly to the network substrate, and packaging of the resultant circuit are necessary steps to a finished product.

Discrete Components for Hybrids

When thin-film technology was in its infancy in the early sixties, compatible discrete components were available from only a handful of suppliers and only in prototype quantitites with long delivery times and at relatively high prices. So few microminiature components types were available in those days that it was possible to list them specifically.

Today, however, with the advent of the more versatile and economical thick-film technology and the widespread development and usage of planar semiconductor technology, the production of compatible discrete components has multiplied. Numerous types of microminiature components are now available off-the-shelf in prototype quantities and in only a few weeks in production quantities. All small-signal silicon planar transistors and diodes can be packaged in a microminiature form. Silicon integrated circuits in flat packs and chip form are compatible with thick films. Small ceramic capacitors are now available off-the-shelf in a wide range of values (to over 1 MFD) due to the development of multilayer construction techniques. Compatible tantalum capacitors are readily available in standard values, as are variable inductors and capacitors. In the last two years, many different suppliers of components for hybrid film microcircuit application have emerged. The line of products is extensive and readily available all except in a component buyers' guide.

The most basic component choice to be made is in the area of active devices. The type of device package chosen impacts upon the choice of network conductor materials and upon the circuit assembly techniques more than any other factor, and is thus worthy of special attention.

The choice of active devices depends on physical size limitations, device parameters, reliability, and final package requirements. One of the first decisions made before a layout is attempted is whether active devices will be used in chip or packaged form. Chips require gold conductor material, die and wire bonding techniques for assembly, and protection in final packaging; they offer significant size and cost advantages. Packaged devices are pre-protected to a large degree, are usually attached by simple

A number of properties are dependent on firing treatment. With the resistor compositions used, increasing the time at peak temperature from five to 30 minutes tends to shift the worst case TCR from a high of +300 ppm/°C to -300 ppm/°C. Such coefficients are usually specified. Much lower TCR's may be obtained with intermediate times, and negative TCR's at low temperatures coupled with positive TCR's at high temperatures give rise to resistors which have less than a 2% variation from -55 to +125°C. For glass encapsulated resistors, the long term stability at 125°C is generally better than 0.1%/1000 hours, assuming 100 hour preconditioning at 125°C. Current noise depends heavily on the resistivity, increasing from approximately -30 dB/decade at 100 ohms/sq. to around +10 dB/decade at 200,000 ohms/sq.

Future Trends in Materials for Thick Films

The development of materials for the thick film process is progressing at a rapid rate. Much work remains to be done with resistive and dielectric pastes. Resistors having low noise and low temperature coefficients are feasible and will be competitive with wire wounds in performance and cost. Thick film capacitors are in their infancy; screenable pastes resulting in sheet capacitance in the 100,000-500,000 pf/in.^{2} range with high voltage breakdown are being developed. Economics favors these devices when several capacitors occur in a circuit.

The deposition of inductors and active elements will also take place. Thermistors, varistors and piezoelectrics offer other possibilities. The unlimited possibilities offered by these devices will result in their integration into functional networks using the reliable and economical thick film process.

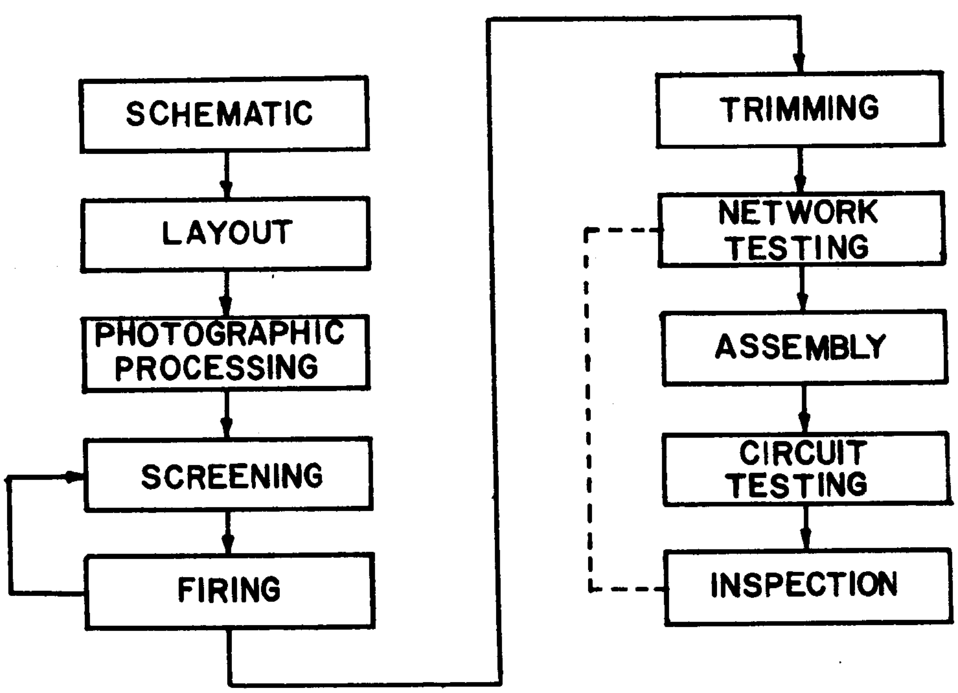

FIG. I

soldering or welding techniques, and lend themselves to handling and testing with less special equipment and skill.

The cost and size advantages of chips are often difficult to realize, especially at the low volume of prototype level because of the difficulty of testing bare chips. The economics of chips also depends on the number of chips per substrate and the parameter specifications of the devices. A circuit produced in quantity with a reasonable number of loosely specified chips can be produced at lower cost and in less space than the same circuit using encapsulated active devices. The choice depends on a specific analysis of the circuit, its device requirements, and the overall economic picture.

Assembly Techniques

Soldering

In selecting and qualifying an assembly process for thick films, it becomes apparent that there are basic differences between the requirements for assembly of conventional P.C. boards and metallized Al_2O_3 substrates. The basic differences are metallurgical and thermal. The conventional solders used for soldering P.C. boards alloy detrimentally with thick film conductors. The addition of alloying elements such as Ag, In, Sb, Bi, and Au to conventional solders such as 60/40 reduces the solution rate but either changes the melting point and the fluxing requirements, or increases the plastic range of the solder beyond practical usefulness. The most practical solders found to date are Pb/Sn/Ag and Ag/In for solders in the 200°C range, and Au/Sn for solder in the 250°C range. A solder composed of 80% wt. Au 20% wt. Sn is especially useful as a high temperature solder for gold frits.

Pulse Soldering

A pulse heated soldering device was built for soldering contacts to the surface of ceramic substrates. In this device the contacts are held in a suitable fixture and several hundred amps are passed through the fixture providing the necessary heat for reflow soldering. High temperature solder joints can be made with this machine, including joints with precious metal solders with melting points around 350°C. Advantages of this process over the more conventional hot plate soldering are (1) the substrate is only locally heated, thereby maintaining integrity of previously made solder joints, and (2) thermal shock is minimized by programming current flow through the heating fixture. Figs. 12 and 13 show substrates with pins installed using the pulse soldering machine. Notice that the laser-welded transistor cluster has been soldered into the circuit.

*Thermoswaging

A reliable process for swaging contact pins into substrates was developed to eliminate fracturing the brittle ceramic, as fracturing is frequently a problem with mechanical operations. In the thermoswage process, the head of the pin is heated until it becomes plastic enough to be deformed with extremely low forces. The process is fast (.010 - .025 seconds per swage) and will swage a variety of materials including copper, nickel, brass, and kovar. A low inertia swaging head minimizes mechanical shock thereby eliminating the cracking problem.

Laser Welding

A laser welder designed and built at Microtek is a valuable production assembly tool. It is used for joining discrete components prior to soldering to thick film conductors. Pulse stretching permits welding a large variety of lead materials. Welding parameters are less critical with regard to lead size and materials than with resistance welding.

Chip Mounting

Chip mounting can be accomplished with standard or slightly modified semiconductor die bonding equipment. AuSi bonds are made at 290-330°C. In special applications conductive epoxies are used successfully for die bonding. Gold-backed chips are preferred for all types of die bonding because scrubbing requirements are minimized. Preforms are generally not required for AuSi die bonds if the circuit metallization is a gold frit.

When several chips are to be bonded to a single substrate the substrate is kept below the liquidus temperature of the bonding system, and a localized heating technique is used to bring the individual chips to bonding temperature. The most popular localized heating technique is hot gas heating in which hydrogen is heated by passage through an electrically heated tube and emerges through a mozzle adjacent to the bonding area. Several other localized heating techniques such as infrared and resistance heating have been used.

Chips are wired to the thick film substrate by any of the conventional wire bonding methods. Any of the forms of thermocompression bonding work well for gold wire to gold frits. Gold or aluminum wire can be bonded to almost any frit at room temperature by ultrasonic welding.

Die and wire bonding of standard semiconductor chips has distinct

*(Patent Pending)

advantages over flip chip bonding because all devices are available in standard chip form and the thermal resistance from junction to substrate is superior in the case of direct die bonding. Using the latter technique, thermal resistances of $3^{o}C$/watt from junction to substrate are possible. Flip chips have economical advantages when power dissipation is no problem and when applicable devices are available.

Encapsulation and Hermetic Sealing

Environmental requirements together with production quantity usually dictate the packaging technique. Conformal coating with epoxies, diallyl phthalate, silicone, and urethane are inexpensive and very popular. Encapsulation in epoxy provides outstanding mechanical protection, lead strain relief, and adequate moisture resistance for all but hermetic requirements. Epoxies can be formulated to meet a number of dielectric requirements.

When required, hermeticity is accomplished by the use of conventional transistor packages such as TO-5 cans or with a variety of square and rectangular enclosures which are available. Sealing is accomplished by means of solders or by resistance welding.

(This paper was presented with a series of slides.)

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Dr. Woulbroun holds three degrees from Massachusetts Institute of Technology, S. B. in general engineering, S. M. and Sc. D. in ceramics. Before becoming a founder of Microtek, Dr. Woulbroun headed Research and Development at Sylvania's Micro-electronics Laboratory. From 1957 to 1960 he was a metallurgist at Rodman Laboratory at Watertown Arsenal, conducting research in powder metalluray and ceramics. On receiving his master's degree, he joined the ceramics division at MIT as a research assistant, having previously taught at the University of Massachusetts Extension and in the Northeastern University Graduate Evening Programs. Serving as a Lieutenant in the U.S.A.F. in 1956 and 1957, he was primarily concerned with radar and presently holds the rank of Captain in the Air Force Reserve.

HENRY H. NESTER is a graduate of Alfred University and M.I.T. As Research Director he is responsible for process development and materials research programs. This activity includes research on semiconductors, dielectric and magnetic materials for new film components.

THOMAS E. SALZER is a Senior Design Engineer responsible for developing assembly and packaging techniques, including thermoswaging and pulse soldering for hybrid circuits and subsystems. He has several patents pending in the fields of microwelding and infrared instrumentation.

THE PRACTICAL PRODUCTION OF THICK FILM CONDUCTORS AND RESISTORS

By: Tom M. Place, Ceramic Consultant

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The majority of electronic projects today, are dedicated to the miniaturization of components, circuits and systems. The interest in thick film concepts had come about with recognition of their long range reliability, the absence of catastrophic failures in many hours of testing and service and the advantages of thick films in low cost microcircuitry.

First, it appears that we need some definition of thick films. The term was coined to distinguish between thin films, a few thousand angstroms thick, made by chemical deposition, vacuum deposition, sputtering, etc. and films made of combinations of Noble metals and ceramic glasses of several microns to a few mils in thickness and thermally bonded to the substrate. In the early stages of development of resistor films, they were classified as cermet films. It would seem appropriate to define thick films as cermets or combinations of Noble metals and ceramic glasses.

A conductor film is a modification of the decorative Noble metal films used for generations of pottery, glass and china and consists of a continuous conductive layer which has become an integral part of the base material by thermal reactions. It may range from .0005 to .0008" in thickness and we use it to produce a reliable, printed circuit on a dimensionally stable substrate. Lead wires and discrete components may be easily attached to the conductor film by soldering or other bonding techniques. The majority of conductor compositions are commercial products, made up as pastes with an organic vehicle, for screen printing.

A resistor film might be described as a further modification of a conductor film which has now become a continuous glassy film with conductive metal particles dispersed through the glass, generally .0007 to .001" thick. Resistor pastes, in a range of values, are available commercially and probably represent the majority of present applications. Proprietary compositions have been developed by a number of organizations for better electrical and physical characteristics.

However, our problems begin with the utilization of these materials; in the selection of equipment, the application of the pastes and the processing to produce acceptable microcircuits.

The silk screen printing process has proved to be dependable and economical for the low cost production of reliable circuits. The process has been highly refined and utilizes precision equipment, some manually operated, others completely automated.

In the selection, or in the design of screen printing equipment, the size of the screen should be at least four times the width and four times the length of the largest substrate size that you may anticipate using. There must be facilities to adjust the face of the printing screen parallel with the face of the substrate. The slides must carry the squeege in a plane parallel with the substrate. The center line of the squeegee should be at 90 degrees with the substrate. The table will require a vacuum or spring detent to hold the substrate and facilities to register the substrate with the screen pattern, especially when several subsequent printings are required.

Stainless steel screen cloth is used instead of silk or nylon screen cloth, to avoid stretching and fuzzing of these materials. With the fine details and precise designs required in microcircuitry, 200 mesh stainless steel cloth, preferably bolting cloth which has a more perfect weave and less wire crimp, is used. The centers of the wires in this weave are spaced .005" The designer can make his pattern replica 10 times or twenty times the pattern size, with a 100 grid and then when photographically reduced to size with a positive film in the final reduction, the edges of the pattern should coincide with the centers of the screen wires.

In the design of circuitry to have good reproducibility and the minimum dispersions in conductor and resistance values, the minimum width of conductor lines should be .010" which represents the width of two screen openings. The minimum spacing between conductor lines would be .010", but .015" or more would be safer. The minimum width of resistors, in order to produce reproducible values, should be .025" and this is required due to the highly resistant edge effect that is created by the surface tension of ceramic glasses in the firing process. The spacing between resistors and conductor lines should be .025". A resistor should overlap the conductor line or pad at least .020".

Stainless steel wirecloth, fitted with metal plates or hood strips to fit the printing frame of the screening machine, can be purchased from a number of sources. These strips on the screen facilitate attaching the screen to the frame with uniform tension and adjusting the screen square with the frame and with the wires straight and at right angles. The screen must then be thoroughly cleaned to remove all oil or grease that may be on the wires from the wire drawing or weaving operations and any other dirt or tarnish. The screen may be cleaned by soaking in a 10% solution of acetic acid for 5 minutes and then rinsing and brushing the screen thoroughly in hot water. Or the screen cloth may be burned off with a bunsen burner, or other flame, using care not to burn or overheat the wire cloth, then brushing the screen thoroughly.

There are two common methods of reproducing the pattern on the screen cloth. The screen may be coated with a photosensitive emulsion which fills the openings in the cloth. This coating is dried out completely in the dark with only very moderate heat. The pattern is then projected on the screen, using a positive film and a suitable arc light. The unexposed pattern is them washed out with warm water. Or the pattern may be projected on a photosensitive film, mounted on mylar backing, developed and the unexposed pattern washed out with warm water. This film is then mounted on the face of the screen. Carbon tissues and other films of this type, which are mounted on the face of the screen cloth only and do not fill the openings in the screen, have produced better print details and many more prints before they must be replaced. It is often necessary to use an optical comparator in order to obtain close register of the pattern with the screen wires and for pattern register for subsequent patterns.

The action of the squeegee, that produces the pattern in the printing operation, is that of a doctor blade. The paste is carried across the screen in front of the squeegee which fills the pattern openings with paste and wipes the screen relatively clean. A medium hard rubber or neoprene is the usual squeegee material, however, plastic compositions are available that give more satisfactory service. The edge of the squeegee is ground to a wedge with a 90 degree included angle.

The edge must be straight and sharp and at the center line of the squeege. Correctly shaped and correctly mounted, this will produce a uniform print with both directions of travel.

Several factors must be considered in the selection of substrates. Thick films require a refractory substrate that will be stable at the relatively high temperatures required to develop thick films. Steatites and sintered alumina are in common use. 96% alumina is generally preferred, for greater thermal conductivity and greater strength. The slightly higher cost of alumina is offset by its advantages. Berylia may be used where greater heat dissipation is required and titanates and other types of porcelain are used in special applications. These materials may require adjustments in conductor and resistor compositions to compensate for differences in coefficient of thermal expansion.

With small substrate sizes, 3/4" square or less, materials as fired by the manufacturer are generally quite satisfactory. The surfaces are improved by barrel or vibration finishing. With larger sizes, the camber, warpage and dimensional tolerances may require lapping or grinding of one surface, perhaps both surfaces and all four edges, in order to produce uniform reproducible patterns, especially when several successive printings are required.

The ground or lapped surfaces of alumina are generally quite satisfactory. The surface finish is not critical and a slightly rougher finish produces a better interfacial bond with films. Due to the normal internal structure of steatites, a ground or lapped surface may contain many fine holes or craters which may cause bubbles and blisters in films printed over them.

Substrate materials are generally well cleaned and well packaged as delivered by the manufacturer and should not require additional cleaning for thick film applications. However, washing and scrubbing with a good detergent and rinsing thoroughly in DI water, then drying in a dust free area is generally adequate cleaning. Substrates should not require any cleaning between subsequent patterns; handling with rubber cots or gloves and protection from dust and lint is recommended.

In setting up the printing machine for operation, the screen frame is mounted in the machine and the machine adjusted for the face of the screen to be parallel with the table or face of the substrate. The height is adjusted to a clearance of .030 to .040" between the face of the screen and the face of the substrate. The screen frame is removed for the adjustment of the squeegee. The squeegee is adjusted is int holder to be parallel with the face of the substrate and the height of the holder adjusted for a clearance of .003" between the edge of the squeegee and the face of the substrate. The screen frame is replaced in the machine and the substrate aligned for correct pattern register. With these adjustments of the substrate, screen and squeegee the printing operation becomes mechanical.

The proper control of the viscosity of the printing pastes is a critical factor in reproducibility. The ratio of solids to liquids controls the thickness of the fired film. The resistance of the film is largely volume resistivity and variations in film thickness can cause wide variations in resistivity. Variations in the thickness of conductor films have caused poor interfacial bond and poor solderability. A Brookfield Viscometer is recommended for this control but this has not proved to be practical or popular for production control. Every paste should be thoroughly mixed and the solids dispersed before use; a stainless steel spatula is a good tool. It takes a little practice and a little skill, but the time required (in seconds) for a ribbon of the paste, allowed to run off the edge of the spatula across the surface of the paste, to level out, has proved a good practical control of paste viscosity.

A quantity of the prepared paste is placed on the end of the screen in front of the squeegee. As the squeegee moves across the screen, it springs the screen down against the substrate with about four wires in contact with the substrate at the edge of the squeegee. The film will be thin at the points of contact of the wires and the printed pattern should be allowed to stand in ambient air for about fifteen minutes to allow the film to level out to uniform thickness. The printed patterns may then be dried at about 250°F on a hot plate, or in a dryer with circulating air, or in a continuous belt dryer. The vehicle will have contained sufficient binder that the films will be hard and will not be damaged by normal handling and in the printing of additional patterns. The dried films can be stored for indefinite periods in a dust free atmosphere without deterioration.

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