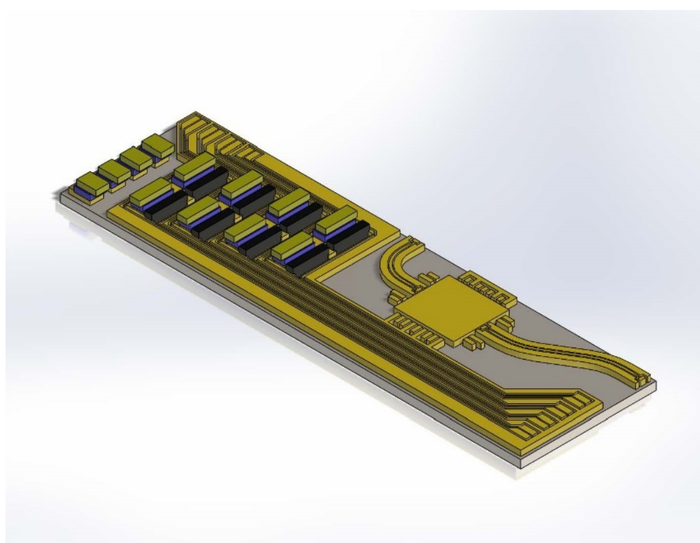
The Essentials of Thick Film Technology

Thick film screen printable pastes are used to develop thick film circuits on a variety of substrate baseplate materials. These substrate materials are higher in thermal conductivity and allow for higher density circuits where space is at a premium. Thick film electronic circuits are also ideal for use in environmentally adverse conditions, for example when the range of ambient temperatures are at extremes, such as 150 degrees centigrade to minus 50 degrees centigrade, or when ambient moisture is extremely high.

Thick film circuits originated in the 1950s and are understood as one of the earliest forms of microelectronics-enabling technologies. At that time, they offered an alternative approach to printed circuit board technology and still offer the ability to miniaturize integrated circuits. By the mid-1960s, thick film was becoming more popular and by the year 1975, hundreds of thousands of ceramic thick film substrates were produced for miniaturized potentiometers and high-reliability circuits.

Laminate circuit boards are frequently used due to cost considerations and are excellent when the demands of the circumstances, as noted above, are not required. More sophisticated demanding applications require the use of thick film ceramic substrates. Some of these applications require:

- Long product life
- Multi-layer designs
- High density circuitry
- Hermetic packaging
- Thermal conductivity/endurance
- Mechanical strength
- Low dielectric losses
- Integrated resistors and capacitors
- Minimal to no outgassing
- RoHS and REACH compliant



The objective of this white paper is to provide an understanding of the materials used, performance capabilities, and the

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manufacturing process of thick film substrates. These tools will better enable a designer to determine if thick film substrates are the appropriate circuit solution for a design and its requirements.

What are the components that make up thick film substrates?

Thick film substrates are predominantly made up of two categories of materials: 1) an insulative substrate material and 2) thick film pastes that are screen printed and fired onto the substrate. In addition, some fired conductors can be etched for fine line circuitry. As an example, CMS Circuit Solutions, Inc. routinely etches 1 mil lines and 1 mil spaces to maximize circuit density.

Substrates

Usually, thick film materials are applied onto ceramic substrates, such as alumina, beryllium oxide (BeO), and aluminum nitride (AlN). This ceramic substrate is the baseplate for the circuit on which the different layers are applied. The ceramic substrate can also be substituted with different types of materials (i.e., ferrite, sapphire, fused silica, etc.) depending on the application requirements.

Thick Film Paste

There are three major categories for thick film pastes: conductors, dielectrics, and resistors. Each paste has two main components: 1) the vehicle (organic solvents and plasticizers) and 2) the paste's functional elements (metals, alloys, oxides, or ceramic glass compounds). Every thick film paste has been engineered for certain characteristics of the metals, alloys, oxides and/or ceramic glass compounds to optimize their characteristics based on the application and assembly techniques.

For more details on thick film paste materials and substrates, please refer to the CMS Circuit Solutions, Inc. white paper titled "The Advantages of Certain Substrate Materials and Relationship to Thick Film Pastes."

Thick film manufacturing methods

Thick film circuit boards are manufactured by starting with the desired substrate material, as described above and in the white paper referred to above. The first layer is frequently metal and is screen printed onto the plate with the desired circuit layout and then dried to drive off the solvents from the vehicle. After this process, the paste is a solid with the appropriate functional particles dispersed within it.

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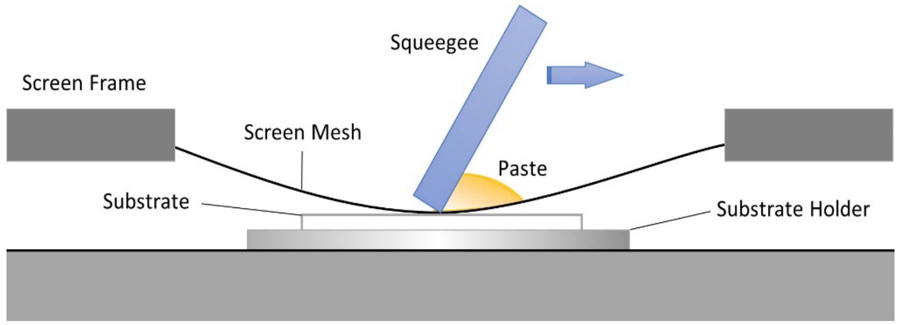
The alumina ceramic board with the first screen printed layer in place is put into a traveling belt furnace to be fired. The furnace has various heater zones that increase the temperature from room temperature to 850°C. When the board reaches between 300°C to 400°C, the remaining polymer portion of the vehicle is pyrolyzed and vented from the furnace. The metal particles (golds, silvers, etc.) begin to sinter as they reach the 850°C temperature zone. After being cooled down to room temperature, the metal has obtained its appropriate conductive properties and is fully sintered into the substrate material.



Additive Thick Film Screen Printing Process

Other functional elements when fired, like dielectrics, are a mixture of glass and specific ceramics that do a combination of melting and dissolving into each other to form a new material during the firing process which generates specific characteristics.

Multilayer Structure

The additive screen-printing process can be repeated multiple times using dielectric thick film material to insulate the conductor. Additional metal and dielectric layers can be added thus achieving a multilayer structure. Small openings, called vias, in the dielectric layers are filled with metal thus connecting various circuit lines to corresponding circuit lines above or below the layer.

Cell Sizing

The size of thick film circuit cells can range from 0.050” (or smaller) square up to 5” x 7”. Larger sizes are possible, but this can introduce inconsistent print accuracies. Most designs are printed as an array onto larger plates for maximum production efficiency. A printed array is singulated via a diamond saw cutting operation or laser scribing and snapping.

Through-hole Metallization

Thick film circuits using various metals can barrel coat and plug holes that are drilled though the substrate. When incorporating metallized through-holes in a design, the opposite side of the board can act as a separated or connected circuit. Through-hole connections can be used to integrate various other conductor layers which is a major advantage when the circuit density requirement is very high.

Etching Fine Lines and Tight Tolerances

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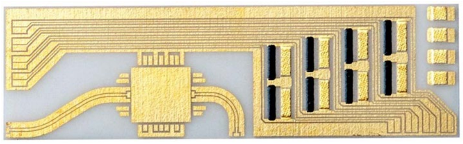
Etched thick film substrates are the best solution for circuits with much tighter line and spacing requirements. When the lines and spaces of the circuit approach the limits of the screen-printing process, it is easy to shift to an etching process which can support 0.001” lines and 0.001” spaces for additional density. Etching is very suitable for high frequency designs due to the ability to meet extremely tight tolerances using the photolithographic process that etching requires. Etching offers circuit density that surpasses standard laminate circuits.



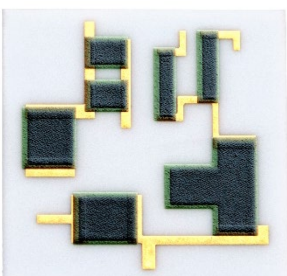
Fine Line Etch

Printed Thick Film Resistors

Integrated resistors in thick film circuits are common. Passive, active, and trimodal resistors can be incorporated into thick film designs.

Most resistors are passive trim, which means that there is no power applied during the time that they are being trimmed. They are only being monitored for resistance value as they are trimmed and can be laser trimmed to ±1% of their specified value upon delivery.

Thick film resistors may also be actively trimmed, which means that a resistor is trimmed while the circuit is in its operating mode. The resistors can then be trimmed to some value as a result in change of voltage, current, frequency, phase, temperature, or a combination of these elements of the circuit.



Integrated Resistors

For a good circuit trimming example, consider a pressure transducer. A certain pressure could be applied to achieve a certain desired voltage at that pressure. When that pressure is applied to the circuit, the circuit can be trimmed until that desired voltage, or other element value is achieved, and this would be considered an active trim. Any circuit that is being used as a sensory device can be placed in an application and actively trimmed to tune the sensor circuit for the exact application.

Why Thick Film?

Wire bonding

Wire bonding is a common solution for interconnections between an integrated circuit (IC), or other semiconductor devices, and its packaging. It can also be used to connect an IC to other electronics or to connect other thick film circuits to each other. Wire bonding is usually considered the most cost-effective and flexible interconnect technology and is used to assemble most semiconductor packages. There are two types of wire bonding—gold and aluminum. The variety of thick film materials available allow you to successfully use either the gold or aluminum.

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Thick film materials have been formulated for wire bonding in high reliability applications. There is no better wire bonding platform than on a thick film substrate. The simplicity in wire bonding to thick film is also beneficial for setting up wire bonding machines and validating the bonding process.

Wire bonding works well for both thin film and thick film, however because thick film is thicker and it is more malleable than thin film and can be better for wire bonding. Thin film has a harder gold surface and therefore it requires a special gold layer to be applied to the wire bonding surfaces.

Temperature

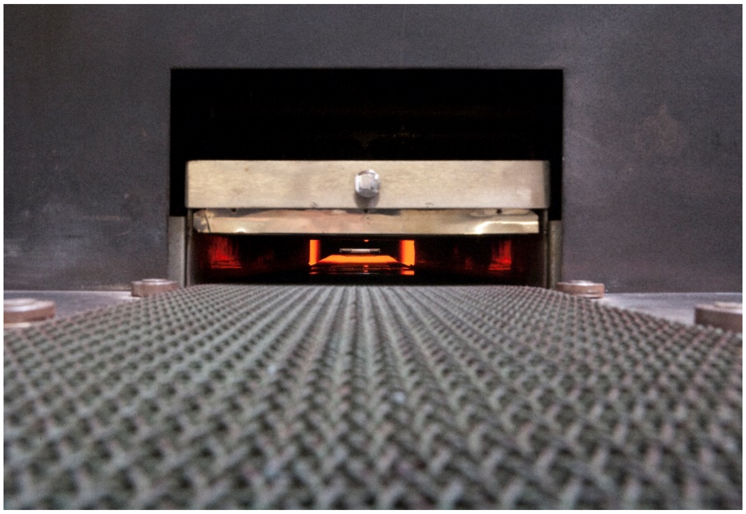
Thick film is well suited for extreme cold and extreme hot temperature operations. It is also well suited for circuits requiring temperature cycling between these extreme temperatures.

A big part of reliability testing is temperature cycling and thick film substrates are very well suited for applications with extreme and numerous temperature cycles. This is true for all the different ceramic materials, whether it is beryllium oxide, aluminum nitride, or alumina. All of them can withstand temperature cycling. FR-4 and other traditional laminates cannot handle the same temperature ranges as ceramics.

The ceramic materials are electrical insulators, as well as excellent thermal conductors with the ability to spread heat evenly across the circuit. If superior thermal conductivity is needed, it is recommended to use aluminum nitride (AlN) or beryllium oxide (BeO).

Hermetic Designs and Zero Outgassing

Ceramic is well suited for hermetic packaging. The materials used in thick film (golds, silvers, dielectrics, resistors, glasses, etc.) do not outgas because they have been fired at 850°C, which removes any contamination from the organics, including poly materials and anything that was on the substrate (fingerprints, oils, cleaning agents, etc.).



Firing at 850°C allows for all volatile contaminates to be fired and removed from the circuit

Certain applications like sensors, space applications, high vacuum applications, etc., cannot tolerate outgassing because it can change the circuit's performance and has already been eliminated from the circuit due to the previously defined high temperature firing.

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The advantage of the thick film manufacturing process is that it is excellent for hermetic designs because you have already eliminated all poly materials being introduced that would cause outgassing.

Thick film possesses good mechanical strength because it retains its high mechanical values and electrical insulating qualities. The ceramic substrate makes it a good thermal conductor. By adding edge clips to the perimeter of the substrate, the design can be incorporated as the final packaged assembly. This is common where cost is a concern by avoiding the cost of a sealable tub package.

Rugged and Rigid Substrate

Although there are some applications where flex is acceptable, many times the application requires rigidity. Ceramic is very rigid and more rugged if it is supported properly. Thick film can withstand harsh and rugged environments and is considered extremely reliable. The reason thick film is selected by circuit designers is because their applications require high reliability.

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What about thin film substrates?

Thin film is suitable for a variety of circuits, especially for circuits which need extreme high accuracy, great stability, and excellent performance. Thin film metal layers are measured in angstroms, whereas thick film is measured in microns. Manufacturing equipment for thin film is more expensive than thick film and the cost of production is considerably higher.

Thin film requires special plating processing for wire bonding. Thin Film has limited layer opportunities and limited resistor value options. Thick film rivals Thin Film capabilities by offering tight tolerances and higher performance in many applications. If a circuit can be manufactured with thin film technology, in many cases it can be realized in etched thick film at a competitive price. One of the major advantages of thick film circuits is the ability to make multilayer circuits without any special processes. Thin film technology typically is a single metal layer approach on both sides of the substrate base interconnected with metalized through-holes in the ceramic base.

What industries commonly use thick film substrates?

Medical

Thick film substrates are used in many medical devices, including some implantable devices. The capability of thick film technology allows the creation of highly accurate sensors as well as transmit receive circuits.

Aerospace and Defense

High reliability requirements are synonymous with applications that are used in the aerospace and defense industry. Circuits launched into space provide the high reliability that is of utmost importance due to the nature of space programs. Thick film is the technology of choice due to the extremely high reliability and thermal cycling requirements for aerospace and defense.

Thick film circuits lend themselves to rugged applications where components need to withstand the g-force and vibrations that occur during the launch cycle. Sensory devices, temperature probes, pressure probes, as well as many types of transducers are made with thick film for use on landing gear, switches, and various other types of external and internal hardware.

Optoelectronics

Ceramic substrates have optical properties—some ceramics are clear at certain wavelengths and opaque at other wavelengths. Therefore, depending on the optoelectronics application, thick film can act as a filter. Hermetic design capabilities are a huge factor for optoelectronics because moisture trapped inside a package part could change the optical characteristics.

Scientific

The 'Noble Metals' used in thick film are necessary in high vacuum applications due to strict outgassing and contamination requirements. The science community frequently uses thick film substrates in varying

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designs to experiment with the reactions of many circuits across a platform to simulate the effect in many manufacturing and commercial uses.

Telecom

Thick film has its advantages in the ability to manufacturer high frequency circuits that are highly reliable and rugged for complex multi-layer circuits for long range transmissions. They are also used to convert the high frequency information into the usable low frequency transmission used in applications such as the common cell phone.

Thick film is generally not well suited to the manufacture or sale of common cell phones due to the high cost and lack of need for longevity or circuit life.

Industrial

Many rugged applications use thick film circuits for systems that achieve extremely high temperatures and high vibrations. Downhole applications, such as oil or water wells, require circuits that can sustain such requirements. One of the most rugged applications in this industry is a drill with a sensor in the drill head which exposes the thick film circuit to extreme environments.

Consumer and Household

Consumer LEDs and heater elements utilize the optimum heat dissipation factors that ceramic offers. Thick film materials also offer some of the best heat dissipation for circuits in the industry.

Semiconductor

Several semiconductor products can be mounted onto a thick film substrate. The semiconductor would interface with thick film at the next level assembly.

Automotive and Transportation

Ruggedness is a big factor in this industry because it exposes circuits to one of the harshest temperature environments and chemicals. Viable applications for thick film in this industry include fuel/air mixture sensors, pressure sensors, engine and gearbox controls, and airbags.

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