The Advantages of Certain Substrate Materials and Relationship to Thick Film Pastes

The substrate is the base material of the thick film circuit board. The characteristics of the substrate factor into the ultimate performance of the circuit within the target application. There are several aspects which are important to consider when the designer is determining the appropriate thick film circuit board substrate material for their design.

- Thermal performance
- Size restrictions
- Circuit density requirements
- Number of layers
- Rigidity or flexibility requirements
- Moisture resistance
- Dielectric losses

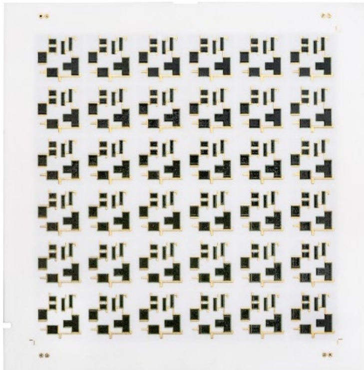
The goal of this white paper is to review the different materials used for thick film circuits and the characteristics and benefits of each. The available substrate and thick film paste options each satisfy certain inter-related requirements that would be important to specific applications.

Substrates

Substrates, or the platform that the thick film layers are built upon, are typically made of some sort of alumina. The most common substrate for thick film is 96% alumina (or Al_2O_3, 96%). Other materials such as 99.6% alumina, aluminum nitride (AlN), beryllium oxide (BeO), and ferrite substrates are also used for thick film circuits.

Alumina

Aluminum Oxide, also known as Al_2O_3, or simply, alumina, is one of the most common substrate materials used. In general, alumina has reasonable thermal conductivity (W/cm-K), dielectric strength (V/mil), and thermal coefficient of expansion (CTE). The purity of alumina can be chosen between 90%-99.6%, depending on the application. Higher purity alumina has greater thermal conductivity, dielectric strength, and CTE advantages.



Multi-Cell Array Printed
Onto 4.5” Square Plate

Aluminum Nitride
Aluminum Nitride (AlN) has better thermal conductivity than alumina, but most thick film pastes have difficulty adhering to AlN because it doesn’t have an oxide associated with it, rather a nitride. Most thick film pastes are formulated with a glass and oxide material that is meant to form an aluminate when fired on alumina.

Beryllium Oxide
Beryllium Oxide (BeO) has great thermal conductivity and in fact cannot be beat. However, BeO has a major problem in that it can cause berylliosis, a chronic-type lung response if not handled properly. Because BeO is toxic in powder or vapor form, special care is required for processing and to use BeO. For this reason, vendors who do not have, or choose not to have, the proper equipment choose not to use BeO.

Ferrite
Ferrite substrates are made from electro-magnetic materials and can be built upon just like alumina with thick film processing. The basic composition of ferrite substrates is cobalt, chromium, nickel, and zinc ferrite nanocrystals. These elements can be combined with special processing in varying ratios to generate the desired properties. They are used in thick film processing to take advantage of the permeability (u) of the material to create circuits such as antennas integrated into the thick film layout. Many thick film conductors have excellent adherence to ferrite. The permeability capability, combined with the ability to screen print these conductors, allow the making of miniature antennas which work well with very low strength signals.

Sapphire

Man-made sapphire is transparent to certain light frequencies and can be used to advantage in some circuit types. Sapphire tends to work well with most thick film gold pastes.

Fused Silica
Fused silica is similar to sapphire but carries its own specific properties. Fused silica has very specific qualities that can be advantageous when making capacitors with very specific special characteristics, such as the capacitors loss tangent or low field measurements.

Custom Substrates
The above summarizes the properties of the most common thick film substrate materials. Thick film can be printed onto a multiplicity of substrate types and there are always new and exciting materials that can be used for thick film substrate circuits.

Thick Film Pastes

There are four main categories for thick film pastes (or inks): conductors, dielectrics, overglaze, and resistors. Each paste has three main components: binder (glass frit), vehicle (organic solvents and plasticizers), and their functional elements (metals, alloys, oxides, or ceramic compounds).

Each thick film paste has been engineered for certain applications or to solve a problem within thick film fabrication. The mix ratios, particle size distributions, and solids content are critical for creating a paste to work with the screen-printing process. Another critical component is the composition of the vehicle system. Selecting the correct paste is often determined by their material properties. Some of the most important properties to consider are:

- Electrical conductivity
- Adhesion to the substrate material
- Wire-bond ability, die attachability, and solderability (these three are next level assembly processes)
- Print definition
- Compatibility with other thick film pastes
- End user application e.g., high reliability, medical, space, extreme temperatures, etc.

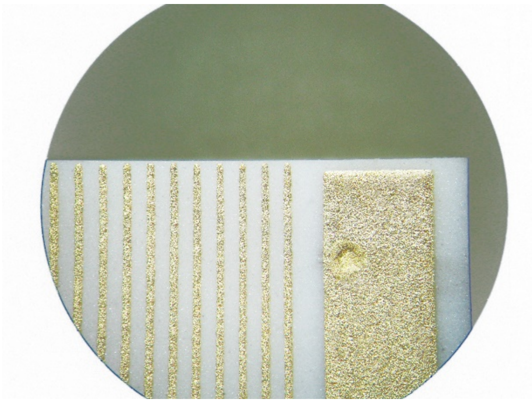
Belt Furnaces for Thick Film Firing

When selecting pastes, a careful study of the technical data sheet is suggested to confirm the properties fit the application requirements. Firing temperature, typical fired thickness, and resistivity characteristics are examples of valuable information specific to each thick film paste.

Conductors

Most thick film conductor pastes are made from four basic elements: gold (Au), silver (Ag), platinum (Pt), and palladium (Pd), or a combination thereof.

Silver has the lowest electrical conductivity for a given trace width. It is measured in ohms/sq. It is also the least expensive material to create a conductor. If used properly silver is also good for soldering and aluminum wire bonding. Silver does have some draw backs, including oxidation and silver migration. Due to these reasons silver is often blended with other elements, such as platinum and/or palladium to make alloys. These alloys will reduce or eliminate the negative characteristics of silver.



Gold Etched Thick Film with Plugged Via

Gold is by far the best conductor choice for high reliability circuits. Gold does not oxidize and is most suitable for gold wire bonding. Gold also has excellent trace resistance, second only to silver. Even though gold does not oxidize, it is not the best for soldering as solder likes to leech the gold into the molten solder. To counter act the problem with the solder leeching the gold, thick film manufacturers have developed gold alloys with platinum and/or palladium.

Palladium Silver (PdAg) is an alloy used to create a paste with good substrate adhesion, solderability, and solder leach resistance. PdAg does still have some silver migration issues and relative high trace resistance, however, thick film manufacturers have made many different PdAg ratios to combat some of these negative properties.

Dielectric

Dielectric pastes are used as insulators (the opposite of a conductors) to separate conductors and can be used in a cross over or multilayer configurations. Dielectrics can also be used as a barrier (dam) to solder. The most common dielectric pastes have a relatively low dielectric constant (k) unless they are meant to be used to create thick film capacitors within the substrate layout.

Overglaze

Overglaze, sometimes referred to as a glaze, is a low temperature glass that it is non-conductive and was designed to be used as a moisture barrier for thick film printed resistors. Overglaze cannot be used as a multi-layer dielectric to insulate between conductor layers. It was designed specifically to be fired at a lower temperature so during its firing it minimizes the shift of all the resistors on the circuit. Another use for overglaze is as a solder or epoxy dam. Solder will not adhere to overglaze.

Thick Film Resistors

Resistor pastes are used to create individual resistors within the substrate layout. These pastes are blends of materials to create decade values ranging from 1 ohm/sq to 10 Meg ohms/sq. Resistor pastes have a wide range of properties due to the differences in the decade values and formulations. The materials within the resistor paste are glass frit materials mixed with metal oxides in varying ratios. Some important properties of resistor pastes are related to their function and temperature stability. The temperature coefficient of resistance (TCR) is the change of resistance over a given change in temperature presented in parts per million/degree C (ppm/°C).

Resistor pastes can be blended to create resistance values between two given decade values, e.g., 5k paste can be made from a blend of 1k and 10k pastes. Resistor targeting is a process of selecting the correct blend of resistor paste to achieve a given resistance range once it is fired. It is typically done on each value of resistor design layer or paste value. Targeting is required to assure that a given production lot will be able to meet the customer requirements after trimming is completed.

Print thickness of a given resistor layer will dramatically affect the resistor value. The value will be lower than expected If the resistor is too thick. Also, the laser trimming process is made difficult and instability may occur when the resistor is too thick. The value will be higher than expected if the layer is too thin. Resistors can only be trimmed up in value and the lowest tolerance of a thick film resistor is approximately ±1%. The value of a resistor is determined by the ratio of length/width. The laser trimming process is used to reduce the width of the resistor, thus increasing the value of the resistor.

For more information on the benefits and recommendations for use of each substrate material and conductor material, refer to the CMS Circuit Solutions, Inc. white paper titled “The Essentials of Thick Film Technology.”

The information and data in this white paper is derived from the combined experience of the authors and from general and/or public online educational forums.

References:
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