

Through-hole Plugs and Thermal Vias

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The demands of many of the current high density and high frequency applications have designers looking for ways to utilize both sides of substrates. Solid through-hole plugs offer a practical solution to a multitude of the current design issues. Through-hole plugs can be used to create a low resistance front-to-back interconnection with reduced capacitance effect. This method is a low cost alternative to Beryllia (BeO) or Aluminum Nitride (AlN) substrates to achieve high thermal conductivity, and a high density interconnect that isolates the front from the back of the substrate.

To meet these increasing demands (increased thermal conductivity, higher density, and performance at higher frequencies) thick film silver, gold and glass compositions along with unique processing techniques and tooling were developed for filling through-holes with a screen printer. Discussed in this paper are applications that benefit from the use of solid through-hole plugs and the detailed process techniques for achieving a solid fill.

Key words: Through-hole, Thermal Via, Wireless, Thermal Conductivity

Introduction

Novel processing techniques employing thick film silver, gold and glass compositions create through-hole plugs in standard Alumina exhibiting low resistance, reduced capacitance and thermal conductivity. These vias provide front-to-back interconnection for double-sided high frequency circuitry or a low cost alternative to Beryllia (BeO) and Aluminum Nitride (AlN) in high power applications. This paper discusses some of the benefits of incorporating solid filled through-holes in circuits, along with processing information.

Applications

With growing health issues involving the use of BeO substrates and limited success finding thick film materials compatible with AlN substrates, solid metal fills using either gold or silver metalizations offer a low cost alternative to achieve higher thermal conductivity for high power applications (*see fig. 1*). Large thermal vias or arrays of vias can be directly under hot components to provide an effective way to dissipate heat to a ground plane or heat sink on the back of the substrate.

The use of high thermal conductive substrates like BeO or AlN does not completely solve temperature equalization between chips. However, the density of thermal vias can be adjusted so that variable cooling can be managed over a range of

thermal impedance. Junction temperature in chips with large disparities in thermal dissipation can be minimized, thus increasing the operational lifetime of the circuit. This concept was first introduced by Poulin and Nuygen [1] and expounded upon in later work by Amey [2].

The rapid growth and increasing demands of high frequency applications and high density interconnect circuits have many designers looking for ways to utilize both sides of the substrate. Solid silver (6344) or gold (5735D) through-hole plugs create a low resistance front-to-back interconnect with reduced capacitance effect associated with coated through-holes. Silver/palladium compositions 7988 & 7988H have been developed to provide a reliable (> 15 re-fires) method to interconnect front-side gold circuitry and a back-side silver ground plane. These materials have also been used as a interface for subsequent thin film metalizations or etchable thick film processing.

Another area of interest for through-hole plugs involves the use of a glass paste for plugging the holes. In some high density interconnect circuits and sensor applications, the side-walls of the hole can be coated with either a gold or silver conductor to provide the electrical front-to-back connection followed by a 7980 (glass paste) print to plug the hole. The 7980 effectively stops flux and/or solder from reaching the other side of the substrate via the through-hole. This method creates a more hermetic plug than either the silver or gold compositions.

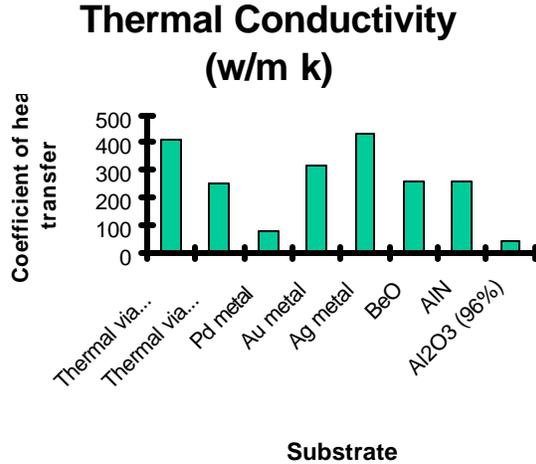


Figure 1: Thermal Conductivity chart

Process Introduction

The intent of this paper is to provide general process information necessary for filling 6-25 mil diameter through-holes in substrates with thick film materials. While the through-holes can be filled using an extrusion “bladder” via filler, this document will cover the setup and tooling necessary for use of a conventional thick film screen printer. It is also important to remember that, while the silver bearing conductors 6344, 7988 & 7988H do not require any process steps prior to the through-hole filling step, both the gold (5735D) and the glass (7980) plugs require an additional process step. The side walls of the through-hole must be metalized prior to the plugging step for these compositions.

Through-hole Filling

Filling Equipment Cost Comparison

<u>Option</u>	<u>Equipment Cost</u>	<u>Relative Speed</u>	<u>Flexibility</u>
Printing	\$25K-\$150K	Medium	High
Extrusion	\$25K-\$100K	Fast	Low

Figure 2: Comparison of Printing vs. Extrusion

Vacuum Tooling Fixture

When we first started using a standard thick film screen printer to fill through-holes with a thick film composition, we found that a vacuum tooling fixture with a porous filter stone (figure 3) was critical to achieving a good fill. The vacuum fixture will hold the substrate in place and aid in the paste pull-through during the printing process.

The tooling fixture consists of a porous filter stone mounted directly into the tooling plate on the printer carriage. The tooling plate is designed with a vacuum reservoir directly beneath the porous filter stone. This will allow a vacuum to be pulled evenly across the substrate during printing.

One or more sheets of clean-room paper or similar material is used to cover the filter stone. This paper is porous, but will prevent the thick film paste from penetrating and clogging the filter stone. Since clean-room paper is also lint-free, it will not contaminate the paste.

Mylar or tape is used to mask off all of the vacuum stone except for an area the size of the substrate. This should allow an adequate vacuum to hold the substrate down during the printing process. The vacuum will also aid in pull-through of the paste during printing. Typically, smaller diameter through-holes (6-8 mil) will require more vacuum to aid in the pull-through of the paste, while the large diameter holes (>12 mil) only require enough vacuum to remove the air from the through-hole as it is being replaced with paste. If the amount of vacuum is excessive for the given application, paste may be pulled out the back of the substrate, resulting in a smear. Placing a regulator on the vacuum is recommended and will allow for increased process control.

A silicone-treated lint-free lens paper is placed under the substrate during printing. The lens paper prevents the paste from being pulled out the back of the through-holes and serves as a carrier that will remain with the substrate through the drying step. The lens paper will also prevent the clean-room paper on the filter stone from being clogged with paste.

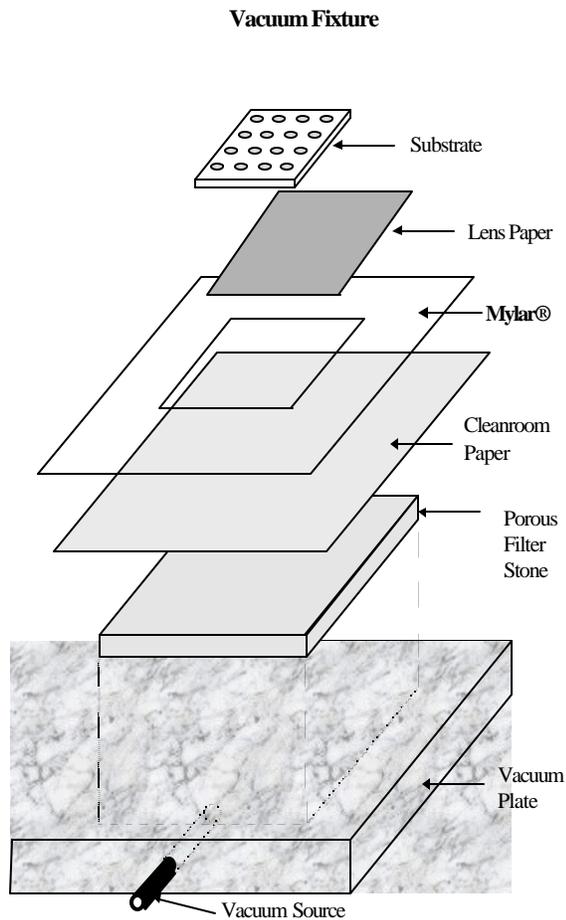


Figure 3: Vacuum Fixture

Process Considerations

Compositions have been evaluated using 6 to 25 mil diameter through-holes in 25 mil thick alumina substrates (96% and 99.6%). Thinner substrates are typically easier to fill. Filling larger and smaller diameter holes may be possible, but the process parameters may need to be modified.

The through-holes should be filled from the side of the substrate in which the holes were laser-drilled since most laser drilled holes are funnel shaped. If multiple diameter through-holes are on the same substrates, it is recommended that each diameter hole be filled separately.

Stencil vs Screen

The thick film materials used for filling through-holes were designed to have high viscosity and high solids. Therefore, it is highly recommended

that either a stainless steel or brass stencil be used for printing these compositions. Screens have been used in some applications, but tend to clog, significantly reducing throughput and process repeatability. A stencil thickness of 2 - 3 mil is recommended. Thicker stencils tend to deposit excess material above the surface of the substrate.

The diameter of the holes in the stencil should be approximately equal to the diameter of the through-holes being filled. In some applications, it may be preferable to use slightly larger (1 - 4 mil) holes in the stencil.

Printing

On-Contact Mode is required for printing with a stencil. The setup parameters for this process are typical for On-Contact Mode printing. Multiple print cycles may be required to completely fill the holes. Our testing has shown that lowering the squeegee attack angle ($<45^\circ$) improves the transfer of the paste. The lower attack angle increases the hydraulic force on the paste. Preliminary testing yielded excellent results with attack angles less than 15° , filling large (25 mil) diameter holes in one print cycle.

Screen Printing Method Off Contact Via Filling

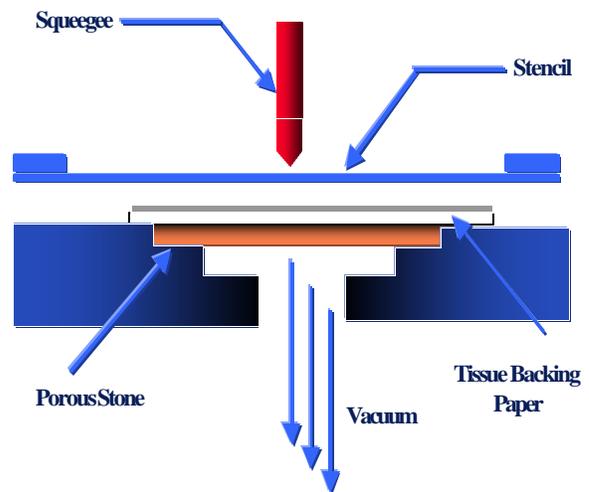
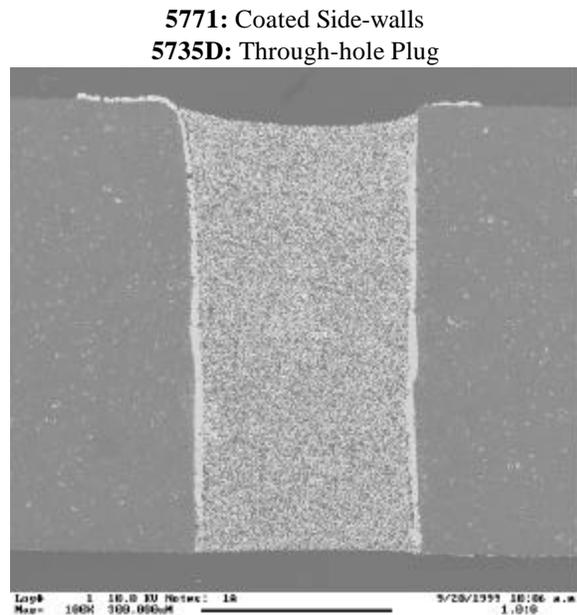


Figure 4: Filling Through-holes with a Screen Printer

Methods to Achieve a Planar Surface

The fired height of the through-hole fill in relationship to the surface of the substrate is adequate for many applications. However, there are applications that require tight tolerances for planarity of the through-hole fill. Additional process steps may be required to minimize the height of the through-hole fill in applications where the circuit operates at high frequency, when thin film is applied directly over the through-hole, or when a component will be mounted directly over the through-hole. There are several optional methods that can be used to achieve a more planar through-hole plug if the printed surface topography does not meet needs.

Excess material can be removed after drying. When 5735D is dried at a lower temperature (i.e., 75° C for 15 minutes), a foam wipe can be used to lightly buff the through-hole fill until it is flush with or slightly above the surface of the substrate. This material does not readily smear or stain the substrate. Since 5735D shrinks slightly during firing, the height of the through-hole plug will typically be 3 – 15 µm below the surface of the substrate (figure 5). Care must be taken (especially with larger diameter holes) not to remove material below the surface of the substrate during buffing. This may result in the depth of the fill being greater than 15 µm below the surface of the substrate.

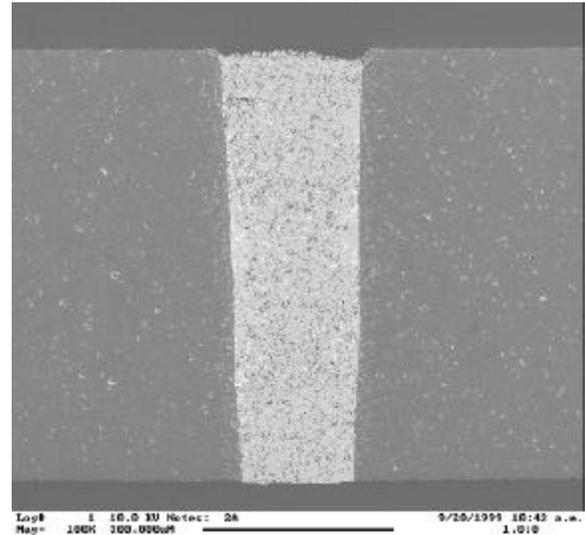


25 mil Thick Substrate
12 mil Diameter Hole

Figure 5: Cross-section

If the dried through-hole fill is above the surface of the substrate (i.e., posting), the excess dried material can be easily removed by shearing the excess off with a piece of ceramic. This can be accomplished by holding a piece of ceramic at approximately a 15° angle to the substrate and shearing the excess material with a knife-like cutting action. Ceramic is used instead of a metal blade because metal tends to contaminate the surface of the substrate. Care must be taken not to smear the excess material into the pores of the substrate. Typically, this procedure will yield fired heights between 0 – 8 µm above the surface of the substrate for 6344 and 7988 (these materials expand slightly when fired) and approximately 5 – 15 µm below the surface for 5735D.

6344: Through-hole Plug
(Ag/Pd)



25 mil Thick Substrate
8 mil Dia. Hole

Figure 6: Cross-section

If the fired fill is above the surface of the substrate (i.e., posting), the excess material can be removed with sandpaper or a polishing wheel, or can be sheared off with a piece of ceramic. When shearing off the excess material in the fired state, wetting the substrate with solvent or water helps prevent staining. Removal of the excess fill in the fired state will provide a very planar surface (figure 7).

Conclusions

The ability to form solid through-hole plugs is an enabling technology. Solid through-hole fills provide a means to form a front-to-back interconnect with lower resistance, reduced capacitance coupling, and very high thermal conductivity. New thick film compositions specifically formulated for through-hole printing and unique processing techniques were developed to achieve uniform and repeatable solid through-hole fills.

References

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