

Benchmarking of 96% Alumina Substrates for Thick Film Hybrids

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Abstract

Alumina substrates have been the foundation of hybrid circuitry for over fifty years. Presently, there are multiple substrate suppliers supporting hybrid technology. Each supplier has proprietary methods for manufacturing their products that result in differences in the fired microstructure of the substrates. 96% alumina is the most commonly used substrate, and this particular composition leaves a 4% margin of variation in the chemical make up from each supplier. Data presented in this paper reflect possible differences between suppliers that affect thick film properties when applied to the substrate. Demands from customers may require the use of more than one substrate vendor, and caution must be taken that fired film properties on different substrates may not be identical. The focus of this evaluation is the variation of substrates; no optimization of paste formulations or processing conditions was included in this study. This paper will focus on the affects of the fired properties of precious metal conductors, such as adhesion, solderability, and conductivity values. Additionally, a comparison of commonly recognized properties of substrates, surface roughness and porosity, is presented. Although this paper will primarily focus on the values and characteristics previously listed, other fired film properties may be affected.

Key words: Thick Film, Lead Free, Alumina Substrate

Introduction

Hybrid manufacturers tend to maintain a loyalty to specific substrate and thick film vendors. This relationship is based on the subjective views of how both the substrate and thick film paste work together as well as the ability to produce the most economical and reliable hybrid products. Vendor loyalty has been challenged by substrate availability, competition and quality. A preliminary evaluation done at Heraeus found variation between 96% alumina substrates from different vendors and performance using a number of thick film paste compositions. Though drop-in replacements may be found on occasion, consideration should be given to the interaction between both paste and substrate chemistry.

Proprietary additive materials in alumina substrates affect the bonding mechanisms of the thick film composition including wetting of the alumina and spinel formation during firing. Other substrate properties such as surface roughness and porosity influence the adhesion of the fired film. Paste performance requirements and testing methods will ultimately determine compatibility between the paste and substrate. This investigation gives an objective view of how

testing can be implemented to prevent a sudden change or problem within a production line due to a substrate supplier change.

Substrate surface

Due to the difference in both the substrate chemistry and substrate manufacturing process there is a significant variation in the microscopic surface structure and composition of each substrate. These differences can make a major impact on properties such as adhesion, solderability, and appearance of the paste when printed and fired.

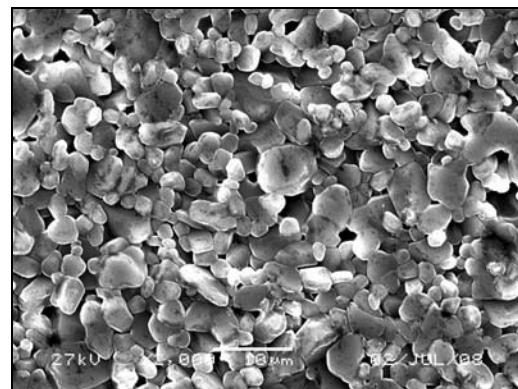


Figure 1A. SEM photo of 96% alumina substrate surface manufactured by Vendor A.

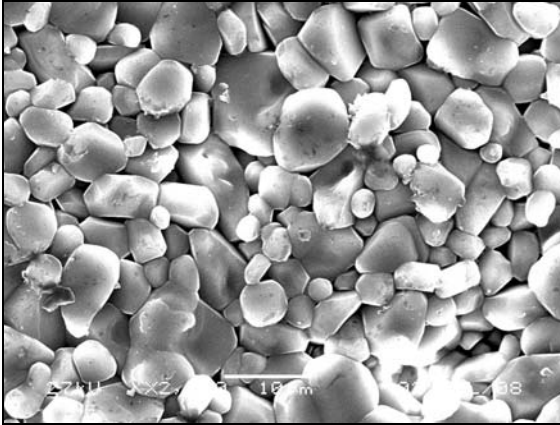


Figure 1B. SEM photo of 96% alumina substrate surface manufactured by Vendor B.

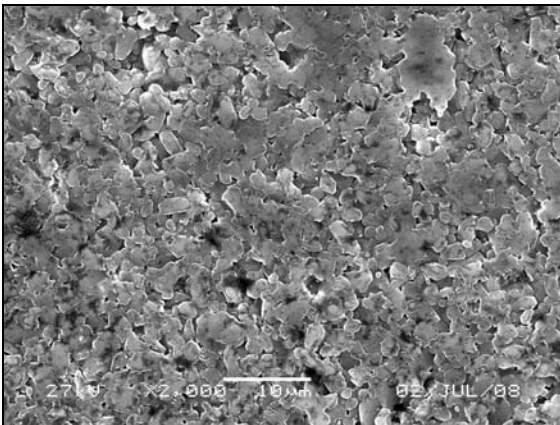


Figure 1C. SEM photo of 96% alumina substrate surface manufactured by Vendor C.

From the SEM pictures it is apparent that each substrate, although all composed of 96% alumina, is different. Variations range from particle size, smoothness, and porosity.

In the two dimensional pictures the only noticeable comparison is the visual representation of each substrate. However three dimensional surface scans show the disparity between each vendor and surface roughness. Each of the substrates photographed (Figures 1A-1C) and scanned (Figures 2A-2C) have the same specification of being 25mils thick.

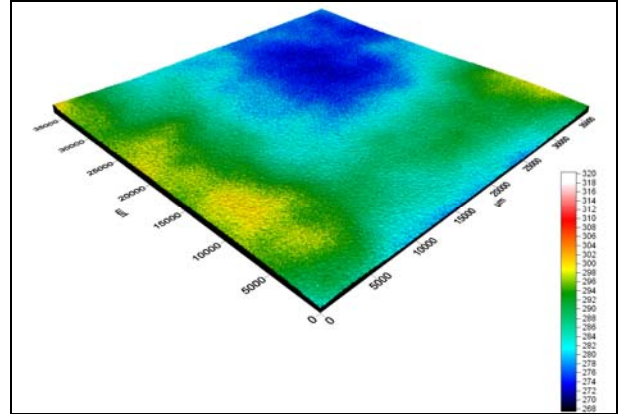


Figure 2A. Cyber 3-D scan of Vendor A surface roughness (μm).

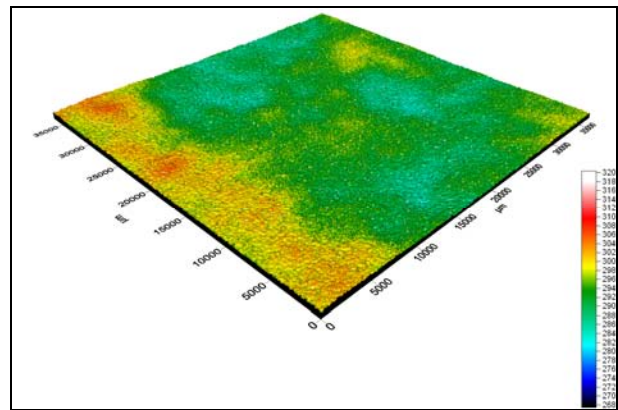


Figure 2B. Cyber 3-D scan of Vendor B surface roughness (μm).

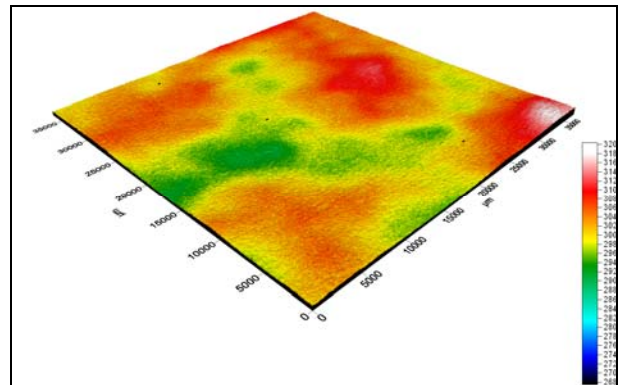


Figure 2C. Cyber 3-D scan of Vendor C surface roughness (μm).

The three dimensional scans of each substrate vendor shows that there is a noteworthy difference in height and roughness. These factors can affect the results of the fired paste properties.

Table I. Average surface roughness and the peak to valley difference for each vendor.

	Vendor A	Vendor B	Vendor C
Average surface roughness (μm)	5.28	4.03	3.92
Peak to valley difference (μm)	39.9	29.34	33.74

Paste choices

Table II. Metals, glass, and lead content of tested thick film pastes.

Paste	Composition	Binder	Pb-free
C4727	Ag:Pt, 99:1	Mixed	yes
C4729	Ag:Pt, 99:1	Frit	yes
C1218A	Ag:Pd, 6:1	Frit	no
C2180	Ag:Pd, 8:1	Frit	yes
C2160	Ag:Pd, 6:1	Frit	yes
C2130	Ag:Pd, 3:1	Frit	yes
C7257	Cu	Frit	no

Heraeus offers a broad range of alloys and binder systems for the many applications of thick film materials. The pastes chosen for this study included those most commonly used directly on alumina substrates. However, gold pastes were not evaluated for this paper. Mixed and frit bonded systems were compared by testing C4727 a mixed bonded system and C4729 a frit bonded system, both Ag:Pt conductors. Mixed bonded is a system which utilizes both glass and oxide as an adhesion mechanism where frit bonded systems use glass as the adhesion mechanism. C1218A was used as a lead bearing frit system, and C2180, C2160, and C2130 provided a series of varying Ag:Pd alloys. C7257 is a Cu conductor and was included for testing a paste fired in an inert atmosphere.

Experimental

The standard printing and firing conditions as described on each products data sheets were used to process the materials.

Solderability: RMA flux, Sn62, 230°C, 5 second dip

Adhesion: 80x80 mil pads, Sn coated Cu wire leads, 90° peel, RMA flux, Sn62, 230°C

Leads are positioned over 80x80 mil pads on the test coupon. The coupons are then placed in a fixture to hold the leads in place and inserted into

the testing arm of the solder dipper. The test coupons are immersed in the flux followed by immersion in the various solder alloys. The test coupons are then cleaned with acetone and allowed to air dry for six hours. The hooks are cut off and the wires are bent to a 90° angle using a mechanical fixture to minimize any variation in the bend angle. Initial adhesion is determined after six hours. The remaining coupons are placed in a 150°C box oven. Adhesion is determined at 48 and 250 hours.

Aged adhesion: All aged parts were soldered and then left to age for the specified amount of time in a box oven set at 150°C

Pull test for adhesion: Lead pull testing is used to determine the force needed to pull the individual leads from the printed conductor pad after soldering. Each lead is trimmed to two inches (flat). A Zwick Z2.5 Pull Tester is used to measure adhesion. The parts are then clamped into the Zwick's specimen grip. Each lead is pulled perpendicular to the substrate until separated from the printed conductor pad. The arm movement is set at a constant speed of 0.5 inches/minute. The grip separation is set at 1.25 inches.

Results

The results listed in this paper reflect the evaluation of different thick film conductors and their performance on 96% alumina substrates from different vendors. All adhesion data is based on a minimum of 12 pulls. Fired film thickness (FFT) is based on measurements obtained by a laser profilometer. The FFT shown is an average FFT of each conductor on each different substrate vendor. There were a minimum of 8 measurements per conductor/vendor combination.

Solderability was tested by comparing the number of 40x40 mil pads out of 80 that were fully soldered after a 5 second dip in Sn62, and examining under a microscope the amount of de-wetting. De-wetting is defined as an area of the thick film pad where soldering has not occurred. Excellent solderability constitutes as the 40x40 mil pad is fully soldered with no de-wetting visible. Good solderability is classified as the 40x40 mil pad mostly soldered with little de-wetting present, and poor solderability has little to no solder present, as almost full de-wetting has occurred.

Adhesion

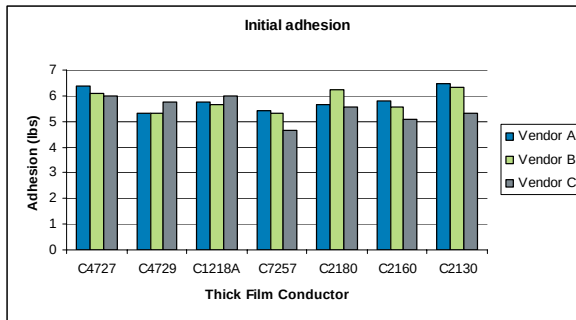


Figure 3A. Initial adhesion of all thick film conductors on each substrate vendor.

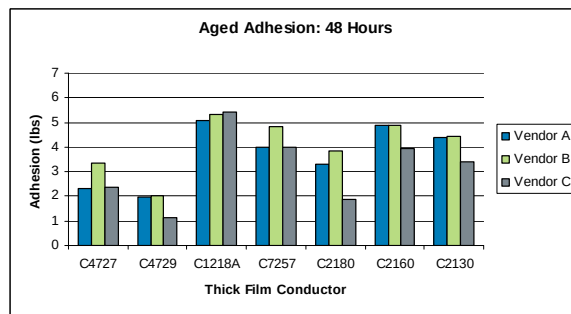


Figure 3B. Adhesion of all thick film conductors on each substrate vendor after 48 hours of aging.

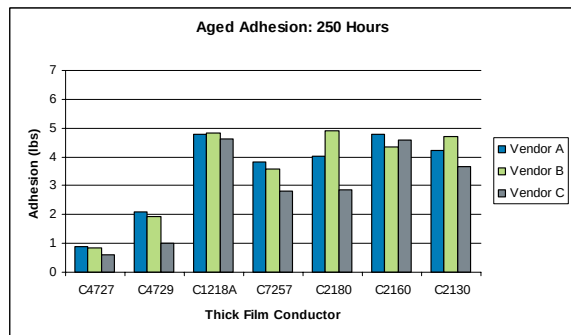


Figure 3C. Adhesion of all thick film conductors on each substrate vendor after 250 hours of aging.

Fired Film Thickness

Table III. Average FFT per conductor on each substrate vendor.

	C2130	C1218A	C2180	C4729	C4727	C2160	C7257
Vendor A	11.5μm	13.8μm	12.8μm	8.5μm	9.5μm	10.7μm	21.2μm
Vendor B	10.7μm	13.2μm	13μm	9.3μm	9.2μm	10.8μm	20.1μm
Vendor C	12.6μm	13.8μm	12.4μm	7.3μm	9.5μm	11.4μm	21.1μm

Solderability

Table IV. Solderability of the thick film conductors on substrate Vendor A.

Vendor A							
	C7257	C2180	C2160	C4729	C4727	C2130	C1218A
excellent	61	80	80	80	80	80	80
good	6	0	0	0	0	0	0
poor	13	0	0	0	0	0	0

Table V. Solderability of the thick film conductors on substrate Vendor B.

Vendor B							
	C7257	C2180	C2160	C4729	C4727	C2130	C1218A
excellent	46	80	80	80	80	80	80
good	13	0	0	0	0	0	0
poor	21	0	0	0	0	0	0

Table VI. Solderability of the thick film conductors on substrate Vendor C.

Vendor C							
	C7257	C2180	C2160	C4729	C4727	C2130	C1218A
excellent	55	80	80	80	79	80	80
good	10	0	0	0	0	0	0
poor	15	0	0	0	1	0	0

Discussion

Across all substrate vendors, the most consistent of the compositions evaluated was the lead bearing 6:1 silver palladium, C1218A. The C1218A was the only lead bearing composition chosen for the testing, so it is uncertain if other lead bearing alloys would show similar results. A well known challenge of thick film suppliers has been to develop equivalent lead-free glass systems. This can be seen when comparing the adhesion to the Pb free Ag/Pd conductors, C2130, C2160, and C2180 in this study where aged adhesion is not consistent across substrate vendors.

Initial adhesion testing was unable to differentiate between substrate vendors, as all of the results were comparable. The best test to differentiate vendors is aged adhesion based on the data provided in this paper. Aged adhesion data shows the variability between substrate vendors, showing that different compositions of pastes (Table II) may react differently with each vendor. This data gives evidence supporting the original hypothesis that proprietary fillers in the compositions of substrates do affect the fired film properties of thick film pastes.

With the variation shown in surface structure and composition (see Figures 1A-1C) it is expected that some variability would be seen when comparing adhesion values. The porous large particles versus the smaller more dense particles appear to play a factor in how the thick film paste reacts with the substrate. A rougher more porous surface is easier to adhere to while it is more difficult for thick film paste to adhere to a denser surface. In general the adhesion data obtained from Vendor B substrates was slightly higher than the others, but not in every case. A denser surface could also lead to glass bleed out and solderability problems. The results, however, did not show this.

For Heraeus thick film materials used for this study, solderability did not seem to be affected by substrate vendor. There was a possibility that the binder systems of the substrate and thick film would have detrimental effects on the solderability of the fired film, but the results were expected to be similar for all vendors. Although there was little effect to Heraeus pastes, other thick film compositions and pastes from other vendors may react differently.

Conclusion

Changing substrate vendors is one option for hybrid circuit manufacturers to improve performance and reduce cost. According to the results of this work; aged adhesion is the property most affected by substrate vendors. This could be due to the different chemistry or a difference in microstructure. It is important that a full evaluation of substrates be performed during qualification, including long term reliability studies.