



## Application Note

### IP 9227 – 2 Layer Lead Free Dielectric for Multilayer Applications

#### Introduction

To achieve a higher level of integration, multilayer hybrid circuits use dielectric layers to insulate stacked conductor tracks. As the core in a multilayer build-up the dielectric plays an important role in preventing overprinted resistors from cracking or chipping provoked by the heat of laser trimming. State of the art dielectrics must be able to support the stringent requirements of wire bond and solder pads. Cost is also paramount in the electronics industry so a new dielectric must be cost effective. These requirements are extremely important in automotive, medical, and power electronic applications which require cost effective alternatives with ever increasing stringent demands. A dielectric that uses only a 2-layer-build-up and low total thickness but still provides high insulation and high breakdown voltage is a cost effective solution. The Thick Film Business Unit of Heraeus Precious Metals GmbH & Co. KG has developed a new 2 layer, screen printable and 850 °C fireable dielectric which is lead, cadmium, nickel and phthalate free and addresses actual and future expectations in terms of *Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS)* and in terms of *End of Life Vehicles (ELV)* legislation.

#### Key Benefits

- Excellent expansion coefficient for minimal substrate bowing
- Extremely dense, hermetic fired film in a two layer, sequentially fired build-up
- Cost saving through a 2-layer-build-up
- Excellent solderability and adhesion of Ag, Ag/Pd, Ag/Pt, Au and Au/Pt conductors on top of dielectric
- High Via Resolution
- Excellent wire bondability of conductors
- Absence of the "Battery Effect"
- Prevents resistors from "Chip-Off" during laser trimming
- Pb, Cd and Ni free
- Phthalate free vehicle system

#### Basics

As a basis for the new dielectric a lead free composition in the system was chosen which matched the Thermal Coefficient of Expansion (TCE) of alumina. On the organic side a new vehicle was formulated to meet the required via resolution of 250 µm or better. The vehicle is phthalate free to comply with current EU regulations. The new dielectric was developed in close cooperation with customers to answer the increasing demands on materials for hybrid circuits.

#### Tasks

**High migration stability** during refirings in a "mixed metal build-up" is one challenge for a multilayer dielectric. Figure 1 shows a simple build-up to test for *battery effect*<sup>1</sup>. The bottom electrode is silver/platinum (99/1) and the top conductor is gold which are insulated by the dielectric to be tested. Each layer is printed, dried and fired sequentially at 850 °C in a 30 minute profile. The fired thickness of each metal layer should be kept low, around 12 µm, to avoid other effects causing blisters. The dielectric layer typically is built up in 2 layers, resulting in a fired thickness of 30 – 45 µm.

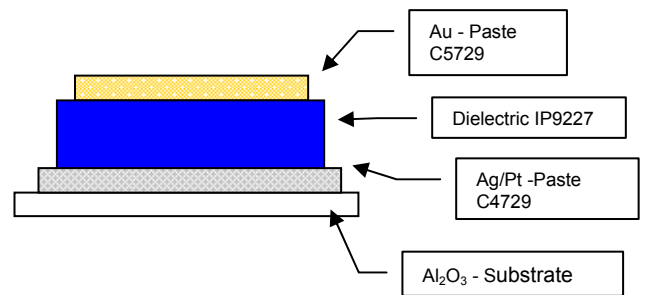


Figure 1: Mixed metal build-up to test for Battery Effect

Figure 2 shows the surface of a test substrate with a unsuitable dielectric after 3 refirings @ 850 °C. This dielectric does not prevent the battery effect. Independently whether gold is on top or printed as the bottom electrode the bubbles will be formed at the gold interface. The dielectric and the top electrode are lifted by blisters showing the pattern of the bottom electrode.



Figure 2: Battery effect after 3 firings (850 °C).  
Bottom electrode: Au, blue layer: dielectric, top electrode: Ag/Pt  
Figure 3 shows the test results of IP9227 for the battery effect after 12 refirings @ 850 °C. There is no formation of bubbles visible. The Fired Film Thickness (FFT) of electrodes was 12 µm, the thickness of the dielectric between 35 – 40 µm (FFT).

Due to the high electro-chemical potential between gold and silver, silver ions always migrate into the gold. The first generation of dielectrics showed blisters under the gold layer from the first refiring. This happens due to silver migration through the dielectric as Ag<sup>+</sup> and O<sup>2-</sup> ions. Oxygen is present due to the firing in air atmosphere and the oxidizing character of glazes in the layers. Recombination of Ag<sup>+</sup> and its electrons in the interface between gold and dielectric leave bubbles of oxygen during firing. Around the peak temperature the softened dielectric acts as an electrolyte.

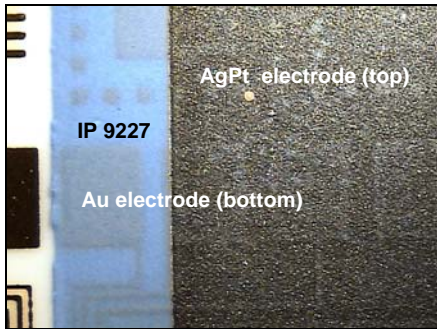


Figure 3: Battery effect-test after 12 refirings @ 850 °C. No bubbles indicate sufficient electro-chemical stability.

## Trimming

Trimming of resistors printed on the top of a dielectric can lead to “chip-off” in the form of shell like chipping of bigger chunks of resistors and glaze. This leads to sudden changes of resistance and causes imprecise online control of the trim process, which results in low accuracy. Furthermore, cracks often begin in the “chip-offs” and propagate into the resistor. This can cause significant resistance drift over time. Due to the high energy input of the laser beam there is a high temperature gradient between the cold surrounding resistor and the trim spot. The difference in thermal expansion of this very spot induces an enormous pressure on the resistor and the dielectric underneath. A dielectric should be able to withstand this thermal stress without “chip-offs”. Figure 4 shows “chip-offs” after laser trimming of a large area printed with R8931DCR (trimmed with a NdYAG-Laser; 0.8 to 1.2 W at 15 mm/s).

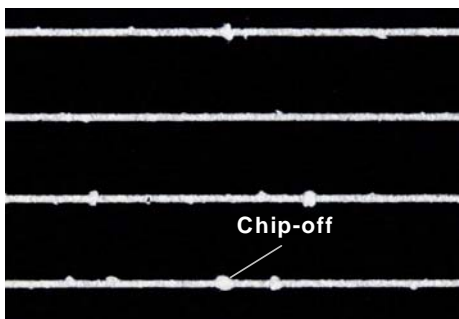


Figure 4: “Chip-off “ on R8931DCR

After trimming of resistors on the new dielectric there is no critical “chip-off” on the trim cut. Figure 5 shows a light microscopic blow-up of trim cuts in R8900DCR resistors were printed on top of IP9227 and as can be seen from the micrograph no “chip off” is evident.

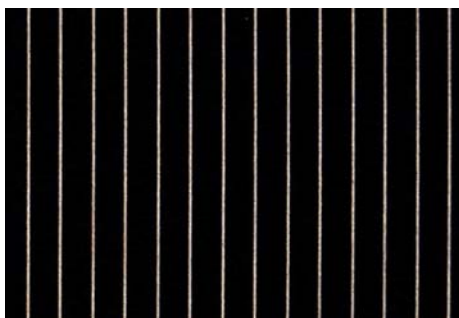


Figure 5: Laser trimmed resistor (R8900DCR series) on top of the new multilayer dielectric IP9227. “Chip off” - free layer

## Stability of trimming

First objective tests on stability of laser trimmed resistors with different geometry (length and with) printed on our new dielectric confirms an excellent stability behaviour. Figure 6 shows us an average deviance of 0.20 % after 1,000 temperature cycle shocks.

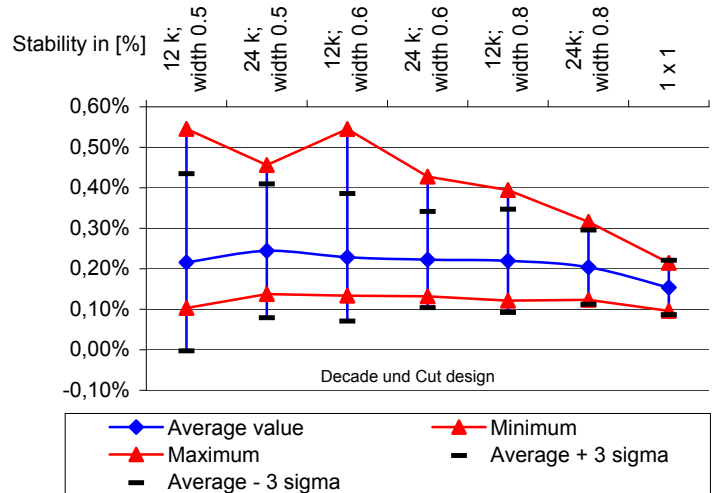


Figure 6: Stability Scan-Cut of IP9227 on 12 kΩ and 24 kΩ with overglaze after 1000 temperature cycle shocks from -40 °C to +150 °C

## Adhesion

First aged adhesion tests of our new dielectric attest excellent adhesion properties with different (lead-free) conductor- and solders pastes (Figure 7 - 9).

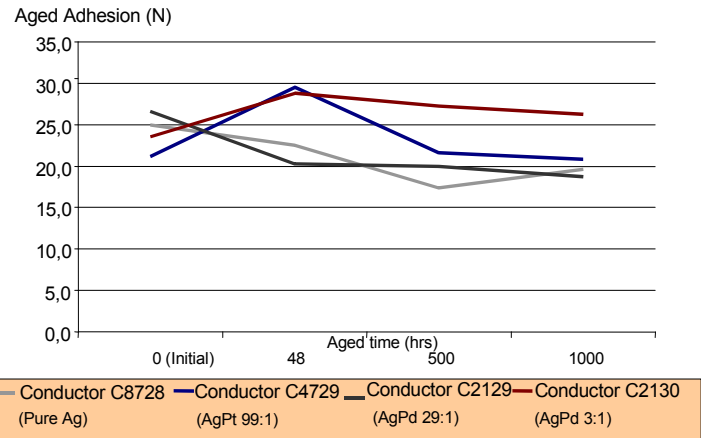


Figure 7: Aged adhesion: comparison of different conductor types on IP 9227; firing 1 x @ 850 °C; 5 sec dips, with SAC 305 solder @ 255 °C, 611 flux

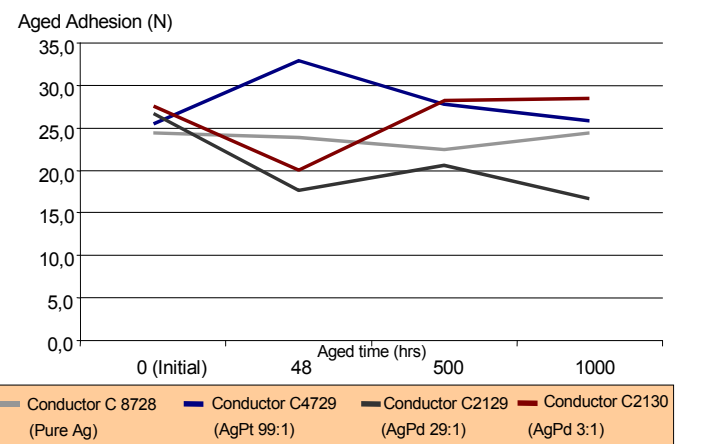


Figure 8: Aged adhesion: comparison of different conductor types on IP9227; firing 5 x @ 850 °C; 5 sec dips, with SAC 305 solder @ 255 °C, 611 flux

## Aged adhesion

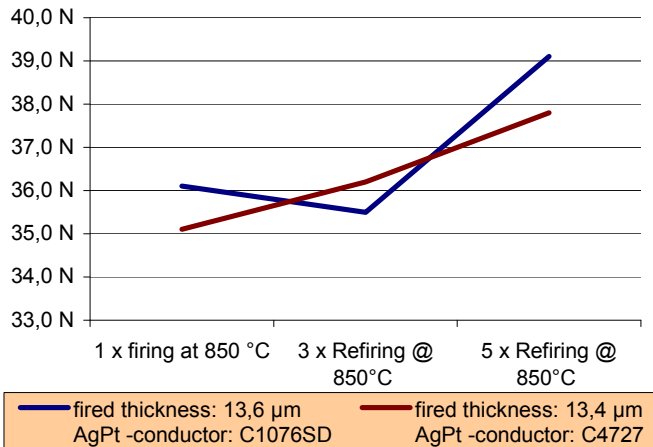


Figure 9: Aged adhesion of IP9227 aged 48 hrs @ 150 °C; Solder: Sn96/Ag3.5/Cu0.5

For adhesion tests the standard wire-peel-test was complimented by a shear test on a critical component, a diode with plastic housing; type "DO 214" (Figure 10). Due to the significant mismatch of the TCE of the housing and the hybrid as the substrate this is a harsh test for adhesion. Standard tests in the automotive industry are "Temperature Shock Cycling" and "High Temperature Storage" which reflect the under-the-hood conditions over a cars lifetime. Shock cycling simulates a situation where either a hot gear box hits icy surface water or a very cold winter day where the cold electronic devices attached to the engine or gear box get hot in very short term. Figure 10 shows the result of an Adhesion-Multilayer test with C4727 on IP9117 and C4727 on IP9227 DO-214AB Sn100 with Heraeus Solder Paste F369-SnAgCu; Shear results after T-shock cycles (TS) -40 °C to +150 °C with 30 min-peak and 3,000 hrs storage (TL) @ 150 °C.

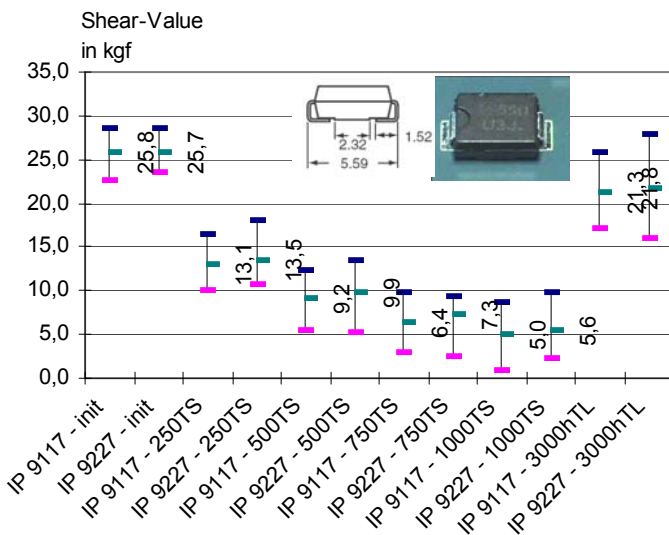


Figure 10: Shear test on a diode with plastic housing; type "DO 214" with C4727 on IP9227 and C4727 on IP9117.

## Wire bonding

The minimum bond strength requirement according to MIL STD 883E for 1.25 mil Al wire is 3.0 grams, for an 8.0 mil Al wire 70 grams and for a 10 mil Al wire 95 grams. The minimum bond strength requirement for 1.25 mil Au wire is 3.5 grams.

Figures 11a and 11b show the temperature cycle adhesion data of various size wires on both Al<sub>2</sub>O<sub>3</sub> and IP9227.

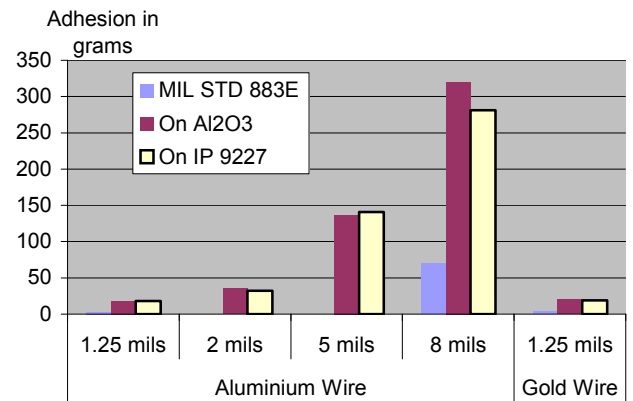


Figure 11a: Initial Adhesion on Al<sub>2</sub>O<sub>3</sub> and IP9227 @ 150 °C in grams; conductor C5729 (Au)

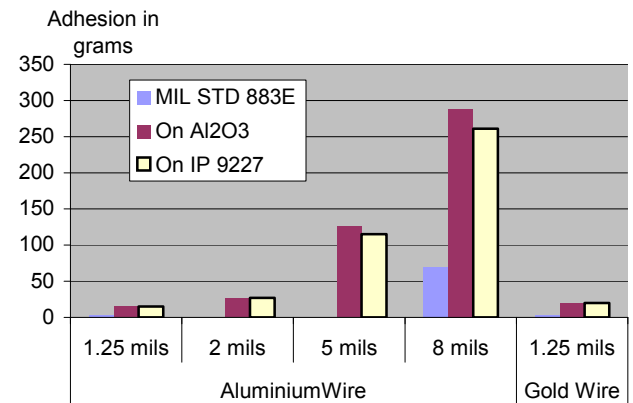


Figure 11b: Temperature Cycle Adhesion on Al<sub>2</sub>O<sub>3</sub> and IP9227 after 150 hours @ 150 °C in grams; conductor C5729 (Au)

**Aging studies** were done @ 150 °C for different size wires on top of alumina substrates and IP9227 dielectric paste. Figure 12 shows the data for the aluminium wires as well as 1.25 mil gold wire aged 150 hours @ 150 °C.

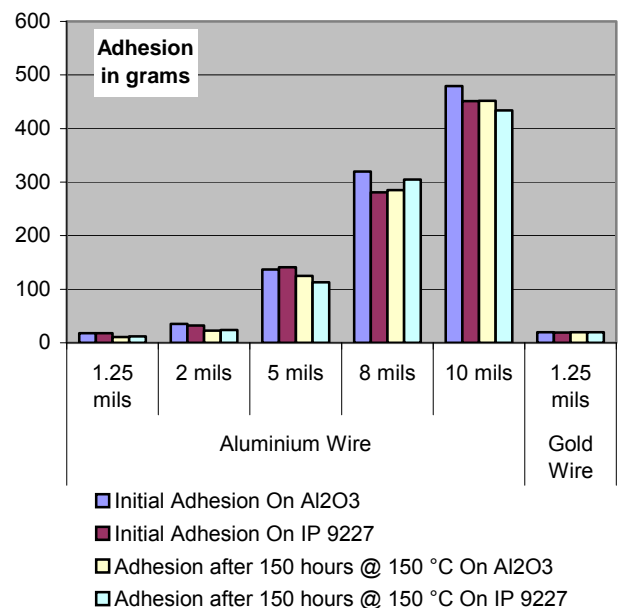


Figure 12: Aged Adhesion on Al<sub>2</sub>O<sub>3</sub> and IP9227; Au-conductor C5729

## Compatibility

Objective studies on compatibility of IP9227 with different gold conductors showed an excellent behaviour of compatibility. The results showed neither blisters nor cracks on overlaid area and boundary. We received the same results with Ag-, Au and Ag/Pt- conductor and resistor pastes (e.g. C1076SD, C5756, C4727 and R8900 Series).

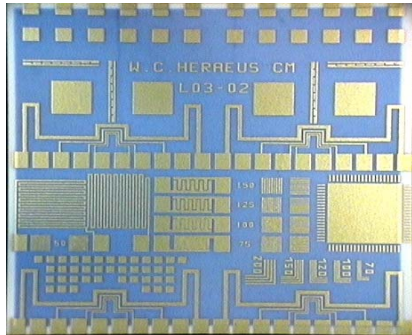


Fig.13a: C5729 on IP9227.

To test for the crossover application our new lead free gold conductor C5729 was printed on top of IP9227. Different drying conditions were used to dry the gold before firing. Parts were dried as low as 100 °C for 10 minutes and as high as 175°C for 10 minutes. The results produced no peel-off of the C5729 conductor from the dielectric. Figure 13a and 13b show a photograph of the test pattern used to evaluate the crossover. The fired dielectric film is 10 mil wide and 45 micron thick and the fired gold layer is 8 mil wide and 12 micron thick.

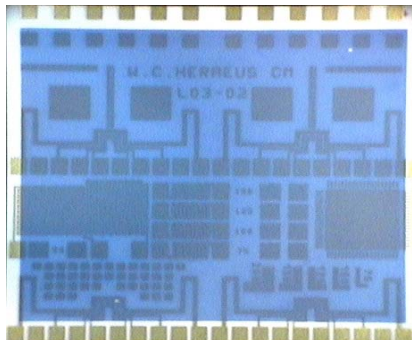
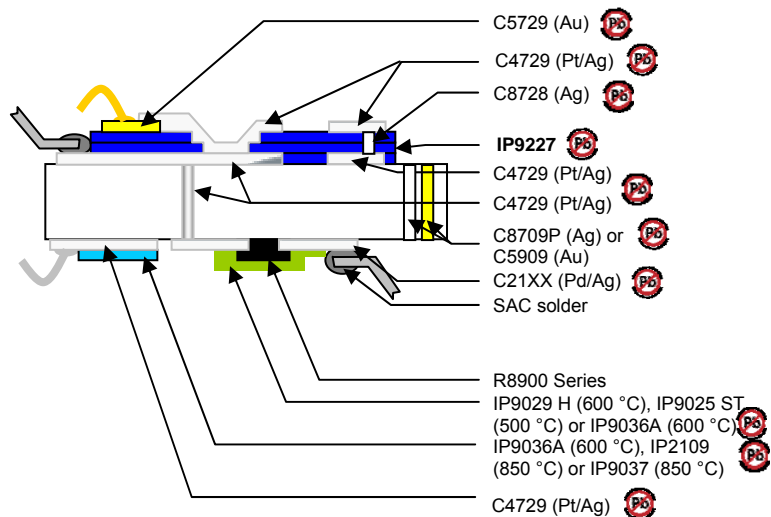


Fig.13b: C5729 with IP9227 on top.

## Additional benefits are:

- **Hermetic density** in a **two layer**, sequentially fired build-up. Break down voltages of 500 VDC at 35 - 45 µm fired thickness. This is an important cost saving factor.
- **Increased printability** for large area shielding on a 6"x4" substrate. The likelihood of pinholes and misprints increases by the 2<sup>nd</sup> order and can negatively influence hermeticity.
- **Optimised rheological properties**, namely via resolution of 250 µm or better in continuous production operation. Prior requirements were only 350 µm.
- **Environmentally compatible contents** The new Heraeus Multilayer Dielectric Paste IP9227 contains neither lead and cadmium nor a phthalate in the vehicle system which addresses actual and future expectations in terms of RoHS and ELV legislation.

## Product Recommendation for Mixed Metal Multilayers:



## Summary

The new Heraeus Multilayer Dielectric Paste IP9227 answers to the current and the future demands of the automotive, medical and power electronic applications for hybrid microcircuits. The absence of battery effect in mixed metal multilayer, improved laser trimmability of resistors along with a high break down voltage on large areas in a cost saving 2 layer build-up are the key features of this new dielectric. Finally an environmentally friendly lead, cadmium and phthalate free dielectric has been developed which addresses actual and future expectations in terms of RoHS and ELV legislation.

The descriptions and engineering data shown here have been compiled by Heraeus using commonly accepted procedures, in conjunction with modern testing equipment, and have been compiled as according to the latest factual knowledge in our possession. The information was up-to date on the date this document was printed (latest versions can always be supplied upon request). Although the data is considered accurate, we cannot guarantee accuracy, the results obtained from its use, or any patent infringement resulting from its use (unless this is contractually and explicitly agreed in writing, in advance). The data is supplied on the condition that the user shall conduct tests to determine materials suitability for a particular application.

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