Challenges of Lead-Free Low Silver Content End Termination Pastes for Inductor Applications

Dong Zhang, Meg Tredinnick, Mark Challingsworth
Heraeus Inc. Thick Film Materials Division
24 Union Hill Road, West Conshohocken, PA 19428 USA
Tel: (610) 825-6050, Fax: (610) 825-7061
Email: dong.zhang@heraeus.com

ABSTRACT

The silver end termination plays an important role for multilayer chip inductors. A basic requirement is to achieve excellent electrical properties with superior adhesion to the chip. Driven by the increasing price of silver, interest has been shown to lower the silver content in the pastes used for terminating chip inductors. However, when decreasing the silver content, conductivity and other properties could be compromised. The challenge is to develop a lower silver content end termination paste while maintaining comparable properties for conductivity, rheology, plateability, solderability, and adhesion.

INTRODUCTION

Traditionally, silver end termination pastes for chip inductors contain around 70% silver. In this paper we investigated multiple end termination paste variations (silver content, Pb-free glass content, and vehicle systems), along with process firing profiles to determine what affect these variations had on the physical and electrical properties of chip inductor for conductivity, adhesion, rheology, solderability, and plateability. Due to environmental requirements for Pb-free formulations this investigation only looked at Pb-free glasses. Pastes with 46% and 53% silver content were formulated to investigate how much affect the silver content had on the fired microstructure, adherence to the chip inductor and Ni/Sn plateability. Optimum metal loading performance was achieved at lower silver when compared to a control. The lower metal loading can result in significant cost savings for chip inductor manufacturers. Also for further potential processing cost reduction, the newly formulated pastes were evaluated at lower firing temperatures.

EXPERIMENTAL

Process and Equipment

Heraeus Thick Film Materials Division's ET1884 (Pb-Free Plateable Silver End Termination) is commonly used as a chip inductor end termination and was used as a control. Two newly developed pastes, CL80-9129 and CL80-9232, with 46% and 53% silver content respectively, were evaluated against the control. White inductor chips with an EIA case size of 0603 (60 × 30 mil) were used in the study. The viscosity of the pastes was measured using a Brookfield RV viscometer and the paste viscosities ranged from 20-40 kcps. The rheology of the pastes was studied using Physica MCR101 from Anton Paar. The pastes exhibited excellent dipping rheological properties for all compositions. Chips were terminated using an ESI 2001 automatic dipping machine. The terminated chips were dried at 150 ^{o}C for 10 minutes. The chips were then fired in a BTU furnace. For the control, paste ET1884, the furnace profile was typical a 45 minute profile, peaking at 780 ^{o}C with a 5 minute dwell. For the experimental pastes, the furnace profile was a 45 minute profile, peaking at 600 ^{o}C with a 5 minute dwell. To ensure electrode/end termination continuity, resistivity was measured by a digital multimeter with two point measurement probes. The chips were nickel, followed by tin plated in a laboratory sized barrel platers. The plating electric current and voltages were controlled by a set of DC Power Supply. The nickel plating bath condition was 12 amps at 135 ^{o}F for 40 minutes at a pH of <5. The tin plating bath condition was 15 amps at 75 ^{o}F for 30 minutes at a pH of <5. For adhesion testing, solid copper leads (0.02 × 1.8 inch), were attached using Sn62 solder, and a RMA flux. The chips were pulled using a Zwick/Roell Z25 Puller. Solderability was tested using different solder fluxes (RMA and R type) in a Sn 96.5/Ag 3.0/Cu 0.5 (SAC) Pb-free solder bath at 492 ^{0}F for 5 second dwell. The microstructure was examined using a Scanning Electron Microscope (SEM).

<u>Formulations</u>

Three sets of samples were made. One set had 53% silver content (Set A), and the second set had 46% silver content (Set B). The third set of samples had the same silver and glass contents but different organic vehicle V1 (Set C), as seen in Table 1. Within Sets A and B the glass content was varied between 2 – 14%. The same Pb-free glass formulation was used for both sets.

Table 1. Paste Formulation Differences.

Samples	**Ag (%)**	**Glass (%)**	**V1**
ET1884	75	2	
A1	53	2	
A2	53	5	
A3 (CL80-9232)	53	7	
A4	53	9	
A5	53	11	
B1	46	2	
B2	46	7	
B3	46	11	
B4 (CL80-9129)	46	14	
C1			min
C2			max

RESULTS AND DISCUSSION

End Termination and Resistivity

After dipping, the chips were dried, fired, and resistivities of the chips were measured as listed in Table 2. The fired chips are shown in Figures 1-3. Compared to the control ET1884, all pastes with different silver and glass contents had similar resistivities.

Table 2. Resistvity of different pastes.

Samples	Resistivity (Ω)	Chip (number)
ET1884	0.3547 ± 0.0384	51
A1	0.3487 ± 0.0435	48
A2	0.3619 ± 0.0425	44
A3	0.3583 ± 0.0386	44
A4	0.3616 ± 0.0467	45
A5	0.3520 ± 0.0434	46
B1	0.2874 ± 0.1094	49
B2	0.3469 ± 0.0451	48
B3	0.3544 ± 0.0428	43
B4	0.3738 ± 0.0596	41

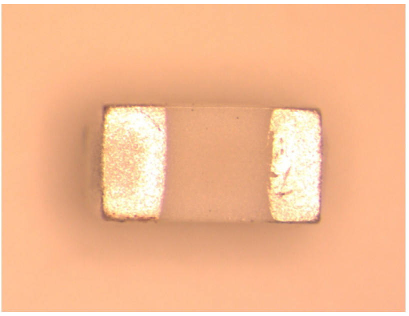

Figure 1. A chip with paste ET1884 end termination after firing at 780 °C.

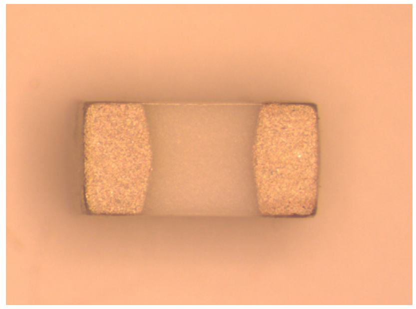

Figure 2. A chip with paste A3 end termination after firing at 600 °C.

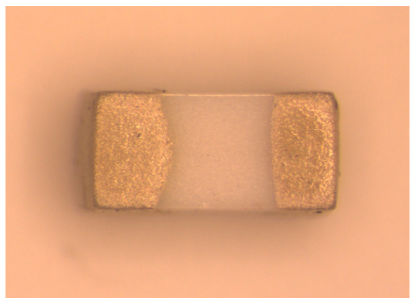

Figure 3. A chip with paste B4 end termination after firing at 600 °C.

<u>Plateability</u>

Typical plated chips are shown in Figures 4-6. The SEM cross sections for ET1884, A3, and B4 are shown in Figures 7-9. All samples exhibited expected plating thickness and coverage for both the nickel and tin layers with no over plating observed. Using the SEM cross sections, one can observe that ET1884 is denser than A3, which in-turn is denser than B4. This is due to the differences in silver and glass contents.

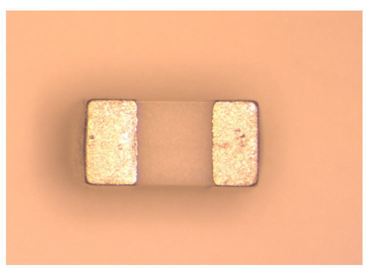

Figure 4. A chip with paste ET1884 end termination after plating.

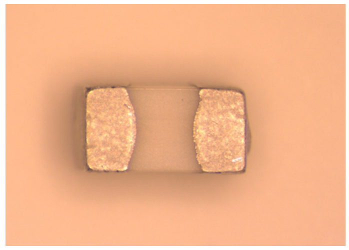

Figure 5. A chip with paste A3 end termination after plating.

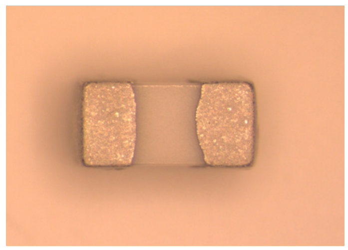

Figure 6. A chip with paste B4 end termination after plating.

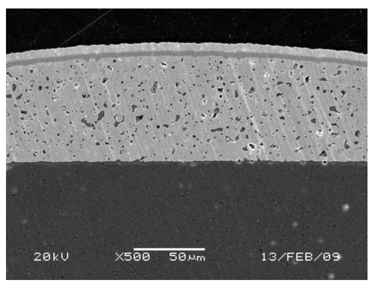

Figure 7. SEM cross section of a chip with paste ET1884 end termination after plating.

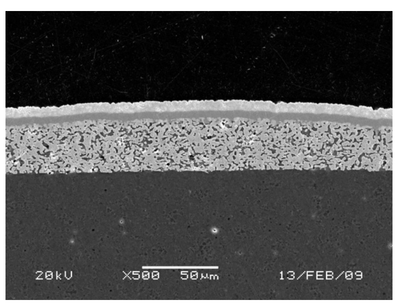

Figure 8. SEM cross section of a chip with paste A3 end termination after plating.

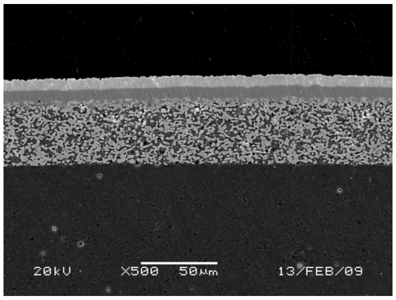

Figure 9. SEM cross section of a chip with paste B4 end termination after plating.

Solderability

The plated chips were soldered with RMA and R type fluxes. Typical soldered chips are shown in Figures 10-15. All samples exhibited excellent solderability with complete solder coverage for both flux compositions.

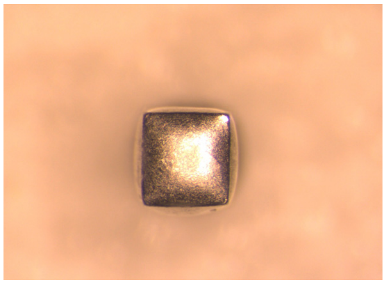

Figure 10. A chip with paste ET1884 end termination after soldering with RMA flux.

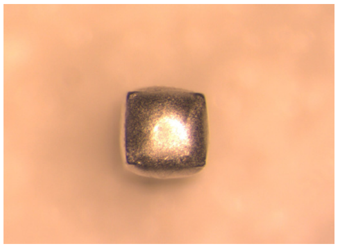

Figure 11. A chip with paste ET1884 end termination after soldering with R flux.

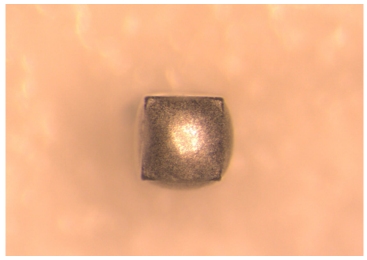
Figure 12. A chip with paste A3 end termination after soldering with RMA flux.

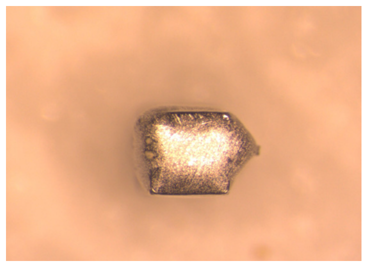
Figure 13. A chip with paste A3 end termination after soldering with R flux.

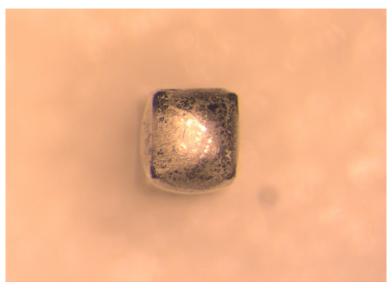
Figure 14. A chip with paste B4 end termination after soldering with RMA flux.

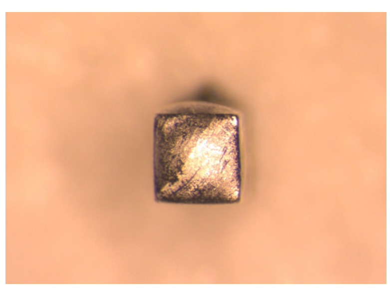
Figure 15. A chip with paste B4 end termination after soldering with R flux.

Adhesion

The adhesion was measured and the results are listed in Table 3. For the control, ET1884, the adhesion failure mode was not seen in the termination, but in the ceramic as shown in Figure 16. For the 53% silver samples, the bond strength reached a maximum at 7% glass content (A3) with the failure mode being observed as ceramic failures (Figure 17). For the 46% silver samples, the maximum glass content (B4) exhibited the best adhesion performance with the highest bond strength and failures observed in the ceramic (Figure 18). For all other compositions except for A3 and B4 the adhesion failure mode was a mixture of ceramic and cohesive failures.

Table 3. Sample adhesion and the corresponding fired peak temperature.

Samples	Bondability (lb)	Fired peak T (^oC)
ET1884	6.6 ± 0.6	780
A1	2.7 ± 1.6	600
A2	5.0 ± 1.4	600
A3	5.7 ± 1.2	600
A4	4.9 ± 1.6	600
A5	3.7 ± 1.3	600
B1	3.2 ± 0.5	600
B2	3.5 ± 0.9	600
B3	4.4 ± 1.6	600
B4	6.2 ± 0.4	600

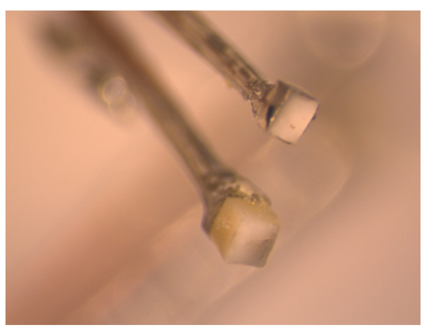

Figure 16. Adhesion failure mode for ET1884 was ceramic failure.

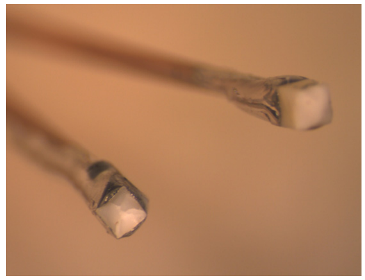

Figure 17. Adhesion failure mode for A3 was ceramic failure.

.

Figure 18. Adhesion failure mode for B4 was ceramic failure.

Rheology Modifications

Initial testing revealed unsatisfactory band control as illustrated in Figure 19 (Paste C1) by the half mooning of the termination bands. To improve the cosmetics, the vehicle system was modified to increase the yield point. Figure 20 shows the improved band control (straight bands) that resulted with paste C2. Figure 21 is a rheological comparison of paste C1 and C2 that quantifies the increase in yield point resulting from the change in vehicle properties.

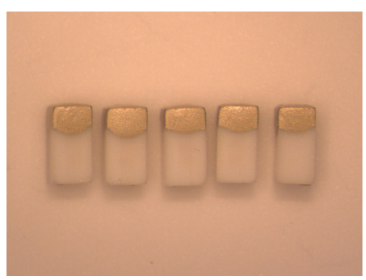

Figure 19. Paste C1 with reduced V1 in the formulation exhibited half-mooning

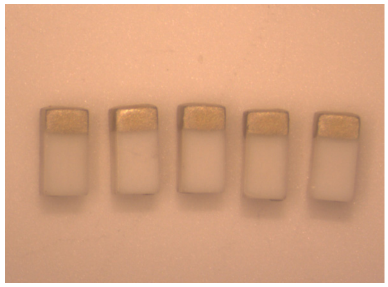

Figure 20. Paste C2 with V1 addition in the formulation exhibited tighter band control than paste C1.

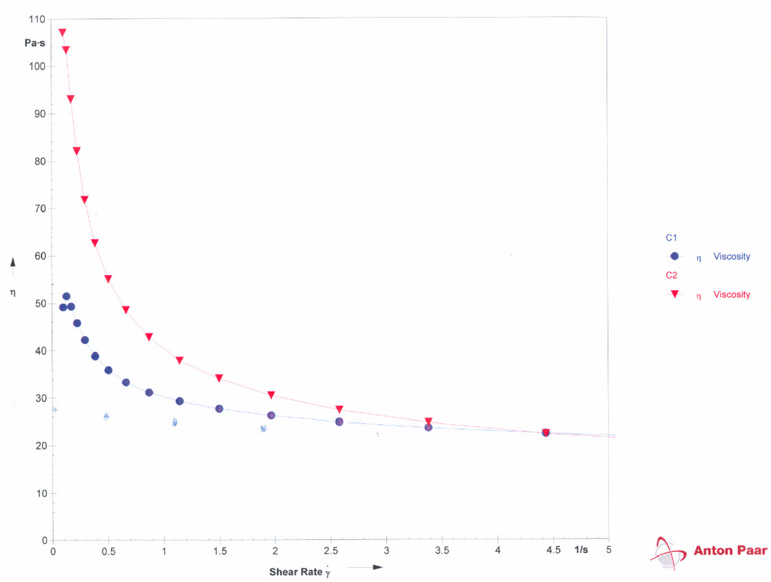

Figure 21. Rheology comparison between paste C1 and C2.

SUMMARY

The results presented in this work have successfully shown that reduce silver content, Pb-free inductor end terminations are viable. CL80-9129 and CL80-9232 have provided equivalent performance for conductivity, plateability, solderability, and adhesion when compared to a 75% silver loaded control termination. The reduced precious metal usage will result in significant costs savings to a chip inductor manufacturer. In addition the performance of the lower precious metal containing pastes was processed at a lower firing temperature, resulting in further potential saving to a chip manufacturer through lower energy costs.