New Wire Bondable Gold Thick Film Conductors
For LTCC Applications

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Abstract

Low temperature co-fired ceramic (LTCC) with silver and gold conductor systems offer a low cost, high performance, and high reliability solution utilizing the advantages of ceramic technology. Gold conductors are generally used in applications requiring best reliability in harsh environmental conditions. Gold conductors are bonded to active or passive components through wirebonding, soldering, or epoxy attachments.

A gold conductor for wire bond applications requires good bond strength to the substrate without weakening the wire. Generally, glass, metal oxides, or a combination of these can be used as adhesion additives in thick film conductors. Upon sintering, the adhesion additives interact with substrate to provide adequate adhesion to the substrate. The selection of adhesion additives can significantly alter the surface of the gold conductor and affect the gold wire bond strength.

This paper describes the development of new wire bondable gold conductors for LTCC applications using Ferro’s A6 tape. It has been found that there is a tendency for glass in the LTCC substrate and in the gold conductor to migrate to the top of the gold conductor surface. Gold conductors with a glassy surface may display inadequate bond strength for gold wire bonds. Effect of oxide additive on the migration of the glass was studied. It is observed that with a proper selection of oxide additives the migration of glass in the LTCC substrate to the gold surface during firing is prevented and gold conductors with less excessive glass on the surface exhibit excellent wire bond strength. The effects of adhesion additives on blister and shrinkage match of the gold conductor to the A6 dielectric are discussed.

Key words: LTCC, gold thick film conductor, wire bond, adhesion, and shrinkage.

Introduction

Low temperature co-fired ceramic (LTCC) systems, such as A6, are typically fired at 850 °C. Due to the low fire, a wide range of thick film conductors, such as silver and gold, can be used. Silver and gold conductors exhibit good conductivity and can be used in high performance applications. The ability to use silver metallization in the LTCC systems also reduces the cost. The multi-layer co-firing process can incorporate other components and enables the fabrication of high density circuits with multi-functions. LTCC is the material of choice for the new generation of packaging materials for wireless communications.

Gold conductors are commonly used for high reliability circuits because of their excellent resistance to corrosion and migration, and the good conductivity. Pure gold also exhibits good wire bondability and provides reliable interconnections of the ceramic package to the surface mounted active and passive components.

In the co-firing process, the surface conductor should have good shrinkage match to the ceramic to ensure flatness. The gold conductor should
also have good adhesion to the ceramic substrate. Inorganic additives, such as glass and oxides, are commonly used for shrinkage match of conductors to LTCC substrate. Inorganic additives can generally modify the shrinkage behavior of the thick film conductors and achieve the flatness after firing. Obviously, these inorganic additives also influence the adhesion strength to the ceramic substrate and surface finish (free of surface defects, such as blisters). The inorganic additives on the surface of the gold also affect the wire bondability. Apparently, the ideal inorganic additive(s) should promote adhesion and shrinkage match to the LTCC substrate, provide a suitable surface for wire bond, and generate no surface defect, such as blister.

A variety of glass, oxides, and their combinations have been tested using A6 LTCC tape system. The monitored properties are gold wire bondability, adhesion strength to the substrate, blisters, and shrinkage match. A new oxide bonded gold thick film conductor has been found to exhibit excellent wire bondability, good adhesion to the A6 ceramic substrate, good shrinkage match to the A6 ceramic, and, at the same time, shows no blistering defect under various firing conditions.

**Experimental Procedures**

Gold conductors were made using the conventional three-roll mill method. Gold powder(s) were mixed together with inorganic additives and organic vehicle to form a viscous paste that is suitable for screen printing applications. A typical paste usually has a viscosity of 800 ~ 1500 poise at 9.6 second^{-1} shear rate using Brookfield viscometer. A typical paste has about 75-80% total solids.

The test parts consisted of seven layers of A6M 5 mil tapes (the M-grade is one type of A6 tapes. A6M is designed for microwave applications). The serpentine pattern with 80x80 mil pads was screen-printed on the top layer. All layers are stacked together on a plate and sealed in a vacuum using a plastic bag. Lamination was done at 70 °C and 3000 psi for 10 minutes. The laminated green parts were placed on top of the fused quartz setter and fired in air using the following standard profile. The batch furnace was ramped from room temperature to 450 °C at 2 °C/min, held for 2 hours at 450 °C for organic burn-out, and then ramped to 850 °C at 8 °C/min and held for 12 minutes. The air-flow rate is 400 to 600 SCFH (standard cubic feet per hour). A typical thickness after firing is 7 to 12 microns. A Ferro gold conductor, FX30-025, was used as a control throughout the study. FX30-025 is a key component in the Ferro A6 LTCC materials system, and has been successfully used as both external and internal conductors in various applications.

After firing the parts were examined under an optical microscope. Gold wire bond strength was tested using 2-mil wire and a thermo-compression wedge bonder. Two major failure modes are observed. One is gold film lift-off, which indicates inadequate adhesion of gold conductor to the LTCC substrate. Another is wire break, which is the desired failure mode.

**Results and Discussion**

1. **Wire bond strength**

It was found that gold conductors with glass additives do not have enough adhesion to the A6 ceramic. 2-mil gold wire bond strength is about 20 to 30 grams (see Table 1). Most of the wire bonds fail at the interface between gold thick film (typically about 8 microns fired thickness) and the A6 ceramic. Many glasses (including the A6 component glasses, such as glass A and B) were tested for improving adhesion. However, most show incompatibility with A6 ceramic and generate blister type of defect on the gold conductor surface, which is discussed in the following section.

<table>
<thead>
<tr>
<th>Table 1. Wire bondable gold conductors</th>
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<tr>
<td>Conductor A</td>
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<td>Conductor B</td>
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<tr>
<td>Conductor C</td>
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<tr>
<td>FX30-025</td>
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Gold conductors with oxide additives generally show clean surface (free from excessive glass) and have good gold wire bondability. Among the oxides tested as adhesion agents, two oxides (oxide A and B) were found to improve the adhesion strength of the gold conductor significantly. In the wire bond strength test, most of the bonds were broken at the gold wire, which is a desired failure mode. Oxides form a reactive bond, which is stronger than the glass bond.

2. Microstructure

Figure 1 shows the typical surface structures of oxide- and glass-bonded gold conductors. Generally, inorganic particles can be seen on the surface. The inorganic impurities, such as, glass particles, prohibit the intimate contact to the gold surface, and therefore, affect the wire bondability.

Oxide-bonded systems, such as, conductor A and B, tend to have clean surface than those of the glass bonded systems. However, in addition to the small oxide particles, small amount of glass crystals can be observed on the surface of gold conductor A [Figure 1 (a)] and B. As discussed in the previous section, those conductors show excellent wire bond strength and wire bondability. Apparently, the small amount of glass crystals may not affect the wire bond strength. No glass was added in the oxide-bonded conductors. It is believed that the glass in the A6 substrate migrates to the top of the gold conductor during firing. The glass migration can also be evident in the glass-bonded conductors. The amount of glass phase at the surface of conductor C seems to be more than the addition level (Figure 1 (b)).

3. Inorganic additives and blister formation

As stated in the previous sections, blisters were observed on the surface of some oxide- and glass-bonded gold conductors. Figure 2 shows typical gold conductor surfaces. The blister formation is presumably due to the incompatibility of the inorganic additives to the substrate ceramics.

A6 is a crystallizing glass in the CaO-B₂O₃-SiO₂ system. Research has been done to study the sintering behavior of the A6 ceramic [1]. Sintering occurs in two stages: viscous sintering followed by crystallization. Some inorganic additives may significantly decrease the glass transition temperature of A6 and result in viscous sintering at lower temperature. The low temperature sintering, in turn, encapsulates the organic volatile and leads to the blister formation.

Table 2 summarizes the differential thermal analysis (DTA) results for A6, A6 component glasses, and two oxides with one of the A6 component glass. Typically, three endo-/exothermic heat effects can be observed in the DTA curves. The first peak is endothermic, and
occurs around 400 °C. This heat effect (at $T_s$) is puzzling. The second peak is also endothermic and is associated with the glass transition ($T_g$). At temperatures above $T_g$, the glass becomes a soft viscous fluid and viscous sintering occurs. The third peak ($T_c$) is associated with the crystallization.

<table>
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<tr>
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<th>$T_s$ (°C)</th>
<th>$T_g$ (°C)</th>
<th>$T_c$ (°C)</th>
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<tbody>
<tr>
<td>A6M</td>
<td>---</td>
<td>663</td>
<td>872</td>
</tr>
<tr>
<td>Glass A</td>
<td>---</td>
<td>714</td>
<td>880</td>
</tr>
<tr>
<td>Glass B</td>
<td>376</td>
<td>652</td>
<td>825</td>
</tr>
<tr>
<td>5% oxide A in Glass B</td>
<td>278</td>
<td>622</td>
<td>823</td>
</tr>
<tr>
<td>5% oxide B in Glass B</td>
<td>478</td>
<td>654</td>
<td>819</td>
</tr>
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Clearly, oxide B does not change the glass (Glass B) transition temperature significantly. However, oxides A significantly decreases the on site glass transition temperature (from 652 °C to 622 °C). It is believed that the interaction of oxide additives to the glasses in the A6 ceramic substrate is mainly responsible for the blister formation on the surface of gold conductors (conductor A in Table 1).

4. Shrinkage match

In the glass bonded conductor system, both solid state sintering and viscous sintering play roles for the shrinkage match of the conductor to the co-fired LTCC substrate. By selecting the glass with a proper softening point, the viscous sintering helps the conductor match the ceramic substrate during the sintering. However, in the oxide-bonded conductor system, solid state sintering is the dominant mechanism. Adjusting factors that affect solid state sintering, such as powder morphology, can provide the proper shrinkage match.

Conclusions

An oxide-bonded gold conductor has been developed. This gold conductor has adequate wire bond strength, better wire bondability, and can be used for various surface mount applications.

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