EFFECT OF CONDUCTOR SURFACE ROUGHNESS AND GEOMETRY ON MICROWAVE LOSS

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ABSTRACT

Low Temperature Co-fired Ceramic (LTCC) technology is being used for various high frequency applications such as T/R modules for radar, Bluetooth communication modules, LAN switches, and automotive radar. One of the key properties of the electronic packages for these applications is microwave loss. LTCC metallizations are typical thick film conductors. Conventional thick film technology has relatively low resolution, poor edge definition, and rough conductor surface. There is a concern about the magnitude of microwave losses resulting from surface roughness and line geometry of the conductor. Photoimageable technology offers fine line (such as 25 micron lines and spaces), better edge definition, and smoother surface. However, the trade-off is that photoimageable process involves several additional manufacturing steps. An understanding of possibilities and limitations of photoimageable technique and improved conventional screen printing methods is helpful for appropriate selection of microwave circuits manufacturing methods.

This paper describes effect of surface roughness of conductor on microwave losses at frequencies < 25 GHz. The insertion loss of a conventional thick film silver conductor was compared to that of a photoimageable silver conductor using the ring resonator configuration and 96% alumina substrate. It is shown that, in the frequency range of 1 to 25 GHz, the insertion loss of photoimageable silver is slightly better than that of conventional screen-printed silver conductor using the ring resonator setup. The implication of this finding for LTCC is discussed. It is proposed that conventional screen-printing may be adequate for some microwave circuits that can tolerate >30 micron lines and spaces and operates below 25 GHz.

INTRODUCTION

Recent advancements in Low Temperature Co-fired Ceramic (LTCC) technology have made it increasingly a material of choice for high frequency packages and interconnects. The benefits of using LTCC technology include proven reliability, size reduction over standard hybrid circuits, superior electrical performance, ability to embed passive components, and better thermal management. Recent development of silver conductor system makes it possible to further advance the technology for low cost and high performance applications [1].

One of the key properties of interest to the packaging designers is the total material loss. LTCC metallizations are typical thick film conductors. Microwave loss typically comes from the following origins: ceramic, metal conductor, metal-ceramic interface, radiation, and surface roughness. There is a concern about the contribution to the microwave loss from the surface roughness. It has been well known that microwave propagates along the conductor surface (skin effect) [2]. For example, the skin depth of silver conductor is about 0.64 micron at 10 GHz. Therefore, surface roughness and conductor trace geometry (edges) may have significant effect on the microwave loss at high frequencies. This paper reports the attenuation of ring resonators built using a conventional silver conductor and a photoimageable silver conductor.

EXPERIMENTS

Microwave electrical measurements were done using a ring resonator setup [3]. The ring resonators were fabricated using 96% alumina substrate (25 mil thick). The ring has a diameter 1.43” in order to have a fundamental resonance frequency of 1 GHz. The width of the conductor trace was designed to meet the requirement of
50-ohm characteristic impedance. The dimensions of the ring resonator test coupon are listed in Table 1. The ring resonator with photoimageable silver conductor was fabricated by Hibridas. The ring resonator parts with conventional silver conductor were made at Ferro using a typical silver thick film paste for hybrid applications and conventional screen-printing method. The parts were fired using a one-hour firing profile with peak temperature of 850 °C and a belt furnace. The parts were then cut into size to fit the fixture for microwave testing. Ring resonator parts made from co-fired silver conductor on A6 LTCC ceramic are also included for comparison. The details of the ring resonator measurement technique have been described in the previous publication [3].

Table 1 Ring resonator dimensions

<table>
<thead>
<tr>
<th>Ag conductor</th>
<th>3309</th>
<th>Photoimageable</th>
<th>33-391</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>96% Al₂O₃</td>
<td>96% Al₂O₃</td>
<td>A6 LTCC</td>
</tr>
<tr>
<td>Substrate thickness (mil)</td>
<td>25</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Width-strip (mil)</td>
<td>25</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>Width-ring (mil)</td>
<td>45</td>
<td>45</td>
<td>36</td>
</tr>
<tr>
<td>Gap (mil)</td>
<td>4</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Roughness, Ra (μm)</td>
<td>0.87</td>
<td>0.33</td>
<td>-</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Figure 1 shows SEM photos of the gaps between strip and ring of the resonator parts. The ring resonator part built using photoimageable silver conductor shows better-defined edges and vertical walls than that built using conventional screen-printed silver conductor.

The surface of the photoimageable conductor is also smoother. The surface roughness (Rₐ) of the conventional silver conductor is 0.87, while the roughness of the photoimageable silver is 0.33 (Table 1). Figure 2 shows the surface profiles of the strip lines of the ring resonator parts. The surface smoothness of the 96% alumina is about 0.5 microns.

Figure 3 shows the attenuation of the ring resonators as a function of frequency. The attenuation of the photoimageable silver is slightly lower that that of conventional silver conductor. However, the microwave losses of the resonator parts using photoimageable...
conductor and conventional conductor seem comparable in the frequency range from 1 to 25 GHz. Several factors (discussed below) may alter the results. It is also interesting that the ring resonator built using a co-fired silver conductor on A6 LTCC performs as well as the 96% alumina system. Alumina normally has lower loss tangent than LTCC, and it is reflected in the overall loss. This result further demonstrates that metal contributes significantly to the total loss at the microwave frequency [4].

Several factors may contribute to the microwave losses reported here. First, the conductor compositions may be different significantly. As it is known that both silver powder morphology and silver particle size distribution affect the firing density of the conductor traces. It is also known that the inorganic adhesion additives in the conductor affect the electrical performance. Second, the gap of the ring resonator using conventional silver is larger than that using photoimageable silver because the photoimageable technology normally provides better line/gap resolution. The ring resonator using photoimageable silver is 'strongly' coupled. The effect of the strong coupling on the finally derived loss is unknown, although corrections are taken during the calculation and normally the quality factor is better for strong coupling. Further investigation is in progress to test the frequency limit at which the conductor geometry and surface smoothness becomes more significant to the microwave loss.

**IMPLICATIONS TO LTCC SYSTEM**

Microwave performance of conventional screen printed pattern seems comparable with photoimageable technology at frequencies below 25 GHz for the ring resonator setup. Assuming that this is also the case in some other configurations, the improved conventional screen printing technique may be a good choice for some applications, where line resolution of >30 micron can be tolerated. Figure 4 shows the dry print of conventional thick film silver conductor on A6 LTCC tape using the improved screen printing technology. It is evidence that the new screen printing technology can achieve 30-micron lines and spaces. The line definition of the conductor traces is inferior to the photoimageable conductor. The impact of the line definition on microwave properties measured using ring resonator technique appears to be minimum below 25 GHz. It is, therefore, proposed that at frequencies below 25 GHz, conventional screen printing technique may show advantages in cost, easy of use, and final yield. Further study is in progress to investigate the effects of line definition on microwave properties above 25 GHz and in other designs.

**CONCLUSIONS**

At the frequency range below 25 GHz, the ring resonators using conventional screen-printed silver and photoimageable silver show good microwave performance. Combined with the
fine-line printing feature, improved conventional screen-printing may be suitable for some low cost and high performance microwave packaging applications below 25 GHz.

ACKNOWLEDGEMENTS

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REFERENCES