Journal of the European Ceramic Society 21 (2001) 1997–2000
www.elsevier.com/locate/jeurceramsoc

Passive RF band-pass filters in an LTCC module made by fine-line thick-film pastes

Markku Lahti *, Vilho Lantto

Microelectronics and Materials Physics Laboratories, University of Oulu, PO Box 4500, FIN-90014 Oulu, Finland

Received 4 September 2000; received in revised form 30 October 2000; accepted 30 October 2000

Abstract

Low-temperature co-fired ceramic (LTCC) materials offer a good possibility to bury passive components and to produce compact electronic circuits. These properties were utilised in this study to realise a passive band-pass RF filter in the LTCC module. The filter consisted of planar inductors, capacitors and microstrip lines. The component values of the filter structure were determined by using the APLAC circuit simulator. Commercial fine-line thick-film Au paste and shrinkage-matched LTCC Ag pastes were used to print narrow conductor lines by gravure-offset-printing on different LTCC sheets. Narrow conductor lines down to 50 μm wide were printed successfully without shrinkage mismatch during firing. A network analyser and different microscopes were used to study, respectively, the electrical and material properties of the patterns and filters. Variations of the printed line widths and of the electrical values of the patterns and filters were about ±10%. The highest centre frequency of the realised filters was about 2 GHz.

Keywords: Electrical properties; Films; Filters; Glass ceramics; Microwave processing

1. Introduction

LTCC materials are currently gaining popularity in the field of microelectronics. They offer the possibility to produce compact multilayer structures with buried passive components.[1,2] It is also possible to vary the dielectric constant from layer to layer which can be utilised in the realisation of passive filters.[3,4]

The miniaturisation of thick-film circuits requires also the development of metallisation methods. Gravure offset printing is a thick-film technique which enables the printing of narrower conductor lines in comparison with screen printing.[5,6] In the printing process, the printing plate is covered by the printing ink which is then removed by a doctor blade to leave the ink only in the engravings of the plate. Then, the ink is picked up by a silicone-rubber pad which is used to transfer the ink onto the substrate.

Shrinkage of the tape occurring during the firing process has been a concern in the use of LTCC materials. Hence, special shrinkage-matched LTCC pastes have been used in order to overcome the shrinkage problem. However, efficient miniaturisation requires also the development of the paste. Therefore, printing of ordinary fine-line thick-film pastes by gravure offset printing on LTCC tapes was studied. Also the realisation of passive band-pass filters with the centre frequency up to 2 GHz was studied.

2. Experimental procedure

Shrinkage-matched LTCC and fine-line thick-film pastes were gravure offset printed on LTCC tapes. The pastes were modified by adjusting their viscosity properties with a mixture of organic solvents and binders to make them suitable for the printing technique. The LTCC tapes were ESL D-41010-70C ($\varepsilon_r = 8$), ESL D-41210-70C ($\varepsilon_r \approx 100$) and Du Pont 943-A5 ($\varepsilon_r = 7.5$). Ag pastes D-901-CT and HF602 were used for ESL and Du Pont tapes, respectively, and D-8881-B was used as ordinary fine-line thick-film Au paste on all sheets.

Holes into green tapes were made by a Nd-YAG laser with a wavelength of 532 nm. The diameter of the holes

* Corresponding author. Tel.: +358-8-5532720; fax: +358-8-5532728.
E-mail address: msl@ee.oulu.fi (M. Lahti).

0955-2219/01/$ - see front matter
PII: S0955-2219(01)00159-5

was about 100 μm. The conductors were double-printed in order to increase their thickness. The printed structures were dried at 80°C to evaporate the organic solvents of the inks. The printed layers were aligned and laminated at a pressure of 210 kg/cm^2 and at a temperature of 70°C for 15 min. The laminated structures were fired with profiles optimised for each LTCC material, separately. The burn-out of the ESL tape took 10 h at a temperature of 400°C followed by the normal thick-film firing with a maximum temperature of 850°C. The burn-out of the Du Pont tape was made by increasing the temperature slowly from 400 to 600°C at the velocity of 5°C/min. The maximum temperature of this firing process was 875°C.

Printing experiments were utilised in the realisation of passive RF band-pass filters. The filter with a centre frequency of 1.2 GHz was realised and the measured electrical results have been published elsewhere.[4] The filter consisted of lumped elements (including, i.e. capacitors and inductors) in three layers with different values of the dielectric constant. This structure was further developed and 3- and 5-stage Butterworth band-pass filters were modified to give component values which are possible to fabricate with the designed centre frequency of 1.8 GHz together with a bandwidth of about 10 MHz. The structure and equivalent circuit of the 3-stage filter are shown in Fig. 1.

The viscosity of the ink was measured using a cone and plate method (Bohlin CS Rheometer). The quality of the printed patterns was studied by a surface profiler (DEKTAK^{3}ST) and by optical, scanning electron (Jeol JSM 6400) and scanning acoustic (C-SAM®) microscopes.

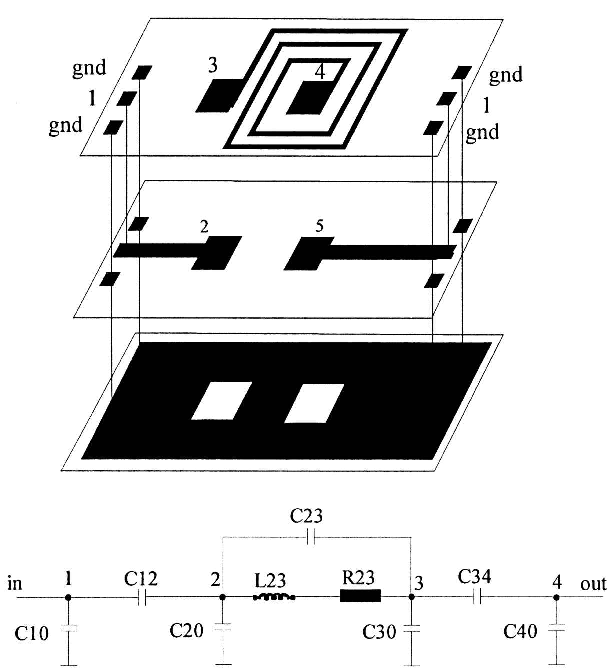

Fig. 1. The structure and equivalent circuit of the RF band-pass filter.

The resistivity of the conductor lines was measured by a four-point measurement method and the transmission parameters were measured by a network analyser (HP8719C). The electrical values of the filter components were simulated by the APLAC 7.10e circuit simulator.

3. Results

3.1. Printing experiments

The amount of mixture of the organic solvent and binder added to the pastes was from 5 to 10 wt.%. Then, the viscosity of the ink was about 20 Pas at the shear rate of 20 1/s. The narrowest line widths printed by the LTCC pastes were 75 μm. Printing of narrower conductor lines was difficult due to the high particle size which was about 5 μm in average. The smaller particle size of the D-8881-B paste (1.1 μm in average) enabled the printing of lines as narrow as 50 μm. The amount of shrinkage during firing varied depending on the tapes and inks as shown in Table 1.

3.2. Electrical properties

The sheet-resistance values of 200 μm wide conductors were determined and the results are shown in Table 2 for different inks. The determination of the resistivity was difficult since the conductor thickness varied from 1 to 3 μm as shown in the cross-sectional photograph in Fig. 2. The estimated resistivity values of the conductors are shown in Table 2 when the average thickness values were used in their determination. The values given by the manufacturers are also shown for comparison.

The transmission parameters of the band-pass filters are shown in Fig. 3. Their centre frequencies were 1.2 and 1.8 GHz with attenuation of 0.7 and 7.6 dB, respectively. The bandwidths of the filters were about 50 and 100 MHz, respectively. The APLAC circuit simulator was used to determine the component values of the filter structure from the measured transmission parameter data. The designed and measured component values of the 3-stage band-pass filter with the centre frequency of 1.2 GHz are shown in Table 3.

Table 1
The mean horizontal shrinkage of some LTCC substrates and conductors

Ink	Shrinkage (%) conductors	Tape	Shrinkage (%) LTCC substrates
D-8881-B	6.5	Du Pont 951	13.4
HF602	5.7	Du Pont 943	11.3
		ESL 41010	12.0

Table 2
The sheet-resistance and resistivity values of the conductors

Ink	Tape	Sheet resistance (mΩ/□)	Resistivity (10^{-8} Ωm) (with thickness of 2 μm)	Resistivity given by manufacturer (10^{-8} Ωm)
D-8881-B	Du Pont 943	26	5.2	1.8–3.6
D-8881-B	ESL 41010	12	2.4	1.8–3.6
HF602	Du Pont 943	23	4.6	2.4–2.9
D-901-CT	ESL 41010	23	4.6	3.6

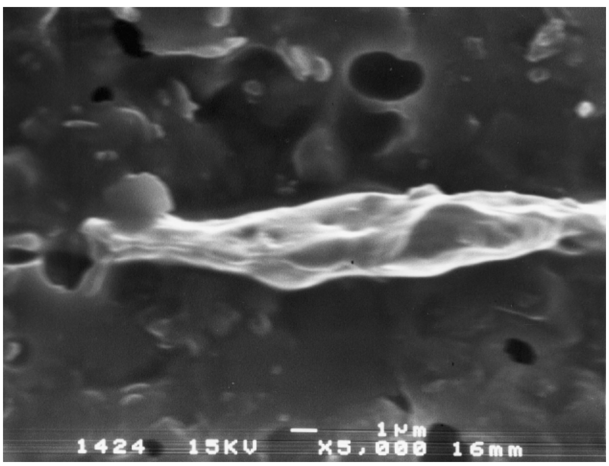

Fig. 2. SEM photograph of the D-8881-B paste printed on the Du Pont tape. The line width of the conductor was about 100 μm and the thickness varied from 1 to 3 μm.

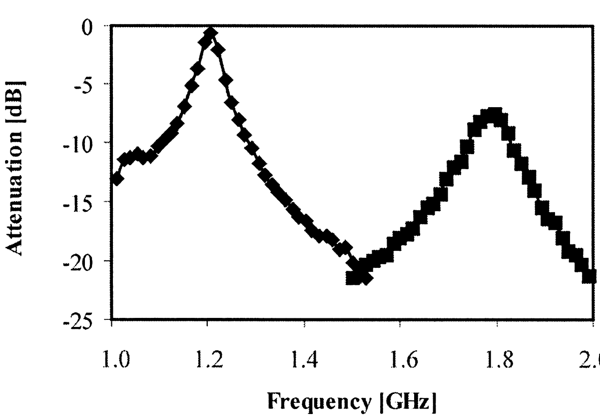

Fig. 3. Attenuation of two band-pass filters as a function of frequency.

3.3. Material properties

The quality of the lamination and firing process was studied by SEM. The sheets with different values of the dielectric constant formed a uniform structure. Although some voids occurred in via holes when using the thick-film paste as seen in Fig. 4, the low conductivity was still achieved. SEM was also used to study the misalignment problems. Typical values of misalignment between the layers were about 20 μm.

Table 3
The nominal and simulated component values of the 3-stage 1.2 GHz filter

Component (see Fig. 1)	Nominal	Simulated
C10 = C40	2.0 pF	1.86 pF
C12 = C34	0.645 pF	0.606 pF
C20 = C30	1.5 pF	0.98 pF
C23	0.02 pF	0.02 pF
L23	22.5 nH	22.7 nH
R23	1.4 Ω	0.6 Ω

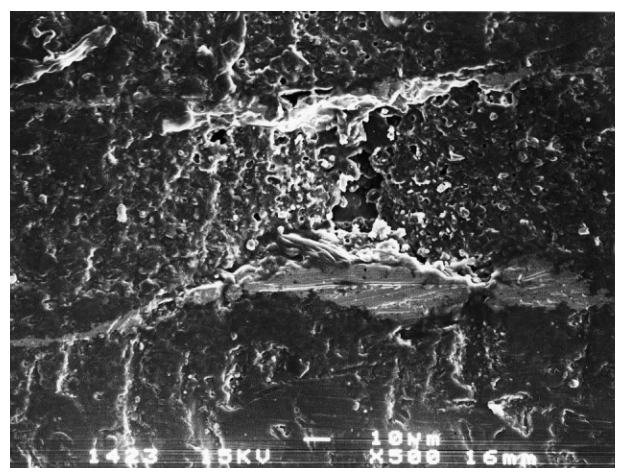

Fig. 4. Cross-section of a via hole filled by the D-8881-B Au paste.

4. Discussion

Narrow thick-film Au conductors down to 50 μm wide were printed by the gravure-offset-printing technique on the LTCC tapes. The conductors were conductive after firing although they shrank slightly more than the conductors printed by the commercial LTCC pastes. The main concern with the technique was the use of solvent in the paste which caused low fired thickness values (from 1 to 3 μm) and, hence, high sheet-resistance values.

The simulations and experimental results showed that it is possible to realise a lumped-element-based filter with a low attenuation at the centre frequency of 1.2 GHz. When the band-pass frequency was increased up to 1.8 GHz the attenuation also increased. The reason for that was the sensitivity of the attenuation to the capacitance value of the series capacitor and to the frequency-dependant resistance values of the inductors. The repeatability of the electrical properties of these filters was also more difficult than in the case of filters with lower value of the centre frequency.

The variation of the capacitance values of the series capacitor was caused by the misalignment of the layers and by the variation of sheet shrinkage. Typical misalignment inside the LTCC module was in the range of 20 μm which corresponds to a difference of about 4 fF when the relative dielectric constant is 100 and the separation of the capacitor plates 80 μm. In the design of the 1.8 GHz filter, the value of the series capacitance was less than 100 fF and, therefore, the variation of the capacitance values caused by the misalignment was relatively high. Unfortunately, the series capacitance had to be controlled with a tolerance of less than 5% in order to keep the band pass within the specifications. The shrinkage variation was $\pm 1\%$ around the average value. The variation of the conductor-line width and electrical values of the filters were $\pm 10\%$. Realising a high capacitance value at a small area by combining layers with different values of the dielectric constant made it possible to decrease the size of the filter.

5. Conclusions

Commercial thick-film conductor pastes were printed successfully on the LTCC tapes. The resistivity of the pastes was comparable with the LTCC pastes. Both pastes were used to fabricate band-pass filters based on lumped elements with the centre frequency up to about 1.8 GHz. The filters with the centre frequency of 1.2 GHz worked well. When the frequency was increased the attenuation also increased.

Acknowledgements

M.L. is grateful to the Graduate School in Electronics, Automation and Telecommunication (GETA) in Finland and to the Finnish Academy for financial support.

References

1. Eustice, A. L., Horowitz, S. J., Stewart, J. J., Travis, A. R. and Sawhillm H. T. Low temperature co-fireable ceramics: a new approach for electronic packaging. In *Proceedings of the 36th Electronic Components Conference*, ed. unknown. IEEE New York, Seattle, 1986, pp. 37–47.
2. Müller, J., Thust, H. and Drüe, K. H., RF-design considerations for passive elements in LTCC material systems. *International Journal of Microcircuits and Electronic Packaging*, 1995, **18**, 200–206.
3. Feingold, A., Huang, C. and Stein, S. J., Low K, low loss, low fire tape system for microwave applications. In *Proceedings of the IMAPS-urope 2000 Conference*, ed. P. Mach and J. Urbanék. International Microelectronics and Packaging Society — Czech and Slovak Chapter, Prague, 2000, pp. 163–168.
4. Lahti, M. and Lantto, V., Realisation of RF band-pass filters in an LTCC module structure. In *Proceedings of the IMAPS-Europe 2000 Conference*, ed. P. Mach and J. Urbanék. International Microelectronics and Packaging Society — Czech and Slovak Chapter, Prague, 2000, pp. 207–211.
5. Lahti, M., Leppävuori, S. and Lantto, V., Gravure-offset-printing technique for the fabrication of solid films. *Applied Surface Science*, 1999, **142**(1-4), 367–370.
6. Shimada, M., Watanabe, H., Tsukamoto, M., Ishida, T. Manufacturing of fine-line films by printing technique. In *Proceedings of the IMC 1990 Conference*, ed. unknown. Society for Hybrid Microelectronics, Tokyo, 1990, pp. 581–586.