RELIABILITY EVALUATION PROCEDURE OF THICK FILM INDUCTORS MANUFACTURED BY VARIOUS TECHNIQUES

Alena PIETRIKOVÁ, Magdaléna BUJALOBOKOVÁ, Juraj BANSKÝ
Department of Technologies in Electronics, Faculty of Electrical Engineering and Informatics,
Technical University of Košice, Park Komenského 2, 043 89 Košice, Slovak Republic, tel.: +421 55 602 3199,
E-mail: alena.pietrikova@tuke.sk, magdalena.bujalobokova@tuke.sk, juraj.bansky@tuke.sk

SUMMARY

The paper deals with reliability evaluation procedure of thick film inductors manufactured by various techniques. Thick film inductors belong to the specific electronic passive components, which properties are known as a component „tailored“according to the application, structure and construction. Evaluation methodology principle of thick film inductors issues from entities of standardized reliability evaluation procedure of classical electronic equipments.

Influence of various factors to the level of quality and reliability of thick film inductors play considerable role according with manufacturing technology. The combination of climatic factors (e.g. temperature, humidity) with manufacturing conditions of thick film inductors influenced the electrical performance of inductors: inductance L, quality factor Q and parasitic parameters: serial resistance R_s and self capacitance C_p. Various reliability test were realized based on the comparison of influence of various climatic factors: accelerated ageing thermal stress test, damp heat test cyclic, dry heat test and thermal shock.

This paper shows on manufacturing possibilities of thick film inductors that were manufactured by three various techniques: conventional thick film technology, application of photosensitive paste Fodel® and etching in combination with photolitography process.

Keywords: *reliability testing, thick film inductors, thick film technologies, electrical parameters*

1. INTRODUCTION

In the last time more and more application of planar inductors have used not only on silicon substrate, but also on the another types of ceramic one.

Application of thick film structures as the potential suitable alternative of classic electronic components substitution becomes larger expansion, which is related to requirements for performance of modern telecommunication systems. High quality inductors realized using LTCC (Low Temperature Cofired Ceramic) technology is possible to use as „externalized“ chips. The estimation of their quality reflects on requirements of adequate criteria of quality and reliability level of thick film structures, what demands using the suitable diagnostic methods.

It isn't possible to use a standard evaluation of thick film structures on LTCC based on standardized test methods assigned for classic electronic devices in consequence of specific characters of used thick film materials. As it's shown in this paper, this procedure of evaluation is adapted to the particularity of thick film structures.

The paper presents the results of investigations on planar inductors electrical performance (inductance L, quality factor Q, serial resistance R_s a self capacitance C_p) based on analyses of various areas of failure appearance, various degradation processes and failure mechanisms. There is a need to know all information about the technological processes, degradation mechanisms and their mutual effects for reliability solution of thick film inductors.

For experiments presented in this paper were used the alumina substrate (96% Al_2O_3) and Low Temperature Cofired Ceramic LTCC 951 GreenTape™ DuPont with the thickness of 114 µm.

2. THICK FILM INDUCTORS

Geometric dimensions, material and production technology of coils are important factors, which limit the coil application in various electronic circuits. The parameters of thick film inductors integrated on various ceramic substrates depend on application and parameters of circuits, frequency and space efficiency. The most important aspects for coil production and processing are inductor design, adjacent conductor space, gap width and their mutual influence or attenuation [2].

Through the thick film technology it is possible to create the coil with inductance 0.05 to 0.5 µH at frequency 75 to 150 MHz and with quality factor greater than 30 on substrate with area size of 3 cm^2. Maximum inductance limit of thick film inductors is restricted by resolution of thick film technology (0.5 mm) and minimum inductance limit is restricted by coil geometry (minimum 2 turns) [3].

Ceramic substrates are usually used for manufacturing of planar thick film inductors for high frequency applications. They should be characterized by increasing inductance L, high performance as well high quality factor Q if parasitic parameter values decreased (serial resistance R_s, self capacitance C_p), in combination with various technologies that are susceptible to reaching the required effect. Secondary factor is the quality of printed layers and decreasing of conductors and spaces width. Suggested model of planar square coil consisted of 12 turns. Conductors and spaces width

(Tab. 1) were adapted to the characters of used technologies: conventional thick film technology, photosensitive technology and photolithography in combination with etching.

Used Technology	*Conductor Width [μm]*	*Space Width [μm]*
Photolithography/ Etching	150	200
Conventional Thick Film Technology	200	300
Photosensitive Technology	150	250

Tab. 1 Geometrical dimensions of tested coils

Conventional thick film technology with its parameters doesn't comply with requirements of coils manufactured for demanding application for the reason of low resolution. Maximal conductor's width was 150 μm and space width was 250 μm. Quality of printed layer doesn't respond to required demands too. The coil manufactured by conventional thick film technology is shown in the Fig. 1a.

Decrease in conductors and space width using the photosensitive technology is one of the possibilities how to reach the required minimal dimension. Increasing quality of thick film inductors based on photosensitive technology is possible due to the minimalization of conductors and space width on the level of 50 μm. This technology is based on application of photosensitive paste Fodel® DuPont on Low Temperature Cofired Ceramic LTCC (Low Temperature Cofired Ceramic) by screen printing, drying, exposure and development of exposed coil motive (Fig. 1b).

Combination of photolithography with etching on LTCC is progressive technique in the last few years. This technique makes it possible for precise conductor's manufacturing with predefined width and depth. It is based on combination of photolithography, advanced etching process and screen printing (Fig. 1c). Presented technique is suitable for construction of conductors on the level of 50 μm.

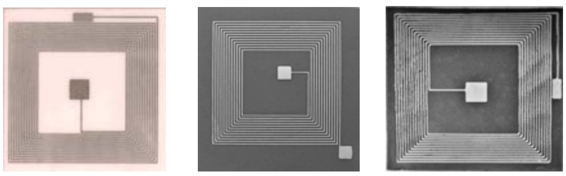

Fig. 1 Thick film inductors manufactured by various techniques (a- thick film technology, b- photosensitive technology, c- photolithography in combination with etching)

3. RELIABILITY TESTS

Reliability tests make possible to obtain the basic information about the failure rates of products in dependence on time at various load and in various operational environment [4]. Economic as well time demands of classical reliability tests led to the implementation of accelerated reliability tests into practice. Acceleration of failure rate mechanisms is achieved by suitable strain, e.g. temperature, pressure, mechanical stress etc. It is possible to achieve increasing sensitivity of accelerated test in these manners: tighten the failure rate criteria or increasing of applied stress [5]. Testing of resistance of structure exposed to various climatic influences is frequented and preferred reliability tests. The most important factor is temperature, which leads to the fatigue and ageing of materials or structures. Humidity causes the electrochemical and chemical changes in material structure. Humidity proved to be the reason of corrosion, inner strains and cracks generation, or changes in functional properties. The combination of both factors based on given information leads to the whole degradation of tested structures as well as to significant degradation of functional properties that exceed the acceptable level of tolerance.

For explanation of climatic factors influence (temperature, humidity) on electrical parameters of thick film inductors were realized following reliability tests: accelerated ageing thermal stress test, damp heat test cyclic, dry heat test and thermal shock. From the possible coil electrical parameters were measured: inductance L, quality factor Q and parasitic parameters: serial resistance R_s and self capacitance C_p.

3.1. Accelerated ageing thermal stress test

Ageing represents the complex of processes in material caused by some stresses (thermal stress, electrical stress, mechanical stress, humidity, atmospheric etc.), which leads to the irreversible changes of important technical properties [6]. Accelerated ageing were realized by following way: set of 30 samples were exposed to temperature 125°C ± 3°C and relative humidity 65% through 1000 hours. Electrical parameters of thick film inductors were measured at 0, 20, 50, 100, 200, 500 and 1000 h. Theses testing conditions were accords with standard STN 35 8001 „Reliability tests of electronic components“ [4].

3.2. Thermal shock test

Principle of thermal shock test resides in coil exposition to the extremely changes of temperature. Accords with standard JESD 22-A106-A „Thermal Shock“ were defined the test temperature -40°C and +125°C for the set of 30 samples. Electrical parameters of tested inductors were measured before the test and after 10, 20, 50, 100 and 175 cycles [7]. Working procedure of thermal shock test during 1 cycle influences from test condition is in Tab. 2.

	Test Conditions		
	Temperature [°C]	*Exp. Time [min]*	*Environment*
Cooling	- 40	2	Cooling Bath (CO_2 + Petrol)
Heating	+ 125	2	Warm Air in Chamber

Tab. 2 Thermal shock test conditions

3.3. Dry heat test

Dry heat tests determine the resistance of coil to influence of increased temperature, e.g. 70°C at specified time exposition 2, 16, 72 and 96 h. At the appointed time, in accords with standard STN 03 8822 „Climatic and mechanical resistance test of technical products, Dry heat test“, were measured the electrical parameters of 30 inductors [9].

Dry heat test, as well as damp heat test cyclic was realized in climatic chamber on the score of specific required conditions. This device was especially developed for reliability tests under various climatic conditions.

3.4. Damp heat test cyclic

The principle of damp heat test cyclic based on monitoring of coil resistance at recent influence of increased temperature (25 – 55°C) and high relative humidity (93 – 95%) during 1, 2 and 6 cycles [8]. This test was realised on set of 30 samples. Graphic pass of experimental cycle is listed in Fig. 2. In selected cycles were measured electrical parameters of thick film inductors.

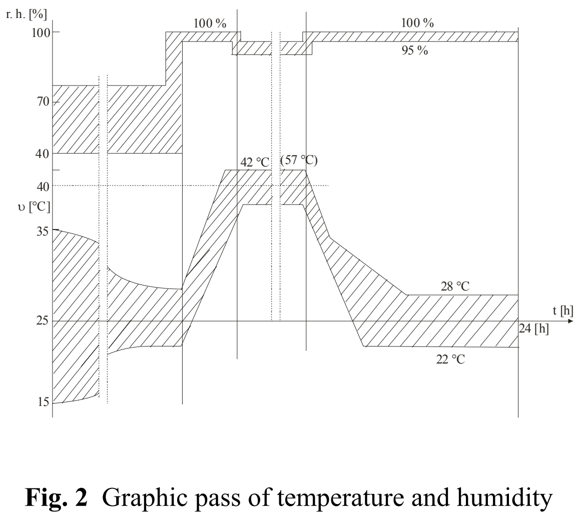

Fig. 2 Graphic pass of temperature and humidity cycle of damp heat test cyclic

4. RELIABILITY EVALUATION PROCEDURE OF THICK FILM INDUCTORS

Reliability evaluation procedure of thick film inductors issues from the estimation of no-failure operation index and durability index reach at individual reliability tests. According to [4] the failure rates λ, as one of the typical no- failure operation index is defined by equation:

$$\lambda = \frac{r_p}{T_{celk}} \quad [\mathrm{h}^{-1}] \qquad (1)$$

where r - number of failures, T – total time of test duration [h].

The value of technical life L_{tech}, is defined by equation:

$$L_{tech} = L_{str} \pm S \quad [\mathrm{h}] \qquad (2)$$

where L_{str} – medium value of technical life [h], S is standard deviation [h].

Presented reliability index were evaluated on the base of measured electrical parameters of thick film inductors: inductance L, quality factor Q, serial resistance R_s and self capacitance C_p. As a selected failure rate criteria was exceeded of ± 10% initial inductance value.

Electrical parameters were measured with TESLA BM 311G equipment that makes measuring of electrical parameters of resonant circuits components possible. The electrical parameters of thick film inductors were measured in frequency range from 9 to 20 MHz. Values of quality factor Q were red directly, another one (electrical parameters) by calculating of measured additive data. Values of measured and calculated electrical parameters are listed in Tab. 3.

Used Technology	*Values of Electrical Parameters*			
	L [μH]	*Q [-]*	*C_p [pF]*	*R_s [Ω]*
Photolithography/ Etching	1,3 - 1,5	2 - 8	6 –11	28 - 44
Conventional Thick Film Technolog	0,7 – 0,9	1 - 2	11 - 33	40 - 70
Photosensitive Technology	1,2 – 1,7	2 -10	6 - 10	8 - 12

Tab. 3 Measured and calculated electrical parameters of inductors manufacturing by various techniques

5. ACHIEVED RESULTS

It is needed to observe correlation among the production technology of thick film inductors, affected climatic factors and degradation mechanisms at evaluation of measured values.

It is obvious from calculating results that the considerable differences in comparison with failure rate values λ (Tab. 4) in dependence on type of applied reliability test are evident.

The smallest degradation influence was registered at the accelerated ageing thermal stress test, in the meantime the biggest failure rate values were detected at damp heat test cyclic.

Used Technology	Failure Rate λ According to Type of Test [h^{-1}]			
	I	II	III	IV
Photolithography/ Etching	1,8.10^{-4}	8.10^{-5}	2.10^{-4}	19.10^{-4}
Photosensitive Technology	2,6.10^{-4}	13.10^{-5}	3.10^{-4}	22.10^{-4}
Conventional Thick Film Technology	16.10^{-4}	12.10^{-5}	16.10^{-4}	33.10^{-4}

Tab. 4 Failure rates for single thick film inductors in dependence on applied tests (I – accelerated ageing thermal stress test, II – thermal shock, III – dry heat test, IV – damp heat test cyclic)

It is possible to analyze the values of technical life length L_{tech} of thick film inductors in relations to applied climatic factors influence accordingly (Tab. 5).

Used Technology	L_{tech} According to Type of Test [h]			
	I	II	III	IV
Photolito-graphy/ Etching	2520±21	1970±13	2208±21	170±13
Photosensi-tive Technology	2300±11	1495±12	2184±16	163±12
Conven-tional Thick Film Technology	1270±4	120±13	1170±32	75±13

Tab. 5 Technical life values L_{tech} of thick film inductors in dependence on applied reliability tests, (I – accelerated ageing thermal stress test, II – thermal shock, III – dry heat test, IV – damp heat test cyclic)

Results document the smallest influence of temperature as the primary influenced factor on operating life of thick film inductors. These facts support theoretical assumes of low nature degradation influence, in which the low humidity doesn't play the important role. On the other hand the combination of temperature and high relative humidity in the case of damp heat test cyclic leads to the sharp reduction of thick film inductors technical life length. These factors influence the degradation of electrical parameters of inductors (Fig. 3) too.

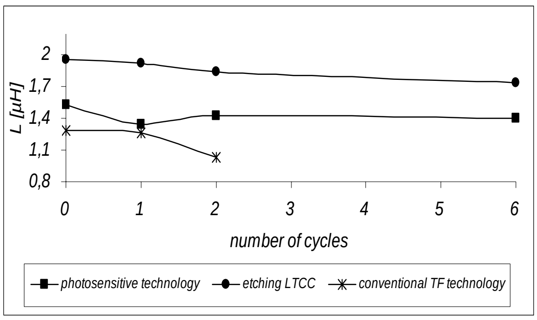

Fig. 3 Dependence of inductance L on number of cycles for inductors manufactured by various techniques for damp heat test cycling

From the point of view of used thick film inductors production technology it is possible to perform the achieved results as follows: photolithography in combination with etching makes it possible the parameters variability of technological process and it's changes in pass of production technology. These possibilities exist due to the steps sequence in technological process. This is one of important factors, which decreased the risk of coil production, which doesn't comply with required parameters.

It is possible to characterize the photosensitive technology accordingly. There is the possibility for optimalization of technological process parameters, which are in accord with relevant requirements and that reduces presence of negative factors and thereby increases the inductors quality level.

Conventional thick film technology is from the point of view of demanding quality on inductors manufacturing technology insufficient. Quality of screen printing, which is conjunctive for all used technologies, influenced the quality of electrical parameters of planar inductors. As it's obvious from the scheme of causes and damages (Fig. 4), there affects the large number of variables (paste, substrate, mesh and human factor) in screen printing.

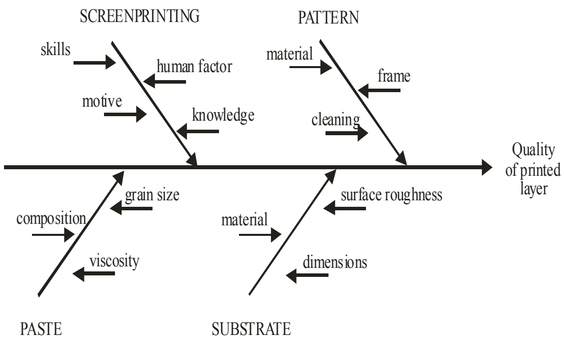

Fig. 4 Scheme of causes and damages of factors affect in screen printing

6. CONCLUSION

The paper deals with the possibilities of reliability evaluation procedure of thick film inductors manufactured by various techniques. Secondary task was to review a mutual interaction of various factors in thick film inductors progressive production technologies and chosen reliability tests. The common factor of reliability tests were study of climatic factors (temperature and humidity) influence.

Analyses of reliability evaluation method used for thick film inductors manufactured by various techniques show on the largest sensitivity for damp heat test cyclic. This sensitivity proved to be included in all technologies used for planar coils production.

The coils created by photosensitive technology on LTCC substrates show on the highest stability of properties in various climatic environments and they can be used in various electronic circuits in modern telecommunication equipments.

Achieved results show on considerable chemical attack of environment if increased temperature and high relative humidity (95%) affect on all types of thick film inductors. The smallest degradation effects and smallest failure rates shows dry heat test and accelerated ageing thermal stress test.

It is evident from the reached results that standard thick film technique is not sufficient to current requests putted on thick film precise structures and that in dependence on requirements it should be replaced by the photosensitive technology and photolitography in combination with etching as the progressive technologies of thick film structures.

Chosen methods of testing and used analyses of results introduce the suitable solution of reliability diagnostics of thick film structures.

Planar thick film inductors should offer a cost efficient solution in electronics.

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BIOGRAPHIES

Alena Pietriková (doc., Ing., PhD.) graduated in Physical Metallurgy at the Metallurgical Faculty at Technical University of Košice in 1980. She defended her PhD. in the field of Material Engineering from Technical University of Košice in 1986. Since 1998 she is working as associate professor at Faculty of Electrical Engineering and Informatics at Technical University of Košice. Her research interests include thick film and micro-electronic materials, lead-free soldering, MCM-C technology and thick film sensors. She is author or co- author more than 100 publications and 4 patents.

Magdaléna Bujaloboková (Ing., PhD.) was born in Košice in 1977. She received Ing. degree in Material Engineering at the Department of Technologies in Electronics, Technical University of Košice, Slovak Republic in 2002. Since October 2002 to September 2005 she worked as PhD. student. Her PhD. thesis deals with quality and reliability of electronic systems. She has been working at the same department as researcher since October 2005.

Juraj Banský (prof., Ing., PhD.) graduated in 1971. His professional orientation is concentrated on unconventional applications of hybrid multilayer LTCC for plasma technology and (bio) sensors. He is a member in editorial board of „International Journal of Microcircuits & Electronic Packaging", published in USA, member of "International Society for Hybrid Microelectronics", USA, vice – chairman of Slovak Association for Electronic Commerce and chairman of Slovak Commision for PhD. study in the branch 26-39-5 Electrotechnology and Materials. He is author or co- author of 93 publications and 5 patents.