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The Influence of Environment on Properties of Thick Film Components

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Abstract:
The work is focused on investigation of behavior of thick film resistors. The changes of parameters of thick film samples exposed to accelerated ageing were analyzed. The samples were exposed in three types of environment during relatively long time. The samples with different sizes of thick film resistors were prepared. Conductive and resistive structures were deposited on corundum substrates by screen-printing. The silver polymer paste for conductive layer and the carbon black polymer paste for resistive layer were used. The resistance and non-linearity of current-voltage characteristic were measured. Non-linearity was measured as distortion of sinusoidal AC powering signal. Non-linearity of C-V characteristic is influenced by defect in polymer resistive layer and mechanism of conductivity in non-homogeneous structure of layer.

INTRODUCTION

The increasing integration in electronics production is requiring the electronics components with smaller size. Low cost production is important requirement often too. Those facts are reason for development of thick film technologies.

The material of thick film layer does not have to be in chemical or mechanical equilibrium after processing. Potential defects such as micro cracks for example can arise during fabrication of electronics thick film component. That defect can develop not in and to cause the failure not in short time during processing but after longer time. Some electronic devices can be exposed to degradation factors such as enhanced temperature and humidity during their working time. These factors are caused and developed a failure of device. The factors mentioned above are possible to detect by testing at accelerated ageing.

The process of accelerated ageing is based on growing rate of process of degradation in non-standard operation conditions. Temperature and humidity belong to accelerated factors for failure mechanism. Thus the testing in environment with combination of enhanced temperature and enhanced humidity is used for estimation of reliability and stability.

TEORETICAL BACKGROUND

Structure of thick film resistor and accelerated ageing

Resistive polymer thick film paste is the dispersion of functional conductive particles with submicronic size in isolative polymer matrix. Conductive particles of resistive polymer thick film layers are carbon black in most cases.

Polymer materials are characterized by structure of macromolecular chains with many reciprocal chemicals bonding. The break-up of macromolecular chains or other change of chemical structure may occur during process of ageing. That changes have a negative influence on electrical and mechanical parameters of thick film layers. Process of ageing causes the decreasing of mechanical resistance, stability, elasticity and adhesion of polymer thick film layer. Decreasing of voltage endurance, increasing of dielectric losses and change of electrical resistance are result of process of ageing from view of electrical properties. The rate of chemical reactions during ageing is depending on molecular structure and is influenced by temperature, humidity, luminous intensity and by presence of chemical accelerator in operating or storage environment.

Conductivity of thick film resistor

Specific resistance of thick film resistor is given by material of functional particles and part by volume of functional and isolative phase in layer. Within the context of thick film layers and pastes do not operate with specific resistance ρ as material parameters. The term of resistance per square is used instead of specific resistance.

Resistance per square R_S represents the value of resistance of layer with square shape (i. e. width of resistor is equal to length of resistor). Value of resistance per square is determinate for given thickness that have the layer at keeping of condition of technological process of layer preparation. The preparation of screen, process of screen-printing and curing has a influence on thickness of layer deposited by screen-printing. Relationship between resistance R, resistance per square R_S and specific resistance ρ represent equation 1:

$$R = R_S \cdot \frac{l}{w} = \frac{\rho}{t} \cdot \frac{l}{w} \qquad (1)$$

where l is length of resistor, w is width of resistor and t is thickness of resistor. Dimensions of thick film resistive layer are shown in fig. 1.

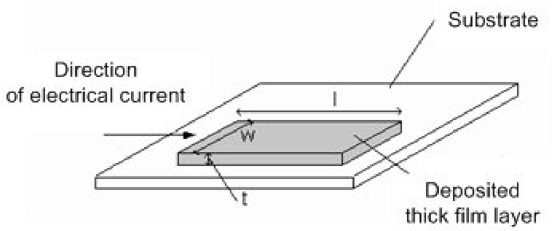

Fig. 1: Dimensions of thick film resistor

Complicated mechanism of conductivity of thick film layers is resulting from structure of thick film layer. Structure of thick film layer is non homogeneous. Conductive grains are separated by isolative material of matrix. Number of mechanism of conductivity is participated on conducting of electrical current through layer. Mechanism of tunneling and hopping are widely known. Conductivity through conductive bridge created by contact of functional particles can take place in layers with high part by volume of conductive functional layer.
The number of models describing behavior of resistive layer in term of conductivity was constructed. Model using percolation theory is described in [1]. Theory of potential barriers is described in [2] for example.

THE SAMPLES

The samples with different sizes of thick film resistors were prepared. The width of resistors was in range from 1 mm to 3 mm and length expressed in number of squares (e.g. ratio length/width) ranged from 0,5 to 4. The dimensions of tested thick film resistors are shown in tab. 1.

Tab. 1: Dimensions of tested resistors

Width of resistor	*Ratio length/width*
3	2
2	4
2	2
1,5	2
2	1
2	0,5
2,5	2
1	2
2	3

The conductive and resistive structures were deposited on corundum substrates by screen-printing. Both silver and carbon black pastes were printed using a 65T polyester mesh. The silver polymer paste CSP 3163 from Korean Chang Sung Corporation was used for conductive layer and the carbon black polymer paste ED 7000 from ELECRADOR Company was used for resistive layer. Conductive silver layers were cured at 130°C at 60 min in box oven. Resistive carbon black layers were cured 2 hours at 160°C at box oven too.
Carbon black paste has the value of resistance per square of 10 kΩ/square. Temperature change of resistance of used resistive paste is 2% over range -15 to 150°C. Best results are achieved using silver terminations.
Thickness of deposited layers was approximately 10 μm. An example of sample with thick film resistors in gauging fixture is shown in fig. 2. Black rectangles in fig 2 are thick film resistors and grey lines are silver conductive path.

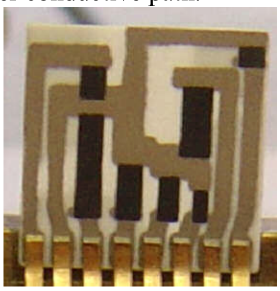

Fig. 2: Sample with measured thick film resistors

The samples were exposed in three types of environment during relatively long time. First was environment with high humidity, second environment with enhanced temperature (50°C) in combination with high humidity and last was environment with high temperature (170°C).

THE PARAMETERS OF THICK FILM RESISTORS AND MEASUREMENT

Non-linearity of current-voltage characteristic of thick film resistors

Thick film resistor is non-linear component. Thus current-voltage characteristic of such component is non linear. Non-linearity of C-V characteristic is associated with non-homogeneity of thick film layer, with dispersion on layer boundary and dispersion on failure of molecular structure.
The non-linearity is caused by mechanism of conductivity in material with non-homogeneous structure too. Charge carrier has to overcome the potential barriers at flowing current in resistor. Potential barriers are arisen on interface between conductive particle and isolative matrix in thick film resistor. Defects of potential type cause the distortion of AC current and lead to rise of third harmonics in course of current [2].
Measurement of current-voltage characteristic is used as diagnostic method for estimation of reliability and stability of thick film resistor.

Method of measurement

Nonlinearity of current-voltage characteristic is quite small and direct measurement of non-linearity is practically impossible. The measurement of third harmonics is one of non-destructive method for non-

linearity analysis. Non-linearity was measured as distortion of sinusoidal AC powering signal.
Non-linearity was measured by the equipment CLT1 made by Radiometer Copenhagen. The principle of used method is shown in fig. 3. The measured sample Zx is powered by sinusoidal signal with frequency of 10 kHz from generator G. The sinusoidal signal with very low distortion is generated. Voltmeter V1 is measured level of first harmonic. Sinusoidal signal is distorted by passing through thick film non-homogeneous structure. Then distorted sinusoidal voltage contains in addition to basic harmonic the higher odd harmonics. The third harmonics of sinusoidal voltage after passing through resistor was measured by voltmeter V3.

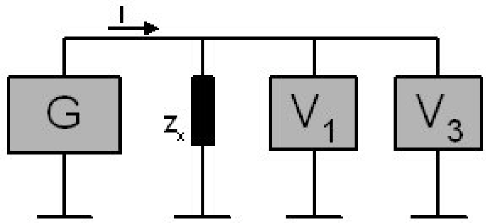

Fig. 3: Principle of measurement method

The measured value of third harmonics voltage is necessary to convert into value of resistance of sample. Fifth and next higher harmonics are much lower than third and are negligible. Amplitude of feeding signal is restricted by allowed power of thick film resistor. Overheating of resistor is caused at higher powers. Increasing of temperature of resistor caused by overheating bring the errors in measurement.

THE RESULTS DISCUSSION

The dependence of non-linearity of VA characteristic on time of accelerated ageing was analyzed. All resistors were measured at same value of current. The comparing and analysis of non-linearity dependencies of thick film resistors with different topology is allowed thank to condition of measurement at current unchanging for all samples.

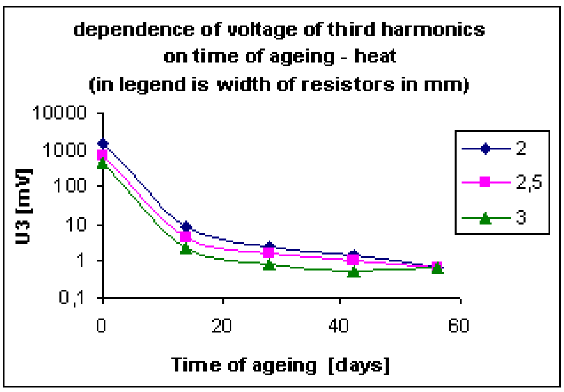

Fig. 4: Dependence of voltage of third harmonics on time of ageing in heat at constant width

The part of samples was exposed in environment with enhanced temperature. The temperature in climatic chamber was 170 °C. The dependencies of non-linearity expressed by voltage of third harmonics on time of accelerated ageing are shown in figs. 4 and 5. From graphs in figs. 4 and 5 results that voltage of third harmonic at the beginning is decreasing rapidly and is stabilized consequently. The effect of additional curing is apparent there. The increasing of voltage of third harmonics is expected after certain time due to degradation process. The time of accelerated ageing of measured dependence is short for development of mechanism of degradation probably.

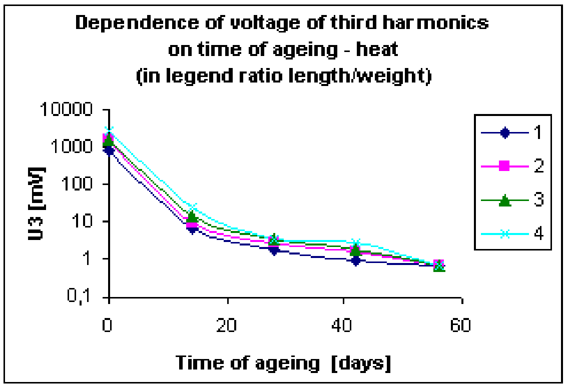

Fig. 5: Dependence of voltage of third harmonics on time of ageing in heat at constant number of square

The second part of samples was exposed in environment with high humidity more than 95% of relative humidity. The dependencies of third harmonics voltage on time of ageing are shown in figs. 6 and 7.

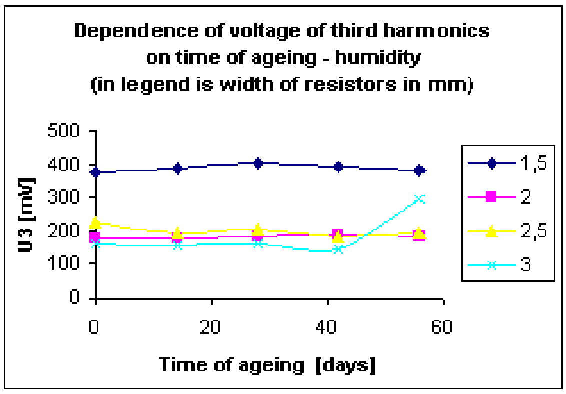

Fig. 6: Dependence of voltage of third harmonics on time of ageing in humidity at constant width

The value of third harmonics voltage is almost constant or is increasing very little during exposition in high humidity. It is assumed that non-linearity will be increased with time of ageing. But time of ageing measured dependence is very short for starting of degradation processes.

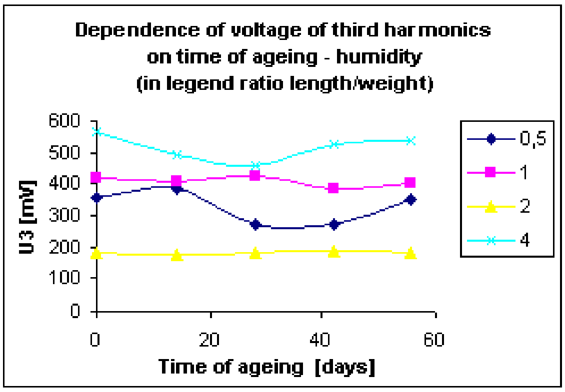

Fig. 7: Dependence of voltage of third harmonics on time of ageing in humidity at constant number of square

The last part of samples was exposed in environment with combination of enhanced temperature and humidity. The climatic chamber was set up to temperature of 50°C and humidity of 97%. The figs. 8 and 9 shown the dependencies of non-linearity on time of ageing. The influence of temperature and influence of humidity are enforced against each other. From graphs in figs. 8 and 9 we can see that non-linearity is slowly decreasing with time of ageing. This fact can indicate that influence of enhanced temperature is predominated.

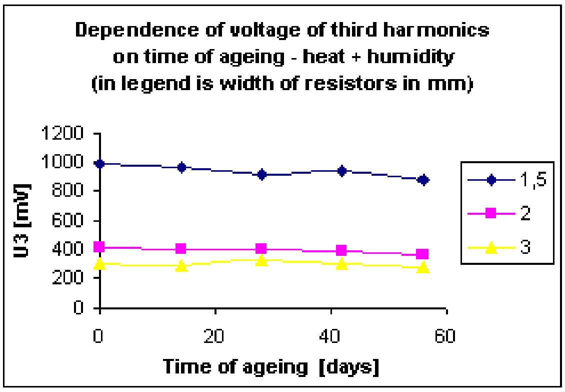

Fig. 8: Dependence of voltage of third harmonics on time of ageing in heat+humidity at constant width

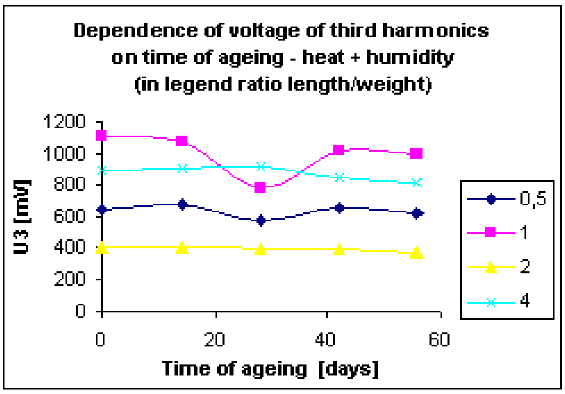

Fig. 9: Dependence of voltage of third harmonics on time of ageing in heat+humidity at constant number of square

The dependencies in figs. from 4 to 9 are depicted with consideration of shape of resistors. Thus the analysis of resistor topology is possible to realize. From graphs in figs. 4, 6 and 8 is possible to discuss the dependence of non-linearity on width of resistor at condition of constant number square of resistor i. e. of constant ratio length/width. Lowest values of non-linearity are for widest resistors. Wide resistors are loaded less than narrow resistors at same current. On graphs in figs. 5, 7 and 9 we can observe the dependence of non linearity on length of resistors there expressed as number of squares (i. e. ratio length/width) at condition of constant width. Non-linearity with increasing number of square is increasing. Charge carrier has to overcome more potential barriers in longer resistor.

CONCLUSIONS

The measured dependencies shown that exposition in enhanced temperature has largest influence on properties of thick film resistors during short time loading. Longer time is needed for indication of degradation processes. Dependencies of non-linearity on shape of resistor confirm the theoretical assumption.

ACKNOWLEDGMENTS

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