THICK FILM RESISTORS NDT BY ELECTRO-ULTRASONIC SPECTROSCOPY

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Abstract

The non-linear electro-ultrasonic spectroscopy was used as a non-destructive testing method for the polymer based and cermet thick film resistors evaluation. We carried out the correlation between this method and standard testing methods as noise spectroscopy and the third harmonic voltage measurements. The measuring set-up with the ultrasonic transducer working on the frequency range 10 kHz to 1 MHz was designed and realized. Proposed method is exploiting two different signal sources – ultrasonic wave and alternating electric current. Mechanical vibrations affect the defects in the sample structure and it influences the electric charge transport through the measured structure. Resulting information is measured on the differential frequency given by the superposition or subtraction of exciting signals frequencies. Low-pass filter with limit frequency 5 kHz was used for the suppression of exciting signals amplitudes. Measured sample together with the ultrasonic transducer creates the resonant system. For the thick film resistor samples prepared on the alumina substrate we achieved high sensitivity measuring on the resonant frequencies determined by the alumina substrate size. Four-point method was used for the elimination of the contact influence on the measured characteristics. The intermodulation signal was measured on the frequency in the range 2 to 5 kHz. The intermodulation signal amplitude increases linearly with the amplitude of alternating electric current, and with the square of increasing voltage on the ultrasonic transducer. The intermodulation signal amplitude is further influenced by the sample technology. The intermodulation voltage is influenced by the AC current value and on the resistance change of contacts among the conducting grains in the thick film resistor structure. Ultrasonic signal changes the area of the contact between the conducting grains in the resistor structure, hence the square-law between the voltage on the ultrasonic transducer and the intermodulation voltage is observed. The method sensitivity is influenced by the measuring set-up noise background. The intermodulation signal amplitude was measured to be about one order above the measuring set-up background noise voltage for the current 1 mA flowing through the structure. In this case no sample heating is observed even for through the long term measurements. The relative resistance change is of the order of 10^{-6} for the polymer based thick film resistors, and of the order of 10^{-8} for the cermet samples. There is a correlation between the resistance value and the intermodulation voltage. At the same time there exists the correlation between the amplitude of intermodulation voltage and the value of the noise spectral density or the value of the third harmonic signal amplitude, respectively. It happens in all cases that with the increasing number of contacts among the conducting grains in the sample there are decreasing the amplitude of intermodulation voltage, as well as the value of the noise spectral density, the value of the third harmonic signal amplitude, and the resistance for the samples with identical geometry. This enables to evaluate the sample technology.

Keywords: Electro-ultrasonic, spectroscopy, resistance change, non-destructive testing

1. Introduction

Accurate method for the resistor stability prediction and quality evaluation is required by the electronic component producers. Low frequency noise and resistance non-linearity measurements are the methods, which are frequently used for the resistor quality assessment. New measuring method – Electro-Ultrasonic Spectroscopy – is based on the interaction of two exciting signals with the granular structure of measured samples. Mechanical vibrations affect the contacts among the conducting grains and the defects in the sample structure and it influences the electric charge transport through the
measured structure. Resulting information is measured on the frequency given by the subtraction of exciting signals frequencies. Measured sample together with the ultrasonic transducer creates the resonant system. For the thick film resistor samples prepared on the alumina substrate we achieved high sensitivity measuring on the resonant frequencies determined by the alumina substrate size. The intermodulation signal was measured on the frequency 2 kHz. The intermodulation voltage is influenced by the AC current value and by the resistance change of contacts among the conducting grains in the thick film resistor structure. The method sensitivity is influenced by the measuring set-up noise background. In our case the background noise voltage spectral density is about $1.6 \times 10^{-17} \text{V}^2/\text{Hz}$, which corresponds to the equivalent noise resistance $1 \text{k} \Omega$. The intermodulation signal amplitude was measured to be about one order above the measuring set-up background noise voltage for the current 1 mA flowing through the sample structure. In this case no sample heating is observed even through the long term measurements.

2. Electro-Ultrasonic Measurement Setup

The electro-ultrasonic measurement setup consists of two parts, the electric and ultrasonic one. The ultrasonic power amplifier consists of WPD 100 in which it is necessary to have power linear actuating harmonic signal on ultrasonic transducer. The measured sample was fixed on the piezoceramic transmitter. Electric part consists of generator Tesla BM492 which has convenient linearity and frequency stability. Signal from the generator is transformed on higher voltage from transformer and it is led to the measured sample over the protective resistor. Harmonic signals of frequencies higher than the differential frequency component $f_m = f_U - f_E$ are trimmed by the low pass passive filter.

Our measurements were performed for ultrasonic signal of frequency $f_U = 31.8 \text{kHz}$ and for electric signal of frequency $f_E = 33.8 \text{kHz}$. In this case the intermodulation frequency is $f_m = 2 \text{kHz}$. Intermodulation voltage $U_S$ is proportional to the ac current flowing through the structure [1]. From the measured intermodulation voltage we can find the resistance change $\Delta R$ as:

$$\Delta R = U_s / I_{AC} \quad (1)$$

3. Low frequency noise

$1/f$ noise can be used as a diagnostic tool in resistance type devices. For stationary and ergodic stochastic process the noise spectral density is proportional to the square of voltage or current $S_U \propto U^2$ or $S_I \propto I^2$. Voltage noise spectral density is than given by:

$$S_U(f) = C_Q \frac{U_{Rs}^2}{f^a} \quad (2)$$

Where $S_U$ is voltage noise spectral density, $U_{Rs}$ is DC voltage applied to the measured sample $R_S$, $f$ is frequency, and $a$ is frequency exponent.

It is very convenient to normalize the measured noise spectral density for applied voltage and frequency and to use noise quality indicator $C_Q$ for the resistor quality evaluation:

$$C_Q = \frac{S_U(f)}{U_{Rs}^2} \cdot \frac{f}{f^2} \quad (3)$$

$C_Q$ is a dimensionless parameter with a value dependent on sample quality and reliability.
4. Non-linearity

Non-linearity of thick film resistors is proportional to the distortion of pure harmonic signal applied to the sample [2-3]. It can be shown, that the number of harmonics can approximate any kind of voltage time dependence with different amplitudes superimposed upon the fundamental frequency. If an AC voltage is applied to a component, where the current paths consist of perfect elements the corresponding current will exhibit a true picture of the applied signal. In this case the transmission is linear. If the elements on the other hand are imperfect, the current will be distorted and generate a voltage inside the component that will produce a correspondingly distorted signal.

The third harmonic voltage $U_3$ measured for the same value of the first harmonic voltage $U_1$ can be used for the resistors quality evaluation.

We apply the first harmonic voltage with frequency 10 kHz, and we measure the amplitude of the third harmonic voltage. The measurements were performed by non-linearity meter RADIOMETER COPENHAGEN, type CLT1.

5. Experimental

The samples were divided into two groups – polymer based thick film resistors and cermet thick film resistors.

Two sets of polymer based thick film resistors were evaluated. The resistive pastes were made from carbon (C) spherical particles and graphite (Gr) flakes suspended in polymer. One type of C/Gr conducting particles and two different polymers were used for our samples. The sets are denoted as Tech 4 and Tech 5. Ten samples were evaluated within each technology. Resistive pastes were applied on the alumina substrate of dimensions 5 by 40 mm. Resistive layer thicknesses was about 20 μm. The contacts were made by dipping silver (DiAg) – polymer based paste with Ag filling. Different DiAg was used for each set of samples to obtain optimal resistor – contact system. The resistance of our samples was measured three times: (i) after the resistive layer application and drying - denoted later as $R_a$; (ii) after the resistor curing – denoted as $R_0$, and (iii) after the storing at the room temperature for 4000 hours - denoted as $R_{4000}$. The mean value of $R_a$ was 165 Ω for Tech 4, and 142 Ω for Tech 5. After the curing at the elevated temperature the sample resistances increased to about 200 Ω for good samples and up to 6times for unstable samples in both technologies.

Four samples of cermet resistors of nominal size 0.5 x 1.0 mm$^2$ (length x width) were evaluated. All samples were made with commercially produced DuPont resistive paste 2041 with sheet resistance 10 kΩ/square. The terminations were done with pre-fired Ag paste for samples denoted as A1 and A2, and with AgPd paste for samples denoted as B1 and B2, respectively. The samples were prepared on the alumina substrate. The resistance was about 4.5 kΩ for samples A1, A2 and about 3.6 kΩ for samples B1, B2.

The noise quality indicator $C_Q$, the third harmonic voltage $U_3$ and the resistance change due to the ultrasonic excitation $ΔR$ were evaluated for all the samples.

The correlation between the sample resistance after the curing and storing and the ultrasound induced resistance change $ΔR$, noise quality indicator $C_Q$, and the third harmonic voltage $U_3$, respectively, measured for polymer based samples is shown in Figs. 1 to 3. We can see that with the increasing sample resistance also the increase of measured parameters $ΔR$, $C_Q$, and $U_3$ is observed.

Good correlation was observed also between the ultrasound induced resistance change
ΔR and noise quality indicator $C_Q$, and the third harmonic voltage $U_3$, respectively (see Figs. 4 and 5), and between the third harmonic voltage $U_3$ and $C_Q$ (see Fig. 6).

Figure 1: Correlation between sample resistance $R_{4000}$ and ultrasound induced resistance change $ΔR$

Figure 2: Correlation between sample resistance $R_{4000}$ and noise quality indicator $C_Q$

Figure 3: Correlation between sample resistance $R_{4000}$ and the third harmonic voltage $U_3$ (for $U_1 = 7$ V)

Figure 4: Correlation between noise quality indicator $C_Q$ and ultrasound induced resistance change $ΔR$
Figure 5: Correlation between $U_3$ (for $U_1 = 7$ V) and ultrasound induced resistance change $\Delta R$

Figure 6: Correlation between $U_3$ (for $U_1 = 7$ V) and noise quality indicator $C_Q$

Figure 7: The relative resistance change $\Delta R/R$ calculated for cermet resistors at $I_E = 4$ mA, $U_U = 5$ V, $f_U = 31.8$ kHz

Figure 8: Noise quality indicator $C_Q$ calculated for all the samples of cermet resistors
The results measured for cermet resistors are shown in Figs. 7 to 9. The relative resistance change $\Delta R/R$ for the cermet samples calculated for constant value of DC current $I_E = 4$ mA and constant value of ultrasonic excitation ($U_U = 5$ V) is shown in Fig. 7. Comparing the noise, non-linearity and electro-ultrasonic spectroscopy data we can see, that the sample A2 gives better results with respect to sample A1, and the sample B1 gives better results with respect to sample B2.

6. Conclusion

Cermet and polymer based thick film resistors were evaluated by three different measuring methods. The relative resistance change is of the order of $10^{-6}$ for the polymer based thick film resistors, and of the order of $10^{-8}$ for the cermet samples. There is a correlation between the resistance value and the intermodulation voltage. At the same time there exists the correlation between the amplitude of intermodulation voltage and the value of the noise spectral density or the value of the third harmonic signal amplitude, respectively. It happens in all cases that with the increasing number of contacts among the conducting grains in the sample there are decreasing the amplitude of intermodulation voltage, as well as the value of the noise spectral density, the value of the third harmonic signal amplitude, and the resistance for the samples with identical geometry. This enables to evaluate the sample technology.

Acknowledgements

This research has been supported by the Czech Ministry of Education in the frame of MSM 0021630503 Research Intention MIKROSYN “New trends in Microelectronics System and Nanotechnologies” and by the Grant GACR 106/07/1393 and GACR 102/09/H074.

References