

QUALITY ASSESSMENT OF METAL OXIDE VARISTORS BY NOISE SPECTROSCOPY

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Abstract – The noise spectroscopy in a frequency domain has been used as a diagnostic tool of high-voltage varistors consisting of grained ZnO. The electrical properties of tested specimens have been described. In this experimental study, we present the applied measurement system and the results of noise spectrum measurements for the selected structures of 280 V varistors. Noise properties are related to electrical characteristics of measured samples. It is suggested that the proposed procedure can be applied as an effective non-destructive testing method focused on defects and structural inhomogeneity detection in tested objects.

Keywords: varistors; diagnostics; noise spectroscopy

1. INTRODUCTION

The noise spectroscopy is the promising method for non-destructive characterisation of tested objects [1-3]. Most of failures result from defects created during the manufacture processes. The sensitivity of excess noise to those defects is the main reason of using the noise as a diagnostic and prediction tool in reliability physics for quality assessment. The noise spectral density depends on stress or damage and the sensitivity of noise characteristics to the structural irregularities is the basic feature of the method. Noise depends on homogeneity and manufacturing quality of the device active region.

Varistors are usually produced from zinc oxide (ZnO) and some additives (e.g. bismuth, cobalt, manganese [4] that significantly influences their properties) as cylindrically-shaped structures whose quality depends on varying technological conditions at stages of their shape forming and firing. These processes depend on how the used materials are mixed and squeezed. Variations of technological parameters lead to various grain size that determines boundary junctions between the grains and the shape of current-voltage characteristic. Then, metal contacts are made on both sides and the product is ready for packaging.

They have a strongly non-ohmic current-voltage characteristic and therefore are used to protect circuits against excessive voltage transients by shunting the current created by this voltage away from the sensitive elements. A varistor quality is determined by the non-linearity degree of a current-voltage characteristic and the ability of transmitting high currents at sufficiently high voltages. All

produced varistors are tested at the final stage of production by the measurement of their leakage current at sufficiently high voltage or determining their ability to sustain intensive current flow for a given period. These often destructive tests are expensive due to energy and time consumption. Therefore, new methods that would nondestructively test varistors are desired. In this exploratory study, we present the utilized system and experimental results from noise spectroscopy of varistors.

2. HIGH-VOLTAGE VARISTOR SPECIMENS

A varistor behaves as a highly resistive resistor ($\sim 10^9 \Omega$) at low voltage region. At breakdown region the DC current I_{DC} is nonlinearly proportional to the applied DC voltage U :

$$I_{DC} = k \cdot U^\alpha \quad (1)$$

The exponent α depends on a type of boundary junctions that exist between the grains. Varistors saturate at higher voltages and their resistance doesn't exceed tens of ohms.

In practice, varistors should exhibit as much as possible nonlinear characteristics. It means high value of a parameter α . There are good, low nonlinear and linear junctions between the ZnO grains. The exponent $\alpha > 30$ indicates the most required grain contacts. The low nonlinear contacts exhibit $\alpha \approx 10$. These various junctions are discriminated by their voltage-current characteristics.

The experiment was performed on two batches of ZnO structures prepared for working voltage 280 V (Fig.1), named as high and lower quality due to different ways of their preparation.



Fig. 1. Tested varistors for working voltage 280 V: ZnO structure after being fired in a stove - top row, with the metal contacts - bottom row

Electrical characteristics of a real varistor as a mixture of various grains depend on amount of different grain types that exist in its structure. The presence of linear or weakly nonlinear grain contacts decreases α and increase significantly required nonlinear varistor characteristic at its relatively low voltage region.

When ZnO grains were squeezed, various pressures resulted in a different grain size after firing. The huge grains of ZnO implicate highly non-linear contacts between them. For smaller grains the contacts are weakly nonlinear or can be even ohmic only [5]. This operation provided a significant number of low quality ZnO structures (Fig. 2) that are not so abundant during standard production.

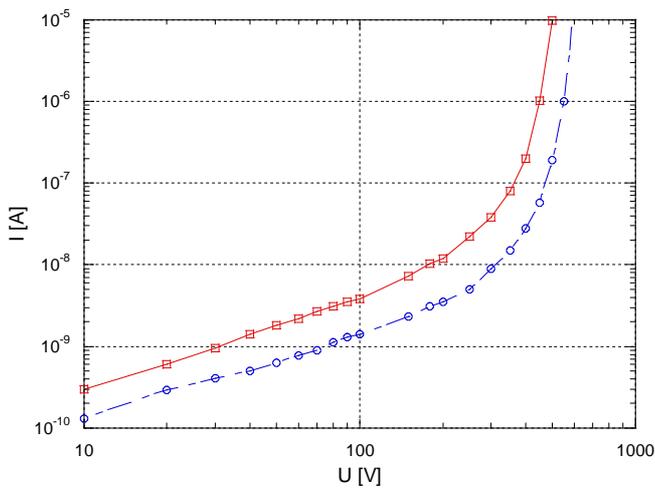


Fig. 2. Exemplary characteristics of two varistors 280 V (log-log scale): higher (red squares) and poor (blue circles) quality

Quality of varistors has to be assessed at the final stage of their production. Industrial standards predict leakage current measurements at DC voltage about 400V and an application of high voltage impulses that cause intensive current flows. A current flows mainly through narrow paths comprised of grains with linear (ohmic) junctions. High current density and intensive heating there causes irreversible destruction of the tested varistor. Therefore, it is valuable to propose another method of ZnO structure selection. A different grain size causes different mechanisms of current conductivity and it has direct influence on noise phenomena in the varistor structure. Noise spectroscopy seems to reflect all these structure properties.

Variations in grain size of ZnO structures suggest differences also in their mechanical properties (for example stiffness, sound velocity) that can be identified by convenient measurements during their fabrication [6].

3. SYSTEM FOR NOISE SPECTROSCOPY

The block diagram of the noise measurement system is shown in Fig. 3. For high-voltage varistors of series 280 V the noise measurements were possible when the specimen bias voltage was not less than 400 V and the flowing current enabled of noise generation having measurable level. The DC Glassman High-Voltage power supply (series EH)

0 – 600 V (enabling to settle a bias current) and MeraTronik voltmeters V541 was used in the system (Fig.4).

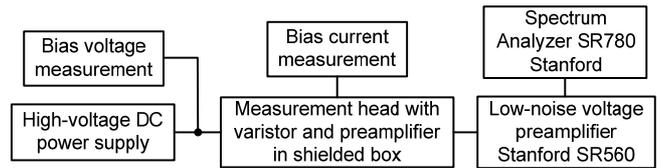


Fig. 3. General block diagram of noise measurement system

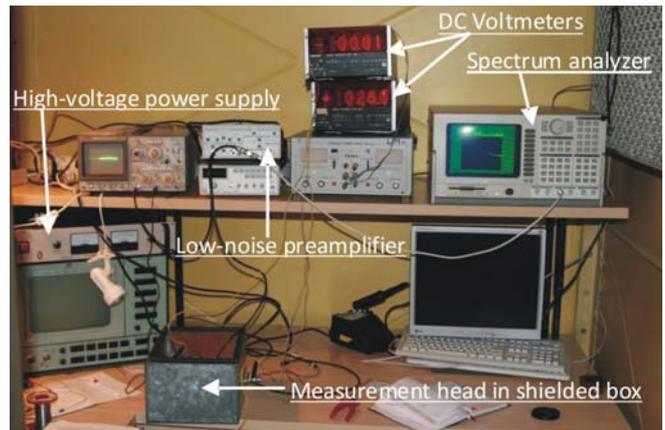


Fig. 4. Noise measurement system in laboratory

As a very low-level noise signal preamplifier we have used a specially constructed ultra low-noise current-voltage converter with two OPA128 op-amps supplied from batteries (Fig. 5). Output voltage fluctuations are proportional to the current noise flowing through the tested sample. It was a rather difficult task; for voltage up to about 400 V the DC resistance of varistors was no lower than tens of GΩ. Only for voltages above this threshold the current was sufficient to measure noise of a sample which was situated together with the preamplifier in an accurately shielded box.

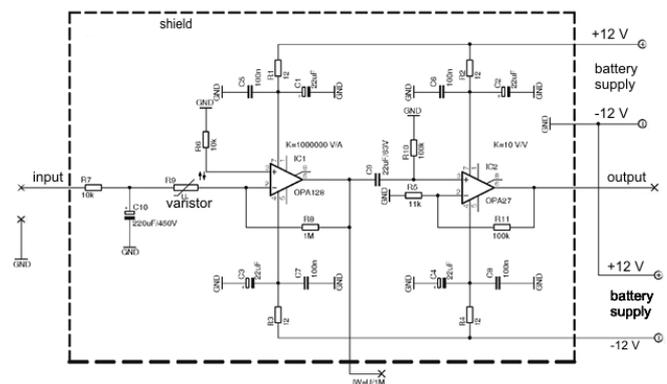


Fig. 5. Schematic of preamplifier built on two OPA128 opamps

The whole system was located in the Faraday's cage.

4. RESULTS OF NOISE MEASUREMENTS

The exemplary results of noise measurement for varistors polarized by DC current equal $11 \mu\text{A}$ are shown in Fig. 6 (for frequency bandwidth up to 1.6 kHz) and in Fig. 7 (for bandwidth up to 6.4 kHz).

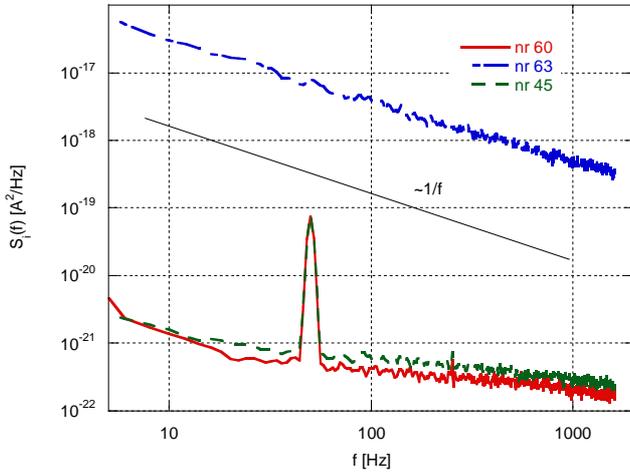


Fig. 6. Power spectral density of current fluctuations for 280 V varistor samples no. 45, 60, 63; $I_{DC} = 11 \mu\text{A}$, frequency bandwidth up to 1600 Hz

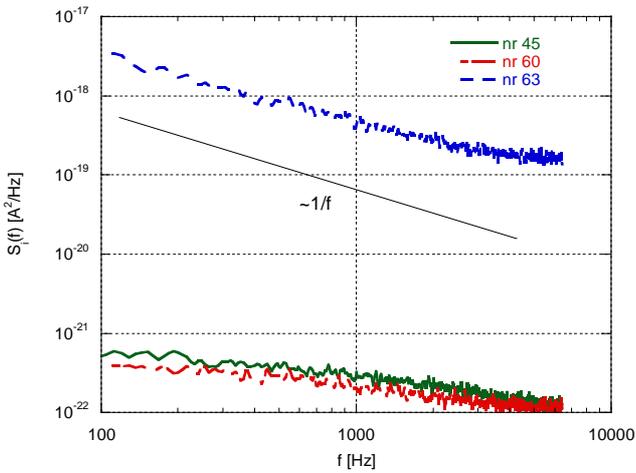


Fig. 7. Power spectral density of current fluctuations for 280 V varistor samples no. 45, 60, 63; $I_{DC} = 11 \mu\text{A}$ frequency bandwidth up to 6.4 kHz

Typically, for measured varistors the $1/f^m$ was observed in the frequency range up to several kHz. For higher frequencies the white noise became dominating.

The power spectral density of the system background noise was no higher than $2 \cdot 10^{-26} \text{ A}^2/\text{Hz}$ in the low frequency range. It can be seen, that the inherent noise of measured varistors polarized above 300 V was some order higher than the level of system noise.

Power spectral density of current fluctuations $S_I(f)$ was proportional to the current I_{DC} squared for all measured varistors (Fig. 8).

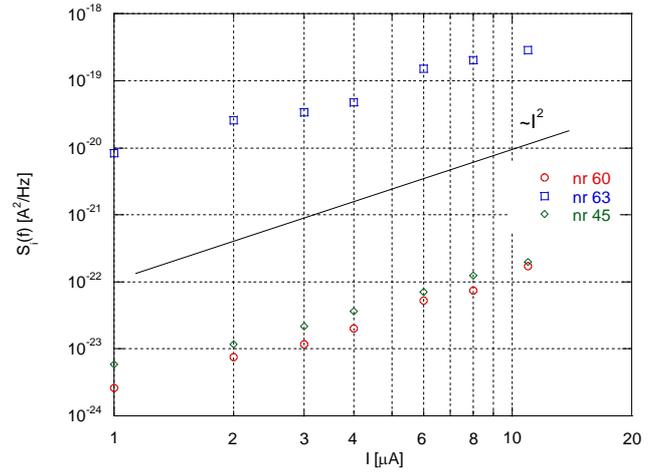


Fig. 8. Power spectral density of noise current $S_I(f_0)$ vs. varistor bias current I_{DC} for frequency $f_0 = 2 \text{ kHz}$

Big differences in noise level (up to 40 dB) for particular samples, was observed. They reflected significant differences in the static current-voltage characteristics (Fig. 9).

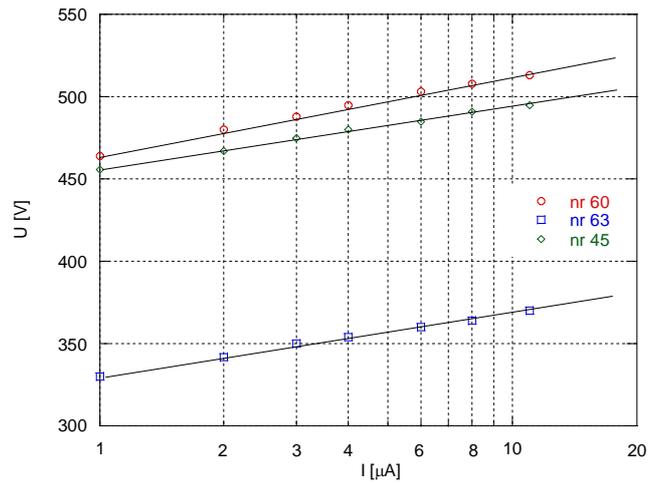


Fig. 9. Static characteristic of measured varistor samples

The varistor sample marked as no. 63 exhibited significant current for relatively low voltages. It has proved that a big number of ohmic grains occurred in its structure causing generation of $1/f$ noise with great intensity.

We have also measured samples with the strongly nonlinear characteristic (e.g. varistor n^o.60) built with grains having very nonlinear contacts and structures with less linear characteristic (e.g. varistor no. 45) built with grains creating less linear contacts. In these cases the level of $1/f^m$ noise (for $m \approx 0,4$) was comparable and considerably lower than in the firstly described cases (eg. varistor no. 63).

5. CONCLUSIONS

A new method for detection of varistors with poor quality and endurance was proposed. The noise spectroscopy is very sensitive tool for identification of varistor structure with different ZnO grains types. Such

measurements, however, can be useful only as a research tool or for confirmation of the results achieved by means of other methods [6].

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