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SOFTWARE FOR DETERMINING LINEAR RESISTANCE LIMITING THE BARRIER CURRENT IN VARISTOR MATERIALS

Abstract. A program for determining linear resistance limiting the barrier current in varistor materials was developed with the usage of HTML, CSS, JavaScript and jQuery library. The program calculates this resistance based on the data, obtained at scanning raster images of analog oscillograms, registered at a strong electric current for a sample of a varistor material. Any Internet browser can be used as a software environment for the program presented in this work.

Keywords: software, languages HTML, CSS, JavaScript, library jQuery, varistor materials.

Introduction. Ceramic materials based on zinc oxide (ZnO) are used for varistor production [1]. Varistors have found wide application in protecting electronic and electrotechnical devices from overvoltage. In particular, varistors are used for protecting power supplies of modern computers from overvoltage.

The intergranular Schottky barriers are a cause of high nonlinearity of the current-voltage characteristic (CVC) of varistor material [1]. Such barriers are formed in the near-surface region of ZnO grains. These barriers define CVC of varistors in the region of current density of 10^{-13} – 10 A cm^{-2}. The nonlinear resistance of near-surface regions of ZnO grains with barriers becomes comparable to the linear resistance of grains volume at electric currents more than 10 A cm^{-2}. Since the volume resistance of grains connects with barriers in series, it limits the electric current through barriers. Therefore, at the region of strong electric current, the nonlinearity of CVC decreases when the current increases. This region of current may be used to determine the linear resistivity ρ_{lin} limiting the electric current through barriers in ceramic varistor materials [2]. Volume resistivity of grains ρ_g in varistor ceramics determines the value of ρ_{lin} at a strong electric current.

The work [3] presents an approach to calculating ρ_g by scanning raster images of analog oscillograms obtained at applying a single voltage pulse of exponential form to a sample. This method uses special Microsoft Excel templates. Creation of a software for scanning oscillogram raster images and calculating the linear resistivity ρ_{lin} on the basis of scanned data is of interest. HTML, CSS, JavaScript languages and jQuery library give certain possibilities for solving such task. With HTML and CSS a convenient user interface can be created. Scripts implemented with JavaScript and jQuery allow loading raster images, performing scanning and conducting necessary calculations using the scanned data. Any Internet browser can be used as a software environment for the program created by the means mentioned above.

Problem statement. The aim of this work is development of a software intended for scanning raster images of analog oscillograms and calculating the linear resistivity limiting the barrier current in varistor materials. The calculation should be done based on the scanned data.

Major part. A method of determining linear resistivity ρ_{lin} is based on the relationship between differential resistivity ρ_{dif} and electric current density J in ceramic varistor materials. An equation describing such dependence is [2]:

$$\rho_{dif} = \rho_{lin} + A^{*}J^{-1}, \quad (1)$$

where A^{*} is a constant.

As it follows from the equation (1), ρ_{dif} has a linear relationship with the inverse current density J^{-1}. Therefore, the linear resistivity ρ_{lin} limiting the barrier current in the region of current density $J_1 \leq J \leq J_K$ can be found by building a relationship $\rho_{dif} \sim J^{-1}$ using a region of CVC for this interval of current density. Linear extrapolation of such dependence to the value $J^{-1} = 0$ allows to determine ρ_{lin}. A region of current-voltage characteristic in any range of electric current can be registered by applying a single pulse of exponential form to a sample. Voltage and current oscillograms obtained this way represent CVC in parametric form, where time t is a parameter. These oscillograms allow to build the dependence (1) and to determine ρ_{lin} value for the given interval of electric current density.

In this work, oscillograms of voltage and current were registered with the analog double-beam storage oscilloscope C8-11. Raster images

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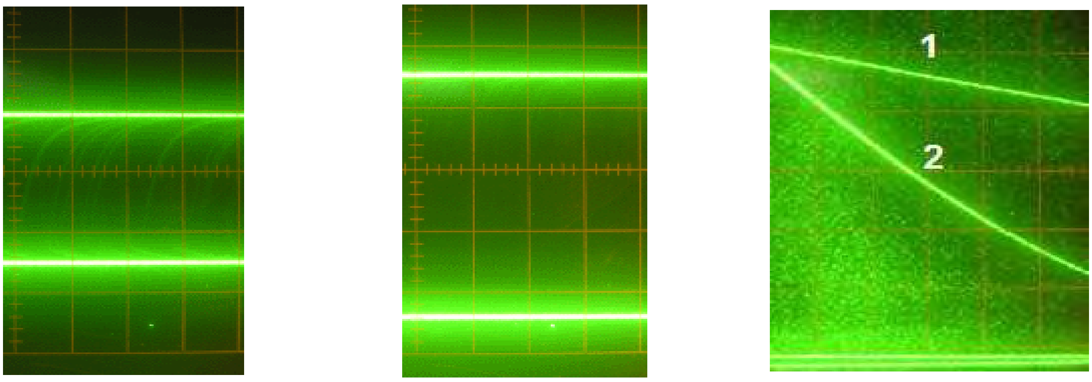
of oscillograms for further processing by the program were obtained with the digital photo-camera “OLYMPUS”. Raster images of the calibration voltage and the calibration electric current were used for determining scale factors M_U and M_I. The program calculates the values of M_U and M_I using the data scanned from these raster images. These scale factors are necessary for determining instantaneous values of voltage U_j and electric current I_j. Fig. 1 shows typical raster images of oscillograms for calibration voltage and calibration current, as well as raster image of oscillograms obtained at applying a single voltage pulse of the exponential form to a sample.



a b c

Figure 1 - Raster images of oscillograms: a – calibration voltage (100 V between lines); b – calibration electric current (10 A between lines); c – voltage (1) and current (2) at applying a single voltage pulse of the exponential form to a sample. Straight lines in a bottom of oscillograms (1, 2) give zero levels for current and voltage. The scale of sweep – 10 μs/ division

Scanning of oscillograms raster images (Fig. 1 c) was performed with step of 50 pixels in the positive direction of the time axis. Arrays of pixel coordinates YU_j, YI_j, XT_j $(1 \le j \le K)$ are the outcomes of scanning. Program uses these arrays for calculating linear resistivity ρ_{lin}. Arrays of coordinates YU_j and YI_j correspond to voltage and electric current of a sample, accordingly. An array XT_j corresponds to the points in time when instantaneous values of voltage U_j and current I_j were registered. Coordinates of zero lines for voltage YU_Z and for electric current YI_Z are determined by scanning too. Using the scanned data, the program calculates values of differential resistance R_{difi} and current I_i $(1 \le i \le N)$. For this purpose, it uses scale factors M_U and M_I, which were found from the scan data obtained from the raster images shown on Fig. 1a and Fig. 1b. In addition, the program uses arrays of coordinates YU_j, XT_j ($1 \le j \le K$) for calculating the time constant τ for a voltage pulse of the exponential form. The calculation is done using the method described in [4].

The program uses increments of voltage and current for calculating the differential resistance R_{difi} ($1 \le i \le N$). These increments are determined by changing the index j for arrays YU_j, YI_j, XT_j with a step equal l. Therefore, if such arrays have a quantity of elements K, then the quantity of elements in the arrays R_{difi}, I_i is determined as $N = K - l$. In the program described in this work we used the values $K = 13$ and $l = 3$. It ensured the quantity of elements $N = 10$ for the arrays R_{difi} and I_i.

The differential resistance R_{difi} and the electric current I_i were calculated as

$$R_{difi} = \frac{M_U(YU_{j+l} - YU_j)}{M_I(YI_{j+l} - YI_j)}, \quad (2)$$

$$I_i = \frac{1}{2} Mi(2YI_Z - YI_{j+l} - YI_j). \quad (3)$$

Based on these formulas, taking into account geometrical sizes of a sample (L – thickness, S – area of electrodes), the program calculates the arrays ρ_{difi} and $1/J_i$ ($1 \le i \le N$). Further, it performs linear regression using the least squares method for obtaining $\rho_{dif} = aJ^{-1} + b$ from the calculated data. According to the equation (1), b factor is the linear resistivity ρ_{lin} which limits the current through barriers in the range of electric current density $J_1 \le J \le J_N$.

In Fig. 2 $\rho_{dif} = aJ^{-1} + b$ obtained by the least squares method is shown as a thick solid straight line. Extrapolation of this straight line to $1/J = 0$ allows to determine the value of ρ_{lin}. The program uses the least squares method for calculating the value $b = \rho_{lin}$ on the basis of arrays ρ_{difi} and $1/J_i$ ($1 \le i \le N$).

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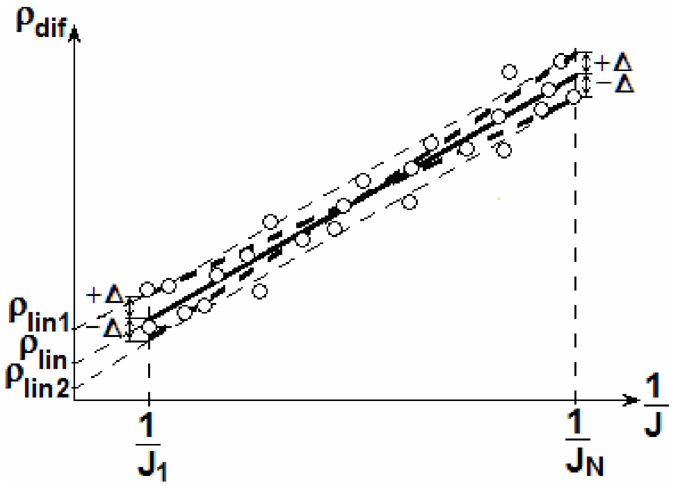

Figure 2 - Calculation of the error in ρ_{lin}

The mean-square deviation Δ of the array elements $\rho_{difi}(1/J_i)$ $(1 \leq i \leq N)$ from the regression line can be calculated by the formula

$$\Delta = \pm\sqrt{\frac{1}{N}\sum_{i=1}^{N}(\rho_{difi} - a\frac{1}{J_i} - b)^2}\,. \qquad (4)$$

The value of Δ gives the possibility to estimate absolute and relative errors in resistivity ρ_{lin}. As it can be seen in Fig. 2, different straight lines can be drawn through the range boundaries $1/J_1 \leq 1/J \leq 1/J_N$, taking into account Δ parameter. These straight lines are located between the lines presented in the Fig. 2 by thick and thin dashed lines. Therefore, the positive absolute error is the difference $\rho_{lin1} - \rho_{lin}$ and the negative absolute error is the difference $\rho_{lin2} - \rho_{lin}$ (Fig. 2). These differences can be found by calculating the values of constants $b_1 = \rho_{lin1}$ and $b_2 = \rho_{lin2}$ for straight lines shown by the thick dashed lines in the Fig. 2. The moduli of such differences are equal. Calculation has shown, that the absolute error in the linear resistivity ρ_{lin} limiting the barrier current in varistor materials is described by the expression:

$$\Delta\rho_g = \pm\Delta\frac{J_1 + J_N}{J_1 - J_N}\,. \qquad (5)$$

Taking into account that $b = \rho_{lin}$ the relative error is equal

$$\delta = \pm\frac{\Delta(J_1 + J_N)}{b(J_1 - J_N)}100\%\,. \qquad (6)$$

Figure 3 shows a window of the program at the final stage of its execution. The program is opened in Opera browser. The program has menu options allowing to open a raster image and to control the data processing. Current cursor coordinates are shown in the top-left corner of the window. By clicking left mouse button these coordinates can be registered in the table located below. The menu option "Обзор" is intended for opening files of raster images in the browser window. It provides access to the file system of a computer by means of a script using FileReader object. «Инструментарий» is a component for performing different stages of data processing (Fig. 3). It contains control buttons and form fields for entering initial data and displaying output of processing outcomes. A detailed user instruction is displayed in this component for every stage of data processing.

The program has nine consecutive stages of processing: 1) Loading a raster image to the browser window; 2). Entering thickness L and area of electrodes S for a sample of varistor ceramics; 3). Determining a scale factor for voltage M_U; 4) Determining a scale factor for electric current M_I; 5). Scanning coordinates for zero level of voltage YU_Z; 6). Scanning coordinates for zero level of current YI_Z; 7) Determining a scale factor for time M_T; 8). Scanning voltage and current oscillograms of a sample being examined (Fig. 1c); 9). Running necessary calculations based on the scanned data using the formulas mentioned above.

At the final stage, after a click on the button "Вычислить ro", the processing outcomes are shown in the fields of the form (Fig. 3). The field «tau=» shows the time constant τ of the exponential impulse used for obtaining oscillograms of voltage and current for a sample of varistor ceramics. The fields «ro=» shows the value of ρ_{lin} and its absolute error. The value of relative error in ρ_{lin} is displayed in the field «Ошибка ro=». Moreover, at the final stage of processing, the program opens windows for displaying the range of current density $J_1 \leq J \leq J_K$ where the value ρ_{lin} was determined, the average current density and the range of the nonlinearity factor of CVC in the interval $J_1 \leq J \leq J_K$ (Fig. 3).

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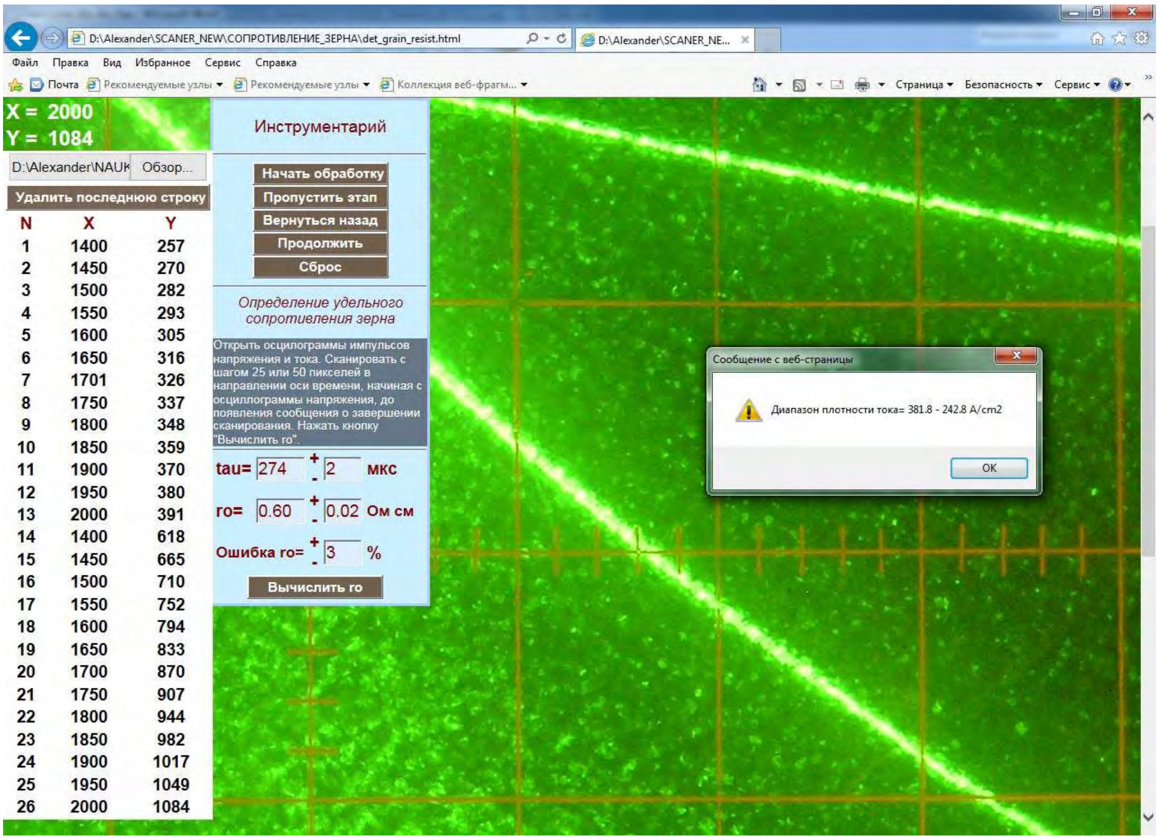

Figure 3 - Window of program at the final stage of execution

Separate scripts implemented with JavaScript and jQuery support every stage of processing of the raster images oscillograms (Fig. 1). Scripts are triggered by events, associated with mouse. Event "mouse-move" runs the script for determining current coordinates of the raster image. It uses properties "offsetX" and "offsetY" of the "event" object to get the current coordinates. A script intended for recording scan data to the table uses these properties too. It is triggered by "click" event, associated with a left mouse button click in a chosen point of the raster image. Menu item «Удалить последнюю строку» is used for data correction in the table of coordinates (Fig. 3). Menu items «Вернуться назад» and «Продолжить» are used for returning to the previous stage and for continuing the processing after data correction. Any stage of processing can be skipped by a click on the menu item «Пропустить этап». The program interface contains a menu item «Сброс» for cleaning all form fields and the table. The program returns to the initial stage at a click on this menu item.

Conclusions. A program for determining linear resistivity ρ_{lin} limiting the barrier current in varistor materials was created by means of HTML, CSS, JavaScript languages and jQuery library. In the program, determination of ρ_{lin} is performed by scanning raster images of oscillograms. The program uses oscillograms of voltage and current obtained in the region of strong current at applying a single pulse of exponential form to a sample. Any Internet browser can be used as a software environment for the designed program.

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