DOI 10.34185/1562-9945-1-126-2020-06
UDC 004.42:621.317.351
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PROCESSING OF THE DIGITAL IMAGES OF ANALOGOUS OSCILLOGRAMS AT PULSED MEASUREMENTS

Abstract. A program for processing the digital images of analog oscillograms at pulsed measurements of the current-voltage characteristics of semiconductor materials and devices in the region of high electric currents is presented. The processing of digital images in this program bases on scanning of coordinates and allows measuring the instantaneous voltages and currents with a relative error of no more than ±1%. The program is created using the languages HTML5, CSS3, JavaScript and Canvas technology. The software environment for program run is the Internet browser.
Keywords: digital image, determination of parameters by scan data, analog oscillogram, current-voltage characteristics.

Problem statement and purpose of research. When measuring in the region of high electric currents the current-voltage characteristics (CVC) of semiconductor materials and devices are used short voltage pulses to exclude thermal breakdown. In particular, such measurements are needed in CVC studying of highly nonlinear zinc-oxide ceramics (ZOC) and varistors based on it [1]. Varistors are widely used for surge protection of electronic and electrical equipment [2]. The effectiveness of overvoltage protection is determined by the clamp ratio, which can be represented as E_J/E_C in the specific electrical parameters of zinc-oxide ceramic. Here E_C is the electric field strength at current density of ~ 10^{-3} A cm^{-2}; E_J is the electric field strength under the action of overvoltage pulse, when current with density *J* flows through the ceramics. The E_J/E_C ratio determines the multiplicity of voltage increase on the protected object under the influence of overvoltage and should be as close to unity as possible. The magnitude of *J* for overvoltage caused by various factors can range from 100 A cm^{-2} to 5000 A cm^{-2}. The value of electric

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

field strength E_J, necessary for estimating E_J/E_C, can be found from the CVC of varistor ceramic sample in the region of high electric currents.

In [3], it was proposed to use single voltage pulses of exponential form for measuring the current-voltage characteristics. Such pulses allow deploy voltage in a certain range. It makes possible when simultaneously register the voltage and current pulses, to obtain information about CVC in some region of voltage. The simultaneous registration of current and voltage pulses can be realized using a two-beam storage oscillograph. As shown in [4], in the case of analog oscillograph, the accuracy of measuring time intervals and voltages by analog oscillograms one can be led to the accuracy of measuring a digital oscillograph if to use the digital (raster) images of analog oscillograms. Such images can easily be obtained by photographing oscillograms using a digital camera directly from the screen of analog oscillograph. Since the quantization step for raster images is 1 pixel [5], using a digital camera with high resolution, it is possible to ensure high accuracy in determining the parameters of objects in raster image from the scanning data of their coordinates. When performing measurements using digital images, software is required for their processing, which makes it possible to extract the necessary information based on the scan data.

The aim of this work is to create a program for processing digital images of analog oscillograms for pulsed measurements of current-voltage characteristics of materials and devices in the region of high electric currents.

Main part. The algorithm for processing digital image of analog oscillogram of voltage and current when measuring the current-voltage characteristic should include the following steps: 1). Input of the initial data. In the case of semiconductor materials: the thickness of a sample L, the area of electrodes S and the value R of resistor used for registration of current; 2). Scaling with using the digital images of oscillograms of calibration signals recorded at the same amplification and sweep duration as the oscillogram of the sample under study; 3). Determination of coordinates of zero line for oscillograms of voltage and current; 4). Scanning with a given step along the time axis of oscillograph the coordinates of lines in oscillograms of voltage and current for the sample under study; 5). Calculation based on the initial data, scales and scan coordinates x_i, y_i ($1 \le i \le N$) of the values of electric field strength E_i and the values of current density J_i, as well as the error in determining these magnitudes; 6). The processing results output.

In this work, we used HTML 5, CSS 3, JavaScript [6] and elements of the Canvas technology [7] for the software implementation of the described algorithm. As an environment for program created by the above means, any Internet browser can be used.

The program interface in the form of a web page was created using HTML 5 and CSS 3 languages. Fig. 1 shows the web page open in the Opera browser at the initial stage of the program. Using <canvas> tag, a canvas with dimensions of 2600–2300 pixels was created on web page. Such dimensions are sufficient for the complete placement of digital images of analog oscillograms obtained with the help of many modern digital cameras. If necessary, the size of canvas can be increased. The presence of canvas on the web page makes it possible to mark on the digital images of oscillograms the points at which the scanning was performed and to connect them by straight lines. This provides the ability to visually verify the correctness of scan.

The program interface contains two blocks for control the processing of digital images. In upper right corner of the browser window is block for displaying the coordinates of mouse cursor. This block shows the current coordinates of cursor and it is served by a script that is started by *mousemove* event. In the upper left corner of browser window there is a set of buttons. When these buttons click, the scripts are performing for various stages of the processing of oscillograms digital images.

The "Choose File" and "Download" buttons are used to select and download the digital images. Fig. 1 shows the program window after clicking the "Choose File" button. The user, using the standard window, has the ability to select the desired raster image file. In Fig. 1, in accordance with the user's instruction, a digital image of oscillogram is selected with the calibration signal U_C of 100 V. This image, after clicking "Download" button, is uploaded on canvas in the program window. The above buttons serve scripts that use properties and methods of the *FileReader* object to load images, and the *drowI-*

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

mage() method of *canvas* for transfer its on canvas. User instructions are displayed in the program window at each stage of processing digital images.

Fig. 2 shows the program window for the stage of initial data input with loaded digital image of the calibration voltage oscillogram. At this stage, a block is opened containing the form fields for introduction of the sample thickness L, of the electrodes area S and of the resistance value R connected in series with the sample for registration of current oscillogram. When pressing "Download", the initial data are saved in the program variables, the "*Initial data*" block is hidden and the "*Scale voltage*" block is opened. Transition to the stage of determining the voltage scale takes place. The display of blocks and user instructions for various stages of processing is controlled in scripts using the *visibility* property of *style* object of JavaScript language.

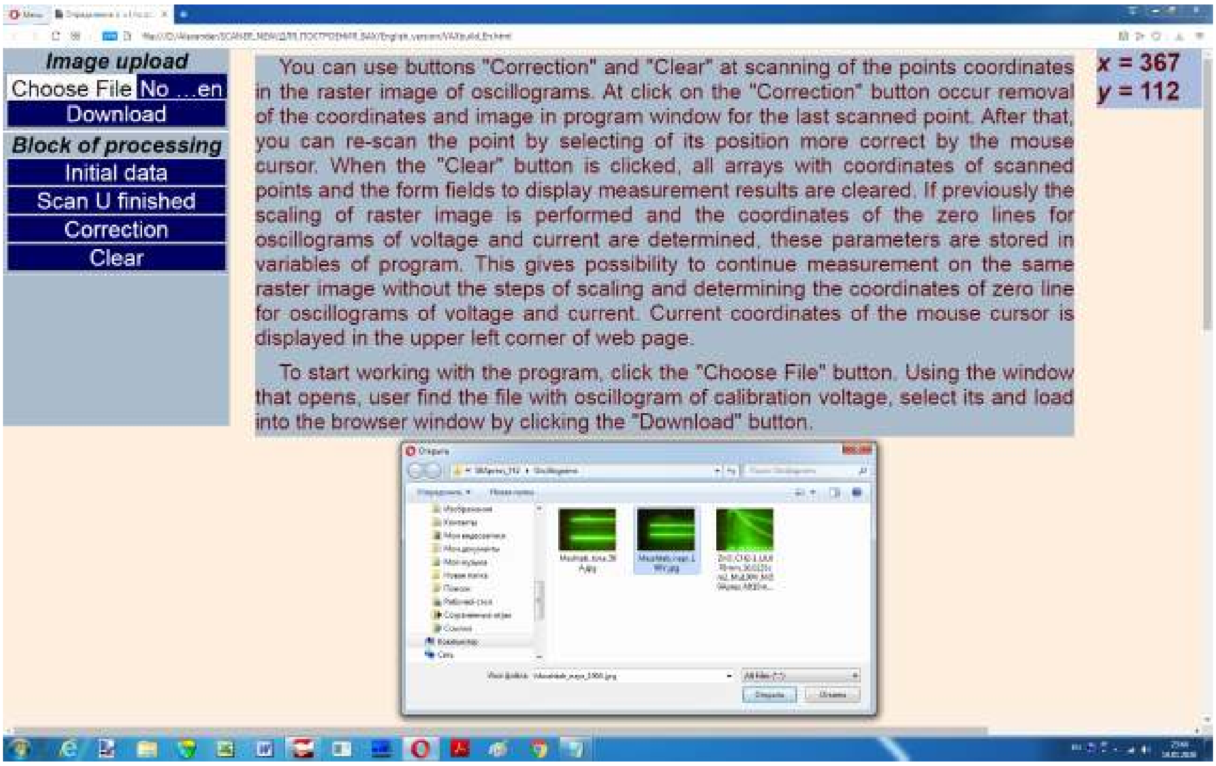

Figure 1 - The program window at the initial stage of execution

To determine the voltage scale, a previously loaded image of the calibration voltage oscillogram is used (Fig. 2). As a calibration signal, we used periodic rectangular pulses with amplitude of 100 V and frequency of 1 kHz. At sweep duration of 10 μs/div, the oscillogram of such pulses is registered as two parallel lines (Fig. 2), the distance between which corresponds to voltage of 100 V. Fig. 3 shows program window at the final stage of determining the voltage scale. At this stage, user introduces the U_C calibration voltage in "U_C =" form field, scans the coordinates of two points on oscillogram lines at the same *x* coordinate value, and press the "Calculate scale" button. The program calculates the value M_{cU} of voltage scale, using the obtained data, as

$$M_{cU} = U_C/|y_{MU1} - y_{MU2}|, \quad (1)$$

where y_{MU1}, y_{MU2} are the vertical coordinates of two scanned points on the lines of calibration voltage oscillogram.

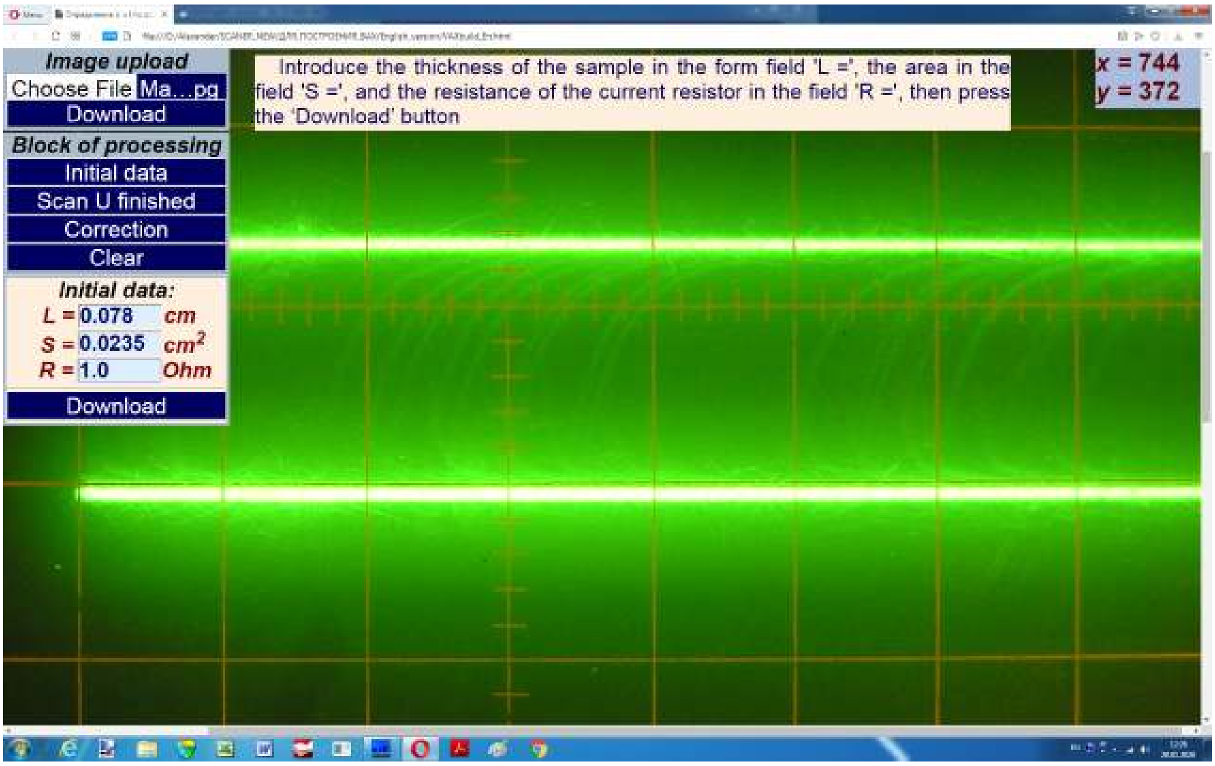

Figure 2 - The program window at the stage of initial data input

Scanning is carried out by clicking the left mouse button at the point selected in the center of the oscillogram line. The *mouseup* event starts script that uses the *pageX* and *pageY* properties of the *event* object to read the point coordinates. These coordinates x_i, y_i are saved in arrays of program. Script contains operators which draw red circles with radius of 4 pixels at the scan points and connect them by straight red lines using the properties and methods of the *canvas* object (Fig. 3). The center of each circle has coordinates of the scanned point. Such visualization makes it possible to evaluate the cor-

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

rectness of scanning with respect to the oscillogram line. If necessary, the user pressed previously the “Correction” button (Fig. 3) can re-scan. In this case by *click* event starts a script, which deletes the coordinates of the last scanned point from the data arrays. The same script removes the image of point and the line connecting its to the previous point. When multiple pressing the “Correction” button one can sequentially delete all scan data and their visualization in the program window.

For stages of the digital image processing involving scanning, the user instructions contain “Remove” button. When pressing “Remove” one can delete the instruction if it interferes with scanning (Fig. 3).

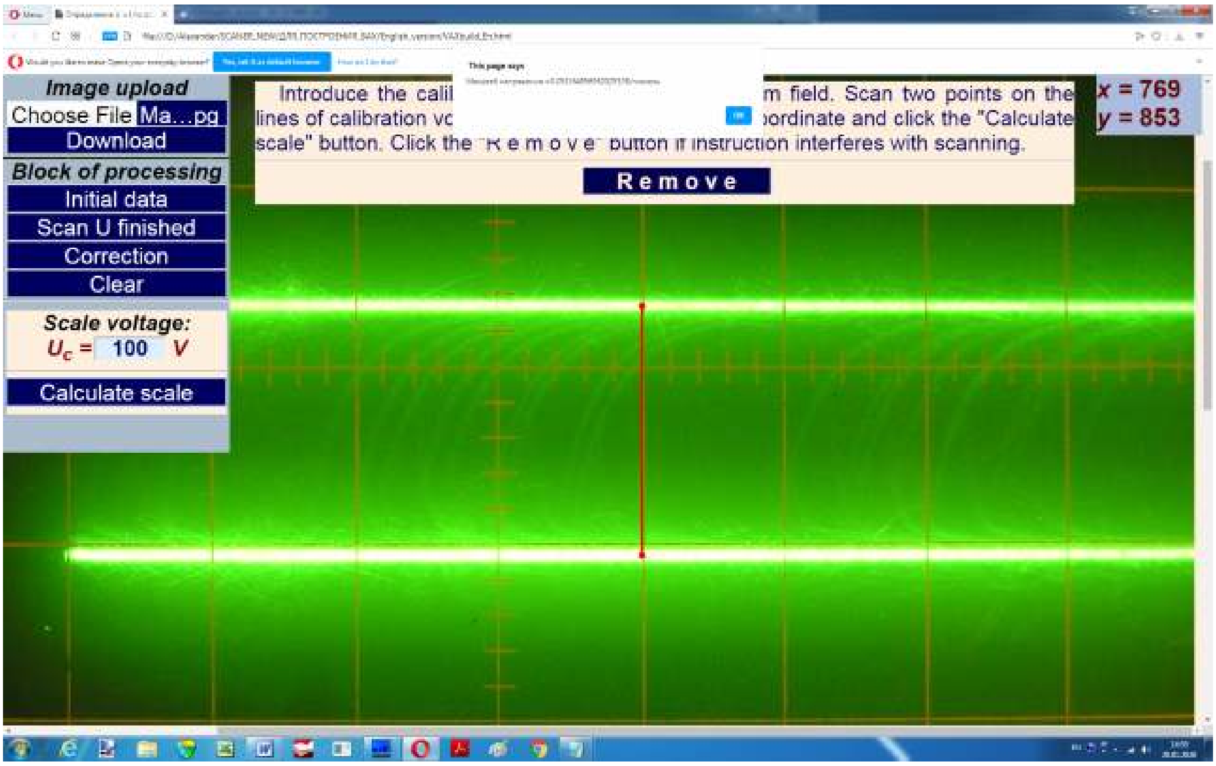

Figure 3 - The program window at final stage of determining the voltage scale

As can be seen in fig. 3, the program window at the final stage of the voltage scale determination contains a dialog window opened by the *alert ()* method of the *window* object. This window contains the calculated value of voltage scale in V/pixel. After pressing the “OK” button of this window, the “*Scale voltage*” block is hidden and the “*Scale current*” block is opened to determine the electric current scale.

This block and its supporting scripts are organized as well as for the voltage scale determination. At this stage using the "Choose File" and "Download" buttons, it is necessary to download a digital image of the calibration current oscillogram. As such oscillogram, we used an oscillogram of rectangular voltage pulses with calibrated amplitude U_C. Since the value of current resistor is R = 1 Ω (Fig. 2), the U_C value is actually equal to the calibration current I_C. In this case, the electric current scale M_{cI} is also calculated by the formula (1), where $M_{cU} = M_{cI}$ and $U_C = I_C$. In the examples presented below for illustrating the work of program the value of calibration current $I_C = 50$ A. After download of the oscillogram for calibration current, user performs the same actions as for determination of the voltage scale. The program calculates the electric current scale in A/pixel.

At stage 3 of the processing algorithm, the program opens the "*Determination of zero voltage*" block. The user downloads digital image of the voltage and current oscillogram obtained when exponential voltage pulse is applied to the sample. The image should have lines of zero voltage and current. These lines are the starting point for measuring of instantaneous voltages and currents.

Fig. 4 shows the program window for the stage of determination the coordinate y_{0U} of the zero voltage line. In this figure the zero voltage line is located below, the zero electric current line is at the top.

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

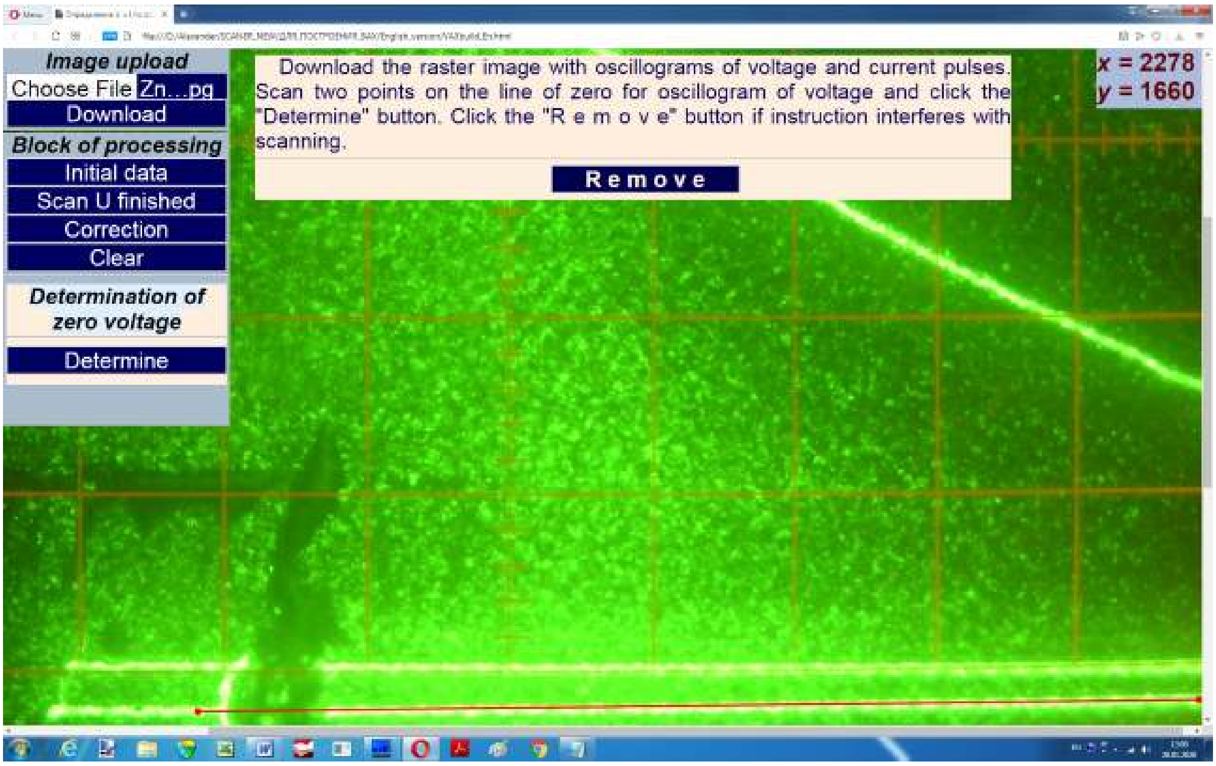

Figure 4 - The program window at the stage of determination the coordinate y_{0U} of oscillogram zero voltage line

The y_{0U} coordinate of the zero voltage line is defined as the average magnitude of y_{1U}, y_{2U} coordinates obtained by scanning of two points on this line. These points correspond to the ends of time interval of oscillogram, where the measurable values of voltage and current are located. Such points can be seen in Fig. 4 after scanning. When pressing "Determine", the value $y_{0U} = (y_{1U} + y_{2U})/2$ is calculated and stored in the program variable for further use. Then the script, acting when pressed the "Determine" button, clears the arrays of scan data, removes their visual display, hides the "*Determination of zero voltage*" block and visualizes the "*Determination of zero current*" block. Determination of the coordinate $y_{0I} = (y_{1I} + y_{2I})/2$ of electric current zero line is performed in the same way as for coordinate y_{0U}. In this case, after pressing "Determine" button, the "Result" block opens for the last three stages of the algorithm for processing of digital image of analog oscillograms (Fig. 5).

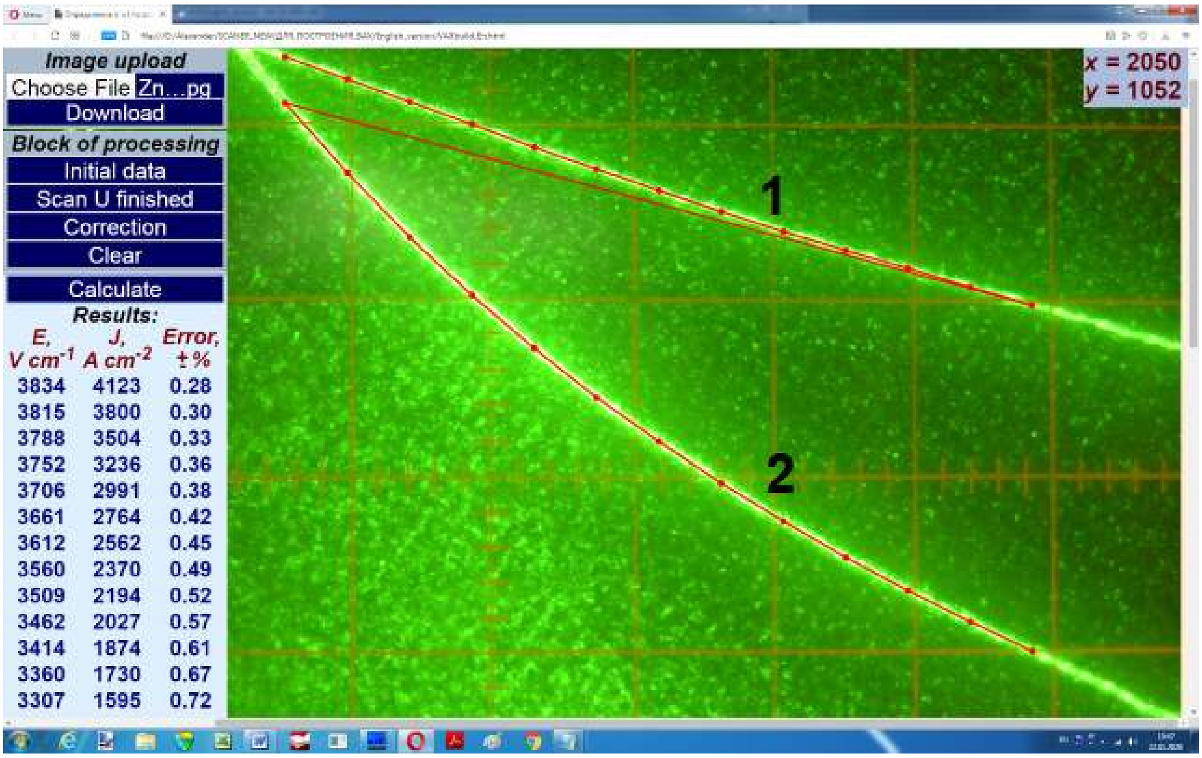

Figure 5 - The program window for final stage of execution. Oscillodrams: 1 – voltage; 2 – electric current. The current-voltage characteristic was measured for zinc-oxide ceramics used in varistors CH2-1

Processing for these stages begins with scanning the oscillogram of voltage. The scanning performs with a constant step in the X-axis direction of digital image. In the example shown in fig. 5, the scan was performed in the interval 850 – 2050 pixels with the step of 100 pixels. User has the opportunity to select any number of *N* points for scanning and to correct scan data using the "Correction" button. After completion a scanning of the voltage oscillogram, he presses the "Scan U finished" button. The script that is executing when this button is pressed using the alert () method opens a dialog window with a message about the number of scanned points and a recommendation to begin scanning the electric current oscillogram. The user scans the electric current oscillogram at the same *x* coordinate values, and in the same sequence as for the voltage oscillogram. For control the value of the *x* coordinate at scanning, the display block of the current cursor coordinates is used. This block located in the upper right corner of the browser window (Fig. 5). After scanning the electric current oscillogram, the program opens a window with

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

message "*Scanning completed. Click the* "Calculate" *button.*" When this button is pressed, a script is executed, using the arrays of scan coordinates x_i, y_i ($1 \le i \le N$) to calculate the values of instantaneous electric field strength E_i and of electric current density J_i. The values of E_i and J_i are calculated by the formulas:

$$E_i = \frac{1}{L}(M_{cU}(y_{0U} - y_{iU}) - M_{cI}R(y_{0I} - y_{iI})), \quad (2)$$

$$J_i = \frac{M_{cI}}{S \cdot R}(y_{0I} - y_{iI}), \quad (3)$$

where y_{iU}, y_{iI} are the vertical coordinates in *i*- scanned point with same coordinate x_i on the lines of voltage and current oscillograms, respectively.

In the formula (2), when calculating the voltage drop across the test sample, the voltage drop across the resistor R, connected in series with the sample, was taken into account.

In accordance with (2), (3), the values of E_i and J_i are determined by the length of lines y_{0U} - y_{iU} and y_{0I} - y_{iU} which separate the scanned point from the lines of zero voltage and current. Therefore, the absolute measurement error of E_i and J_i is primarily determined by the absolute measurement error of the length of these lines by the scan data. Assuming that the absolute error of scanning in the center of oscillogram line is ±2 pixels, for the absolute error of the line length determining, we obtain a value of ±4 pixels. Therefore the relative error δ at definition of E_i and J_i can be calculated as

$$\delta = \frac{4}{y_{0I} - y_{iI}} \cdot 100\%, \quad (4)$$

Script executed after pressing the "Calculate" button displays the processing results in the hidden form fields (Fig. 5). As can be seen, the relative error in measurement of voltages and currents at using the digital images of analog oscillograms does not exceed ±1%.

After measurement of CVC, the program provides the ability to clean the arrays of scan data x_i, y_i and delete the visual results of scan. In this case, the initial data, M_{cU}, M_{cI} scales and the coordinates of zero lines of voltage and current oscillograms y_{0U}, y_{0I} are stored. For this purpose the "Clear" button is used (Fig. 5). After pressing of this button it is possible to measure the current-voltage characteristic, using the same or another part of oscillograms, without overload of the digital image, the scaling and determination of zero.

Conclusions. A program has been created for processing the digital images of analog oscillograms at pulsed measurements of the current-voltage characteristics of semiconductor materials and devices in the region of high electric currents. The program is created using HTML5, CSS3, JavaScript languages and Canvas technology. The Internet browsers are software environment for program execution. The program allows, using the scan data of digital images of oscillograms, to measure instantaneous values of voltage and current with a relative error of no more than ±1%.

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Received 14.01.2020.
Accepted 16.01.2020.

Обробка цифрових зображень аналогових осцилограм при імпульсних вимірах

Створена програма для обробки цифрових зображень аналогових осцилограм при імпульсних вимірах вольтамперних характеристик напівпровідникових матеріалів і приладів в області сильних електричних струмів. Програма реалізована засобами мов HTML5, CSS3, JavaScript і технології Canvas. Програмним середовищем для її виконання є браузери мережі Інтернет.

Осцилограму напруги і струму зразка, що тестується, регіструють двопроменевим аналоговим осцилографом. Її перетворення у цифрову форму здійснюється шляхом фото-

SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)

графування цифровою фотокамерою з екрану осцилографа. При обробці цифрових зображень аналогових осцилограм за допомогою програми, описаної в роботі, миттєві значення напруги і струму можна визначити з відносною похибкою не більше ±1%, використовуючи дані сканування.

Обработка цифровых изображений аналоговых осциллограмм при импульсных измерениях

Описана программа для обработки цифровых изображений аналоговых осциллограмм при импульсных измерениях вольтамперных характеристик полупроводниковых материалов и приборов в области сильных электрических токов. Программа реализована средствами языков HTML5, CSS3, JavaScript и технологии Canvas. Программной средой для ее выполнения являются браузеры сети интернет.

Осциллограмму напряжения и тока тестируемого образца регистрируют двулучевым аналоговым запоминающим осциллографом. Ее оцифровка осуществляется путем фотографирования цифровой фотокамерой с экрана осциллографа. При обработке цифровых изображений аналоговых осциллограмм с помощью программы, представленной в работе, мгновенные значения напряжения и тока можно определить с относительной погрешностью не более ±1%, используя данные сканирования.

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SSN 1562-9945 (Print)
ISSN 2707-7977 (Online)