Programming the Measurement System by using VEE Pro to Determine Cyclic I-V Characteristics: Resistive Switching Device Application

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Abstract

In this study we introduce a simple program for cyclic current–voltage (I–V) measurements for bipolar and unipolar resistive switching devices. This cyclic I-V measurement (CYC-IV) program was developed under the Keysight VEE Pro (Visual Engineering Environment Program) software and has a graphical interface. CYC-IV was developed for programming the Keysight B2912 Precision Source/Measure Unit (SMU) for I-V measurement of resistive switching devices in sweep mode. CYC-IV can be used in six different sweep modes. Moreover, the ramp rate, upper and lower limits of bias, cycle delay time and number of cycles easily define by user. Measurement results were visualized in three graphs that can be viewed simultaneously with the measurements.

Keywords: Cyclic I-V, Sweep mode, VEE Pro, Resistive switching devices, SMU

Döngüsel I-V Karakteristiklerinin Belirlenmesi için Ölçüm Sisteminin VEE Pro kullanarak Programlanması: Dirençli Anahtarlama Aygıtları Uygulaması

Öz

Bu çalışmada, iki kutuplu ve tek kutuplu dirençli anahtarlama aygıtları için döngüsel akım-gerilim (I–V) ölçümleri için basit bir program hazırlanmıştır. Bu döngüsel akım-gerilim ölçüm programı (CYC-IV) Keysight VEE Pro (Visual Engineering Environment Program) yazılımı altında geliştirilmiştir ve grafik arayüze sahiptir. CYC-IV, tarama modunda dirençli anahtarlama cihazlarının I-V ölçümü için Keysight B2912 Hassas Kaynak/Ölçüm Birimi'ni (SMU) programlamak üzere geliştirilmiştir. CYC-IV altı farklı tarama modunda kullanılabilir. Ayrıca gerilim artış hızı, üst ve alt gerilimin limitleri, döngü gecikme süresi ve döngü sayısı kullanıcı tarafından kolaylıkla tanımlanabilir. Ölçüm sonuçları, ölçümlerle aynı anda görüntülenebilen üç grafikte görselleştirildi.

Anahtar Kelimeler: Döngüsel I-V, Tarama modu, VEE Pro, Dirençli anahtarlama aygıtları, SMU

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1. Introduction

Today, research laboratories are places where researchers from many disciplines work together and multi-tasks are carried out together. For this reason, researchers have to gain different abilities for different tasks, rather than specializing in a particular subject. For example, in a study on thin films, one or more of the thin film production techniques and basic characterization techniques should be known and easily applied by researchers. In addition, it is expected that the produced films will carry out studies on the possible application area. Such as, performance measurements of a film produced using metal-oxides for solar panel applications, applications to determine possible sensor properties or electrical characterization to be used as a possible electronic device. Due to the requirements mentioned above, researchers need to buy a new equipment or rearrange their basic equipment to measure the desired parameter in order to realize some specific applications. In its simplest form, this arrangement can be in the form of purchasing a new software package or making basic modifications as appropriate for the purpose [1-4].

Researchers generally uses a measurement setup, which has a software package that, come with this hardware. For this reason, studies for new applications of measurement setup are limited to this software. Many measurement devices can be reprogrammed for the purpose of the researcher using different programming languages and common command systems such as Standard Commands for Programmable Instruments (SCPI). However, in order to do this, the researcher needs to know programming languages such as C+, XML and/or Phyton [2, 5-7]. However, some manufacturers also offer the main software packages to the users in order to allow more flexible use of their devices [8]. Programs, such as VEE Pro and LabView, allow users to make appropriate measurements and calculations without the need to know any programming language [9-11]. In these type of interfaces, visual objects are used instead of command lines, variables and data can be defined with pre-defined programming objects instead of codes (see Figure 1.). So, this software packages allows the user for data recording, visualization, and basic calculations. VEE Pro is one of the most important graphical programming environment and generally used for building test systems and computation for researcher's specific demands [1, 2, 7, 11-14].

Non-volatile memories built on semiconductor substrate make an impressive progress and successfully scaled down to achieve large-capacity memories through improvements in photolithography technique [15]. However that they come up against technical and physical limits in the near future, so, three-dimensional structures and new materials are presented as alternatives. In this context, some metal oxides and polymers have attracted a great deal of attention for use as next-generation nonvolatile memories due to their resistive switching (RS) behavior. RS devices are cyclically changing their electrical resistivity values between different stable voltage levels under some certain electrical stresses conditions. These resistive states could be controlled and used to represent logic states in memories and computations [15, 16]. In this study, a program is introduced to make a programmable current-voltage measuring device used for current-voltage measurements of transistors and Schottky diodes suitable for multiple cyclic current-voltage measurements of RS devices using VEE Pro. Thus we create a program can perform cyclic I-V measurements (when the equipped with SMU such as Agilent B2912), basic calculations, saving and visualizing the measurement results synchronously (Cyclic I-V measurement program, CYC-IV). Also our program allows users to control the electrical measurement processes of devices, which it’s not possible for many commercially available programs. It provides flexible measurement solutions and offers a new approach for user requirements in the electrical measurement process of RS devices.

2. Material and Methods

Basic electrical characterization of RS devices is based on cycled I-V data. Thus, electrical measurements are important for device fabrications and have to be performed with the high-precision source-measure units under the certain conditions. Controlling the measurement environment and conditions is essential. In addition, it is necessary to define the measurement parameters flexibly in the program, to following the measurement process closely, and automatically save the data that emerges at the end of the process. All these requirements have been taken into account in the preparation of our program using VEE Pro. The prepared program (CYC-IV) contains more than 30 types VEE Pro objects in total. These objects includes instrument control transactions for B2912, loop elements, graphical interface, test data display elements, variables, program flow modifiers, some subscripts required for data logging, components that allow the user to input data, etc. (Figure 1.) [17].

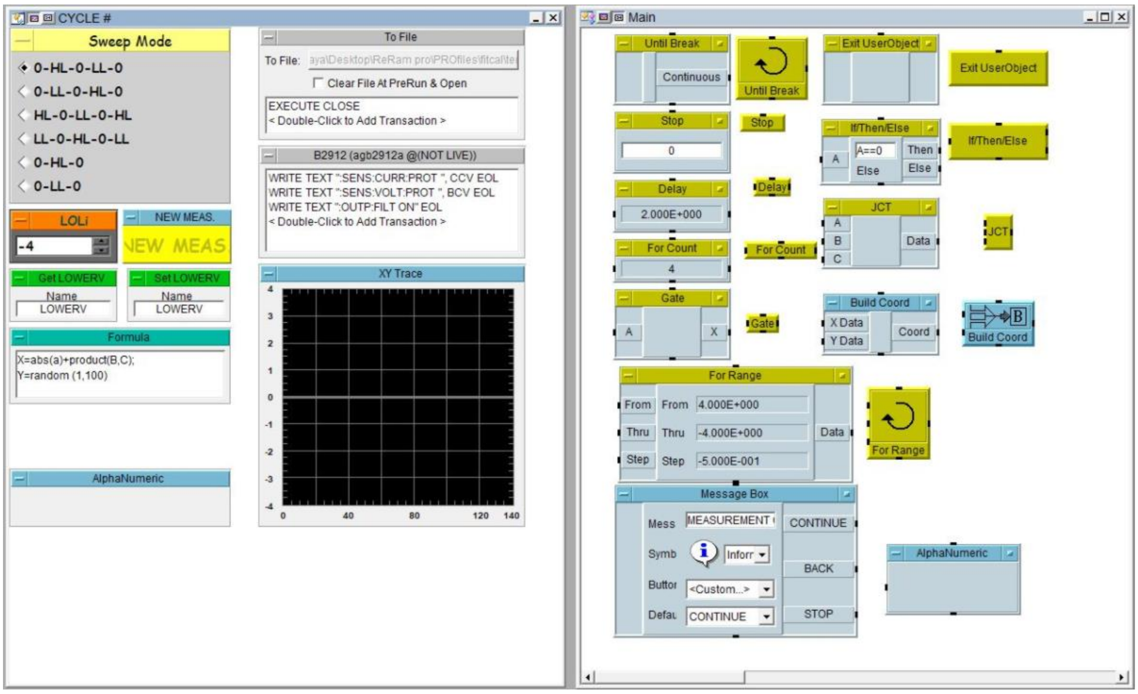


Figure 1. Some of programming elements of VEE Pro used in CYC-IV.

The components included here are combined using appropriate variable definition and data transmission paths. The basic steps of programming are as follows (Figure 2.);

i. Creating of basic files
ii. Defining variables and assigning values to some variables by the user
iii. Defining process (measurement) parameters

iv. Measurement start, new variable assignments, temporary recording of results
v. Completion of data permanently recording at the end of the measurement

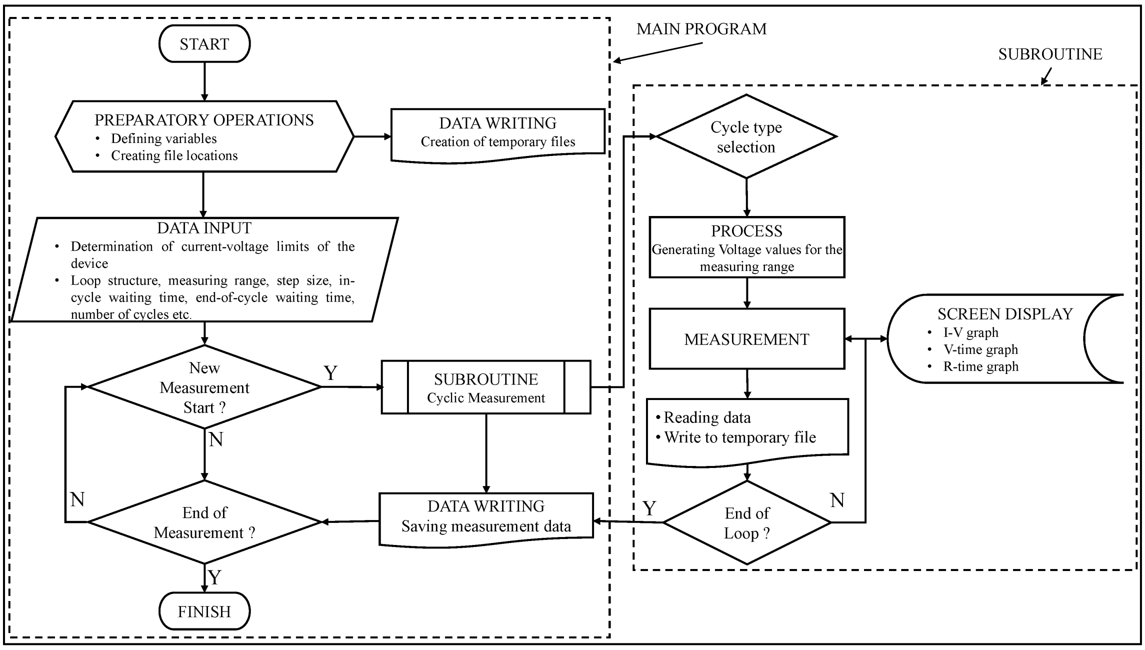


Figure 2. Main flow diagram and measurement subroutines of CYC-IV.

3. Results and Discussion

3.1. RS Devices Characteristics and Cyclic I-V Measurements

RS devices usually represent their switching characteristic parameters such as resistance value of high-resistance state (RHRS or R_{ON}) and resistance value of low-resistance state (RLRS or R_{OFF}) ad their ratio (R_{ON} / R_{OFF}), which could be used to calculate the energies set and reset condition (E_{SET} and E_{RESET}) can be easily found with the cyclic I-V measurements method. Typical I-V plots were obtained during the applied ramped voltage stresses (RVS) and current vs time (I-t) plots were obtained during the applied pulsed voltage stresses (PVS). In this method, RS behavior can be detected by applying RVS, which current raises and transitions occurs between the HRS-to-LRS (called a SET) and current drops and transitions occurs between the LRS-to-HRS (called a RESET) (Figure 3.). So, the current values in the forward and backward sweep directions are different for a given certain voltage (typically ~0.1 V), and their resistances (RHRS and RLRS) can be calculated [16].

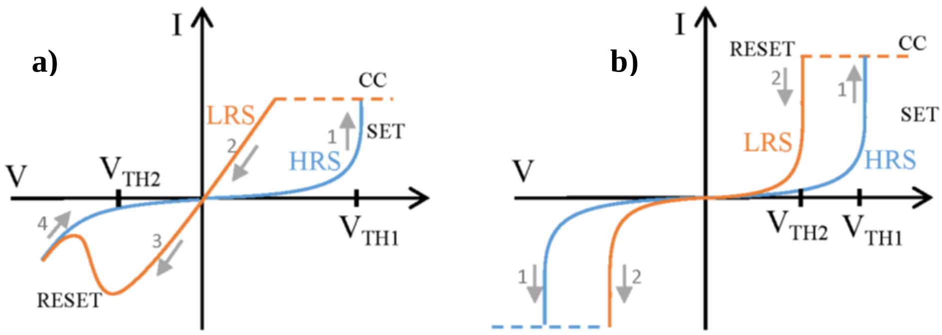


Figure 3. a) Typical I–V sweeps showing one cycle of bipolar RS device and b) unipolar RS device.

3.2. Programming Details of CYC-IV

CYC-IV was developed for cyclic I-V measurements of some devices by using the VEE Pro (v7.5). This program is focused on automation of Agilent B2912 SMU to help measure the cyclic switching behavior of RS devices. Throughout the programming steps, five programming stages are considered and applied on our flow diagram. Firstly, some requirements such as control the B2912A SMU for output status, bias/current compliance values, bias travel range and directions, certain increment rates for bias etc.) are defined. Also, all measurement data are could record without user command and sweep parameters can be described by user before the measurement. Secondly, basic programming task was created and virtual instrument components were used in process. In addition, a subroutine has been developed that will take place under the main loop of the program and will actually performs I-V measurements cyclically according to the parameters defined by the user

Thirdly, Graphical User Interface (GUI) based development environment of VEE Pro was used for creating a task and some communication objects (instrument–computer), variables, data input objects for user, data display objects, loop/flow elements and file management components etc. in accordance with the flow chart. After that, start screen objects were placed in main user panel (user welcome screen) (Figure 4a.) and then, subroutine for the measurement task is arranged to sequentially run by user command (Figure 4b.). Also in here, “Current Directory Settings” button allows the user for file directory selection of measurement results. User can be select file names and their location on computer.

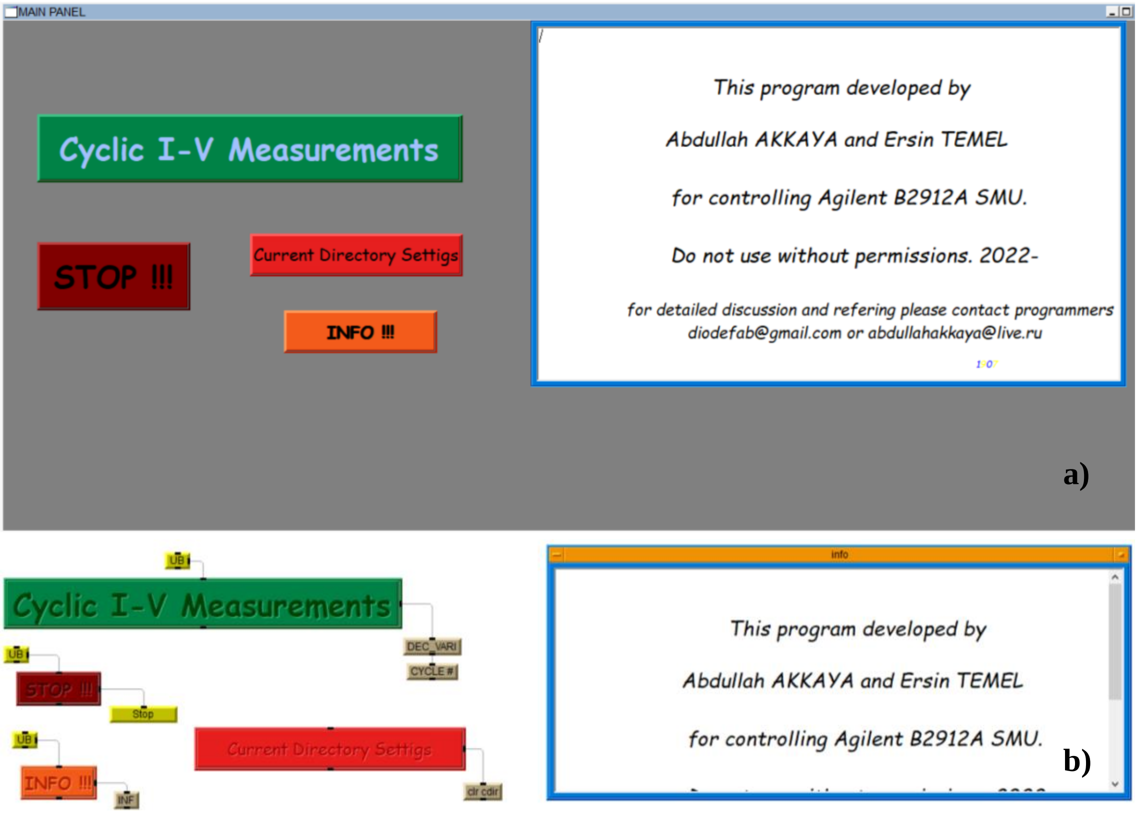


Figure 4. a) Main user panel view and b) arrangement of programming objects and user-defined functions in the main panel.

Subroutine part of our program allows the user for entering some measurement parameters and starting cyclic measurements (Figure 5.). Also, this subroutine was prepared to perform six different types of cyclic I-V measurements (sweep mode) and work with a user command (sweep mode) in Figure 5a.). Each type of f sweep mode has its own loop for generating a bias data (see on Figure 5b.). First four sweep mode scans both direction positive and negative biases and can be used bipolar RS device characterization. Last two mode performs voltage sweeps only one direction (semi-cycle) and belongs to unipolar RS device characterization.

Panel view of subroutine can be seen in Figure 5a. In this panel, top-left side contains subroutine control buttons such as error clear for B2912A, cancel, back, polarity/connection control (Check Connection/Polarity - CCP). Bottom-left side of panel view contains user parameter define/select objects for measurement conditions such as compliance values for current and voltage of B2912 SMU, upper, lower and step size of bias cycle, cycle number, delay time for internal measurements and between the each cycles, and bias status graph for cycles. Right side of panel consist of two real-time graph, upper graph is I-V (logarithmic or linear scale can be chosen by user) and bottom graph is R versus time.

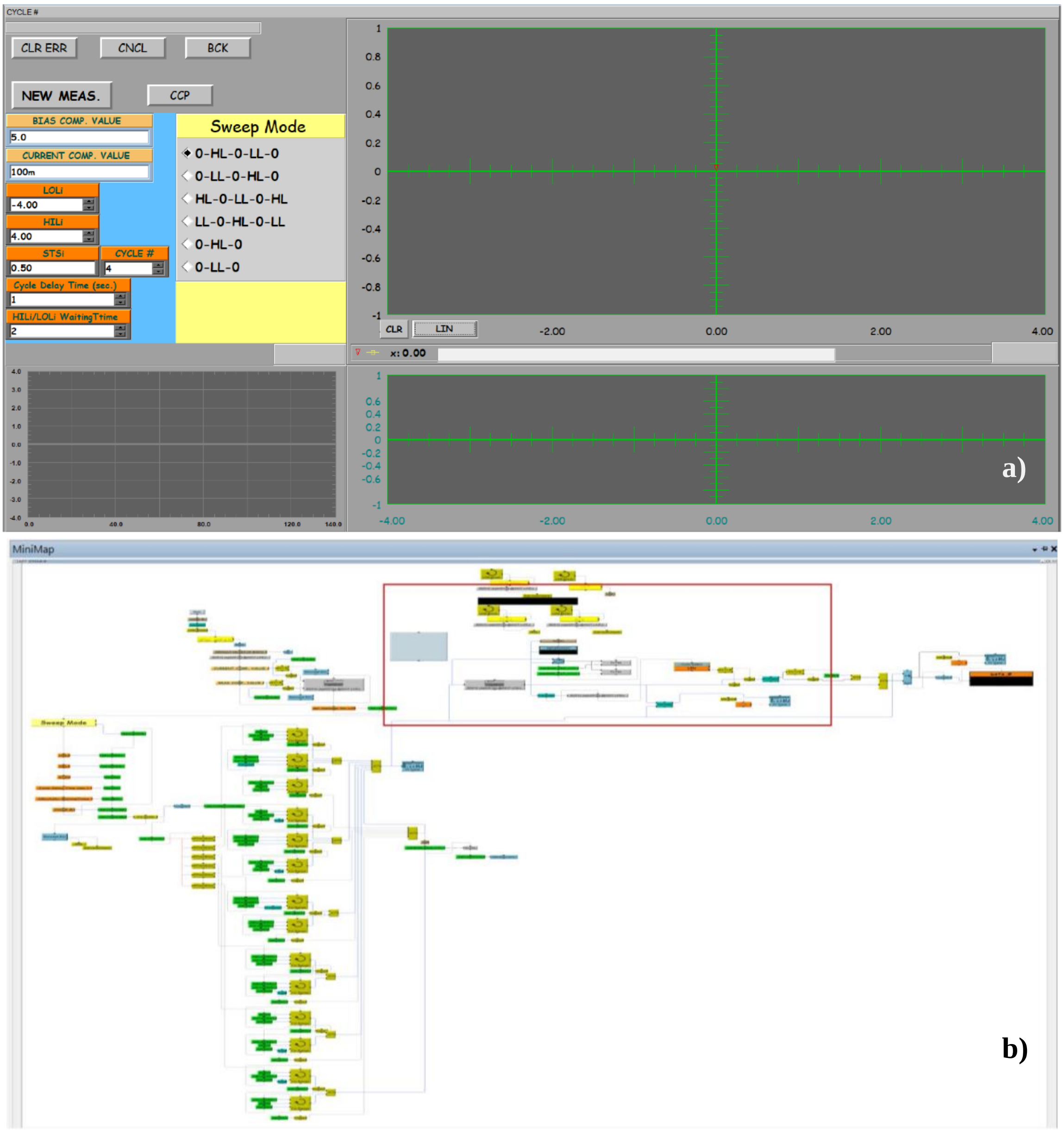
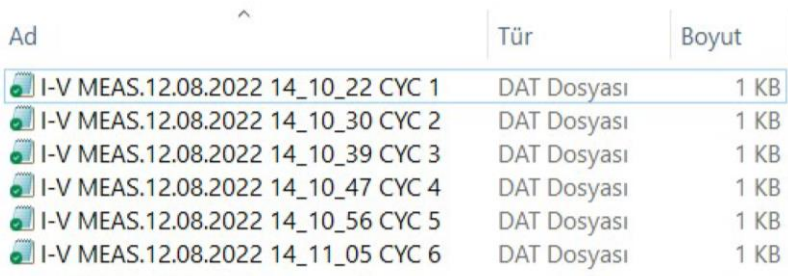


Figure 5. a) Subroutine's panel view and b) objects of the program and their flow routine.

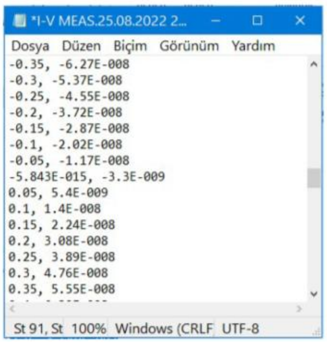
Finally, each cycle was tested for stability under the different measurement parameters and data record options (dry run), and all program was documented.

3.3. User Manual and Features of CYC-IV

CYC-IV only runs under the VEE Pro software packages. Installing the VEE Pro or creating a RunTime version (see on user manual) of CYC-IV measurements can perform. After the run command main panel elements appears and clicking "Cyclic I-V Measurements" button starts the subroutine and its panel view. In here, user can select the measurement mode and define cyclic measurement parameters. For example, first mode for cyclic structure (sweep mode) is (0-HL-0-LL-0) starts with the applying 0 V on device via B2912 and continue with the increment (increment value equals the step size) up to the higher voltage limit (ramped voltage), then reaches the higher voltage limit and returns the 0 V by decreasing the bias (first half of cycle). After that, bias voltage is carried out the lower limit of cycle then bias returns the 0 V similarly of first half (second half of cycle). The subroutine repeats this loops up to the number of cycles defined by the user. When the measurement completed all data files (*.dat) saved to “DATAS” folder, can be found in same directory with CYC-IV, with the time stamped and cycle numbered file name (Figure 6.). A “new measurement” or “stop” is selected in the pop-up window that opens after all cycles are completed.



a)



b)

Figure 6. a) Typical data folder and b) data file.

4. Conclusion

Unlike its commercial equivalents, this program can be arranged to perform cyclic I-V measurements and make basic calculations. This allows the measurement system to be rearranged in line with user requirements in laboratories where different processes are carried out simultaneously and multidisciplinary studies are carried out. The program interface was GUI-based, allowing users to create programs without the need to write code. The CYC-IV program was successfully applicable to the cyclic I-V measurements of RS devices and re-design for easily expand other similar applications such as sensors. Also, our program was still open to development and can be carried out to simulation and calculation of some specific parameters (e.g. set and reset times) of RS devices.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

Abdullah AKKAYA performed writing-original draft, software, validation and conceptualization. Ersin TEMEL performed writing-review and editing; conceptualization.

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