Wireless software-hardware complex for testing semiconductor structures

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Abstract. Wireless system for measuring current-voltage characteristics was developed. Software for a smartphone was developed in the integrated development environment Unity. The data about current and voltage was transmitted by Bluetooth and Wi-fi for smartphone and computer respectively. I-V curves were built on computer using program, developed in the Visual Studio package and coded in C#. For data verification the simulation of diodes’ parameters was provided by solving the Poisson equations and the drift-diffusion model.

1. Introduction
Semiconductor structures based on silicon and germanium [1] continue to apply actively in modern electronics. The progress in information technology, including wireless technologies allows to make the testing of developing semiconductor elements easier [2]. The combination of the results of such measurements with the data of computer simulation allows to develop the wireless systems for measurement of new devices’ parameters [3, 4]. The aim of this paper is the development of software-hardware complex for testing the parameters of semiconductor diodes in situ using wireless interface.

2. Results and discussion
Objects of research are silicon and germanium diodes: 1N5818, KD510A, KD212A, 1N4007, D9I. The simulation was carried out by numerical methods by solving the Poisson equation and the standard diffusion-drift model by method, described in [5].

The wireless system, shown on Fig. 1a, was developed for the measurement of current-voltage characteristics.

Fig.1 (a, b) (a) Wireless system (b) Circuit diagram of measurement scheme
The value of reference voltage is set by user used the program on Unity. The value of this signal is transmitted by Bluetooth to microcontroller Arduino Uno. The circuit diagram of measurement scheme is shown on Fig. 1b. The input signal is processed by low-pass filter. Value of the formed signal is very low and do not exceed 20 mA. For the amplifying of the signal, the Darlington configuration VT1, VT2 is used. It has current gain 150. Value of the signal in the output A0 accords to voltage R5.

Voltage of measured diode $V_D$ determines by difference of the electric potentials on output A1 and resistor R5. Received signal $V_D$ is recalculated in current by Ohm’s law $I_D = V_D / R5$ in Arduino. Signals $V_D$ and $I_D$ are transmitted back by Bluetooth to smartphone. For the visualization of graphics the program, used Unity and Visual Studio was coded. The signals $V_D$ and $I_D$ are transmitted to computer by Wi-fi, using Wi-fi module.

An user sets the sequences of voltages $V_D$ for the building of the graphics of current-voltage characteristic, wherein on the screen of computer the sequence of dots $(V_D, I_D)$, forming I-V curve, is displayed. On the Fig. 2a the results of the measurement of current and voltage of five different diodes are shown. The examples of the developed software for computer and smartphone are shown on Fig. 2b and Fig. 2c respectively.

3. Simulation

COMSOL Multiphysics software is used for simulation of current-voltage characteristics. This software package contains many modules for modeling of different physics, including the physics of semiconductor structures. The parameters with a specific value and a unit of measurement are defined during the simulation. After that, geometry of the structure is built as it shown on Fig. 3a. Thickness of the diode structure is 7 μm.

Fig. 2 (a, b, c) (a) I-V curve of the testing diodes (b) The computer program (c) The program for smartphone

Fig. 3 (a, b, c) (a) Geometry of the diode structure (b) Acceptors’ distribution (c) I-V curve of the germanium diode
The simulated diode is made of germanium. Main equations, which is solved in the simulation, are Poisson-equation and drift-diffusion model.

\[
\rho = q(p - n + N_d^+ - N_a^-) \tag{1}
\]

\[
J_n = q\mu_n n E_n + qD_n \nabla n \tag{2}
\]

\[
J_p = q\mu_p n E_p + qD_p \nabla p \tag{3}
\]

Where \( \rho \) – volume charge density, \( q \) – elementary charge, \( p \) – hole concentration, \( n \) – electron concentration, \( N_d^+ \) – ionized donors concentration, \( N_a^- \) – ionized acceptors concentration, \( J_n \) and \( J_p \) – current densities of electrons and holes respectively; \( \mu_n \) и \( \mu_p \) – mobilities of electrons and holes respectively, \( E_n \) и \( E_p \) – effective electric fields of electrons and holes respectively, \( D_n \) и \( D_p \) – diffusion coefficients of electrons and holes respectively, \( \nabla \) – Laplacian

Electrons and holes concentrations are given by Analytic Doping Model in n-type and n’-type regions. The hole distribution in p-type region (anode) is given by Geometric Doping Model. Background doping concentration in all regions is \( 10^{15} \text{ cm}^{-3} \). Donor concentration in the cathode area is \( 2 \cdot 10^{17} \text{ cm}^{-3} \). In the anode area, the acceptors are distributed as it shown of Fig. 3b. It is considered that Shockley-Read-Hall recombination is occurred in all structure.

Metal contacts are ideal ohmic on anode and cathode. The positive potential is fed on anode, while cathode has zero potential. Using this and solving the Poisson equation and drift-diffusion model, the current-voltage characteristic, shown on Fig.3c, is calculated.

4. Hardware

Program for microcontroller Arduino Uno was coded on C in the Arduino IDE. According to circuit diagram on Fig. 1b, digital pin 9 is used as output, where control signal is supplied., while analog pins A1 and A0 are used as inputs, where the voltage is read.

Program contains constants, such as maximum value of control signal is 1.1 V, maximum current is 50 mA, resistance on resistor R5 is 4 \( \Omega \) and the delay is 100 ms.

The algorithm scheme of the program’s main function is shown on Fig.4:
The main function of the program is the loop. It contains the steps for the command processing from the control device (smartphone) and the calculating of the level control signal, supplied to the measuring scheme.

Data of current and voltage are read from pins A0 and A1 respectively as a 10-bit value, i.e the number from 0 to 1023. To convert this value to the voltage $V_{A0}$ on the resistor R5, the formula is used:

$$V_{A0} = \left(\frac{A0 \cdot V_{ref} \cdot 1000}{1023}\right)$$  \hspace{1cm} (4)

Where $A0$ – 10-bit value read from pin A0; $V_{ref}$ – reference voltage equals 1.1 V;

As the voltage and the resistance on the resistor R5 are known, the electric current could be calculated by Ohm’s law: $I_p = \frac{V_{A0}}{R5}$

The voltage on the pin A1 is calculated by formula

$$V_{A1} = 2 \cdot \left(\frac{(A1 \cdot V_{ref} \cdot 1000)}{1023}\right)$$  \hspace{1cm} (5)

Where $A1$ – 10-bit value read from pin A0.

The voltage $V_D$ on the diode VD1 (see Fig.1b) is the difference between voltages analog pins:

$$V_D = V_{A1} - V_{A0}$$  \hspace{1cm} (6)

Receiving and transmitting data are carried out by standard functions of integrated development environment through a serial port. As soon as the control device is ready for the transfer of next command, this command would be written in the appropriate variable. Command is the string, which contains word “Reset” or value of control signal. If command “Reset” is received, the value of current variables sets to zero and on the output zero value is supplied.
Otherwise, received string is converted to a number value; the value of control signal is calculated and increased (or decreased) until the required value. After each change of output signal the values of voltage on pins A0 and A1 are read and a current on the diode is calculated. If the value of current is reached maximum allowed value, the process interrupt. When current command is executed, the device switches to standby and the process repeats.

5. Software for a smartphone and computer
Graphical user interface (GUI) was developed with Unity game engine. The program for GUI was coded on C#. The interface contains buttons “+” and “-”, which are used for increment and decrement of value of control signal (see Fig.2c). Voltage increase in 0.1 V on every step. Data of voltage and current are transmitted in the smartphone and their values are displayed. Computer program receives data from a smartphone and displays I-V curves (see Fig.2b). The I-V curve is blue, when the voltage increase, and red, when the voltage decrease. Data about measured voltage and current are stored as vector, while object LineRenderer is used for connection of the points and displaying curve.

6. Conclusions
The wireless software-hardware complex for the measurement of semiconductor devices’ parameters was developed. Measurement system use the data exchange by Bluetooth and Wi-fi. The scheme of calculation of current from the data about voltage was proposed. The graphic visualization of I-V curves is provided on the computer, using Unity and Visual Studio packages. The computer program for solving Poisson equations and drift-diffusion model was proposed for the working out of the technology of producing of the semiconductor diodes

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