Scientific Research and Essays Vol. 5(10), pp. 1155-1163, 18 May, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2010 Academic Journals

Full Length Research Paper

Diode parameter extractions and comparisons using the least square method, neural networks and genetic algorithms

Fahri Vatansever and Ali Fuat Boz*

Department of Electronics, Faculty of Technical Education, Sakarya University, Esentepe Campus, 54187-Sakarya, Turkey.

Accepted 15 April, 2010

In the literature, many studies are conducted to obtain the mathematical models of semiconductor elements such as diodes, transistors, etc. These elements are commonly used in the circuits and systems. Main objective in this subject is to establish a mathematical model (or expression) to describe all the features of the semiconductor circuit elements. One of the most popular circuit elements is a diode. A general diode equation, which is commonly used in the solid-state physics literature, uses the diode leakage current, temperature values and material dependant coefficients other than the diode voltage. Major factor to get results as close as possible to actual results using this equation is to obtain the leakage current accurately. Otherwise, error in the results will be unacceptable. Therefore, in this study, a work has been carried out to obtain acceptable reverse saturation currents (or leakage currents) of a diode using three different methods, which are least squares, neural network and genetic algorithm. In addition, a new mathematical model of a semiconductor diode has been also proposed. This model is created using the actual measured diode current-voltage values. The new model is not using the diode leakage current, ambient temperature or coefficients of the diode construction materials. To obtain the diode characteristics using the above mentioned methods, a graphical user interface program has been also designed. The simulation/experimental results are obtained and compared using this program. By this way, validity of the proposed approximate model and other methods are proved.

Key words: Diode, least square, neural network, genetic algorithm.

INTRODUCTION

With the development of semiconductor technology, there have been major changes in circuit elements as well. Diodes, bipolar transistors and field effect transistors, which have PN junctions, are major semiconductor circuit elements and they are widely used in many applications. However, it is very difficult to obtain the mathematical models of such elements. In the literature many studies have been conducted in this direction and as a result of this, various models for the semiconductors have been proposed.

One of the basic devices in electronics circuits is the p-n junction diodes. On the other hand, many of other electronic devices are basically variations of a simple p-n junction diode. Such as photo diodes, light emitting diodes, zener diodes, Schottky diodes etc. Therefore, it is very important to develop the diode characteristics not just for a p-n junction diode but also for all other device variations.

After the developments of artificial neural networks and genetic algorithms, these techniques were also applied in the modeling and simulation fields. In the literature, many studies are carried out for the semiconductor circuit elements using artificial neural networks and genetic algorithms (Liang et al., 2008; Keser and Joardar, 2000;

*Corresponding author. E-mails: fahriv@sakarya.edu.tr, afboz@sakarya.edu.tr. Tel: +90.264.2956451. Fax: +90.264.2956424.

Abbreviations: LE, Least squares; **NN,** neural network; **GA,** genetic algorithm.

Almashary, 2005; Menozzi et al., 1996). As it is known, general diode current-voltage characteristics are given as a simple equation which consists of the diode saturation or leakage current, diode voltage, ambient temperature and constructed semiconductor material dependant coefficients. One of the major factors to collect the diode current-voltage characteristics as close as possible to actual results is dependant to accuracy of the diode saturation current. Thus, it is very important to obtain acceptable diode saturation current. As a solution of this, three different methods are presented in this study to obtain or calculate the reverse saturation current of a diode. These methods are the Least Squares (LE), Neural Network (NN) and Genetic Algorithm (GA) methods. Furthermore, a new mathematical model for a semiconductor diode current-voltage characteristic has been also proposed. This model is formed by using the measured actual diode current-voltage values. Actually, new model does not use the diode leakage current, ambient temperature or coefficients of the construction materials. Therefore, it is very easy and practical to use it in the calculations. A graphical user interface program has been also designed to obtain the diode current-voltage characteristics using the above mentioned least squares, neural network, genetic algorithm and proposed approximate model based methods. Various simulations were carried out using the designed interface program and the obtained results were compared as well.

The paper is organized as follow. In the sections 2 - 5, general diode current-voltage characteristic equation, the least squares method, artificial neural network and genetic algorithms are summarized, respectively. In the section 6, the proposed approximate model is presented and with the other three models based simulation results are given comparatively. Finally, conclusion and future work are presented in the seventh section.

MATERIALS AND METHODS

Materials

The diode

Structurally, diodes are simplest elements of the semiconductors and they are often used in many applications. Basically, a p-n junction diode behaves like a switch, such as it conducts current when it is forward biased and it does not conduct when it is reverse biased. General equation of a diode current in the solid state physics can be given as follows;

$$i_d = i_s\left(e^{k.v_d/T_k} - 1\right) \tag{1}$$

where, i_s is the reverse saturation current, T_k is the absolute temperature in ^{o}K and $k = \frac{11600}{\eta}$ with $\eta = 1$ for Germanium (Ge), $\eta = 2$ for Silicon (Si) for relatively low levels of diode current (i_d), $V_D < V_T$, and $\eta = 1$ for Si for relatively high levels of diode current, $V_D \geq V_T$, where, V_T is the threshold voltage of a diode (Boylestad and Nashelsky, 1999).

The least squares method

In today's science world, many data are obtained from the applied science experiments and observations. Various methods are used for making these data useful by using fitting in the most appropriate function (curve fitting) or calculating the intermediate values of the data (interpolation). One of the most effective curve fitting methods is the least squares method. The least squares method is based on minimize sum of the squared differences between the approximate fitted function and the real function values. If the real function is $y = f(x)$ and the approximate fitted function is $z = g(x)$, then, using n known (measured) data points values to minimize,

$$e = \sum_{i=1}^{n}\{g(x_i) - f(x_i)\}^2 \tag{2}$$

error function yields the coefficients of $z = g(x)$ function. For minimizing the error or the differences, first derivative of the error function should be made of equal to zero (Vatansever, 2006; Burden and Faires, 1997).

The neural network

Artificial intelligence is such a science that covers and aims machines to gain human being characteristics such as learning, understanding, association, solving problems, deciding and abstract thinking, drawing conclusion from the interaction with the environment and establishing good communication skills. Most popular artificial intelligence techniques are artificial neural networks, fuzzy logic, expert systems and genetic algorithms, which introduce different solutions to the problems and they are based on to achieve the intended results imitating the human like characteristics.

Artificial neural networks have many advantages such as learning, generalization, verification, being non-linear, fault tolerance, adaptation and paralleling and they are used in different application areas such as engineering, medicine, manufacturing, finance, optimization, classification and forecasting (Nabiyev, 2005; Sagiroglu et al., 2003; Elmas, 2003; Mathworks, 2007). The block diagram of artificial neural structure, which is developed based on the biological neural structures (Figure 1a), are shown in Figure 1b.

Moreover, comparison or matching of the biological neural with the artificial neural is located in Table 1. As it was shown in Figure 1b, inputs are summed after multiplying them with the weights. So, the output function of the summing,

$$v_i = \sum_{i=1}^{n}\{w_{ij}x_i + \theta_j\} \tag{3}$$

is applied to the activation function and then the output is obtained. Some of the most commonly used activation functions are linear, sigmoid and hyperbolic tangent functions (Nabiyev, 2005; Sagiroglu et al., 2003; Elmas, 2003; Mathworks, 2007). Artificial neural networks are classified according to architecture as:

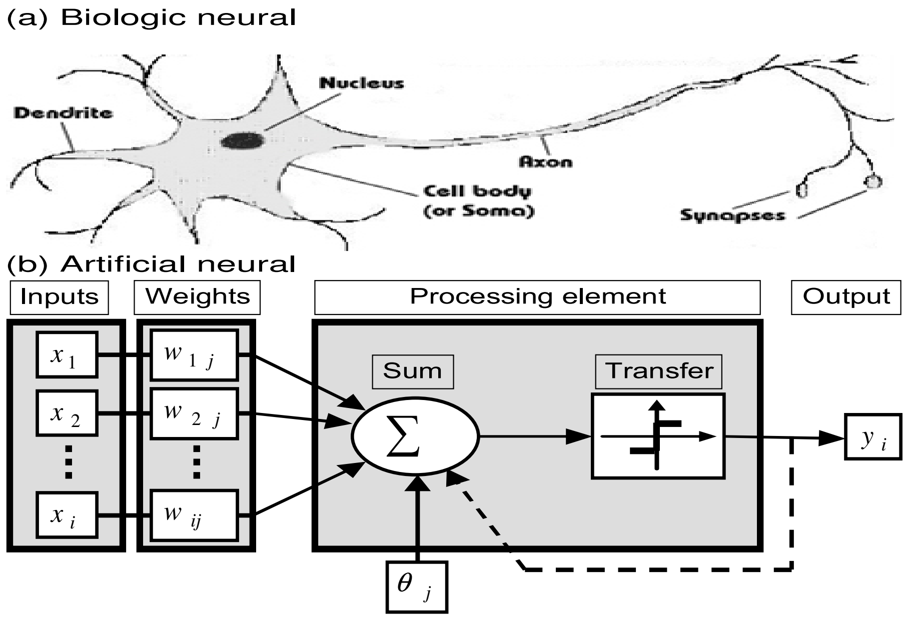

Figure 1. Structures of (a) biologic and (b) artificial neural.

Table 1. Matching the structures of biologic and artificial neural.

Biologic neural system	Artificial neural system
Neuron	Processing element
Dendrite	Sum function
Cell body (or soma)	Transfer/activation function
Axon	Output
Synapse	Weight

(i) Forward-feeding.
(ii) Feedback.

According to the learning approach as:
(i) Supervised,
(ii) Unsupervised,
(iii) Reinforcement.
As a learning rule,
(i) Hebb rule,
(ii) Hopfield law,
(iii) Kohonen learning law,
(iv) Delta rule
are used (Nabiyev, 2005; Sagiroglu et al., 2003; Elmas, 2003, Mathworks, 2007).

The genetic algorithm

Basically, the genetic algorithms (GA) are based on the life/evolution process experiences of the living creatures in nature. In this process, good / strong generations or in other words, the generations that are best suited to the life conditions can survive, the bad/weak generation is not. By modeling of these biological processes in nature, the genetic algorithms, which have solutions with probabilities and iterations, were emerged.

Genetic algorithms are first developed in 1975 by John Holland. GA is a heuristic search technique that use random search techniques to find solutions based on encoding parameters.

Optimization problems, automatic programming and information systems, machine learning and economics are the main application areas of genetic algorithms (Nabiyev, 2005; Elmas, 2003; Mathworks, 2007; Goldberg, 1989). In the genetic algorithms, the possible solutions of the problems are held in the comprised of *genes* in the chromosomes. The population comprises by accumulating a lot of chromosomes. Generally, operation of the genetic algorithms (Figure 2) is as follows (Nabiyev, 2005; Elmas, 2003; Mathworks, 2007; Goldberg, 1989):

(i) Forming the initial populations: the initial population is created from the chromosomes that indicate the possible solution of the problem. Generally, the creation of this is random and often recommended to made up of 30 - 100 individuals
(ii) Calculation of the adaptation values: An Adaptation value of each chromosome in the population is calculated. Being high in this value, it maintains the assets of chromosome in the population and strengths to transfer its properties to the new generations.
(iii) Termination/sensitivity criteria:

(a) If the termination criterion is provided: GA is terminated and the chromosome, which has highest adaptation value, is selected as a solution.
(b) If the termination criterion is not provided: By using the GA operators (diagonally, mutation), new generations are created from the parents in the existing population. Then, new population (next generation) is produced with the selection mechanisms. It will be continued to iterate like this way.

Methods

In the performed work, the diode current-voltage characteristics are obtained using the three different methods. Also, reverse biased diode saturation currents, which are used in the general diode equation to calculate the diode characteristics are obtained using the least squares, artificial neural networks and genetic algorithms

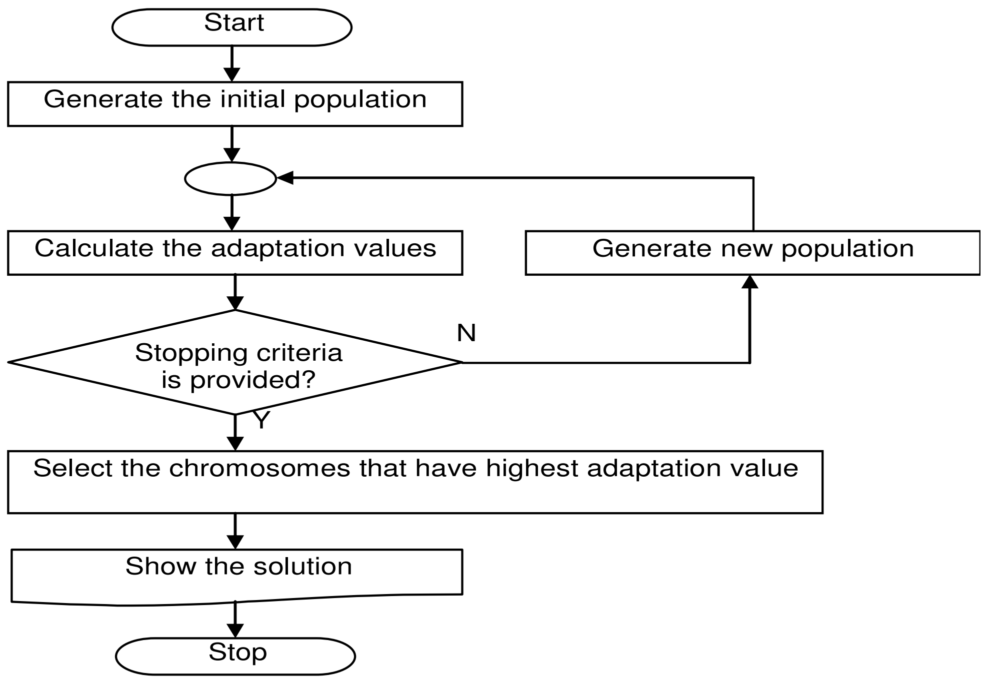

Figure 2. Overall functioning in the GA.

methods. Furthermore, a simplified new model of a diode is proposed, so the number of the parameters in the general diode equation is reduced. Then, the resulted diode characteristics are compared. These characteristics are obtained first using the proposed approximate model then using the general diode equation for three different methods with conjunction to the obtained saturation currents.

The least squares method to obtain the leakage current is as follow. Designed program uses the Equation 5 for calculating the reverse side leakage current for the least square method. If the least square method is used for calculating the leakage current in the diode equation, then, the following error function is obtained.

$$i_d = i_s\left(e^{k.v_d/T_k} - 1\right) \tag{4}$$

$$Ln(i_d) = Ln\left(i_s\left(e^{k.v_d/T_k} - 1\right)\right) \tag{5}$$

$$Ln(i_d) = Ln(i_s) + Ln\left(e^{k.v_d/T_k} - 1\right) \tag{6}$$

$$H(i_s) = \sum_{i=1}^{n}\left\{Ln(i_s) + Ln\left(e^{k.v_d/T_k} - 1\right) - Ln(i_d)\right\}^2 \tag{7}$$

By minimizing this function,

$$\frac{dH(i_s)}{di_s} = 2\sum_{i=1}^{n}\left\{Ln(i_s) + Ln\left(e^{k.v_d/T_k} - 1\right) - Ln(i_d)\right\}\frac{1}{i_s} = 0 \tag{8}$$

$$Ln(i_s) = \frac{1}{n}\left\{\sum_{i=1}^{n}Ln(i_d) - \sum_{i=1}^{n}Ln\left(e^{k.v_d/T_k} - 1\right)\right\} \tag{9}$$

$$i_s = e^{\frac{1}{n}\left\{\sum_{i=1}^{n}Ln(i_d) - \sum_{i=1}^{n}Ln\left(e^{k.v_d/T_k} - 1\right)\right\}} \tag{10}$$

is obtained.

Proposed diode current-voltage characteristic equation is given in Equation 11.

$$i_d = \alpha.e^{\beta.v_d} \tag{11}$$

Steps to form the proposed approximate model are given as follow.

First of all, to calculate the α and β values from the n measured or known current (i_d)-voltage (v_d) values by using them in the least squares method, linearization of the model is required.

$$\begin{aligned} Ln(i_d) &= Ln\left(\alpha.e^{\beta.v_d}\right) \\ &= Ln(\alpha) + Ln\left(e^{\beta.v_d}\right) \\ &= Ln(\alpha) + \beta.v_d \end{aligned} \tag{12}$$

So that the error function takes the form as follow :

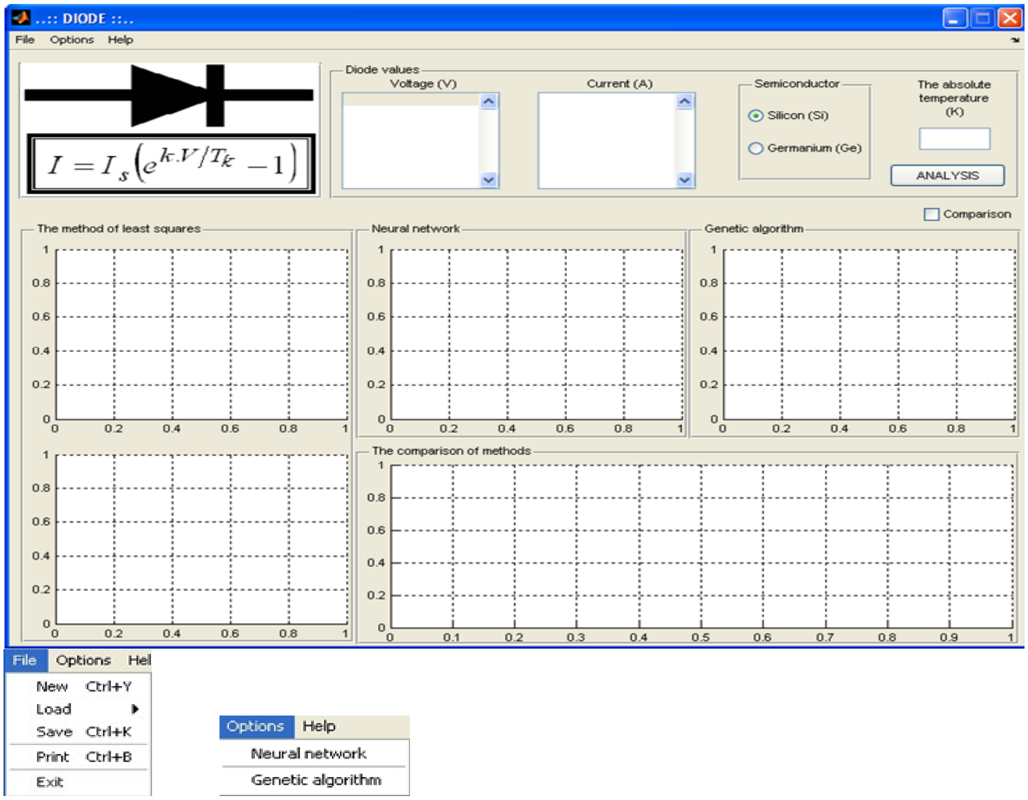

Figure 3. Screenshot of the designed program.

$$H(\alpha,\beta)=\sum_{i=1}^{n}\left\{Ln(\alpha)+\beta.v_{d_i}-Ln\left(i_{d_i}\right)\right\}^2 \tag{13}$$

Taking its partial derivatives and then equating to the zero yields

$$\frac{\partial H(\alpha,\beta)}{\partial\alpha}=2\sum_{i=1}^{n}\left\{Ln(\alpha)+\beta.v_{d_i}-Ln\left(i_{d_i}\right)\right\}\frac{1}{\alpha}=0$$

$$\frac{\partial H(\alpha,\beta)}{\partial\beta}=2\sum_{i=1}^{n}\left\{Ln(\alpha)+\beta.v_{d_i}-Ln\left(i_{d_i}\right)\right\}v_{d_i}=0 \tag{14}$$

$$\begin{bmatrix} n & \sum_{i=1}^{n} v_{d_i} \\ \sum_{i=1}^{n} v_{d_i} & \sum_{i=1}^{n} v_{d_i}^2 \end{bmatrix}\begin{bmatrix} Ln(\alpha) \\ \beta \end{bmatrix}=\begin{bmatrix} \sum_{i=1}^{n} Ln\left(i_{d_i}\right) \\ \sum_{i=1}^{n} v_{d_i}.Ln\left(i_{d_i}\right) \end{bmatrix} \tag{15}$$

Then,

$$\alpha=e^{\frac{\begin{vmatrix} \sum_{i=1}^{n} Ln\left(i_{d_i}\right) & \sum_{i=1}^{n} v_{d_i} \\ \sum_{i=1}^{n} v_{d_i}.Ln\left(i_{d_i}\right) & \sum_{i=1}^{n} v_{d_i}^2 \end{vmatrix}}{\begin{vmatrix} n & \sum_{i=1}^{n} v_{d_i} \\ \sum_{i=1}^{n} v_{d_i} & \sum_{i=1}^{n} v_{d_i}^2 \end{vmatrix}}} \tag{16}$$

and

$$\beta=\frac{\begin{vmatrix} n & \sum_{i=1}^{n} Ln\left(i_{d_i}\right) \\ \sum_{i=1}^{n} v_{d_i} & \sum_{i=1}^{n} v_{d_i}.Ln\left(i_{d_i}\right) \end{vmatrix}}{\begin{vmatrix} n & \sum_{i=1}^{n} v_{d_i} \\ \sum_{i=1}^{n} v_{d_i} & \sum_{i=1}^{n} v_{d_i}^2 \end{vmatrix}} \tag{17}$$

are calculated.

To use these formulae and the other methods, a graphical user interface program is designed in the MATLAB (Mathworks, 2007). By using the program, where its screenshot and menus are shown in Figure 3, and loading the measured / simulated values of the diode characteristics, calculations are performed using the specified criteria and the results are given both individually and as a comparative graphics. Moreover, the results can be saved numerically and graphically using the program. So that performance of the methods can be observed interactively and instantly. In addition, the program accepts measurable data as well as it can produce the simulation data by itself. In the artificial neural networks section, loaded data are taught to artificial neural network by entering/selecting the data using the network type, training function, adaptation learning function, performance function and numbers of layers options of the program window menu, which is shown in Figure 4.

Similarly in the genetic algorithm section, the appropriate reverse side leakage current is calculated from the loaded data, which can

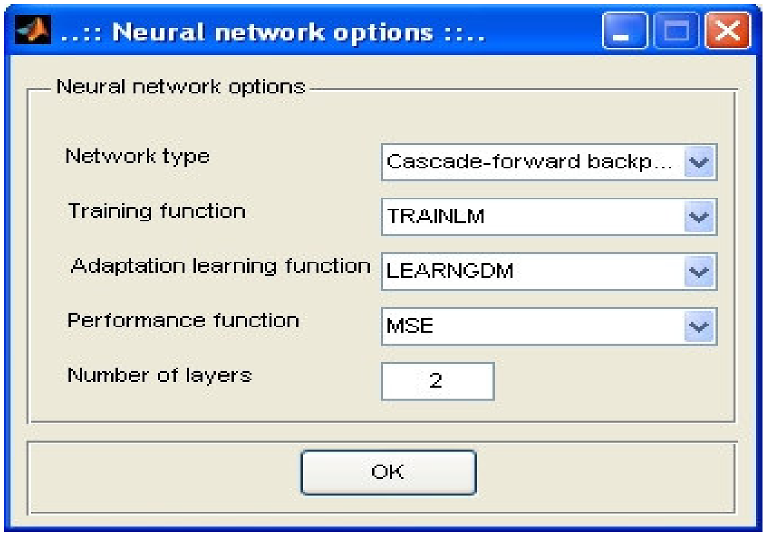

Figure 4. Artificial neural network window.

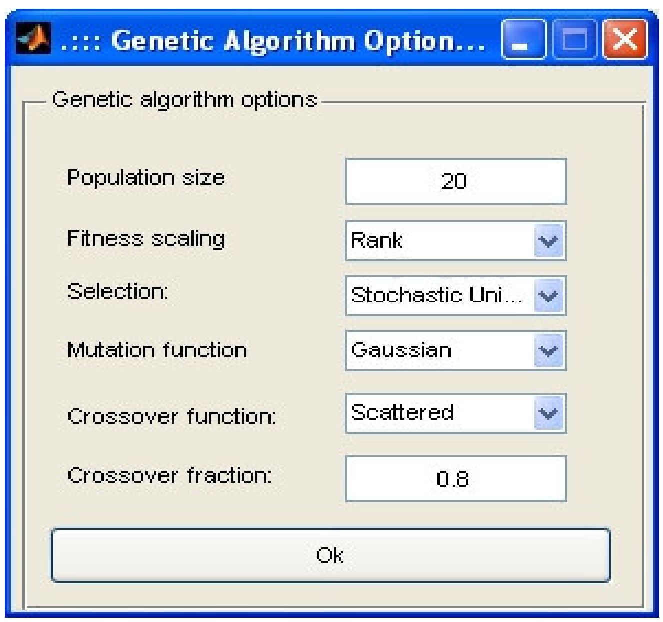

Figure 5. Genetic algorithm window.

be entered / selected using the population size, fitness scaling, selection, mutation function, crossover and crossover fraction options of the program window menu shown in Figure 5. Design steps of the presented and proposed methods are summarized in the block diagrams in Figure 6, respectively.

RESULTS

For first simulation, results window of a Si diode, which has a leakage current of 1 μA at room temperature of 25˚C, is shown in Figure 7. As a second simulation, the characteristics of a widely used 1N4001 diode are obtained using its measured current-voltage values in the proposed and other three methods as shown in Figure 8. In addition to this, absolute error values of the diode currents are given in Figure 9 comparatively for this simulation. As shown in Figure 9 that, Neural Network based approach has been considerably affected from the learning and thus, it may yield different or relatively large scale errors. On the other hand, the error values in the other three approaches are very small and they are changing linearly.

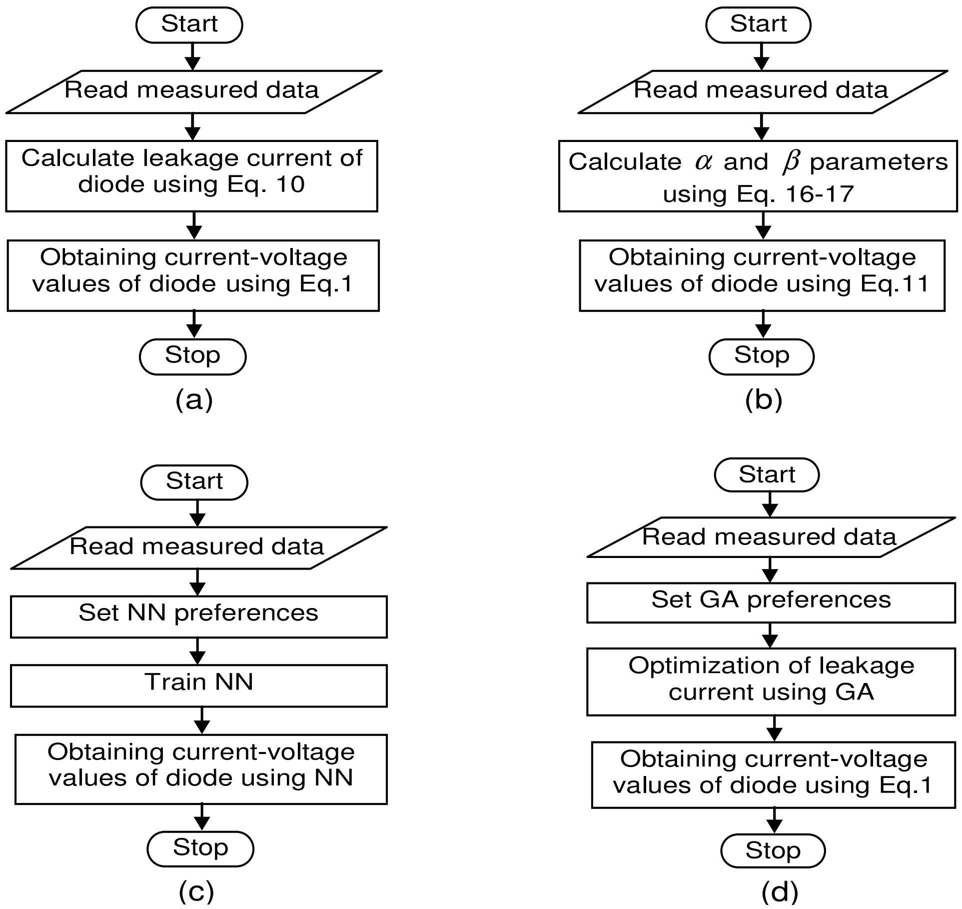

Figure 6. Block diagrams of (a) LE approach for general diode equation (b) LE for proposed approximate model (c) NN approach (d) GA approach.

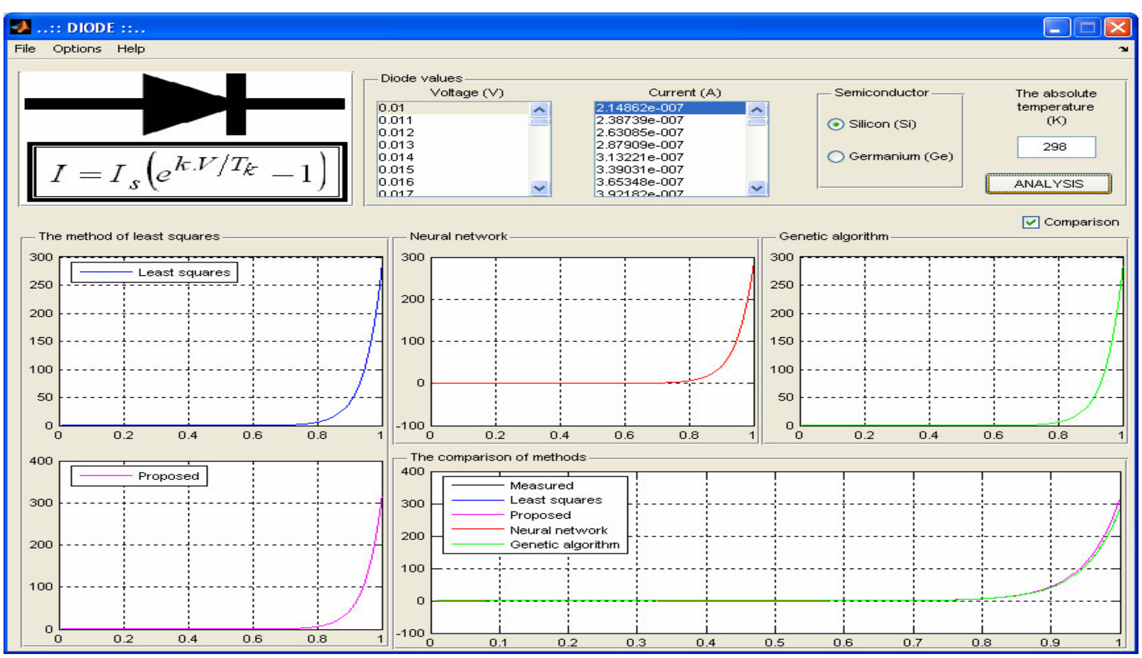

Figure 7. Screenshot for first simulation.

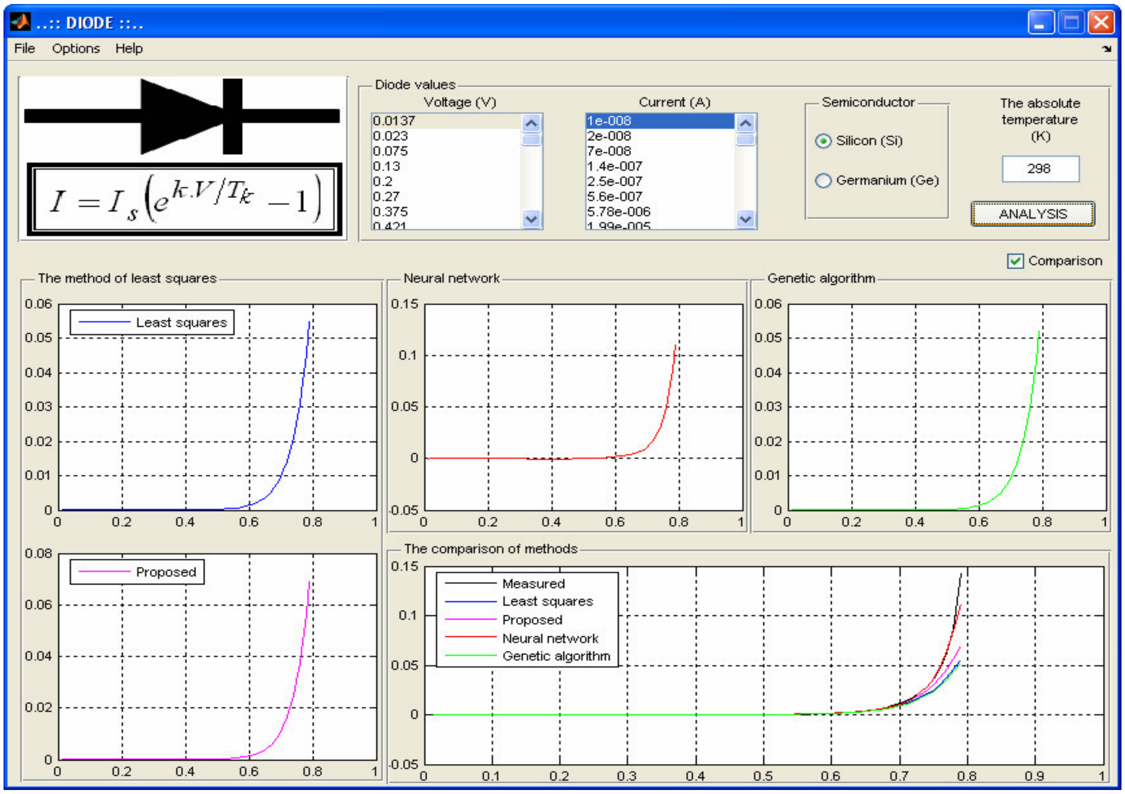

Figure 8. Screenshot of the second simulation for 1N4001 diode.

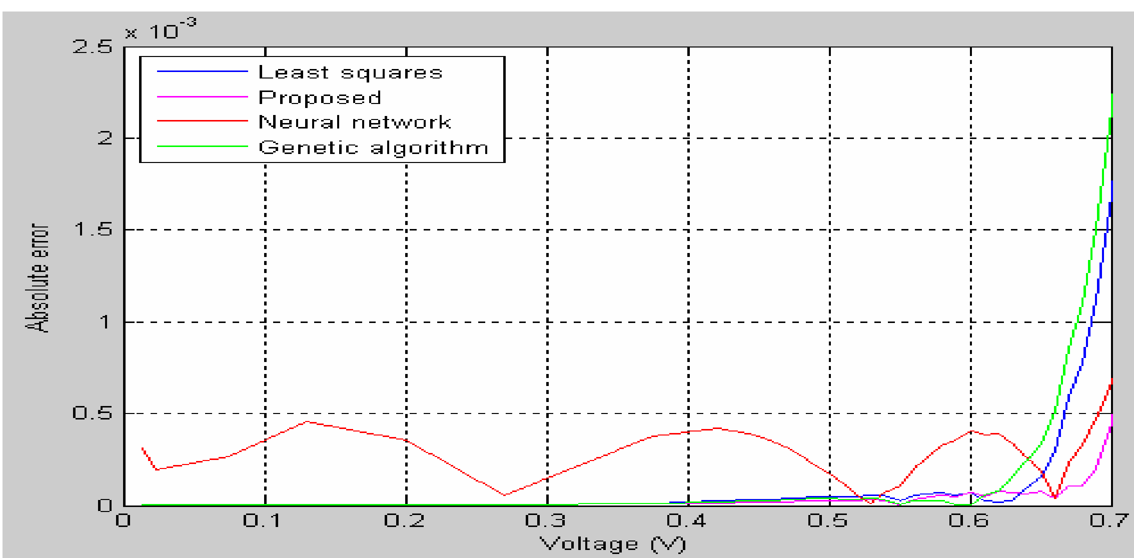

Figure 9. Absolute errors of the second simulation for 1N4001 diode.

DISCUSSION

In this study, three different methods, which are the least squares, artificial neural networks and genetic algorithms methods have been used to calculate the diode leakage currents. Then, these currents are used in the general diode equation to obtain different diode current-voltage characteristics. Also, a simplified diode equation has been proposed to compare the resulted characteristics with other three methods. Furthermore, a graphical user interface is designed to calculate or obtain the diode characteristics using the different methods. By using this interface and the mentioned methods, obtained results were compared as well. Also, it has been shown in the work that the general diode equation can be obtained effectively, efficiently and easily from the measured data by simulating / using the designed program. Moreover, effect of the parameter / method changes of the artificial neural network and genetic algorithm methods for the results can be observed comparatively at the program results. As a future work, obtaining the other semiconductor devices' characteristics (or equivalent circuit models) using these techniques (artificial neural network, genetic algorithm, least square method, Lagrange interpolation method and etc.) can be realized. Also, new approximate models can be proposed to obtain the characteristics of other semiconductor devices.

REFERENCES

Almashary BA (2005). Genetic algorithm based diode model parameters extraction. J. King Saud Univ. Eng. Sci. (2)18: 249-260.
Boylestad R, Nashelsky L (1999). Electronic Devices and Circuit Theory. Prentice Hall, New Jersey, USA.
Burden RL, Faires JD (1997). Numerical Analysis. Sixth Edition. Brooks/Cole Publishing Company, USA.
Elmas C (2003). Artificial Neural Networks. Seckin Yayincilik, Ankara, Turkey.
Goldberg DE (1989). Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley Publishing Company Inc.,USA.
Keser M, Joardar K (2000). Genetic algorithm based MOSFET model parameter extraction. MSM 2000, Motorola SPS, USA. Pp. 341-344.
Liang A, Xu Y, Jia S, Sun G (2008). Neural networks for nonlinear modeling of microwave Schottky diodes. ICMMT 2008, Nanjing pp. 558-561.
Menozzi R, Piazzi A, Contini F (1996). Small-Signal Modelling for Microwave FET Linear Circuits Based on a Genetic Algorithm. IEEE Transactions on Circuts and Systems-I: Fundamental Theory and Applications 43 (10): 839-847.
Nabiyev VV (2005). Artificial Intelligence. Seckin Yayincilik, Ankara, Turkey.
Sagiroglu S, Besdok E, Erler M (2003). Artificial Intelligence Applications in Engineering-I: Artificial Neural Networks. Ufuk Kitap Kirtasiye-Yayincilik, Kayseri, Turkey.
The MATLAB (2007). Neural Networks and Genetic Algorithm and Direct Search Toolbox. The Mathworks Inc.
Vatansever F (2006). Advanced Programming Applications. Seckin Yayincilik, Ankara, Turkey.