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Prediction of the Breakdown Voltage of n-GaN Schottky diodes at High Temperatures using Online Neural Network Analysis

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Abstract: Variation of the Breakdown Voltage of n-GaN Schottky diodes over Temperature range (300-900 K) were predicted using online backpropagation neural analysis, based on the existing Sze and Monemar models. The results obtained show that the Breakdown Voltage of n-GaN Schottky diodes do not decrease rapidly with temperature increase, which is in agreement with the experimental results by Cao and earlier calculations using electronic calculator by Alade and Akande. Very high Breakdown Voltage (V_{BD}>2 kV) is possible. The device can be useful to achieve stable electronic systems (solar panels, amplifiers and mixers) operating at high temperature.

Key words: High temperature, breakdown-voltage, n-GaN schottky diodes, neural network analysis, prediction

INTRODUCTION

Schottky diode, a metal-semiconductor junction diode with no depletion layer has become an important element in microwave amplifiers, microwave frequency converter (mixer) for modern communication (satellite) and radar applications. It has been applied as Field Effect Transistor (FET) gate, Transistor Transistor Logic (TTL) gates; the electrodes for high-power oscillators; photodetectors and solar cells. Its choice for most applications rests on the fact that it is a majority carrier device. The study review carried out shown that despite different types of Schottky diodes such as Si, Ge and even GaAs investigated and employed as amplifiers and mixers to provide better performance, it has proven difficult to achieve stable electronic systems (solar cells, amplifiers and mixers) at high temperatures (Sze, 1981; Morkoc *et al.*, 1999).

It is well know that the modern circuits are multifunctional-such as integrated circuit IC, System on Chip (SOC) and System on Package (SOP). As a result, the constituent components in the electronic system generate heat and the resultant heating effect may be so much that the constituent components breakdown performances could be affected. For instance, the Schottky diode's parameters such as barrier height, breakdown voltage V_{BD}, current, capacitance, junction resistance, current sensitivity and conversion loss, which are recognized as determinants of the performances of the device, may be affected by the temperature increase (i.e., heating in the systems) (Shurmer, 1971). A question now arises: Is it possible to get Schottky diodes that will offer better performance in the presence of harsh temperature condition?

Consequently, in this study, the n-GaN Schottky diode is suggested for use in the modern electronic circuitry systems (solar cells, microwave amplifiers and mixers) because of its reported superior properties (particularly thermal stability) to the existing devices (Morkoc *et al.*, 1999; Cao *et al.*, 1999; Dang *et al.*, 2000). The effect of high Temperature (T) (from 300-900 K) on, one of the device's important parameters, the Breakdown Voltage, V_{BD}, is investigated using backpropagation neural network analysis, based on the existing Sze and Monemar models (Alade and Akande, 2004). The detail theoretical and modeling of n-GaN Schottky diodes' Breakdown Voltage are still lacking in the literatures. The few experimental reports available only described the variations of n-GaN Schottky diodes' V_{BD} with limited Temperature ranges of 273 K to about 310 K (Sze, 1981; Morkoc *et al.*, 1999; Cao *et al.*, 1999).

In recent years, one of the most important and promising modeling and simulation research fields is the neural network technique (Seda, 2005). It is scientific approach to use natural (biological) inspiration to device computing architectures that can perform useful tasks. It is an efficient and economical method that has been used to design microwave semiconductor devices (Materka and Kacprzak, 1985). The development of high performance n-GaN Schottky diode requires accurate

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modeling, adequate analysis and optimization of the device in terms of its parameters. This could be expensive experimentally. However, in this research, the neural network approach employed has minimized the need for expensive and exhaustive experimental trials and thereby reduced time factor. It is more accurate and reliable method than statistical modeling, namely, the least square regression analysis where, underlying data distribution is assumed.

In this research, data where generated from the existing physics model (Eq. 1) (Alade and Akande, 2004) and trained by backpropagation 3-layer perceptron, online Neural Networks (NN) (Zhang and Gupta, 2000). The Breakdown Voltage/Temperature (V_{BD}/T) online neural model obtained for n-GaN Schottky diode agreed favorably with the available experimental results, in Cao *et al.* (1999), at the temperature ranges of 273-310 K. The V_{BD}/T model obtained for n-GaN Schottky diode is used to predict the effect of high Temperature (T) (300-900 K) on the Breakdown Voltage of the device. The online neural V_{BD}/T model obtained will be a very useful tool for the analysis and optimization of the device.

MATERIALS AND METHODS

The n-GaN Schottky diode's breakdown voltage is modeled in terms of temperature using neural networks technique for the device optimization. The first step for neural networks modeling is to ensure that data are available for neural network training (Zhang and Gupta, 2000). Data can be generated experimentally and by simulation of the physics models. In this research, data were generated by simulation method because, it is very expensive to generate data experimentally in this area of research.

The breakdown voltage V_{BD} expression used in this research is given by Alade and Akande (2004):

$$V_{BD} = 60\left[3.1845 + \frac{4.6182\times10^{-4}T^2}{T-996}\right]^{\frac{3}{2}}\left(\frac{N_D}{10^{16}}\right)^{-\frac{3}{4}} \quad (1)$$

N_D is the optimized background doping concentration for n-GaN Schottky diode and it is equal to $1\times10^{17}cm^{-3}$ (Morkoc *et al.*, 1999; Cao *et al.*, 1999; Dang *et al.*, 2002).

One hundred and twenty five samples of V_{BD} data were generated ($301 \le T \le 425$, step 1) from the original physics model (Eq. 1) of the devicee by simulation method using visual basic 6.0 program compiler. For the neural network modeling, the input vector contains the background doping concentration N_D (process parameter), a constant in this case and the temperature T (physical parameter), a variable. The data were trained using backpropagation 3-layer perceptron, (an input layer, one hidden layer and an output layer), online neural networks with the aid of MATLAB 6.5 version neural toolbox. Backpropagation refers to an iterative procedure whereby, the error between the neural response and the corresponding target of the breakdown voltage of n-GAN Schottky diode is feedback and used to adjust the weight parameter w of the V_{BD}/T neural model until the model responses agree with the targets (i.e., the performance function, Mean Square Errors (MSE) $\rightarrow$ 0) under the predetermine condition (set goal). Figure 1 shows, the structure of the model. The transfer function σ employed for the hidden layer is sigmoid, while linear function is used to activate the output layer. The bias b is applied in order to reduce the effect of the oscillation. The trained model $V_{BD(N)}$ = f(T,w) for the n-GaN Schottky diode was tested with the same data sets used for the training and also validated with the available experimental measured data from Cao *et al.* (1999). The performance of the model was measured by the errors between the neural model responses and the corresponding targets using the Mean Square Errors (MSE) and the post regression analysis (Table 1).

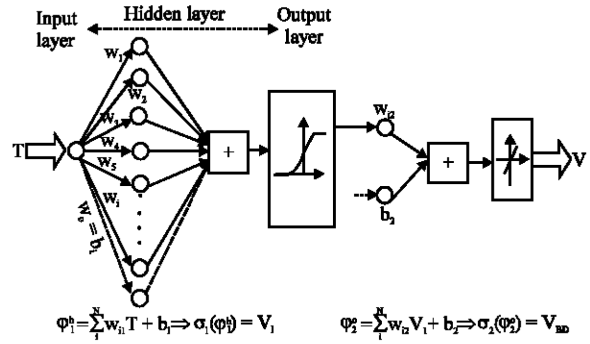

Fig. 1: Structure of the V_{BD}/T neural model for n-GaN Schottky diode

Table 1: Model performance

Temperature range (K)	Simulation type	Goal	Performance (MSE)	R-values	χ-values
301-425	Training	0.01	0.00553106	-	-
301-425	Test	0.01	0.00553106	0.983	1
273-310	Validation	0.01	0.00553106	0.963	1
300-900	Prediction	0.01	0.00927651	-	-

RESULTS AND DISCUSSION

Figure 2 shows the training response of the V_{BD}/T neural model for n-GaN Schottky diode. The performance function (MSE) decreases rapidly and the set goal is met after 15 iterations, when the MSE is 0.00563106.

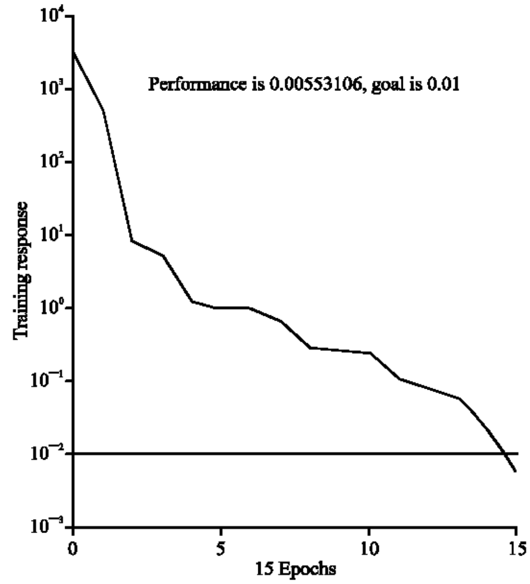

Fig. 2: Training performance response

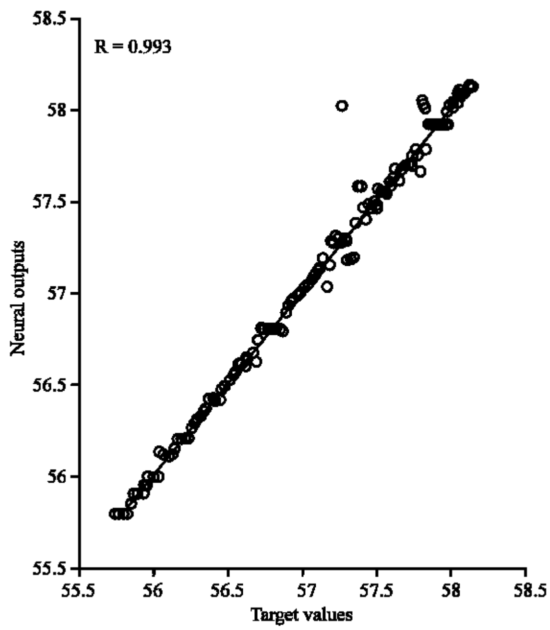

Fig. 3: Regression curve of the test set

Figure 3 and 4 show the regression curves of the test and validation sets, respectively for the model. In both cases, the correlation coefficients of determination (R-values) and χ-values are very close to unity (Table 1). That is, the best fit of theory to experiment is obtained.

Figure 5 shows that there is good agreement between the variations of the desired values, neural outputs and experimental measured values of V_{BD} with the temperature rise.

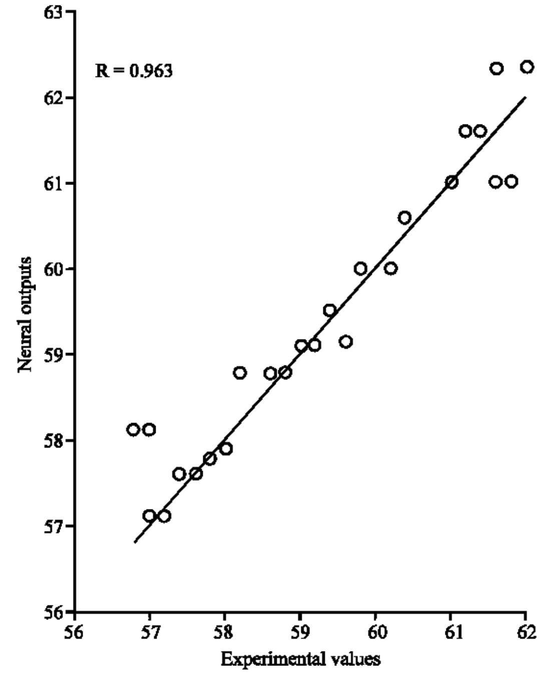

Fig. 4: Regression curve of validation set

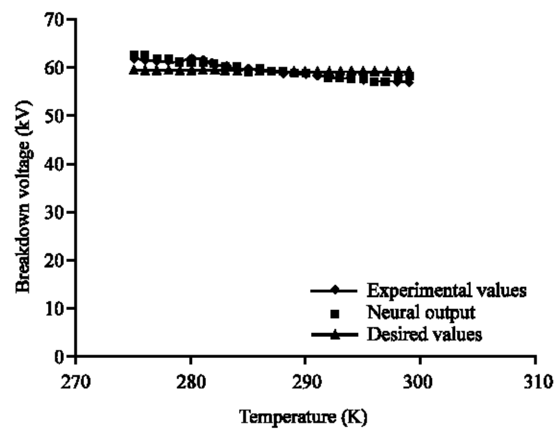

Fig. 5: Graph of the neural outputs, desired values and experimental values against the temperature

Figure 6 shows the V_{BD}/T neural model prediction performance response. The performance function decreases rapidly until the set goal is met after 14 iterations, when the minimum MSE of 0.00927651 is obtained.

The result of the V_{BD}/T neural model prediction of the effect of the temperature rise from 300-900 K on the n-GaN Schottky diode's breakdown voltage is displayed in the Fig. 7.

The V_{BD} decreases with the temperature increase, but the decrease is not linear. At very high temperature,

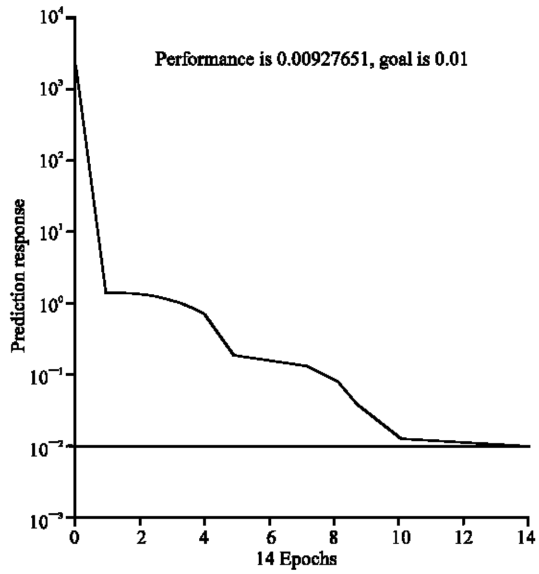

Fig. 6: V_{BD} neural model prediction response

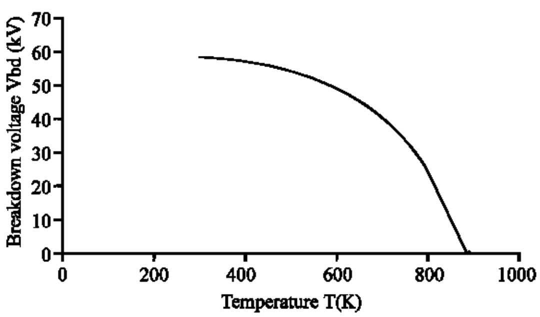

Fig. 7: Prediction result of V_{BD}/T neural model of n-GaN Schottky diode showing the effect of temperature rise from 300-900 K on the breakdown voltage of the device

above 800 K, very high Breakdown Voltage, >2 kV is possible, which is in agreement with Cao *et al.* (1999) and Dang *et al.* (2000).

CONCLUSION

The electronic devices that can operate under harsh temperature condition are required in order to reduce the ageing effect and thermal noise due to temperature rise and increase the efficiency of modern electronic systems. The results obtained, in this research, indicate that the breakdown voltage of n-GaN Schottky diode does not degrade with temperature rise. The study revealed that very high V_{BD} (>2 kV) is possible for the n-GaN Schottky diode at room temperature and above. The device can be employed as solar cells, low noise amplifiers and mixers.

Appendix: Program for data generation

```
Private Sub Command1_Click()
Dim E, T, n, V As Single
Dim strB, strE, strM As String
'strB = "T = "
strE = "  " 'and "V = "
n = 1E+17
For T = 275-425
E = Abs (3.503 + ((0.000508 × T × T) / (T - 996)))
V = 60 × ((E / 1.1) ^ (1.5)) × ((n / 1E+16) ^ (-0.75))
'strM = strM and strB
'strM = strM and CStr(T)
strM = strM and strE
strM = strM and V and vbCrLf
txtdisplay.Text = strM
Refresh
Next T
End Sub
```

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