

Temperature Dependence of Breakdown Voltage in Silicon Abrupt p-n Junctions

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Abstract

Temperature dependence of breakdown voltage in silicon abrupt p+n junction has been calculated using a modified Baraff theory¹⁻³ and measured experimentally from 77°K to 500°K, and with the substrate doping from 10^{15} cm^{-3} to 10^{18} cm^{-3} .

Experimental data are in good agreement with the results of the theoretical calculations. These results strongly substantiate the validity of the modified Baraff theory which has been pointed out by Sze and Cowell.

General Description

The breakdown mechanism is one of the most important phenomena in semiconductor junctions. Not only it is a limitation of the reverse bias condition, it also plays important role in IMPATT, TRAPATT and avalanche photodiode. Based upon the modified Baraff theory¹⁻³, the present work calculates the temperature dependence of breakdown voltage and its temperature coefficient at various background doping and temperatures, which were also verified by experiments.

In dealing with the breakdown phenomena, let's consider the optical phonon mean free path firstly which has been given by Crowell and Sze (3) as follow,

$$\lambda = \lambda_0 \tanh (\langle E_p \rangle / 2KT) \quad (1)$$

and

$$\langle E_p \rangle = E_p \tanh (E_p / 2KT) \quad (2)$$

where E_p is the optical phonon energy. For silicon, $E_p = 0.063 \text{ eV}$, and $\lambda_0 = 76 \text{ \AA}$ for electron and $\lambda_0 = 55 \text{ \AA}$ for hole respectively⁴.

The parameters λ and $\langle E_p \rangle$ which can be fitted to the Baraff equa-

tion and thus the ionization rates for electron and hole can be obtained. It can be seen obviously that the ionization rate are of temperature dependence and thus the breakdown voltage is also. The measurement of ionization rathe in Si, Ge, GaAs and GaP at various temperature has been made by several authors³⁻⁶.

Result

At breakdown condition, the ionization rates have the following relationship,

$$\int_0^W \alpha_p \exp \left[- \int_0^X (\alpha_p - \alpha_n) dx' \right] dx = 1 \quad (3)$$

In incorporated with the temperature variation of band gap and also based upon Eq. (3) the breakdown voltages at various temperature and doping concentration are obtained and shown in Fig. 1, that of temperature coefficient is shown in Fig. 2. For $N > 10^{18} \text{ cm}^{-3}$, the mechanism is due to tunneling⁷ and not included here.

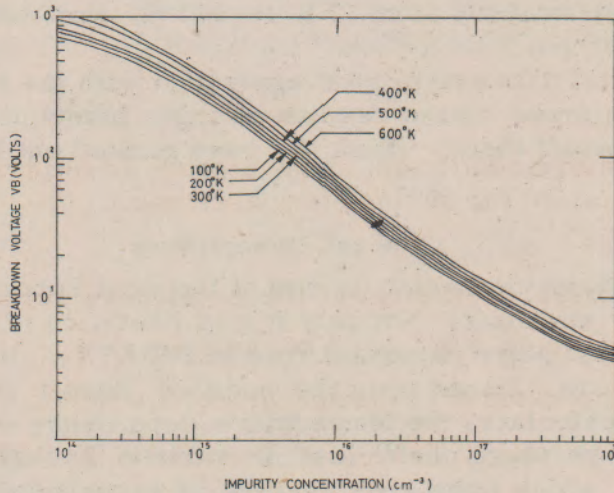


Fig. 1 Calculated breakdown voltage versus impurity concentration with temperature as a parameter.

In Fig. 1, the breakdown voltage V_B increases with increasing temperature T , this can be seen from Eq. (1) that as T increases, λ decreases accordingly. When a carrier transport across the junction, it gains energy from the field and loses part of its energy due to optical phonon scattering. At higher temperature the possibility of such scattering processes has been increased and thus requires higher energy from field to ionize the electrons from the valence band edge to the minimum of the conduction band.

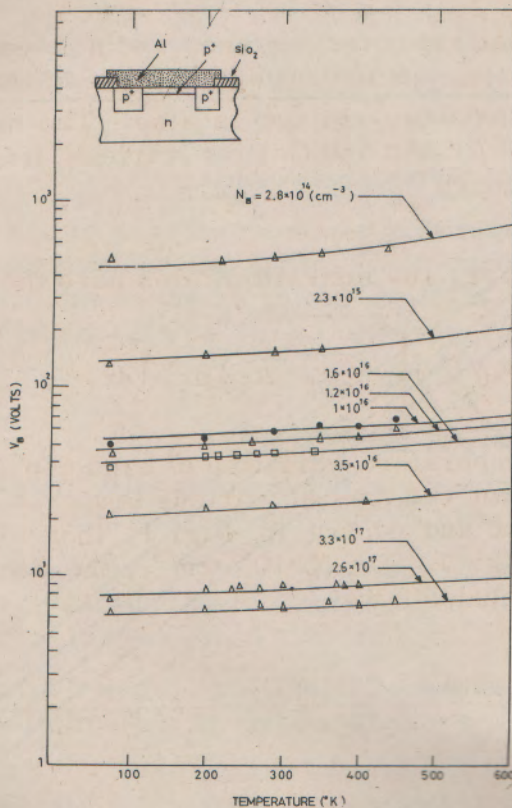


Fig. 2 Temperature coefficient: of the breakdown voltage versus impurity concentration for various temperatures.

The temperature coefficient of the breakdown voltage $\frac{\partial V_B}{\partial T}$ is also found and is shown in Fig. 2. The unit is $v/^{\circ}k$. At a doping of $N=10^{14} \text{ cm}^{-3}$, and operated at a temperature $T=300^{\circ}K$, $\frac{\partial V_B}{\partial T}=1 \text{ volt / K}$, whereas at $N=10^{17} \text{ cm}^{-3}$, $T=300^{\circ}K$, $\frac{\partial V_B}{\partial T}=0.001 \text{ v}/^{\circ}K$. This might be a useful information for device design consideration.

The p+n abrupt junction has been fabricated by typical silicon planar process, firstly thermally oxidize the n type substrate to grow a silicon dioxide layer and then open the guard ring window by KPR process, and followed by a boron diffusion to obtain a 5 μm depth of p type guard ring layer, finally the center area is cut for a shallow diffusion of p thin layer to make a abrupt junction. The structure ensure a true breakdown condition without introducing the junction curvature effect. The diodes were metalized and bound to TO-5 header, thus the diode can be easily put into the liquid nitrogen dewar or high temperature oven for measurement.

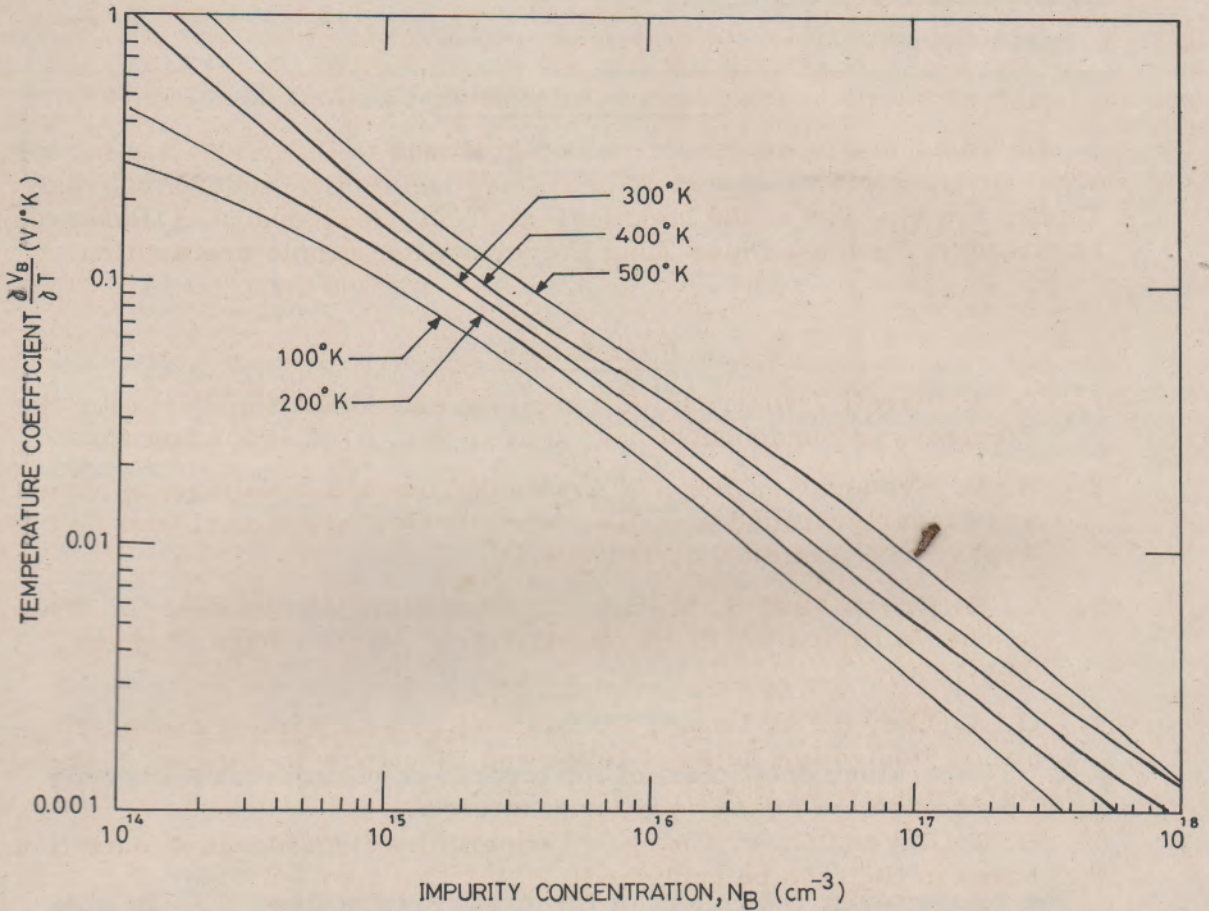


Fig. 3 Experimental breakdown voltage versus T with impurity concentration as parameter.

The experimental results are shown in Fig. 3. The background doping N_B shown were obtained from the C-V measurement by using Boonton capacitance bridge 74D at 100KHZ.

The breakdown voltages were measured under the condition when the diode current reaches 1 μ a.

The temperature dependence of V_B coincides closely with the calculated one. However at liquid nitrogen temperature, the fitting is slightly off the calculated curve, that is due to the inadequate approximation of the temperature variation of band gap which has been made in the calculation of E_I . In our approximation, the E_g , which is obtained by curve fitting technique and it is slightly higher than the true value at $T=100^\circ\text{K}$.

Our present work shows that the modified Baraff theory can adequate-

ly describe the temperature dependence of impact-ionization phenomena in semiconductors.

Acknowledgement

We would like to express our deep gratitude to Dr. S. M. Sze for his constructive suggestions and discussions during the course of study. Thanks are also due to the technical staff of Semiconductor Research Laboratory, National Chiao Tung University for sample preparation.

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