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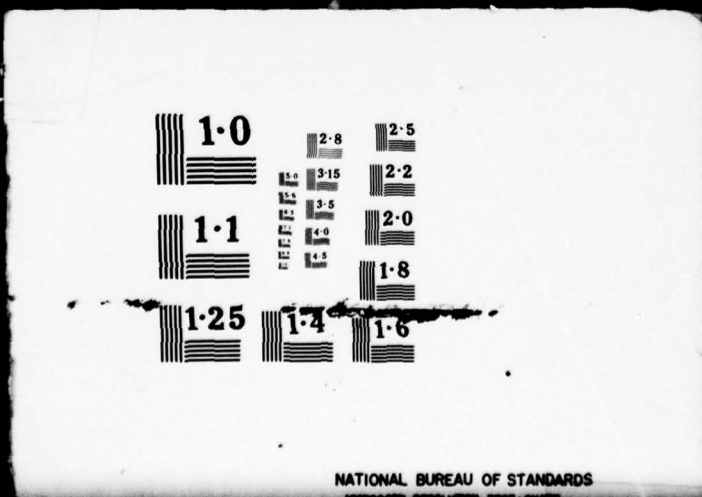
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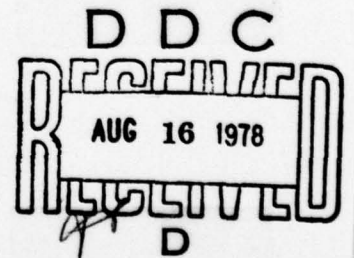
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**ENGINEERING & INDUSTRIAL RESEARCH STATION  
ELECTRICAL ENGINEERING-MISSISSIPPI STATE UNIVERSITY**

**A NUMERICAL MODEL FOR  
THERMAL SECOND BREAKDOWN**

by

**WAYNE H. CAUSEY, JR.**



**Final Report**

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space charge effects. Simulations are defined through 271 parameters which specify diode design, thermal conductivity perturbations, and control of the simulation. The program generates graphic output and requires short run times.

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A NUMERICAL MODEL FOR  
THERMAL SECOND BREAKDOWN

FINAL REPORT

BY  
Wayne H. Causey, Jr.

May 1978

U. S. Army Research Office

Contract Number  
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## ABSTRACT

A computer model is developed for simulating reverse bias thermal second breakdown (TSB) transients in thin film diodes. The model performs a one-dimensional electrical and a two-dimensional thermal simulation. Simulations are performed up to the onset of the TSB transition to a high conductance state. This condition is defined as a maximum junction temperature of 700 °K. The model is driven by a constant current source and features temperature and electric field dependent avalanche ionization coefficients, temperature, electric field and doping level dependent mobilities, and depletion region space charge effects. Simulations are defined through 271 parameters which specify diode design, thermal conductivity perturbations, and control of the simulation. The program generates graphic output and requires short run times.

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## INTRODUCTION

A diode model is developed for simulating TSB (thermal second breakdown) in SOS (silicon-on-sapphire) type diode structures. The model is capable of evaluating the dependence of TSB on semiconductor parameters and diode design. Diode and simulation specifications for simulations are easily changed to facilitate investigation of different diode designs. Run times of approximately two minutes make investigation and characterization of different designs economically attractive. These features make the model particularly useful for preliminary investigations of different diode designs. Once the general characteristics of these devices have been determined, more comprehensive models [1,2] that require substantially longer run times can be used to further resolve the observed TSB behavior.

The SOS type diode structure [3,4] consist of a thin layer of silicon deposited on a sapphire substrate or header (for the purposes of this report the terms substrate and header are used interchangeably to identify the material which supports the deposited semiconductor thin film). Fig. 1 shows a typical SOS diode configuration. The diode model for this structure is broken down into three distinct but closely coupled models: diode electrical, diode thermal and header thermal models.

The significant electrical effects leading to the onset of the TSB transition are assumed to be one-dimensional and along the diode axis. The TSB transition time from a high voltage state to a post-TSB

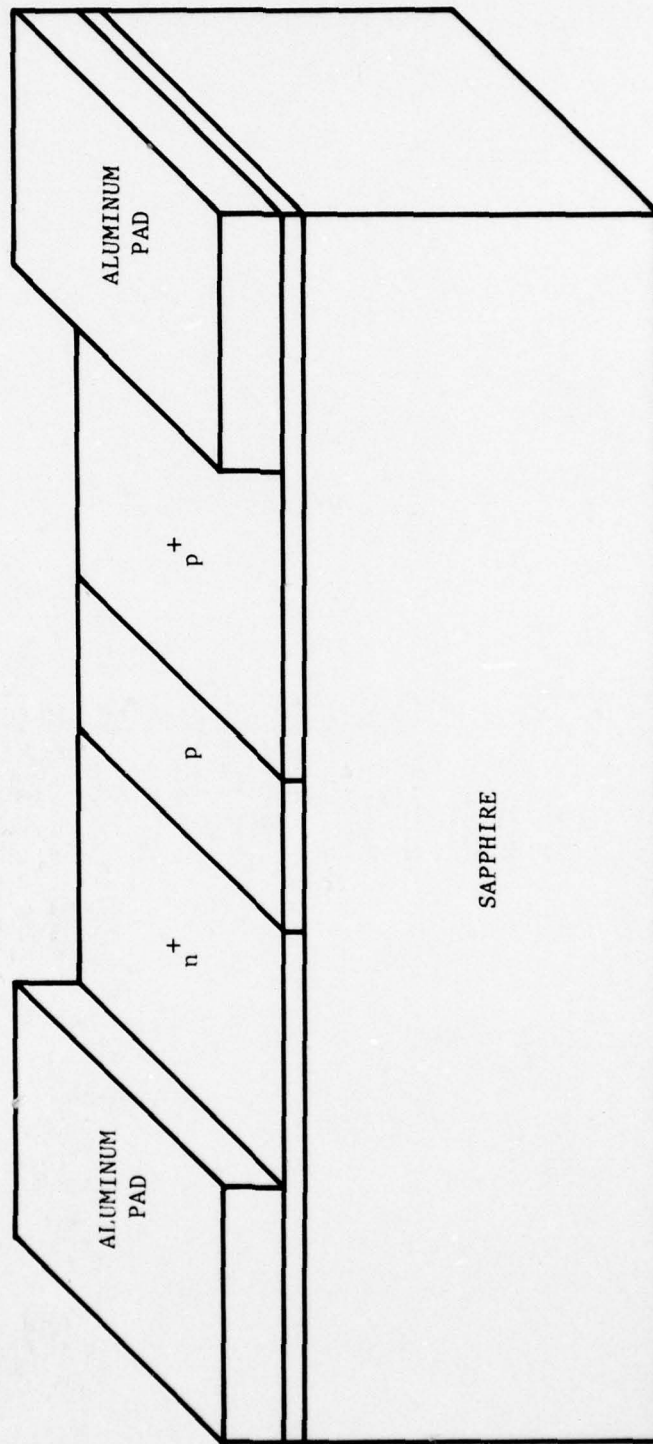


Fig. 1. Silicon-on-Sapphire (SOS) Diode Structure

low voltage state is assumed to be short in comparison with the delay time required to achieve the critical TSB transition temperature. Under these conditions, the transient time required for the diode to obtain the critical temperature represents the TSB delay time. A value of  $700^{\circ}\text{K}$  has been chosen for the critical temperature for SOS diode structures. This value was predicted by simulations with a more comprehensive diode model [1]. The electrical model features temperature, impurity and electric field dependent mobilities, temperature and electric field dependent avalanche ionization coefficients, and temperature dependent bulk region electric fields.

The diode and header thermal models combine to account for thermal conduction along the diode axis and perpendicular to this axis into the substrate. The two model concept reduces model complexity and maintains compatibility with the more comprehensive diode model developed previously [1]. As a consequence of the thin film structure of the semiconductor, the diode thermal model is quasi-two-dimensional. This model accounts for heat generation and thermal conduction along the diode axis and thermal conduction into the substrate. Four different header thermal models were developed for thermal conduction through the header. One of these models is quasi-two-dimensional and was developed previously [5]. The three new models feature two-dimensional thermal conduction and differ only in the numerical implementation of the energy continuity equation.

A flowchart for the diode model is shown in Figure 2.

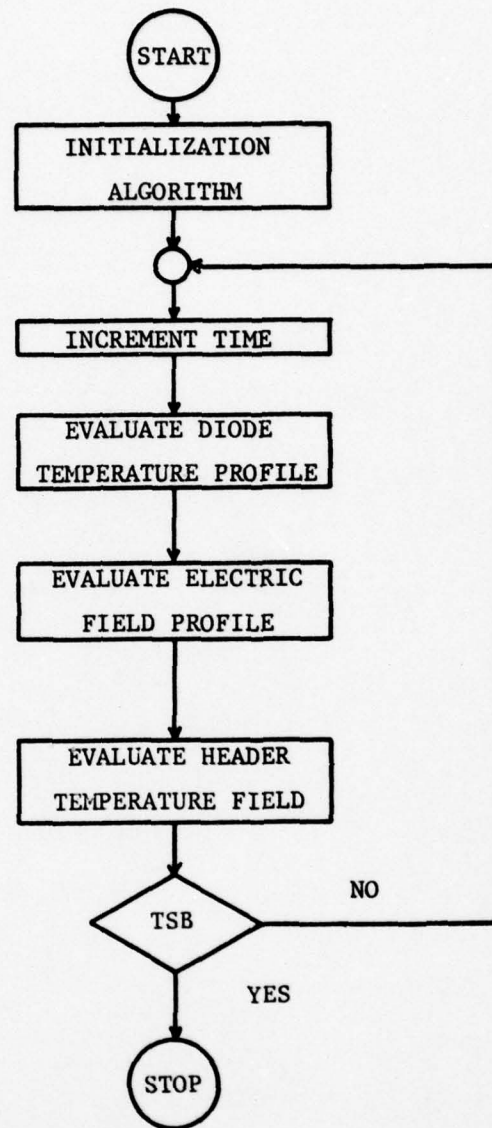


Fig. 2. Flow Chart For Simulation of the TSB Transient.

## DIODE THERMAL MODEL

Quasi-two-dimensional thermal conduction for the diode is modeled by the one-dimensional energy continuity equation which may be written as:

$$\rho_D c_D \frac{\partial T}{\partial t} = K_D \frac{\partial^2 T}{\partial x^2} + |J E| - \phi \quad (1)$$

where:

- $\rho_D$  - diode density
- $c_D$  - diode specific heat
- $T$  - diode Temperature
- $t$  - time
- $K_D$  - diode thermal conductivity
- $x$  - position
- $J$  - current density
- $E$  - electric field intensity
- $\phi$  - heat loss by mechanisms other than conduction along the diode axis.

Heat loss into the diode header through thermal conduction is accounted for through the  $\phi$  term to yield quasi-two-dimensional thermal conduction.

$\phi$  is defined as:

$$\phi \equiv \frac{K_H}{\Delta X_{DT}} \frac{T(N) - T(N,1)}{\Delta y} \quad (2)$$

where:

$K_H$  - header thermal conductivity

$X_{DT}$  - diode film thickness

$\Delta y$  - header node spacing perpendicular to diode axis

$T(N)$  - diode temperature profile

$T(N,1)$  - adjacent header temperature profile

An electrical analog of this thermal model is shown in Figure 3.

Thermal conduction from the diode into the header is a function of the temperature difference between the respective diode and header node points. The numerical algorithm for the diode thermal model was developed by combining equations (1) and (2), and applying finite difference techniques in a fully implicit formulation [6,7]. This procedure yields the following system of linear equations:

$$\Delta t A T(N-1)^{s+1} + [\Delta t \Delta x^2 B - (\Delta x^2 + 2 \Delta t A)] T(N)^{s+1} \quad (3)$$

$$+ \Delta t A T(N+1)^{s+1} = -\Delta x^2 [T(N)^s + \Delta t C(N)] + B T(N,1) \Delta x^2 \Delta t$$

where:

$$A \equiv \frac{K_D}{\rho_D c_D}, \quad B \equiv \frac{K_H}{\rho_D c_D \Delta y x_{DT}}, \quad C(N) \equiv \frac{|J E|}{\rho_D c_D}$$

$s$  - present iteration number

$s+1$  - next iteration number

$N$  - diode node number,  $1 \leq N \leq NN$

$NN$  - total number of diode nodes

$\Delta t$  - time step size

$\Delta x$  - distance between adjacent nodes along diode axis

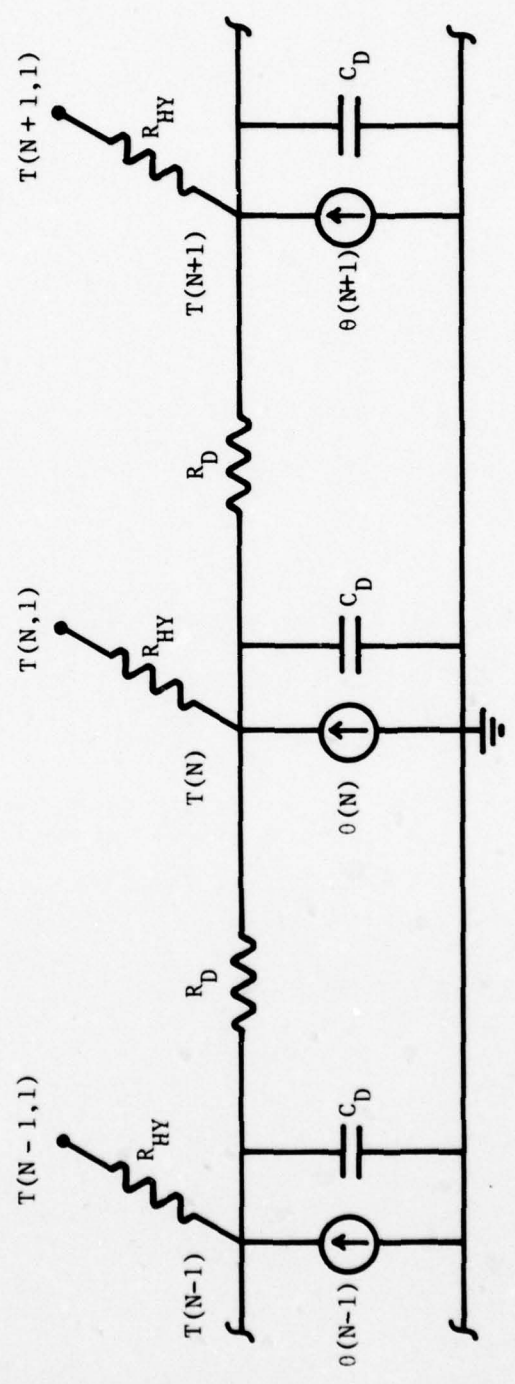


Fig. 3. Electrical Analog for the Diode Thermal Model. (T - temperature, C - specific heat, R - thermal resistance,  $\theta$  - heat generation, H - header, D - diode, Y - y axis, X - x axis, N - x axis node number, M - y axis node number)

or,

$$A_1 T(N-1)^{s+1} + A_2 T(N)^{s+1} + A_3 T(N+1)^{s+1} = A_4 \quad (4)$$

where:

$$A_1 \equiv \Delta t A$$

$$A_2 \equiv [\Delta t \Delta x^2 B - (\Delta x^2 + 2\Delta t A)]$$

$$A_3 \equiv \Delta t A$$

$$A_4 \equiv -\Delta x^2 [t(N)^s + \Delta t C(N)].$$

The second order energy continuity equation requires two boundary conditions on temperature. The model assumes constant ambient temperature boundary conditions by default. Blocking or insulating boundary conditions may be specified through the appropriate simulation parameter.

The resulting system of NN-2 linear equations must be solved for each iteration to generate an improved approximation for the diode temperature profile at the next point in time. Iterations are performed until a specified maximum RMS (root-mean-square) change in the diode temperature profile is achieved between successive iterations, or a specified maximum number of iterations are performed. With the completion of each iteration sequence, the diode temperature profile is advanced by one time step. The iterative sequence between time steps is required only if the energy continuity equation coefficients are temperature dependent. Although the computer program has been formulated with the full iterative capability, the energy continuity equation coefficients are presently assumed constant. Hence, simulations presently require single iterations in the diode thermal model.

Perturbations in the diode and header thermal conductivities may be specified through the diode simulation parameters. Two perturbation factors are assigned to each of the diode node points. One is associated with thermal conduction between diode node points. The other is associated with thermal conduction between diode node points and the respective header node points. In both cases, the perturbation factors are multiplied by the respective thermal conductivity values to yield position dependent thermal conductivity values for the diode thermal model. The perturbation factors are assigned default values of one. Any of the perturbation factors can be redefined through the simulation parameters. The demonstration execution of the diode model presented in appendix A has a diode thermal conductivity perturbation specified.

## HEADER THERMAL MODELS

The computer program offers four different header thermal models. The first model was developed earlier [5] and is a quasi-two-dimensional thermal model identified as DHTEMP. This model features one-dimensional thermal conduction from each of the diode temperature node points through the header to the ambient temperature heat sink. No thermal conduction is allowed between these one-dimensional thermal paths through the header. An electrical analog of this header thermal model is shown in Figure 4.

Implementation of this model is very similar to the diode thermal model. However, since only thermal conduction with heat storage occurs through the header, the energy continuity equation, equation (1), reduces to:

$$\rho_H c_H \frac{\partial T}{\partial t} = K_H \frac{\partial T}{\partial x^2} \quad (5)$$

where:

- $\rho_H$  - header density
- $c_H$  - header heat capacity
- $K_H$  - header thermal conductivity

The boundary temperatures for the model are specified as the corresponding diode temperature and ambient temperature, respectively.

The numerical algorithm for solving equation (5) is developed using the same techniques as used previously for the diode thermal model. The resulting system of equations can be written as:

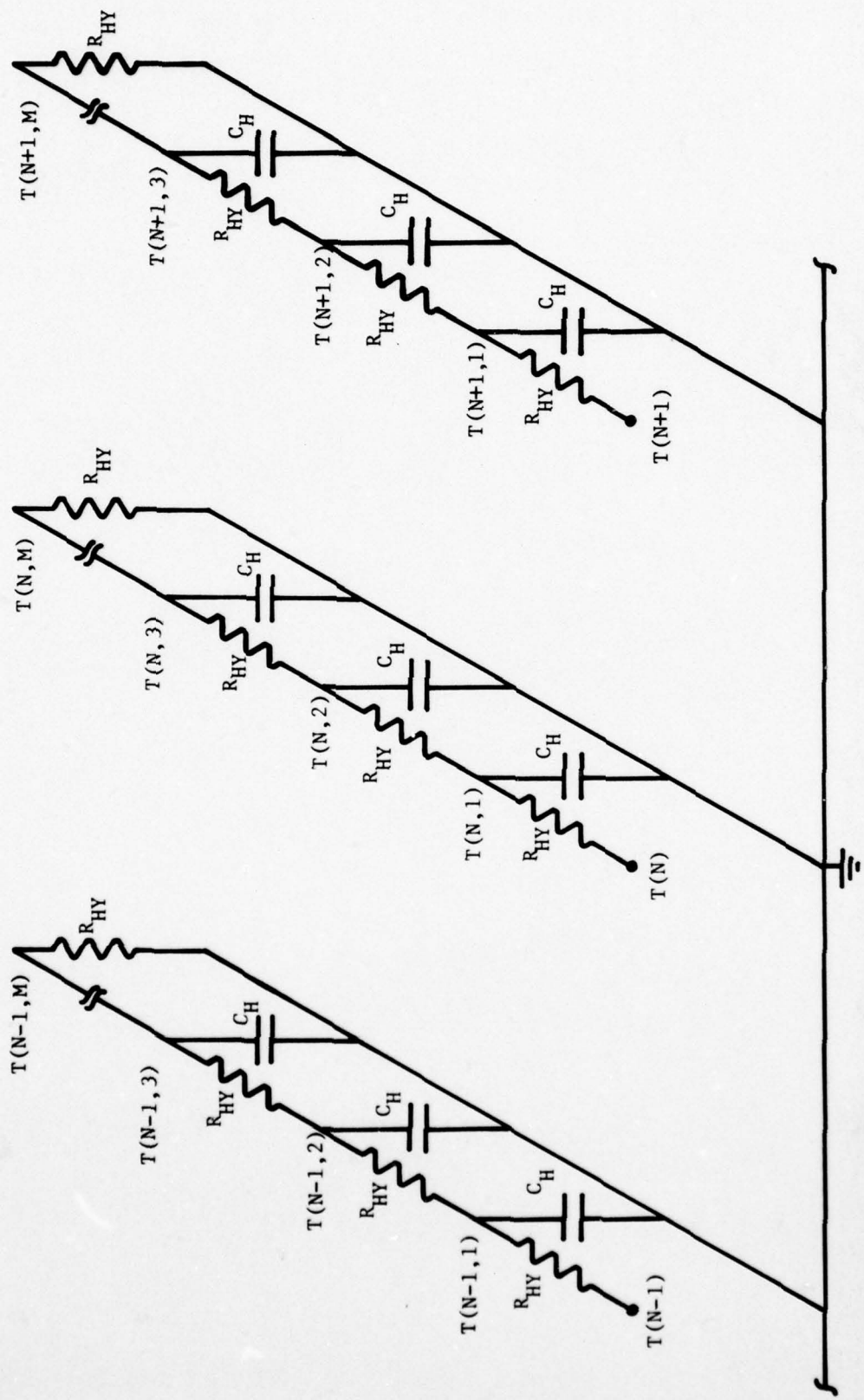


Fig. 4. Electrical Analog for the Quasi-Two-Dimensional Thermal Header Mode. (T - temperature, C - specific heat, R - thermal resistance, H - header, Y - y axis, X - x axis.

$$A_1 T(N,M-1)^{S+1} + A_2 T(N,M)^{S+1} + A_3 T(N,M+1)^{S+1} = A_4 \quad (6)$$

where:

$T(N,M)$  - header temperature profile beginning at diode temperature node  $N$ , ( $0 \leq N \leq 12$ ).

$\Delta x_H$  - header node spacing.

and,

$$A = \frac{K_H}{c_H \rho_H}$$

$$A_1 = \Delta t A$$

$$A_2 = (\Delta x_H^2 + 2 \Delta t A)$$

$$A_3 = \Delta t A$$

$$A_4 = - \Delta x_H^2 T(N,M)^S$$

After the diode temperature profile has been updated, the above algorithm is applied to each header temperature profile to generate the new header temperature profile for the next point in time.

The remaining three header thermal models represent two-dimensional thermal conduction within the header. All three of these models are quite similar except for the respective numerical algorithms employed. In all three cases the two-dimensional continuity equation is written as:

$$\rho_H c_H \frac{\partial T}{\partial t} = K_{Hx} \frac{\partial^2 T}{\partial x^2} + K_{Hy} \frac{\partial^2 T}{\partial y^2} \quad (7)$$

where:

- $\rho_H$  - header density
- $c_H$  - header heat capacity
- $K_{Hx}$  - longitudinal header thermal conductivity
- $K_{Hy}$  - transverse header thermal conductivity

Figure 5 shows an electrical analog for these header thermal models. Note that as with the previous thermal model 'DHTEMP', there is no power dissipation within the header yielding an energy continuity equation of reduced complexity. This equation requires two boundary conditions on temperature for each of the two axes of thermal conduction. The boundary conditions on thermal conduction perpendicular to the diode axis are the same as for DHTEMP, i.e., the respective diode temperatures and the ambient temperature. The temperature boundary values for thermal conduction parallel to the diode axis are always the same as those specified for thermal conduction along the diode axis, i.e., ambient temperature by default and blocking boundary conditions when specified through the appropriate simulation control parameter.

All three models incorporate an iterative solution procedure which is controlled by a specified maximum RMS change in temperature between successive iterations on a maximum number of iterations. If the maximum number of iterations is achieved without obtaining the specified convergence, a convergence failure message is generated.

The first two-dimensional header thermal model formulated is 'DHT2D'. This model is implemented using a vertical line procedure and incorporates the latest temperature values on an iteration basis.

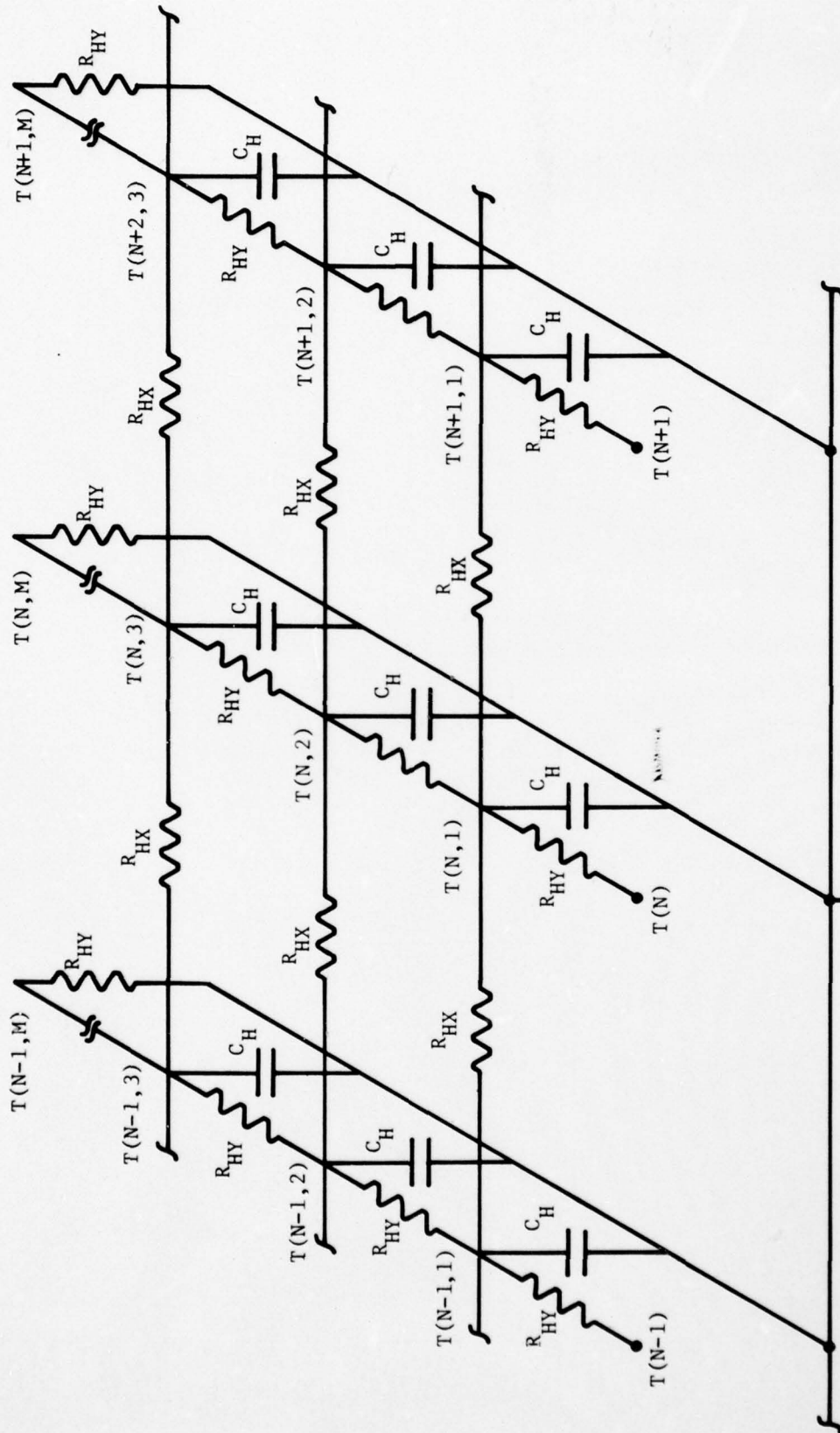


Fig. 5. Electrical Analog for the Two-Dimensional Header Thermal Models. (T - temperature, C - specific heat, R - thermal resistance, H - header, Y - y axis, X - x axis, N - x axis node number, M - y axis node number)

The vertical line approach requires that the partial derivative of temperature along the vertical axis (axis perpendicular to the diode axis) be formulated by an implicit finite difference scheme and that the horizontal partial derivative (axis parallel to the diode axis) be formulated by an explicit finite difference scheme. The restriction placed on the usage of the latest temperature values relates to the implicit formulation and means that although some new values of temperature do become available during each iteration through the temperature field, these values are not to be used in evaluating the remaining temperatures for the same iteration. Rather, the temperature values evaluated during a given iteration are used by the succeeding iteration only. Application of this algorithm to the two-dimensional continuity equation yields the following system of equations:

$$A T_{S+1}^{J+1}(N, M+1) + B T_{S+1}^{J+1}(N, M) + B T_{S+1}^{J+1}(N, M-1) = D_{N, M} \quad (8)$$

where:

- J - time step number
- S - iteration number
- N - node number along the diode axis
- M - node number perpendicular to the diode axis
- T - header temperature field
- $\Delta x$  - node spacing along x-axis
- $\Delta y$  - node spacing along y-axis

and,

$$A = -K_{Hy} \Delta t \Delta x^2$$

$$B = 2 K_{Hy} \Delta t \Delta x^2 + \Delta y^2 \Delta x^2$$

$$C = -K_{Hy} \Delta t \Delta x^2$$

$$D_{N,M} = \Delta x^2 \Delta y^2 T^J(N,M) + K_{Hx} \Delta y^2 \Delta t [T_S^{J+1}(N-1,M) + T_S^{J+1}(N-1,M) - 2 T_S^{J+1}(N,M)]$$

Note that solving the above system of equations yields a single temperature profile through the header. Accordingly, one iteration of this algorithm requires that the above system of equations be solved for each node point along the diode axis except for the respective end nodes which are accommodated through the boundary conditions applied at these points. Thermal coupling between these linear profiles is provided through successive iterations.

The second two-dimensional header thermal model is developed to accelerate convergence and improve stability of the above algorithm. The only change is to use the latest temperature values as they become available during an iteration rather than delaying until the next iteration. Only the 'D' coefficient of the previous formulation is changed by this innovation and it becomes:

$$D_{N,M} = \Delta x^2 \Delta y^2 T^J(N,M) + K_{Hx} \Delta y^2 t [T_S^{J+1}(N+1,M) + T_S^{J+1}(N-1,M) - 2 T_S^{J+1}(N,M)] \quad (9)$$

Note that the  $T_{S+1}^{J+1}(N-1,M)$  temperature represents the latest approximation for temperature at that node rather than the temperature value evaluated during the previous iteration. It is shown in the simulation results section that this change does increase both stability and the rate of convergence.

The third two-dimensional header thermal model is formulated like the previous model except that a horizontal line technique is employed rather than the previously used vertical line approach. In this case, the horizontal partial derivative is formulated implicitly; whereas, the vertical partial derivative is formulated explicitly. Applications of the line technique in analysis of two-dimensional semiconductor impurity diffusions [8] suggested that the horizontal line approach would be more effective for the header thermal model than the vertical line technique. The convergence test presented later supports this conclusion. As with the previous model, DAT2D1, this model, named DH2D2, incorporates the new temperature values as they become available rather than on an iteration basis. The subsequent implementation of DHT2D2 yields the following system of equations:

$$A T_{S+1}^{J+1}(N+1,M) + B T_{S+1}^{J+1}(N,M) + C T_{S+1}^{J+1}(N-1,M) = D_{N,M} \quad (10)$$

where:

$$\begin{aligned} A &= -K_{Hx} \Delta t \Delta y^2 \\ B &= [2 K_{Hx} \Delta t \Delta y^2 + \rho_H c_H \Delta x^2 \Delta y^2] \\ C &= -K_{Hx} \Delta t \Delta y^2 \\ D_{N,M} &= \rho_H c_H \Delta x^2 \Delta y^2 T(N,M)^J + K_{Hy} \Delta t \Delta x^2 [T(N,M+1)_S^{J+1} \\ &\quad + T(N,M-1)_S^{J+1} - 2 T(N,M)_S^{J+1}] \end{aligned}$$

Whereas the previous two two-dimensional header thermal models resulted in a system of linear equations for temperature profiles perpendicular to the diode axis, this model evaluates temperature profiles parallel to the diode axis. That is, the above system of equations must be solved once for each row of nodes in the header, except for the bottom row which is maintained at ambient temperature. This procedure constitutes one iteration. Thermal coupling is maintained between the row-wise temperature profiles through the iterative solution procedure.

Different header thermal conductivities were defined for the header vertical and horizontal axes such that the new two-dimensional header thermal models could conveniently simulate the earlier quasi-two-dimensional model by defining  $K_{Hx} = 0.0$ . This provided a means of testing the two-dimensional models during their early development.

In all, four header thermal models have been developed, and are named: DHTEMP, DHT2D, DHT2D1, and DHT2D2. DHTEMP is a quasi-two-dimensional model and DHT2D, DHT2D1 and DHT2D2 are two-dimensional models. The essential difference between the three two-dimensional models involves the numerical techniques used. A comparison of convergence characteristics and TSB transient simulations using the above header thermal models is made in the simulation results section. Figure 6 shows an electrical analog for the total diode thermal model which includes both the diode and two-dimensional header thermal models connected together.

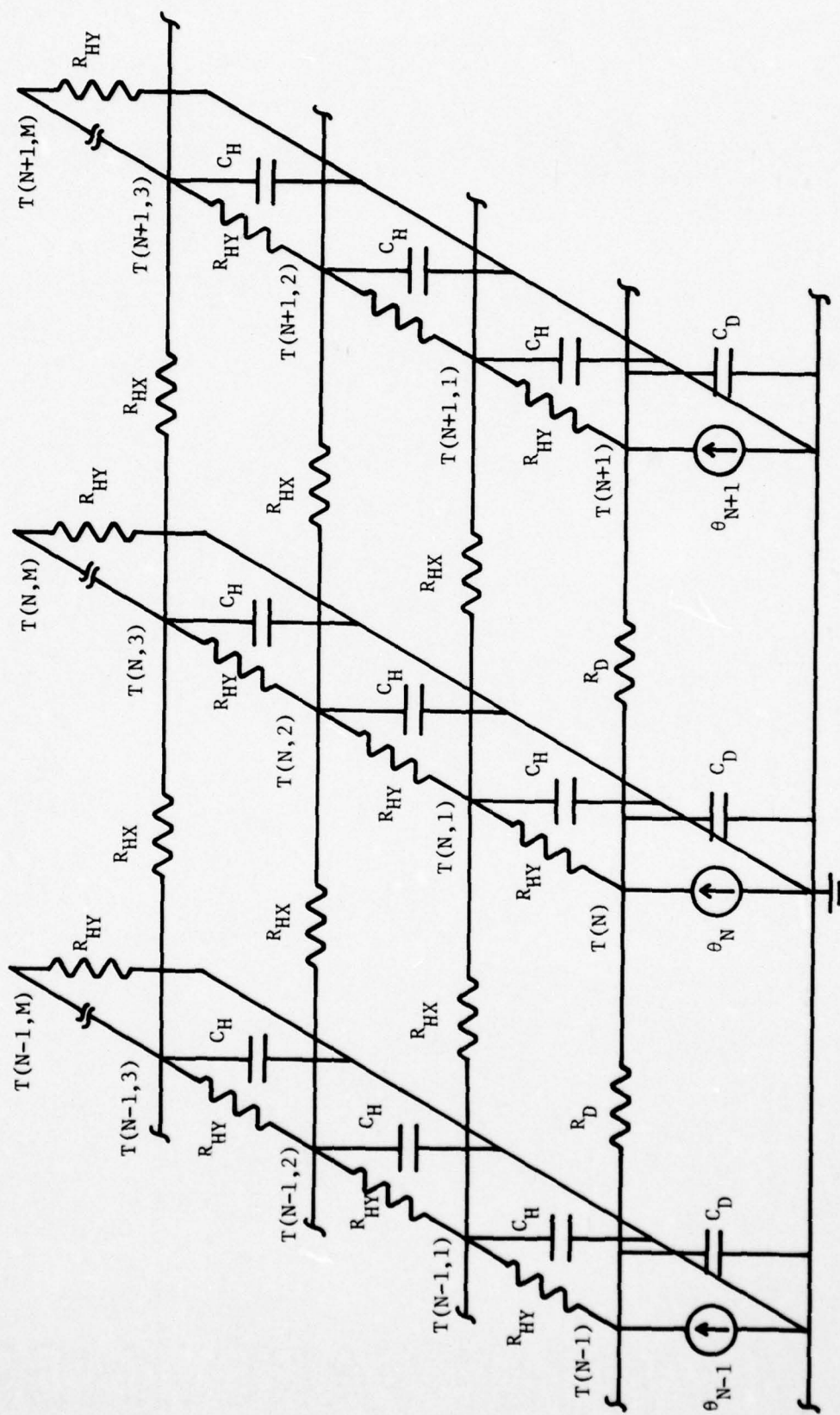


Fig. 6 . Electrical Analog for the Two-Dimensional Diode Thermal Model. (T - temperature, C - specific heat, R - thermal resistance, H - header, D - diode, Y - y axis, X - x axis,  $\theta$  - heat generation, N - x axis node number, M - y axis node number).

## DIODE ELECTRICAL MODEL

The one-dimensional diode electrical model is time dependent and is designed to maintain the condition of avalanche breakdown throughout the TSB transient simulations. As a consequence of the temperature dependence of the avalanche ionization coefficients, hole and electron mobilities, and intrinsic carrier concentrations, the diode electrical model is closely coupled to the thermal transient which accompanies TSB.

The maximum depletion region electric field is assumed to occur at the diode metallurgical junction and the depletion region electric field profile is evaluated analytically from this value. The diode impurity profile is assumed to be an epitaxial configuration as shown in Figure 7. This configuration readily reduces to the classical two-sided abrupt junction by assigning equal values to the epitaxial and upper region (background) doping levels. Space charge effects in the depletion region are taken into consideration by using effective space charge densities in evaluating the depletion region electric field profile. The effective space charge densities are defined as:

$$\rho_M = \frac{J}{v_{sat}} \quad (11)$$

$$\rho_L = q N_L - \rho_M \quad (12)$$

$$\rho_{Ep} = q N_{Ep} - \rho_M \quad (13)$$

$$\rho_U = q N_U - \rho_M \quad (14)$$

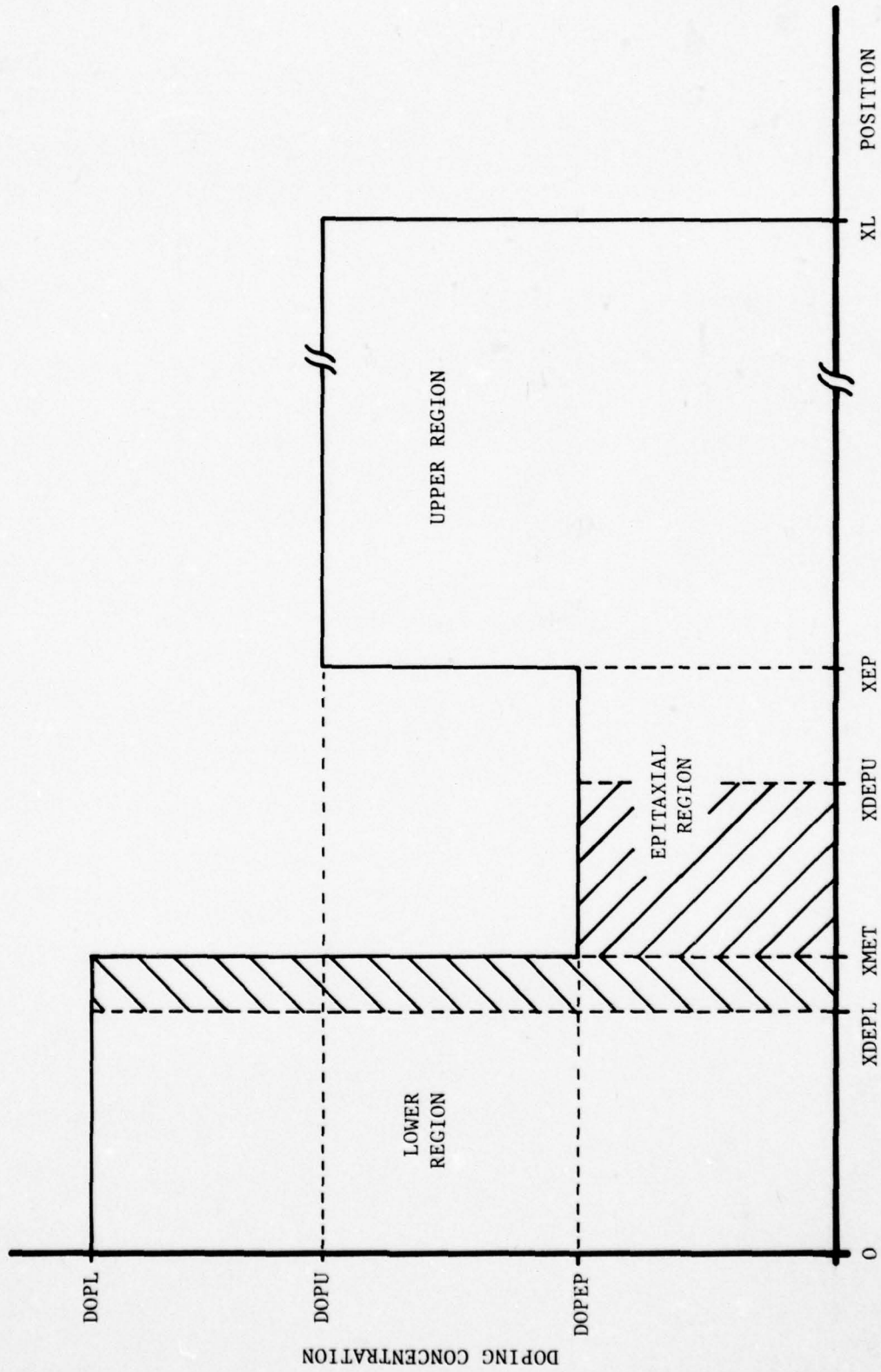


Fig. 7 . Diode Doping Profile.

where:

- J - diode current density
- $v_{sat}$  - carrier saturation drift velocity
- q - unit charge
- $N_L$  - lower region doping concentration
- $N_{Ep}$  - epitaxial region doping concentration
- $N_U$  - upper region doping concentration
- $\rho_M$  - mobile space charge density
- $\rho_L$  - net lower region space charge density
- $\rho_{Ep}$  - net epitaxial region space charge density
- $\rho_U$  - net upper region space charge density

Two assumptions are made for the above calculations. First, current carriers within the depletion region are assumed to move at their saturation velocity. Second, the current on the n-side of the junction is assumed to be an electron drift current and the current on the p-side is assumed to be a hole drift current. These approximations allow space charge effects to be included in the model without calculating the hole and electron profiles through the depletion region. Otherwise, the model would become overly complex.

The depletion region electric field profile is analytically calculated using the effective space charge densities evaluated above and the maximum electric field value. The program iterates on the maximum electric field value between each time step to determine the value of maximum electric field that will satisfy the avalanche breakdown integral.

The diode is assumed to be in avalanche breakdown when the avalanche breakdown integral [9] is equal to one, plus or minus a specified error.

$$\int_0^W \alpha \, dx = 1 \pm \gamma \quad (15)$$

where:

- W - depletion region width
- $\alpha$  - avalanche ionization coefficient corresponding to the lower region impurity type (n or p).
- $\gamma$  - specified error for avalanche breakdown integral

The avalanche ionization coefficient in the above integral is chosen to correspond to the lower impurity region type, assuming that this region represents the high doped side of the junction. Under these conditions, the carriers injected from the epitaxial or background regions will dominate the avalanche breakdown mechanism and will correspond to the majority carrier type for the lower diode region. The avalanche ionization coefficients are evaluated by the following relations:

$$\alpha_p = a_p [1 - \beta(T-T_0)] e^{-b_p/E} \quad (16)$$

$$\alpha_n = a_n [1 - \beta(T-T_0)] e^{-b_n/E} \quad (17)$$

where:

$$a_p = 3.8 \times 10^6 \, \text{cm}^{-1}$$

$$b_p = 1.74 \times 10^6 \, \text{V cm}^{-1}$$

$$a_n = 2.25 \times 10^7 \text{ c}_m^{-1}$$

$$b_n = 3.26 \times 10^6 \text{ v c}_m^{-1}$$

The above description of the ionization coefficients was derived from Sze's [10] characterization of these coefficients and represents an empirical approximation of their thermal dependence. The avalanche ionization thermal coefficient  $\beta$  has units of  $^{\circ}\text{K}^{-1}$  and specifies a linear dependence on temperature.  $\beta$  is assigned a value of  $2.5 \times 10^{-3}$  and may be changed slightly to enhance the thermal dependence of the avalanche ionization coefficients.  $\beta$  was named ALFATD for the computer program version of the diode model. It should be emphasized that although this formulation for the thermal dependence of the ionization coefficients is not completely accurate, it does exhibit a reasonably good description of the thermal behavior of the coefficients.

Iterations on the maximum electric field are controlled by an interval halving routine. Lower and upper limits for the maximum electric field are established through simulation parameters and are reinitialized at the beginning of each series of iterations. The average of these two limits is used as a trial value for the maximum electric field. Next, the electric field profile and the avalanche breakdown integral are evaluated. If the integral yields a value greater than one, the trial value for the maximum electric field is too large and the trial value replaces the upper limit. If the integral is less than one, the trial value is too small and the lower limit is replaced by the trial value. This procedure is repeated until the avalanche breakdown integral takes on the specified value

or a maximum number of iterations is performed. If the latter case occurs, a convergence failure message is generated.

Once the depletion region electric field has been determined, the bulk region electric fields are evaluated. This computation is performed assuming that the currents within these regions consist entirely of drift components and that the carrier concentrations correspond to the thermalequilibrium values,

$$J = q (\mu_n \bar{n} + \mu_p \bar{p}) E \quad (18)$$

J - diode current density

q - unit charge

$\mu_p$  - hole mobility

$\mu_n$  - electron mobility

$\bar{n}$  - thermal equilibrium electron concentration

$\bar{p}$  - thermal equilibrium hole concentration

E - electric field

Since the carrier mobilities are strongly dependent on impurity concentration, electric field, and temperature, it is necessary that the mobility coefficients be formulated in terms of these quantities. Accordingly, the mobilities are evaluated using the following equation [1, 11, 12]:

$$\mu = \mu_0 T^{-\gamma} \left[ 1 + \frac{N}{\frac{N}{b} + a} + \frac{\left(\frac{E}{c}\right)^2}{\frac{E}{c} + d} + \left(\frac{E}{c}\right)^2 \right] \quad (19)$$

where for silicon:

	$\mu_0$	$\gamma$	a	b	c	d	e
Holes	480	2.5	$4 \times 10^{16}$	81	$6.1 \times 10^3$	1.6	$2.5 \times 10^4$
Electrons	1400	2.5	$3 \times 10^{16}$	350	$3.5 \times 10^3$	8.8	$7.4 \times 10^3$

$\mu$  - mobility

T - temperature

N - impurity concentration

E - electric field

$\mu_0, \gamma, a, b, c, d, e$  - parameters

The mobility dependence on electric field prevents an analytic solution of equation (16) for the electric field as a function of current density, temperature, and impurity concentration. Rather an algorithm based on the Newton-Raphson technique is used to iteratively evaluate the electric field at each node point along the diode axis.

Once the depletion region and bulk region electric field profiles have been evaluated, they are combined to yield the diode electric field profile.

A flow chart for the diode electrical model is shown in Figure 8. The relationship between the electrical model and the rest of the program is best demonstrated in the system flow chart presented in Figure 2. In this figure, the electrical model is represented by the 'Evaluate the Electric Field' block.

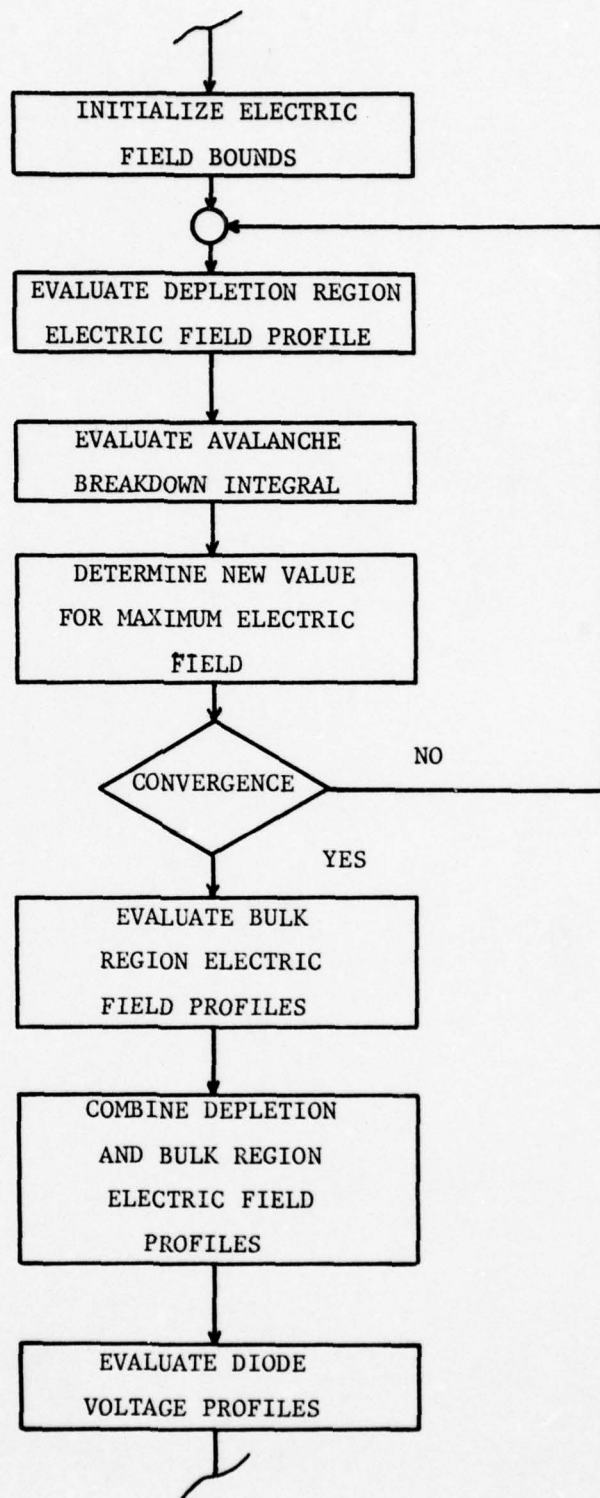


Fig. 8. Flow Chart For Diode Electrical Model.

## PROGRAM DESCRIPTION

The numerical diode model developed in the previous section is programmed in the Univac FORTRAN V computer language. This program is designed to simulate TSB transients up to the onset of the TSB transition. The program is very versatile and allows convenient specification of diode design and simulation conditions. This section defines the diode and simulation parameters and provides both instructions and suggestions for executing the diode model.

The diode model consists of a main program and several subroutines. Listings for these programs are presented in Appendix B. Both the main program and the subroutines are well documented with comment statements.

The TSB transient simulations performed by the diode model are defined through two groups of parameters. The first group controls the simulation and is named SPARM. The second group specifies the diode design and is named DPARM. Default values and definitions for these two parameter sets are presented in Tables 1 and 2.

As many parameters as desirable may be specified for a simulation with all unspecified parameters taking on their respective default values. Parameter specifications must be made on a group basis with appropriate starting and terminating sentinels for each group. An example simulation parameter set, with each line representing an input line is shown in Figure 9. The resulting simulation printout for this example is presented in Appendix A. The parameter groups must appear in the order and format shown. As many simulations as required may be specified in a single run by adding additional sets of parameter specifications. When

First Parameter	↗	\$SPARM	} SPARM parameter set
Set Group Name		CUR = 7.5E3	
		NNH = 12	
		DTIME = 5.0E-9	
		LTRNIN = 1	
		LTEMP = 1	
		LDHTEM = 1	
		PLOT = 1	
First Parameter		PVOLTX = 500	
Set Terminator	↘	IDHTMO = 4	
		SMAX = 20	
		PLTIME(1) = 100.0	
		\$END	
Second Parameter	↗	\$DPARM	} DPARM parameter set
Set Group Name		THKDPF(31) = 0.5	
Second Parameter	↗	\$END	
Set Terminator			

Figure 9. SPARM and DPARM Parameter Sets for a Thermal Second Breakdown Demonstration Simulation (simulation output listing presented in Appendix A).

TABLE 1  
SIMULATION CONTROL PARAMETER SET (SPARM)

<u>Parameter</u>	<u>Default Value</u>	<u>Parameter Definition</u>
1. CUR	= $1.25 \times 10^4$ amps/cm <sup>2</sup>	diode current density
2. NND	= 101	number of diode node points along diode axis, $\leq 101$
3. NNH	= 0	number of node points in diode header, maximum of twelve, and zero assumed for NNH < 4
4. IBND	= 0	temperature boundary condition sentinel, = 0 - constant temperature boundary conditions, $\geq 1$ - blocking boundary conditions
5. TIMEMX	= 1.0 sec	maximum simulation time
6. TMAX	= 700.0°K	maximum simulation temperature (TSB temperature)
7. TPMAX	= 800.0°K	maximum value for temperature plots
8. ITSNMX	= 200	maximum number of time steps
9. DTIME	= $1.0 \times 10^{-9}$ sec	time step increment
10. LTRNIN	= 2	transient data print increment
11. LTEMP	= 0	= 1 - diode temperature profiles are printed at times specified in parameter array PLTIME
12. LDHTEM	= 0	= 1 - temperature listings are printed at times specified in parameter array PLTIME
13. PLOT	= 1	= 1 - temperature, impurity, and electric field profiles and voltage transients are plotted at the times specified in parameter array PLTIME
14. PVOLTX	= 250.0 volts	maximum value for voltage plots
15. IGRID	= 0	grid sentinel for plots, = 1 - grid generated

TABLE 1 (continued)

## SIMULATION CONTROL PARAMETER SET (SPARM)

<u>Parameter</u>	<u>Default Value</u>	<u>Parameter Definition</u>
16. IRMSMI	$= 1.0 \times 10^3$	maximum RMS temperature change allowed between successive iterations for diode axis temperature profile
17. ITERMX	= 10	maximum number of iterations between time steps for diode axis temperature profile
18. ITLST	= 10000	iteration diagnostic print interval for diode axis temperature profile
19. IDHIMO	= 1	header thermal model sentinel, 1 - DHTEMP, quasi-two-dimensional 2 - DHT2D, two-dimensional transverse 3 - DHT2D1, two-dimensional transverse 4 - DHT2D2, two-dimensional longitudinal
20. SMAX	= 10	maximum number of iterations between time steps for header thermal model
21. DTHMAX	$= 1.0 \times 10^{-4}$	maximum RMS temperature change allowed between successive iterations for header temperature model
22. ITPRH	= 0	iteration diagnostic print interval for the header thermal model
23. PLTIME(1)	= 100.0 sec	diode temperature profile plot and/or list times (diode temperature profiles are available at simulation termination by default), timers must be stored in array PLTIME in Chronological order
.	.	
.	.	
32. PLTIME(10)	= 100.0 sec	
33. EMAXL	$= 1.0 \times 10^5$ volts/cm	lower bound for electric field at metallurgical junction (maximum junction electric field)
34. EMAXU	$= 1.0 \times 10^6$ volts/cm	upper bound for electric field at metallurgical junction (maximum junction electric field)

TABLE 1 (continued)

## SIMULATION CONTROL PARAMETER SET (SPARM)

<u>Parameter</u>	<u>Default Value</u>	<u>Parameter Definition</u>
35. EMAXB	= $1.0 \times 10^5$ volts/cm	maximum electric field value for bulk regions
36. EINT	= 100.0 volts/cm	starting value of electric field for determining bulk region electric field profiles
37. UPE	= 1	time dependent electric field sentinel 0 - time independent electric field 1 - time dependent electric field
38. AERMAX	= 0.1	maximum error allowed in avalanche breakdown integral
39. EERMAX	= $1.0 \times 10^{-4}$	maximum RMS change in bulk region electric field allowed between successive iterations
40. ITCMAX	= 10	maximum number of iterations for header temperature
41. IDB0	= 0	diagnostic print sentinel for subroutines: Not Used
42. IDB1	= 0	INAFLA
43. IDB2	= 0	BKDEPL
44. IDB3	= 0	EPROF
45. IDB4	= 0	DOPLG
46. PDTP	= 0	diode temperature profile plot sentinel, 1-profiles at times specified in parameter array PLTIME
47. PDIP	= 0	impurity profile plot sentinel. 1 - plot generated
48. PDEP	= 0	electric field plot sentinel, 1 - plot initial and final electric field profiles
49. PDVP	= 0	diode transient voltage plot sentinel, 1 - plot final diode voltage profiles. (A - lower bulk region voltage, B - depletion region voltage, C - upper bulk region voltage, D - total diode voltage)

TABLE 2

DIODE DESIGN AND PHYSICAL PROPERTY  
PARAMETER SET (DPARM)

<u>Parameter</u>	<u>Default Value</u>	<u>Parameter Definition</u>
1. THKD	= 1.0 watts/cm <sup>0</sup> k	diode thermal conductivity (silicon)
2. THKHX	= 0.46 watts/cm <sup>0</sup> k	header longitudinal thermal conductivity (sapphire)
3. THKHY	= 0.46 watts/cm <sup>0</sup> k	header transverse thermal conductivity (sapphire)
4. DDEN	= 2.3 gm/cm <sup>2</sup>	diode density (silicon)
5. HDEN	= 4.0 gm/cm <sup>2</sup>	header density (sapphire)
6. DSPEC	= 0.7 J/gm <sup>0</sup> k	diode heat capacity (silicon)
7. HSPEC	= 0.79 J/gm <sup>0</sup> k	header heat capacity (sapphire)
8. XDT	= 1.0 x 10 <sup>-4</sup> cm	diode thickness
9. XDH	= 2.5 x 10 <sup>-2</sup> cm	header thickness
10. XLDEP	= 0.0 cm	lower depletion region boundary (not used)
11. XMET	= 2.0 x 10 <sup>-3</sup> cm	metallurgical junction location
12. XEPDEP	= 4.0 x 10 <sup>-3</sup> cm	epitaxial layer boundary
13. XUDEP	= 0.0 cm	upper depletion region boundary (not used)
14. XL	= 4.0 x 10 <sup>-3</sup> cm	diode length
15. DOPL	= 1.0 x 10 <sup>17</sup> cm <sup>-3</sup>	lower bulk region doping concentration
16. DOPEP	= 1.0 x 10 <sup>16</sup> cm <sup>-3</sup>	epitaxial region doping concentration
17. DOPU	= 1.0 x 10 <sup>16</sup> cm <sup>-3</sup>	upper bulk region doping concentration
18. VEL	= 1.0 x 10 <sup>7</sup> cm/sec	mobile carrier saturation velocity (silicon)
19. ALFARD	= 2.4 x 10 <sup>-3</sup> °k <sup>-1</sup>	avalanche ionization coefficient thermal dependence factor
20. NP1	= 1	diode orientation, 0 - PN, 1 - NP

TABLE 2 (continued)

DIODE DESIGN AND PHYSICAL PROPERTY  
PARAMETER SET (DPARM)

Parameter	Default Value	<u>Parameter Definition</u>
21. THKDEP(1)	= 1.0	diode thermal conductivity
.	.	perturbation factor
.	.	.
.	.	.
.	.	.
121. THKDPF(101)	= 1.0	.
122. THKHPF(1)	= 1.0	diode-to-header thermal conductivity
.	.	perturbation factor
.	.	.
.	.	.
222. THKHPF(101)	= 1.0	.

multiple simulations are requested, only parameter changes between successive simulations should be specified. The default values are used for the first simulation only. For succeeding simulations, the previous simulation parameter values are treated as default values.

The program requires 36 K words of memory for execution. Typical run times on a Univac 1107 computer are from one-to-two minutes.

Several guide lines are listed to facilitate program execution:

1. If the number of node points in the header (NNH) is less than four, quasi-two-dimensional thermal conduction without intermediate header node points is assumed.
2. A simulation is terminated when one of the following conditions is achieved:
  - A. Simulation time  $\geq$  TIMEMX
  - B. Time step count  $\geq$  ITSNMX
  - C. Maximum diode temperature  $\geq$  TMAX
3. The transient data print increment (LTRNIN) must be chosen such that no more than 500 transient data lines are printed.
4. Two-dimensional temperature listings for the diode-header combination is generated at the times specified in the PLTIME array and at program termination by default, if LDHTEM = 1.
5. The diode axis temperature profile is stored at the times specified in the PLTIME array and at program termination by default. A listing of these profiles is generated if LTEMP = 1 and a plot is generated if IPLOT = 1.
6. The time step increment should be specified to yield a one hundred to two hundred time step simulation.
7. For most simulations, the diode maximum temperature transient plot and listing are adequate. Both of these outputs are generated by default.
8. The thermal conductivity perturbation factors are listed only when one or more of these factors are assigned a value other than one.

## SIMULATION RESULTS

The results presented in this section are intended to characterize the diode model. Several different type simulations are presented to demonstrate the capabilities and flexibility of the model. The convergence characteristics of the four header thermal models and the sensitivity of the diode to various model parameters is also presented.

Ten different series of simulations involving in excess of one hundred simulations were performed to accumulate the data presented in this section. A simulation series is considered to be a series of closely related simulations which involve systematic changes in a parameter or parameters. A summary of these simulation series is presented in Table 3. This table shows the changes made in the default parameter values in order to perform the respective simulations. The parameters that were varied in a particular simulation series are indicated by PAR. The different series are numbered in the table and are identified on the various graphs presented in this section by the respective simulation number preceded by SS, e.g., SS-5. There are several common parameter values among the simulations presented. These are summarized here for convenience:

NND = 101	number of diode node points
NNH = 0 or 12	number of header node points
TMAX = 700°K	TSB temperature
THKD = 1.0 watts/cm - °K	diode thermal conductivity (silicon)
THKHX = 0.46 watts/cm - °K	longitudinal header thermal conductivity (sapphire)

TABLE 3  
SPECIFICATIONS FOR TSB SIMULATION SERIES

SIMULATION SERIES NUMBER	1	2	3	4	5	6	7	8	9	10
PARAMETER NAME										
DEFAULT VALUE										
<u>SPARM</u>										
1. CUR										
2. NND										
3. NNH										
4. IBND										
5. TIMEMX										
6. TMAX										
7. TPMAX										
8. ITSVMX										
9. DTIME										
10. LTRNIN										
11. LTEMP										
12. LDHTEM										
13. PLOT										
14. PVOLTX										
15. IGRID										
16. TRMSMI										
17. ITERMX										
18. ITLST										
19. IDHTMO										
20. SMAX										
21. DTHMAX										
22. ITPRH										
23. PLTIME(I)										
24. EMAXL										
25. EMAXU										
26. EMAXB										
27. EINT										
28. UPE										





THKHY	= 0.46 watts/cm = °K	transverse header thermal conductivity (sapphire)
DDEN	= 2.3 gm/cm <sup>3</sup>	diode density (silicon)
HDEN	= 4.0 gm/cm <sup>3</sup>	header density (sapphire)
DSPEC	= 0.7 J/gm - °K	diode heat capacity (silicon)
HSPEC	= 0.79 J/gm - °K	header heat capacity (sapphire)
XDT	= 1.0 μm	semiconductor film thickness
XDH	= 250 or 4.8 μm	header thickness
XMET	= 20 μm	location of metallurgical junction
XL	= 40 μm	diode length
DOPL	= 1.0 x 10 <sup>17</sup> cm <sup>-3</sup>	lower region doping concentration
DOPEP	= DOPU	epitaxial region doping concentration
DOPU	= $\geq 10^{15}$ , $\leq 10^{17}$ cm <sup>-3</sup>	upper region doping concentration
VEL	= 1.0 x 10 <sup>7</sup> cm/sec	carrier saturation velocity
NP1	= 1	np diode orientation

Simulation SS-1 was a demonstration simulation and the output listing for this simulation is presented in appendix - A.

A comparison between TSB delay times for the quasi-two-dimensional header thermal model with zero and twelve header node points is shown in Fig. 10. For short delay times, these models yield similar results; whereas, for long delay times the results differ by two orders-of-magnitude. This behavior is expected since increasing the number of node points in the header tends to increase the rate of heat transfer out of the diode. Of course, this effect saturates quickly as the accuracy of the transverse header temperature derivative increases. The unexpected result is the inflection point exhibited by the more comprehensive quasi-two-dimensional model (NNH=12). This anomaly is suspected to be associated with the quasi-two-dimensional thermal model concept [13].

Fig. 10. Comparison of TSB Delay Times for the Quasi Two-Dimensional Substrate Thermal Model for Zero and Twelve Intermediate Substrate None Points.

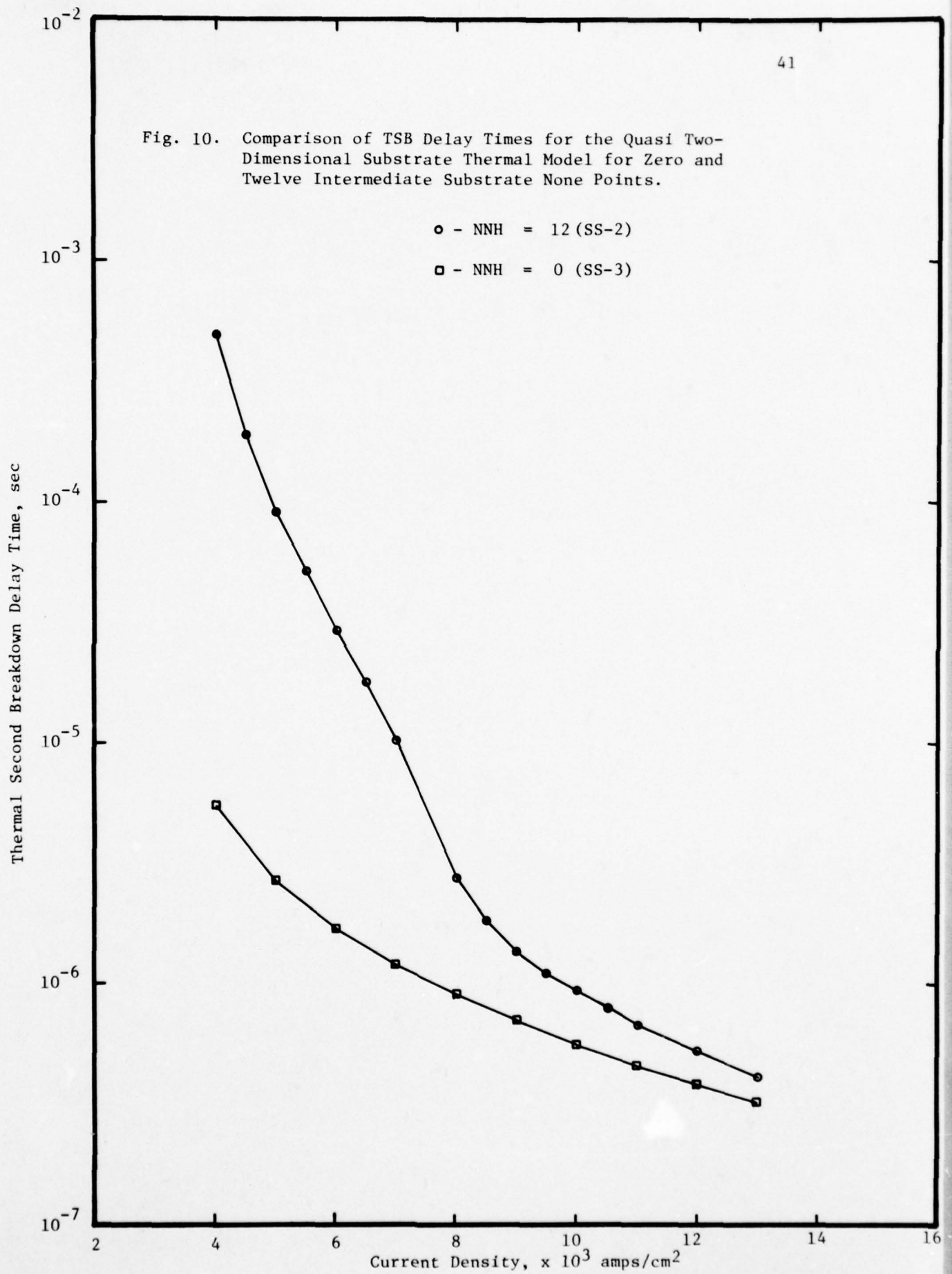


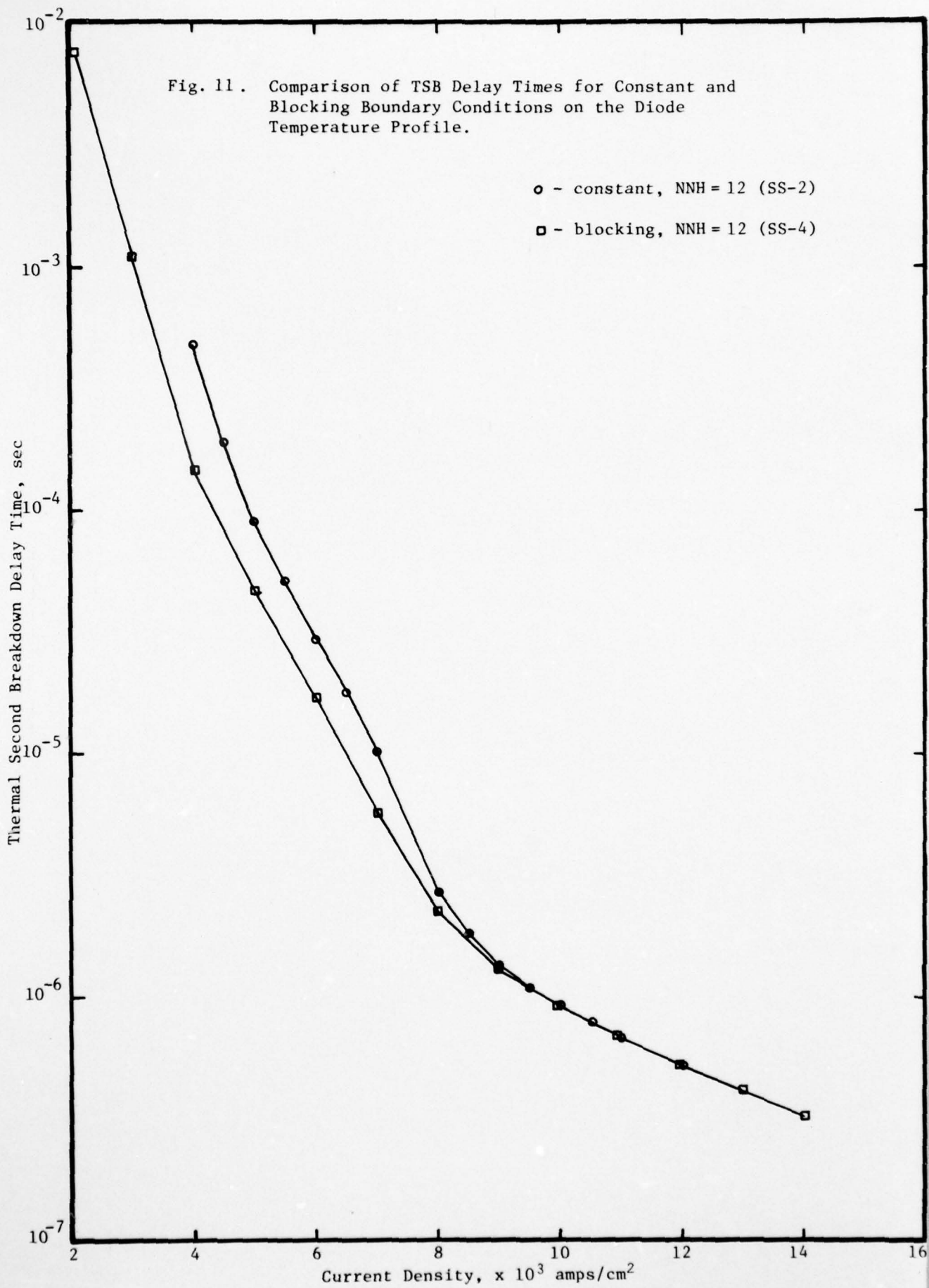
Fig. 11, shows a comparison of TSB delay times between constant and blocking temperature boundary conditions. Both cases are for comprehensive quasi-two-dimensional thermal conduction ( $NNH=12$ ) and both curves exhibit the previously noted inflection point. As expected, the boundary conditions on temperature at the diode contacts have virtually no effect on the delay time for high currents. For low currents the constant temperature boundary conditions exhibit slightly longer delay times corresponding to a greater heat loss at the contacts.

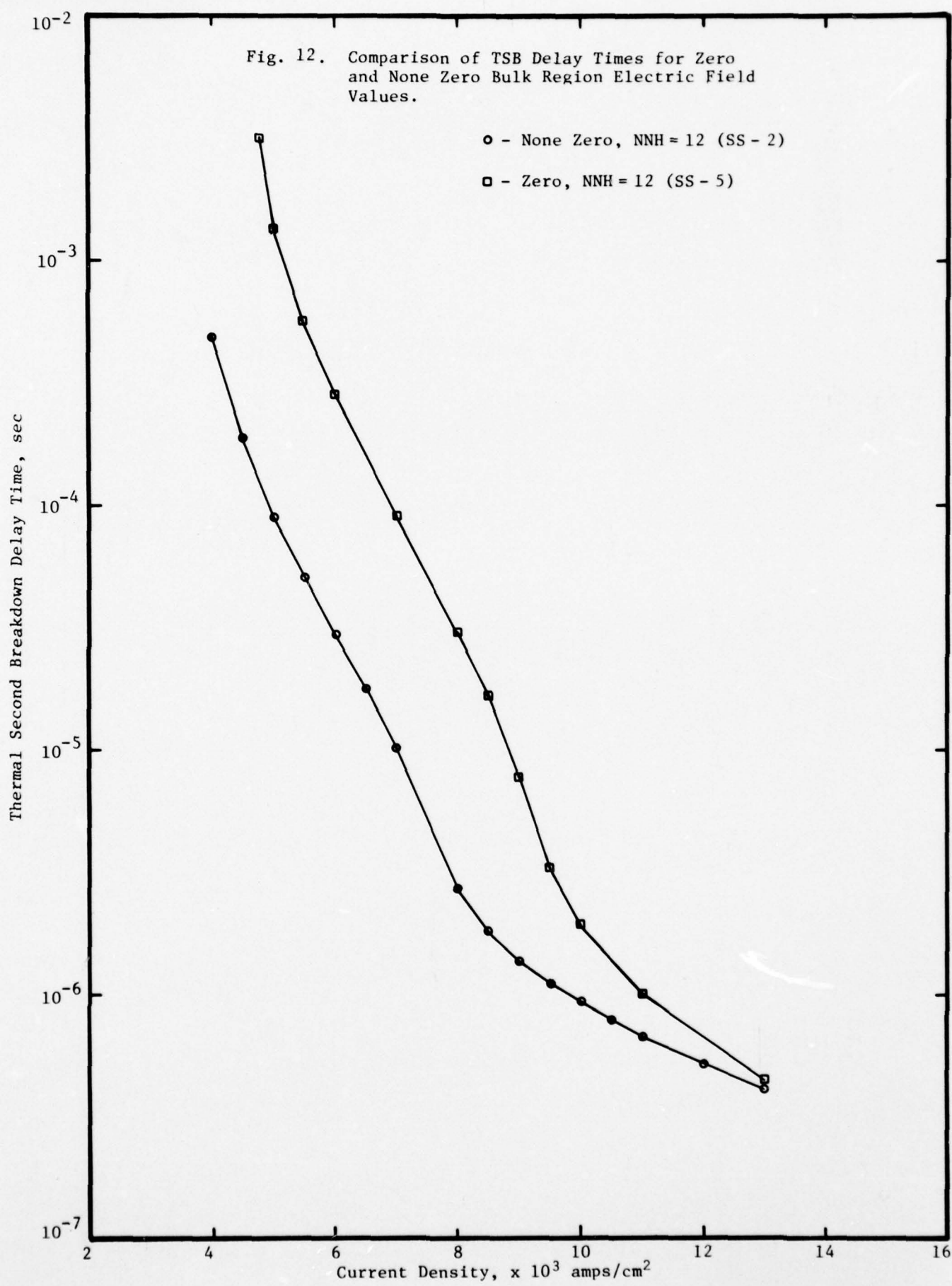
Fig. 12, presents a comparison of TSB delay times for zero and non zero bulk region electric field values. Both curves represent comprehensive quasi-two-dimensional thermal conduction ( $NNH=12$ ) and exhibit the previously observed inflection points. The bulk region electric fields are seen to make a significant contribution to the TSB delay times. The difference is essentially one order-of-magnitude at low current values.

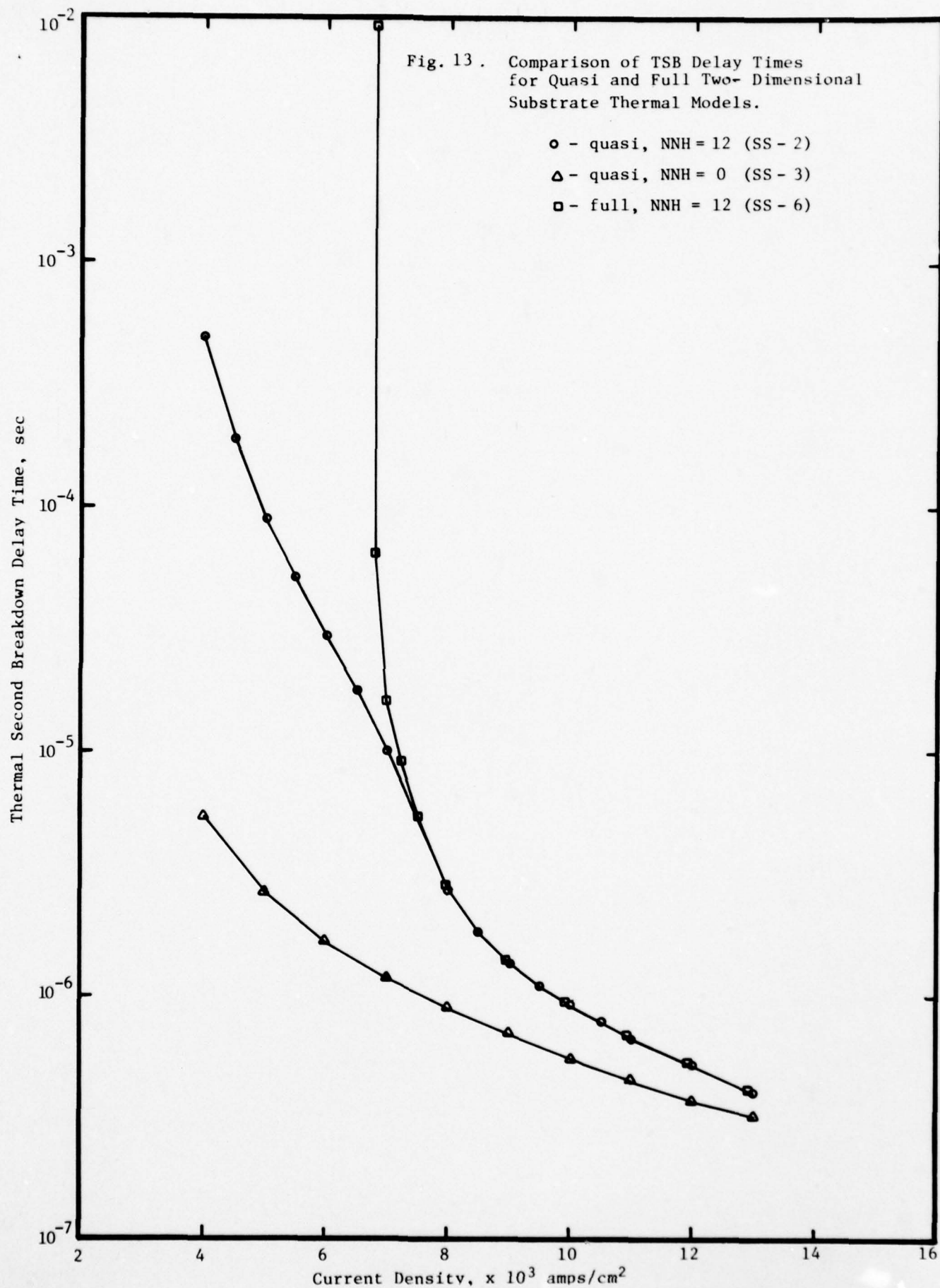
A comparison of TSB delay times for quasi and full two-dimensional header thermal models is shown in Fig. 13. The two models agree well for high currents. However, they differ greatly for low currents as expected. Further, the two-dimensional model does not exhibit the inflection point observed for all the comprehensive quasi-two-dimensional simulations. It appears that the inflection point is associated with the quasi-two-dimensional thermal model concept as predicted earlier. The full two-dimensional model exhibits a very strong delay time dependence on current for low current values.

Fig. 14, presents maximum junction temperature transients for several different driving currents and the two-dimensional header thermal model. These curves emphasize the effects of the avalanche

Fig. 11. Comparison of TSB Delay Times for Constant and Blocking Boundary Conditions on the Diode Temperature Profile.







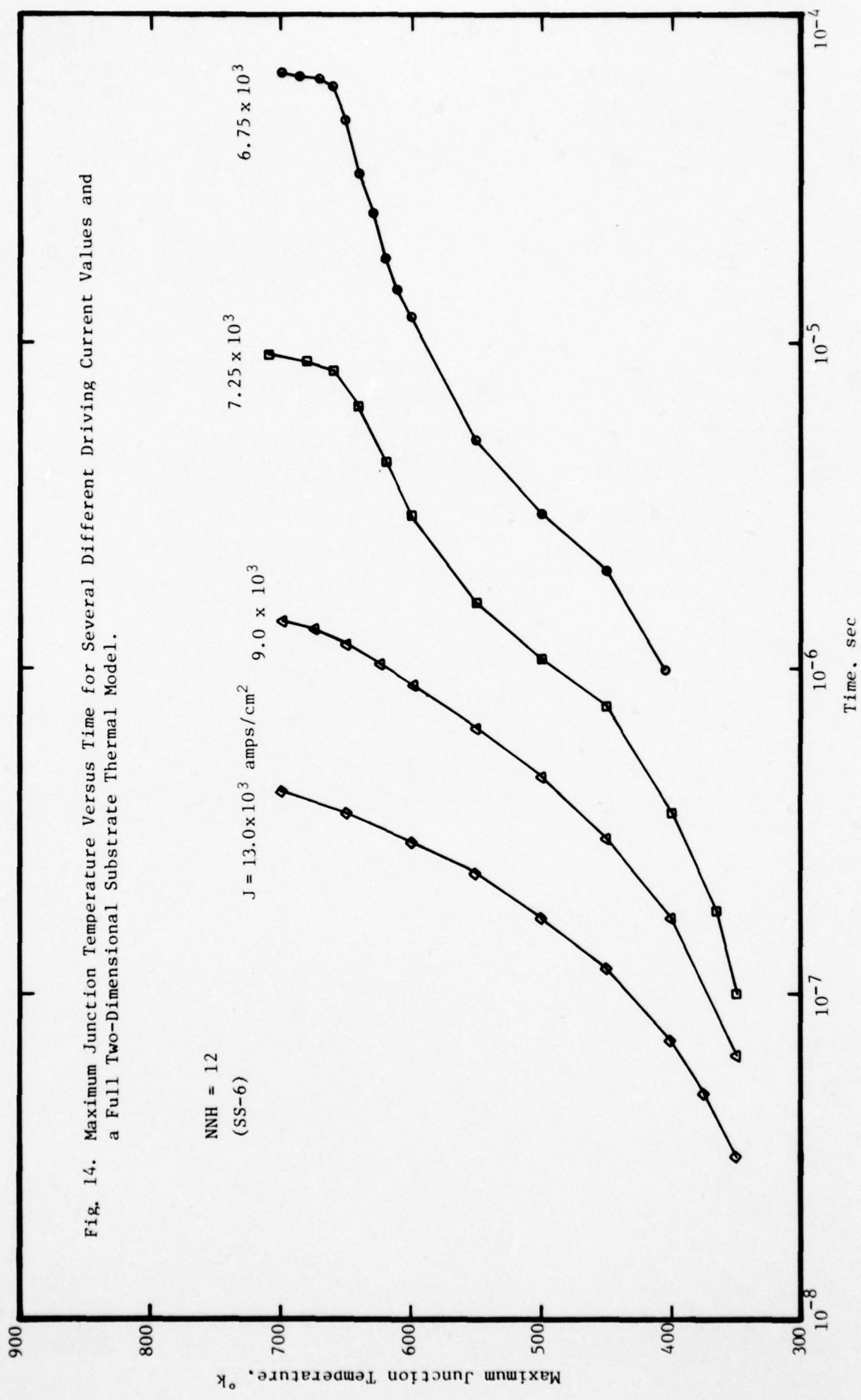


Fig. 14. Maximum Junction Temperature Versus Time for Several Different Driving Current Values and a Full Two-Dimensional Substrate Thermal Model.

ionization coefficient thermal dependence. For low current values, the temperature transient almost saturates before reaching the TSB temperature. However, temperatures sufficiently high to cause an appreciable decrease in the avalanche ionization coefficients are finally achieved after long delay times. Once the avalanche ionization coefficients begin to decrease, the junction electric field is forced to increase rapidly to maintain avalanche breakdown. This increase in electric field causes a corresponding increase in power dissipation within the junction. A thermal runaway condition occurs. These effects are manifest in the diode temperature transient as the TSB temperature is approached. These effects also occur at high currents, but are masked out by the rapid increase in diode temperature associated with the high current level.

Delay time versus doping concentration characteristics for the reduced quasi-two-dimensional header thermal model ( $NNH=0$ ) are shown in Fig. 15. The delay time is shown to increase as the low doping concentration is increased. This corresponds to a decreasing depletion region width and a decreasing resistivity for the low doping concentration, both of which tend to increase the delay time. For comparison, one point for each of the two driving current values is also shown for the full two-dimensional thermal model. Note that the two-dimensional model increases the delay time only slightly at the high current value; whereas, the delay time becomes infinite for the low current value. The infinite delay time implies that the diode achieves a thermal steady state without reaching the TSB temperature.

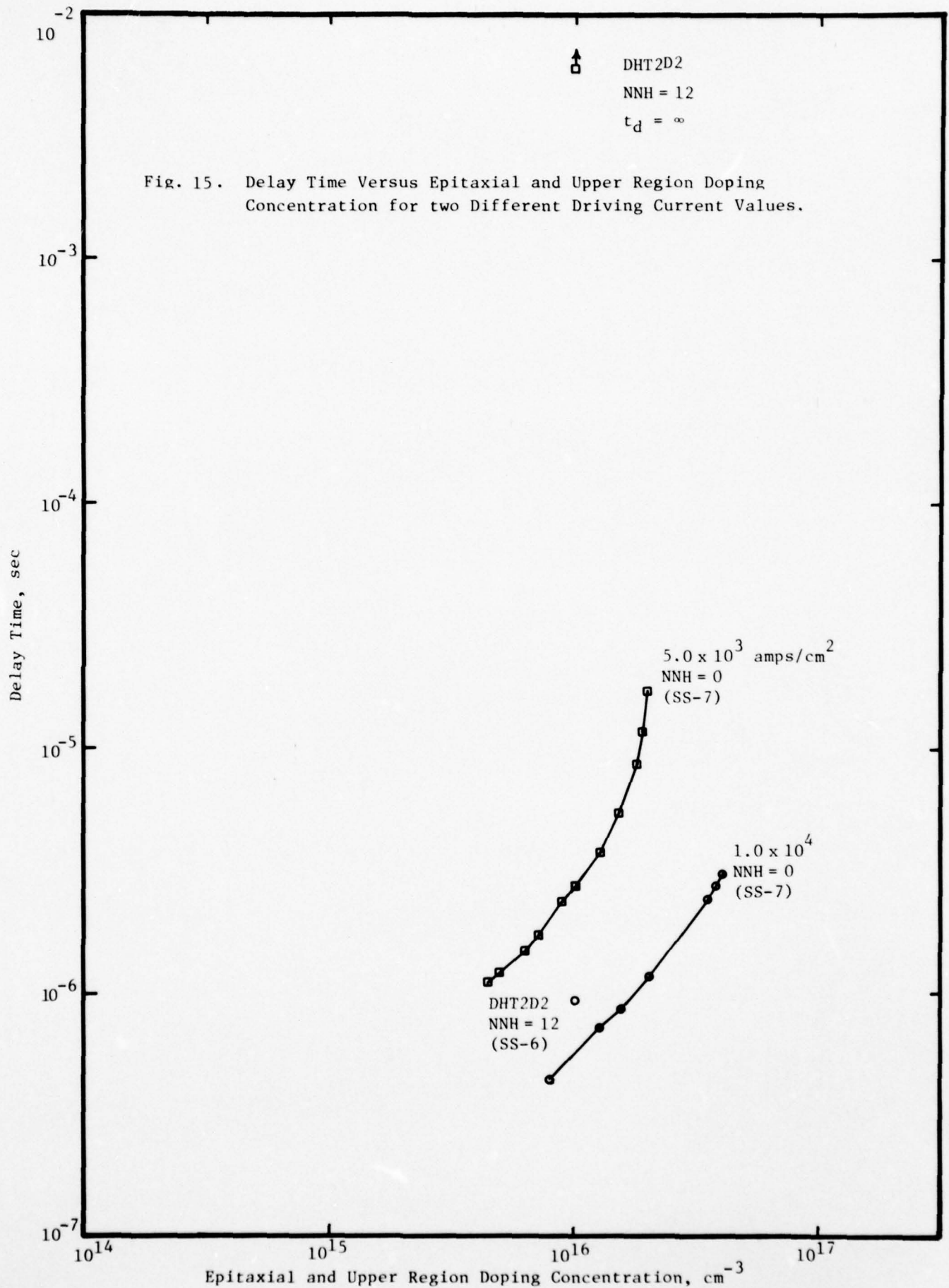
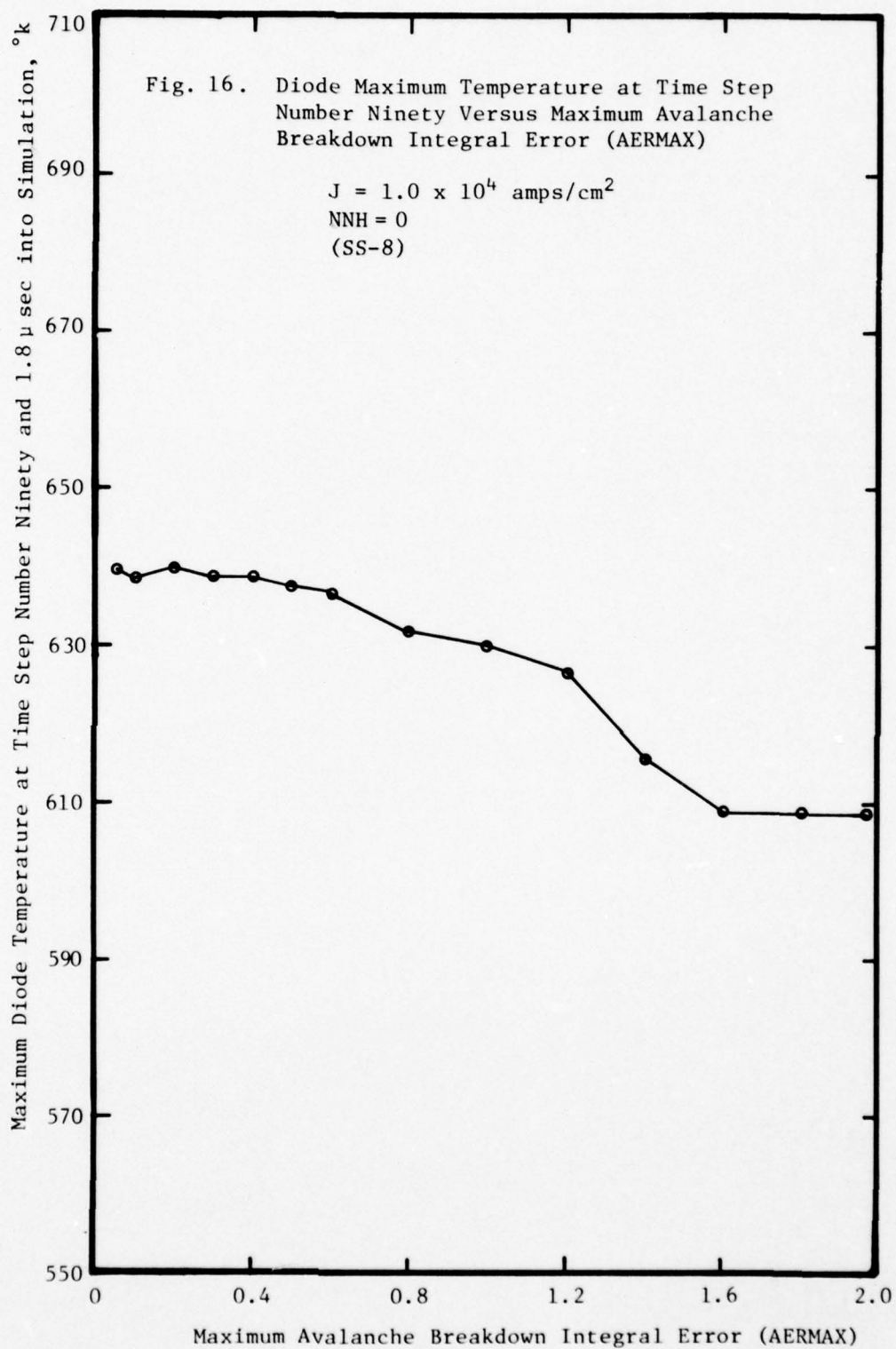
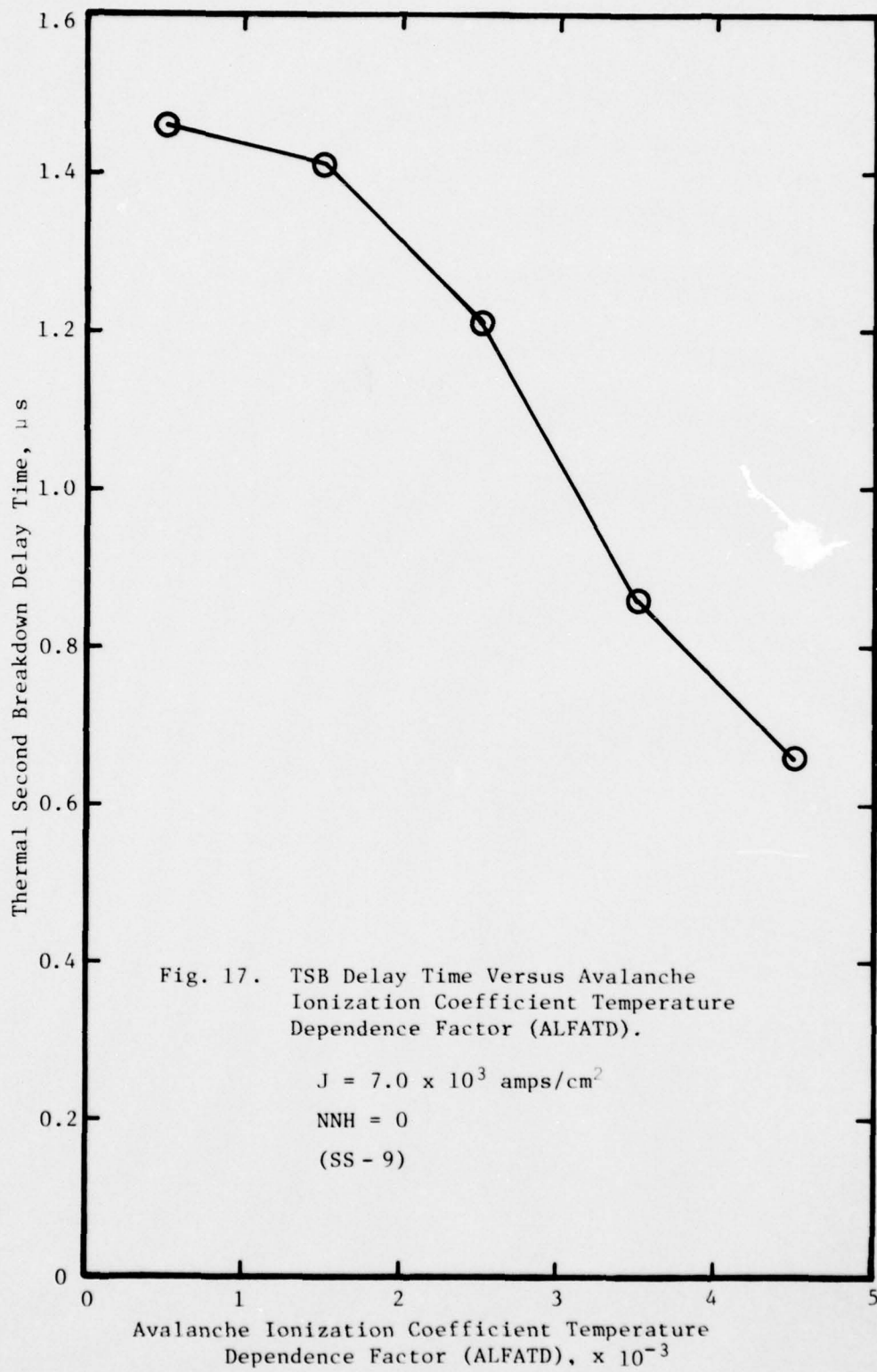


Fig. 16 characterizes the dependence of TSB transients on the specified avalanche breakdown integral error, AERMAX. The maximum junction temperature at 1.8  $\mu$ s into the simulation is plotted as a function of this error. The simulations were made with the reduced quasi-two-dimensional model and with a driving current of  $10^4$  amps/cm<sup>2</sup>. The results indicate that an avalanche breakdown integral error less than or equal to two tenths is most desirable. The trade off for further decreases is a corresponding increase in execution time.

The effects of the avalanche ionization temperature coefficient ( $\beta$  or ALFATD) on the TSB transients are shown in Figs. 17 - 19. Fig. 17, shows the TSB delay time as a function of  $\beta$  for the reduced quasi-two-dimensional model and a driving current of  $7.0 \times 10^3$  amps/cm<sup>2</sup>. As expected, increases in  $\beta$  result in a decreased delay time. Further refinement of the value for  $\beta$  may be warranted. Figs. 18 and 19, show maximum junction temperature transients for several of the data points in Fig. 17. The critical temperature for the avalanche ionization coefficients is set equal to 700 °K for the diode model. This is the temperature at which the avalanche ionization coefficients take on a value of zero as a consequence of their thermal dependence.  $\beta$ , the avalanche ionization temperature coefficient, simply determines the sensitivity of the ionization coefficients to changes in temperature as the critical temperature is approached. The formulation for the ionization coefficients is shown in Equation 16. Although the TSB temperature and the avalanche ionization critical temperature have both been assigned a value of





700 °K for the simulations presented, further refinement may show that one or both of these values require adjustment. Although the avalanche ionization coefficient critical temperature breakpoints are not obvious for the logarithmic time scale in Fig. 18, they can be clearly seen on the linear time scale of Fig. 19.

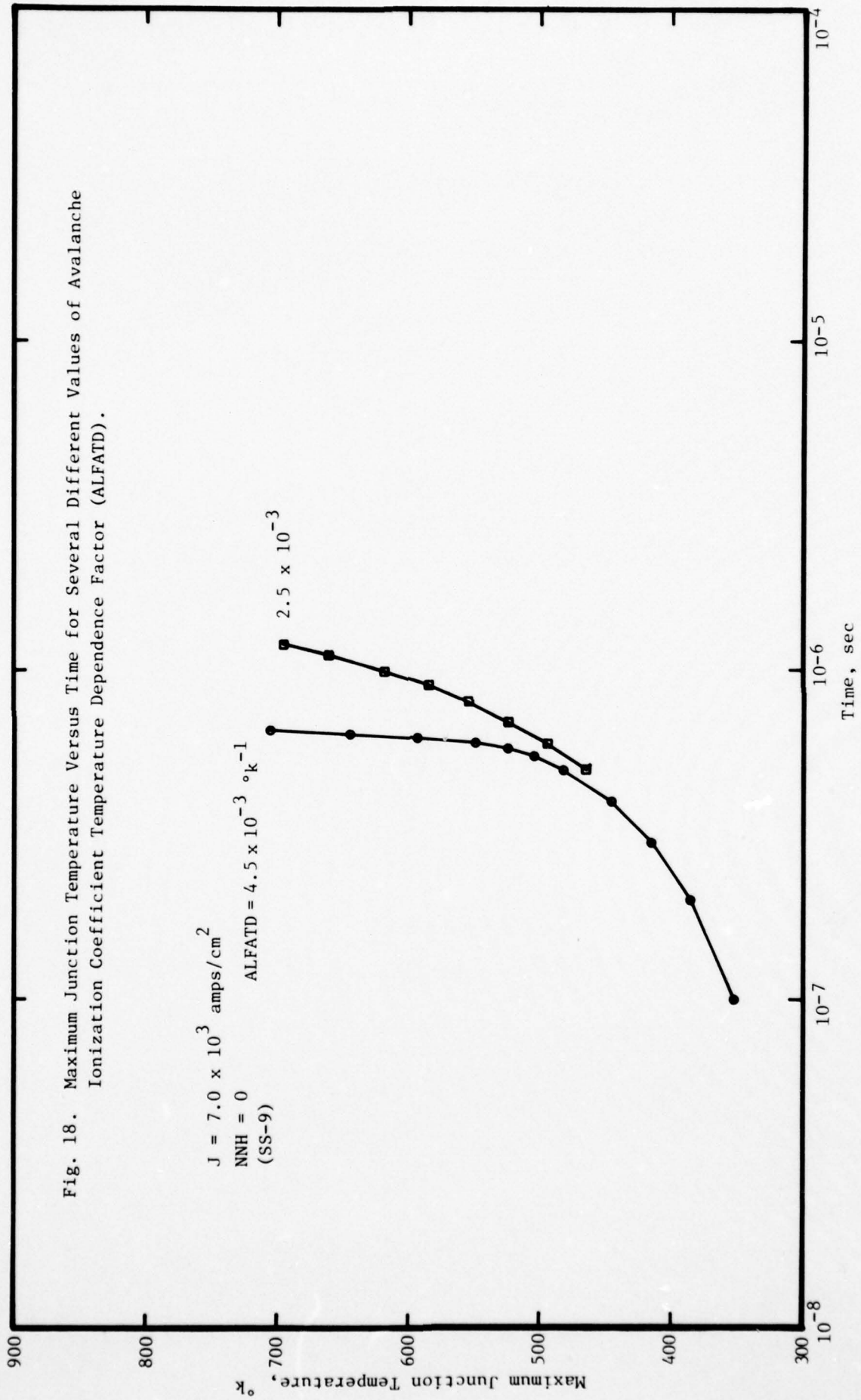
Figs. 20 - 26, show the convergence characteristics for the three two-dimensional header thermal models. All the curves shown represent iterations for the first time step of a simulation with a driving current of  $8.0 \times 10^3$  amps/cm<sup>2</sup>. Fig. 20, shows the convergence behavior for DHT2D for eight different time step sizes. This model uses the vertical line technique and fails to converge for time steps greater than 3 nsec. Further, the convergence rate is very sensitive to the time step size. Fig. 21, compares the convergence behavior of DHT2D for two different header thicknesses. The graph shows that the model convergences more rapidly for the larger transverse header node spacing. On the other hand, the stability behavior is very similar for the two cases.

Figs. 22 and 23, show the convergence behavior for DHT2D1 which features the vertical line formulation and incorporates the very latest values of temperature during the iteration procedure.

A comparison between the two vertical line models, DHT2D and DHT2D1, for two different header thicknesses is shown in Fig. 24. In both cases the formulation incorporating the most recent temperature values exhibits the greater stability.

Figs. 25 and 26 show the convergence behavior for DHT2D2 which employs the horizontal line formulation and uses the most recent

Fig. 18. Maximum Junction Temperature Versus Time for Several Different Values of Avalanche Ionization Coefficient Temperature Dependence Factor (ALFATD).



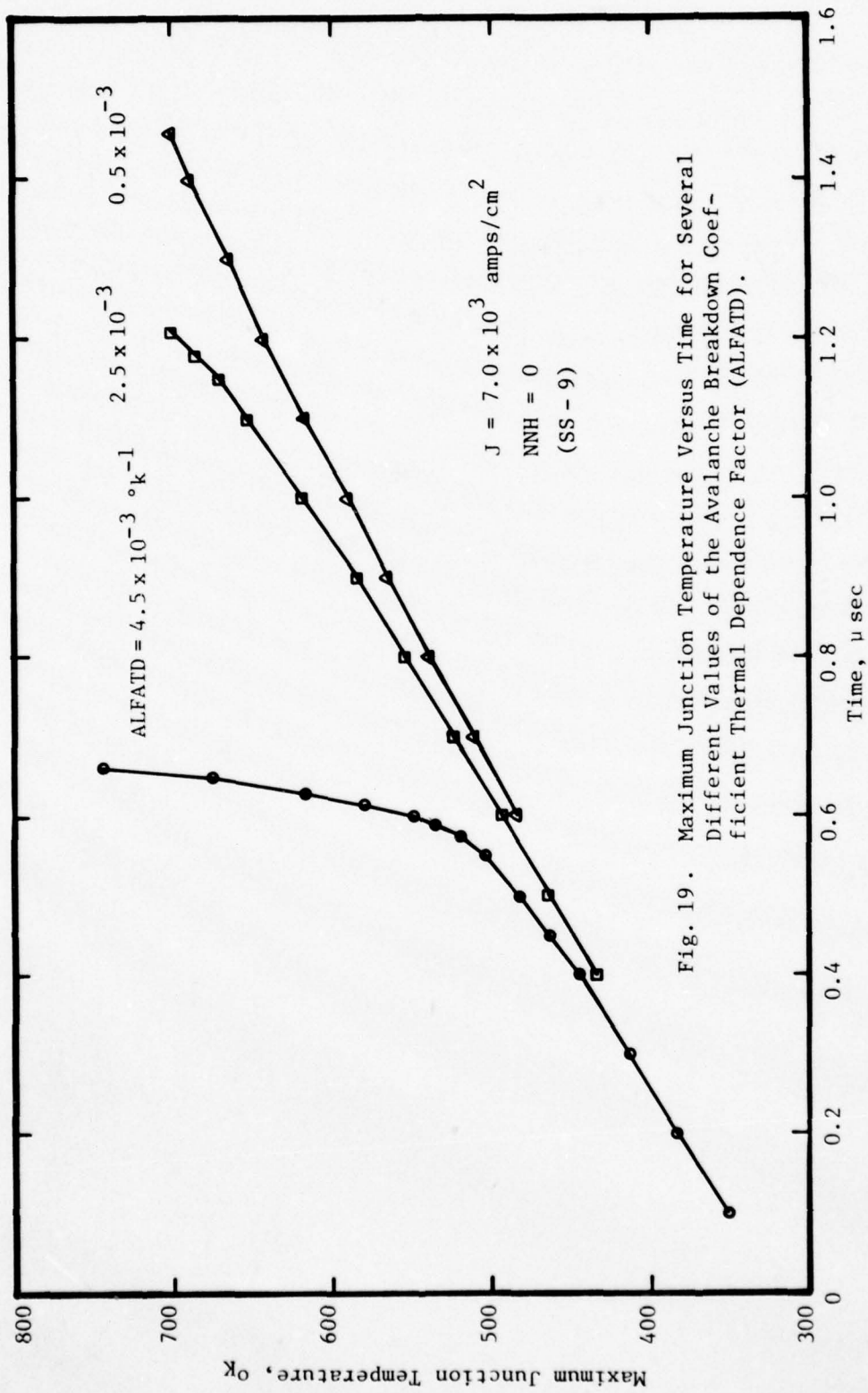
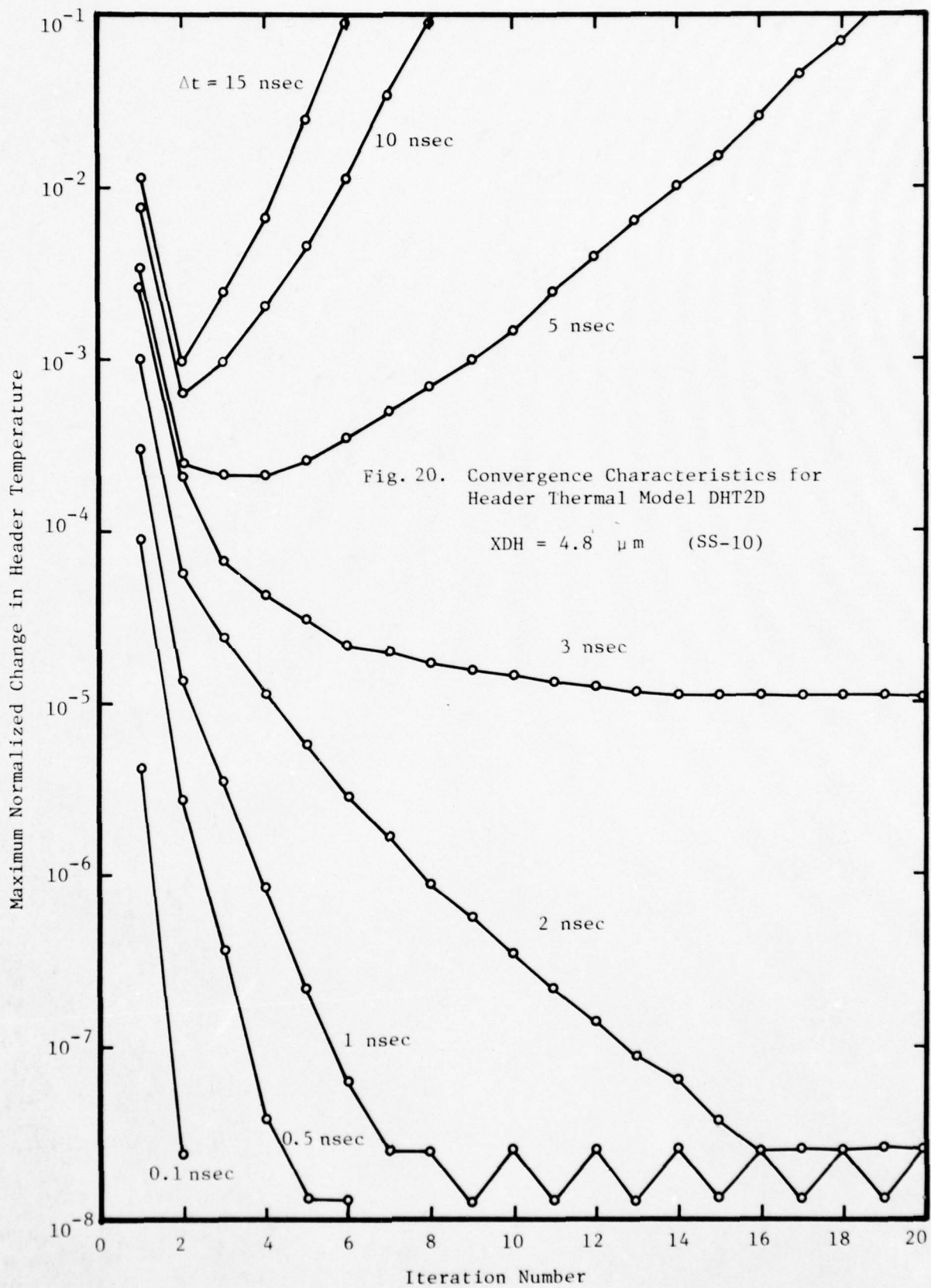
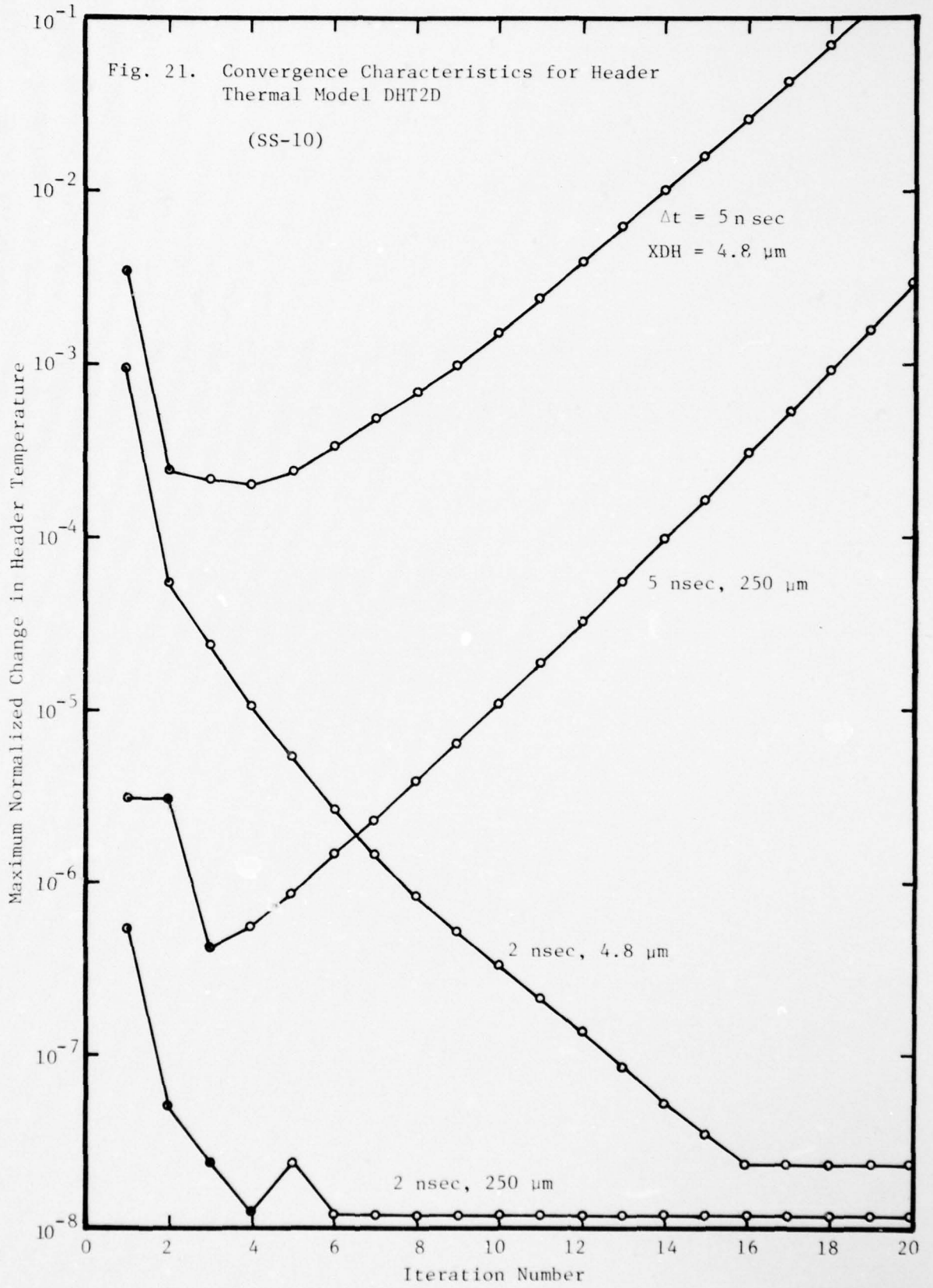
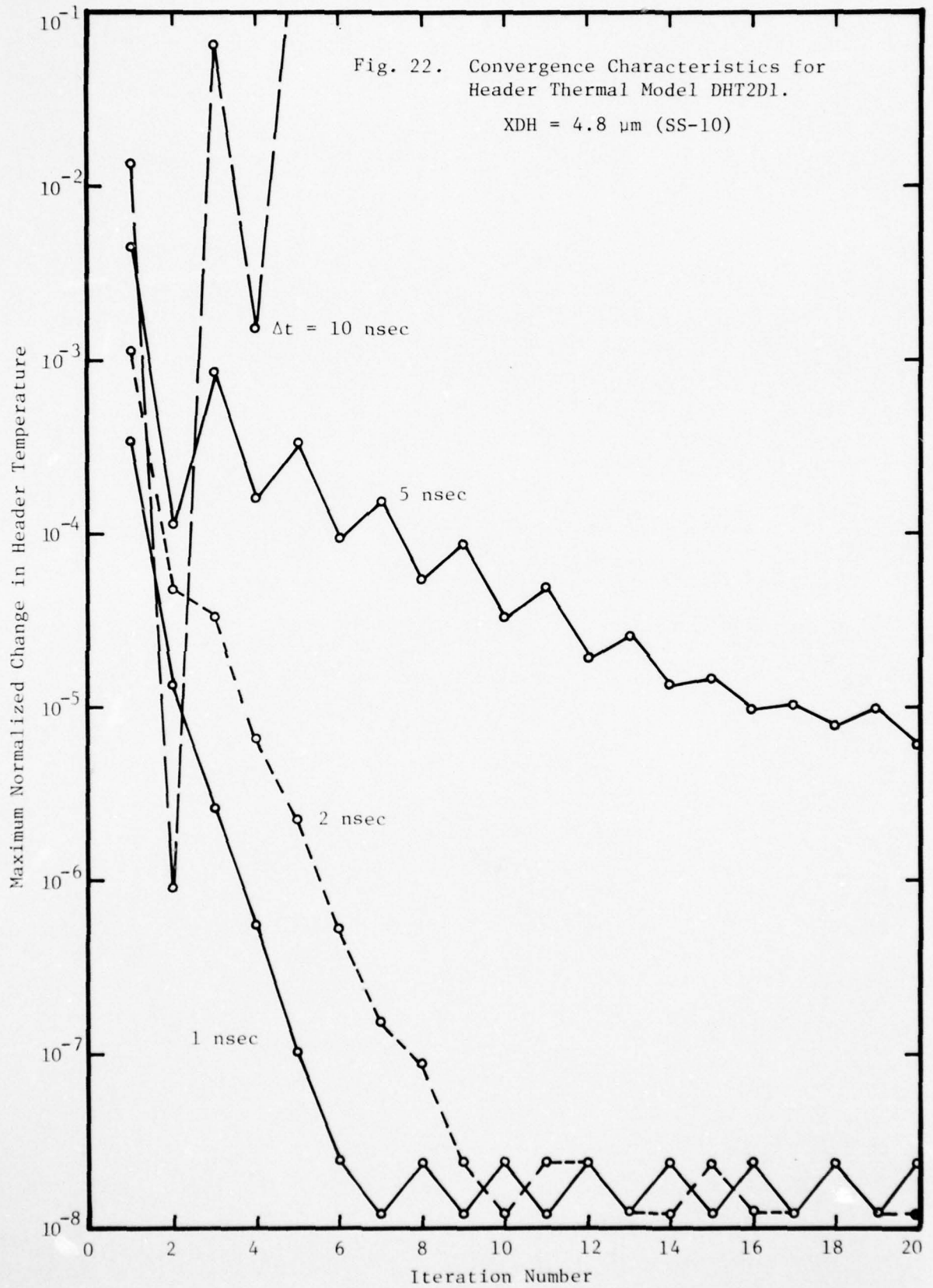
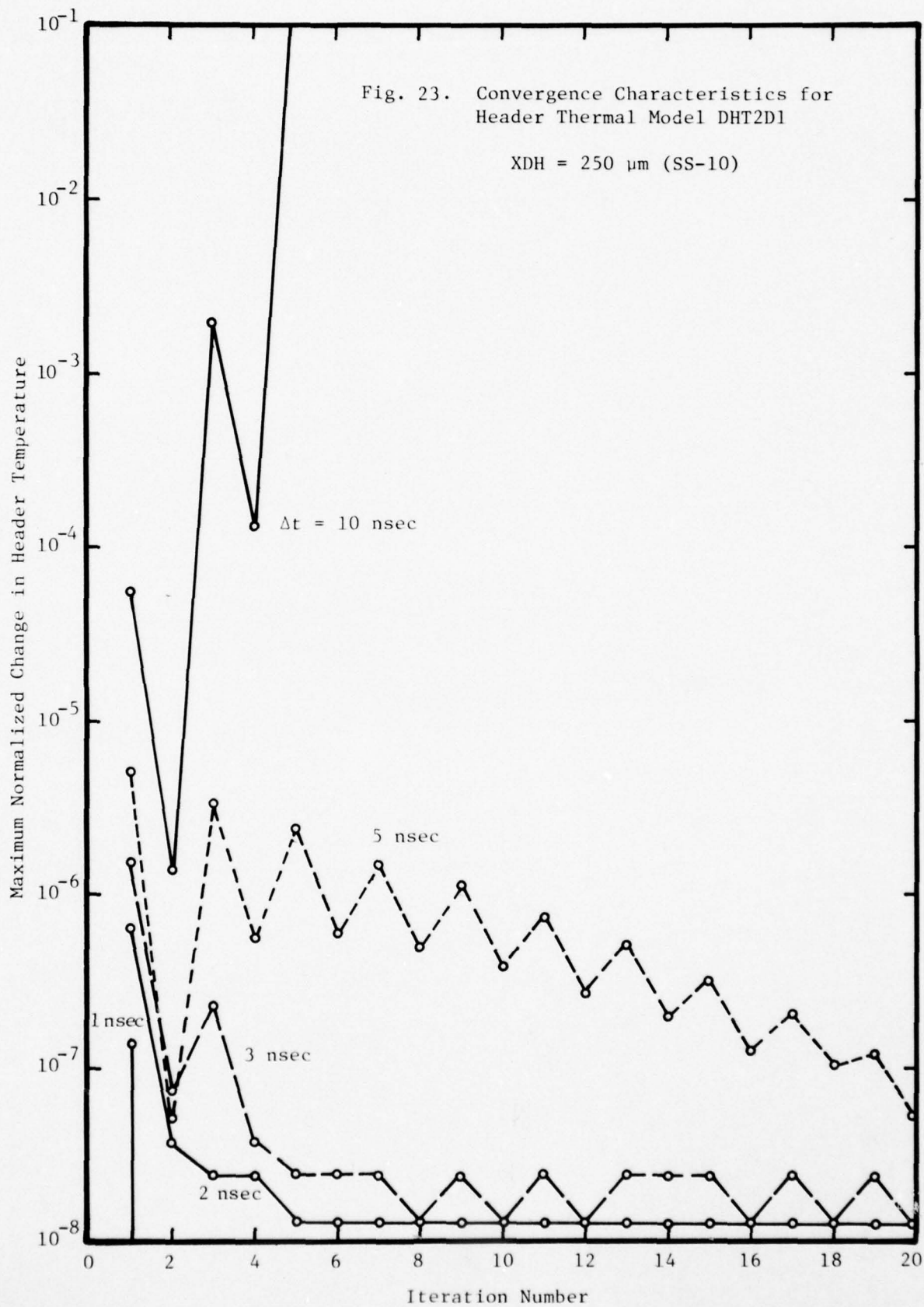


Fig. 19. Maximum Junction Temperature Versus Time for Several Different Values of the Avalanche Breakdown Coefficient Thermal Dependence Factor (ALFATD).

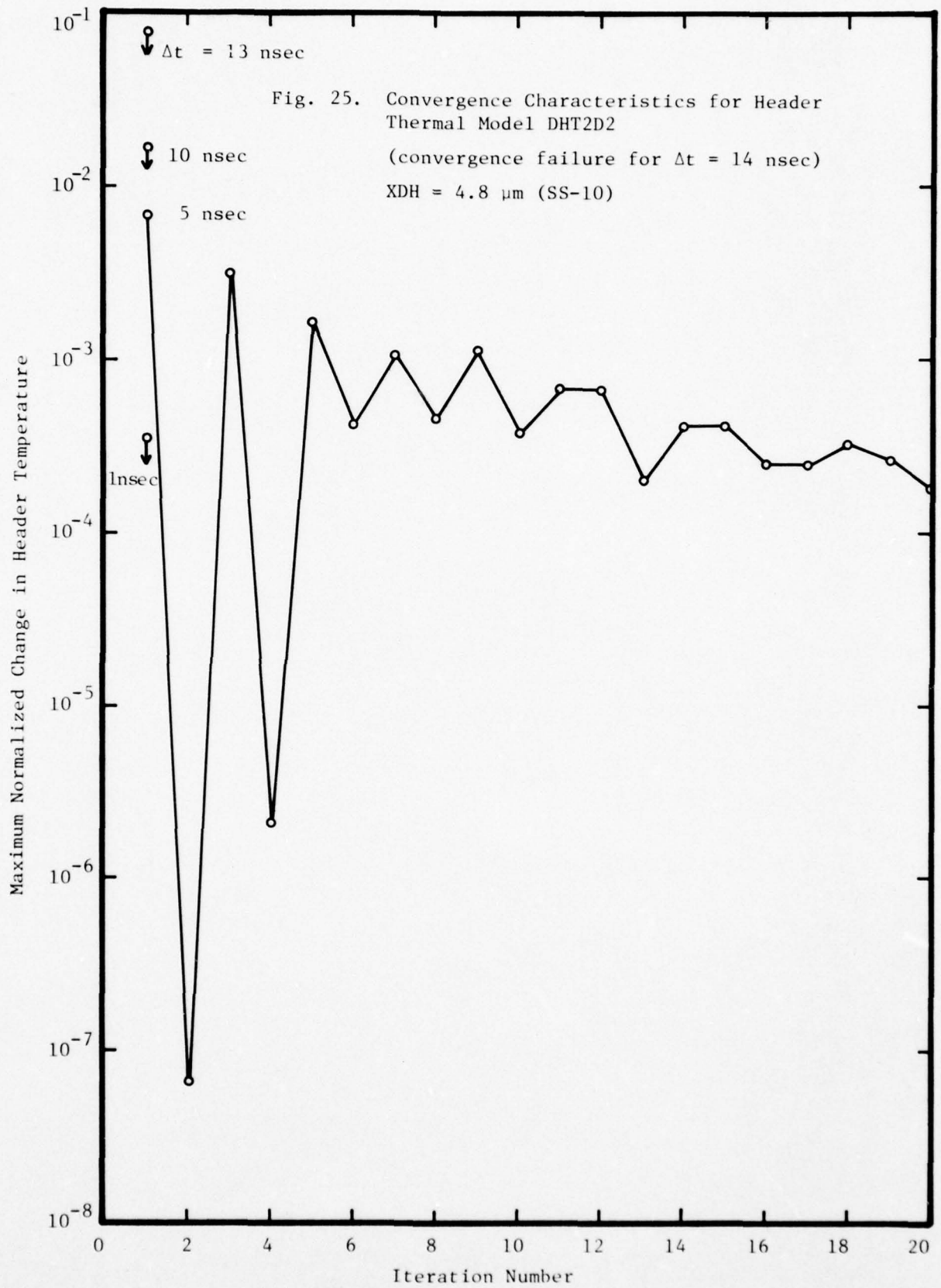


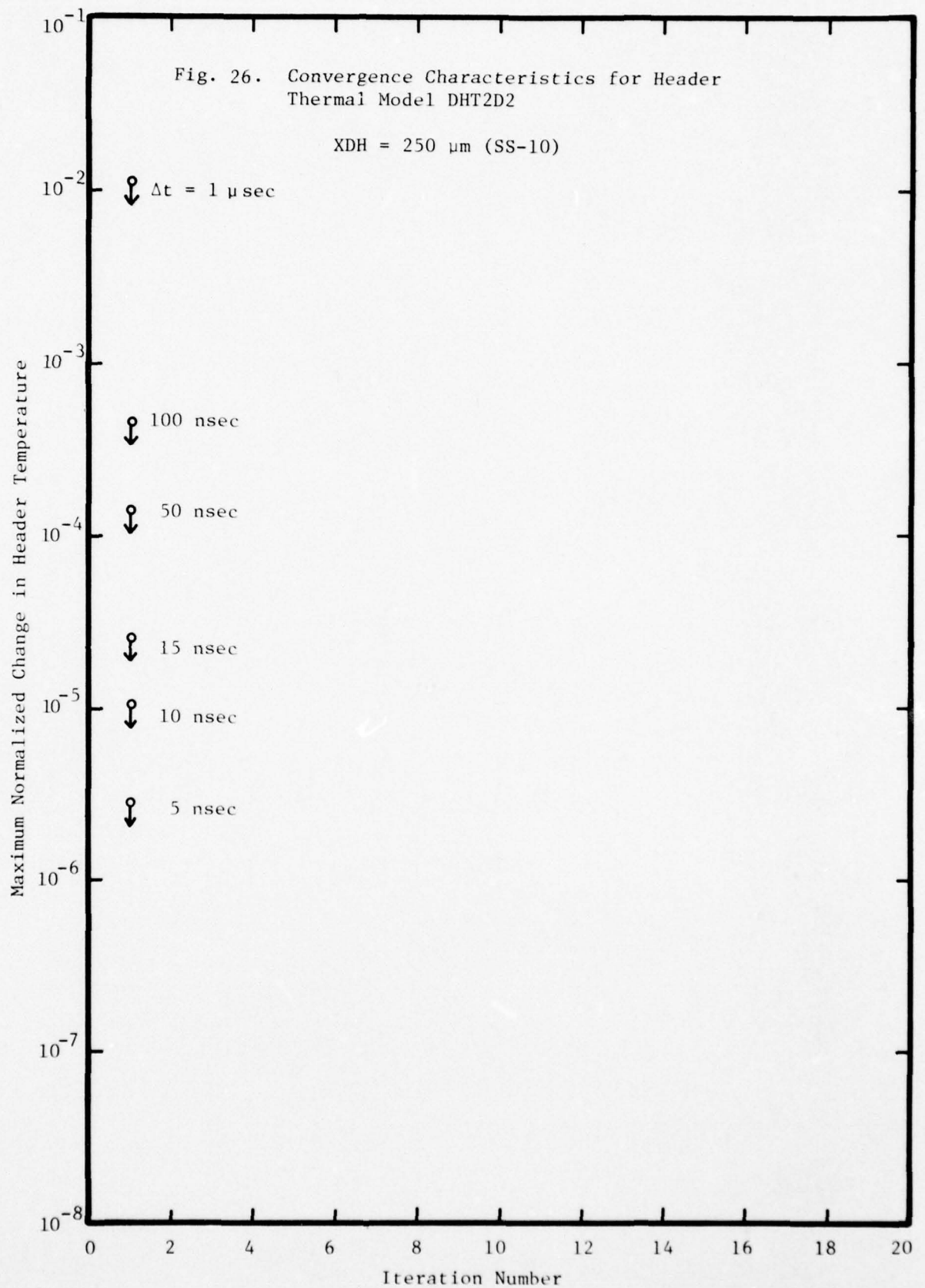












temperatures values. These curves show a further improvement in both rate of convergence and stability. Of the three two-dimensional header thermal models developed, DHT2D2 which uses the horizontal line technique, exhibits the best convergence and stability performance.

## CONCLUSIONS AND RECOMMENDATIONS

A computer model has been developed for simulating TSB in thin film diodes. The model performs a one-dimensional electrical and either quasi or full two-dimensional thermal simulation. The onset of the TSB transition from a low conductance to a high conductance state is assumed equivalent to the diode achieving a maximum temperature of 700 °K. Further, the TSB delay time is assumed to be approximately equal to the time required for the diode to reach this critical temperature in response to a constant current reverse bias overstress. Simulations are defined through 271 parameters which specify the diode design, thermal conductivity perturbations, and simulation control parameters. Execution times are usually less than two minutes on a Univac 1107 system and the program has a graphic output capability to facilitate data analysis.

The diode electrical model maintains avalanche breakdown by varying the electric field maximum value to satisfy the avalanche breakdown integral. The junction electric field profile is evaluated from the electric field maximum value and the net space charge density in the respective doping regions of the diode. The net space charge density accounts for space charge effects in the junction. Bulk region electric fields are evaluated by assuming that the currents in these regions are primarily drift currents and determining the electric field required to support the diode current. Coupling between the electrical model and thermal models is maintained through the thermal dependence of the avalanche

ionization coefficients, mobilities, and intrinsic carrier concentration.

Four different header thermal models were formulated and characterized with respect to stability and convergence behavior. The full two-dimensional header thermal model with horizontal line formulation and incorporation of the most recent temperature values available demonstrated the best performance. All of the two-dimensional models eliminated the inflection point previously observed in TSB delay time data obtained with the comprehensive quasi-two-dimensional header thermal model. The quasi and full two-dimensional thermal models agreed well for high currents, but differ appreciably for low currents, as expected.

A limited number of simulation results were presented. These include delay time as a function of current density for different header thermal models, diode temperature boundary conditions, avalanche ionization temperature coefficients, and with and without bulk region electric fields. In all cases, the model demonstrated the expected qualitative results.

As for recommendations, a comparison between the simulation results and experimental data for SOS diodes is required for a qualitative evaluation of the model. This comparison would also allow further refinement of several of the model parameters, e.g., TSB temperature, avalanche ionization thermal coefficient, etc. There are also several types of simulation which have not yet been performed. These include various epitaxial configurations, thermal conductivity perturbations, and changes in the diode dimensions.

Several improvements or additions to the diode model may be desirable. First, evaluation of the reverse saturation current would eliminate the necessity for a TSB temperature. Rather, the diode voltage could be monitored for the onset of the TSB transition. This refinement may be required to obtain agreement between the model and laboratory results. A more accurate numerical algorithm for evaluating the avalanche breakdown integral would further enhance the convergence of the diode electrical model.

A primary application of the model developed here is the preliminary investigation of TSB behavior in diodes for the purpose of defining simulations for more comprehensive diode models which require a corresponding increase in computation time.

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## APPENDIX A

DEMONSTRATION SIMULATION OUTPUT LISTING  
(SS-1)

DESCRIPTION	Page
Simulation Parameters . . . . .	A1
Thermal Conductivity Perturbation Factors . . . . .	A2
Transient Data . . . . .	A4
Diode and Header Temperatures at 0.330 $\mu$ sec . . . . .	A5
Transient Data . . . . .	A7
Diode and Header Temperatures at 0.935 $\mu$ sec . . . . .	A8
Transient Data . . . . .	A10
Diode and Header Temperatures at 2.25 $\mu$ sec . . . . .	A11
Transient Data . . . . .	A13
Diode and Header Temperatures at 5.55 $\mu$ sec . . . . .	A14
Plot of Maximum Temperature Versus Time . . . . .	A16
Diode Temperature Profiles . . . . .	A17
Plot of Diode Temperature Profiles . . . . .	A19
Plot of Impurity Profile . . . . .	A20
Plot of Initial and Final Electric Field Profiles . . . . .	A21
Plot of Diode Voltage Transient . . . . .	A22

## APPENDIX B

## COMPUTER LISTINGS FOR DIODE MODEL

ALGORITHM	Page
Subroutine BANDA6 . . . . .	B1
Subroutine BKDEPL . . . . .	B3
Subroutine DEPV . . . . .	B5
Subroutine DHTEMP . . . . .	B6
Subroutine DHT2D . . . . .	B8
Subroutine DHT2D1 . . . . .	B13
Subroutine DHT2D2 . . . . .	B18
Subroutine DOPLG . . . . .	B24
Subroutine EFIELD . . . . .	B25
Subroutine EMOBS . . . . .	B28
Subroutine EPROF . . . . .	B29
Subroutine HMOBS . . . . .	B31
Subroutine INALFA . . . . .	B32
Subroutine IONCOF . . . . .	B34
Subroutine LPLOT . . . . .	B35
Program TEMPTRIØ . . . . .	B38

SIMULATION PARAMETERS

```

+SFARI
CUF      .75000000E+04
MRE      +1101
MID      +112
IDLC     +0
IDLCMX  .10000000E+01
IDLCM   .70000000E+03
IDLCMX  .80000000E+03
ITRMAX  .55000000E-07
LTEMP   +1
LCTEM   +1
PLVLTX  .50000000E+03
TRM     .10000000E+04
ITERMX  +10000
ILSTMO  +4
SMAX    .10000000E-03
UTRMAX  +20
ITERH   .32000000E-06
PLTIME  .10000000E+03
EMAXL   .10000000E+06
EMAXU   .10000000E+07
EJNT    .10000000E+03
UME     .10000000E+01
ALEKMAX .10000000E+00
LEKMAX  .10000000E-03
ITCMAX  +10
IDJ     +0
IDJ3    +0
IDJ5    +0
IDJ7    +0
IDJ9    +0
PLTP    +1
PLJIP   +1
PDEP    +1
PCVP    +1
SEND
ICDARM*
TMRD    .10000000E+01
IKHX    .40000000E+00
IKHY    .40000000E+00
LVEN    .23000000E+01
LDEN    .40000000E+01
USPEC   .79000000E+00
XDT     .10000000E-03
ADJEP   .20000000E+01
ANE     .20000000E+00
XFEDEP .40000000E-02
XULEP   .40000000E+01
XL      .40000000E-02
UOF L   .10000000E+17
UOF EP  .10000000E+17
UOF U   .10000000E+17
SCUNC   .56874999E+16
JUCPL   .53125000E+17
SUCPEP .53125000E+16
JUCPU   .20000000E+05
ALL ATU .20000000E-02
*PI
387.D

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THERMAL CONDUCTIVITY PERTURBATION FACTORS

MODE	POSITION	DEPTH	F FFLD	TKLHPF	TKHHPF
1	00000	10000+1A	.69552+03	1.0000	1.0000
2	40000-04	10000+1A	.69552+03	1.0000	1.0000
3	80000-04	10000+1A	.69552+03	1.0000	1.0000
4	12000-03	10000+1A	.69552+03	1.0000	1.0000
5	16000-03	10000+1A	.69552+03	1.0000	1.0000
6	20000-03	10000+1A	.69552+03	1.0000	1.0000
7	24000-03	10000+1A	.69552+03	1.0000	1.0000
8	28000-03	10000+1A	.69552+03	1.0000	1.0000
9	32000-03	10000+1A	.69552+03	1.0000	1.0000
10	36000-03	10000+1A	.69552+03	1.0000	1.0000
11	40000-03	10000+1A	.69552+03	1.0000	1.0000
12	44000-03	10000+1A	.69552+03	1.0000	1.0000
13	48000-03	10000+1A	.69552+03	1.0000	1.0000
14	52000-03	10000+1A	.69552+03	1.0000	1.0000
15	56000-03	10000+1A	.69552+03	1.0000	1.0000
16	60000-03	10000+1A	.69552+03	1.0000	1.0000
17	64000-03	10000+1A	.69552+03	1.0000	1.0000
18	68000-03	10000+1A	.69552+03	1.0000	1.0000
19	72000-03	10000+1A	.69552+03	1.0000	1.0000
20	76000-03	10000+1A	.69552+03	1.0000	1.0000
21	80000-03	10000+1A	.69552+03	1.0000	1.0000
22	84000-03	10000+1A	.69552+03	1.0000	1.0000
23	88000-03	10000+1A	.69552+03	1.0000	1.0000
24	92000-03	10000+1A	.69552+03	1.0000	1.0000
25	96000-02	10000+1A	.69552+03	1.0000	1.0000
26	10000-02	10000+1A	.69552+03	1.0000	1.0000
27	11200-02	10000+1A	.69552+03	1.0000	1.0000
28	12400-02	10000+1A	.69552+03	1.0000	1.0000
29	13600-02	10000+1A	.69552+03	1.0000	1.0000
30	14800-02	10000+1A	.69552+03	1.0000	1.0000
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34	19600-02	10000+1A	.69552+03	1.0000	1.0000
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THERMAL CONDUCTIVITY PERTURBATION FACTORS (Continued)

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7	7	7	7	7	7
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5	5	5	5	5	5
4	4	4	4	4	4
3	3	3	3	3	3
2	2	2	2	2	2
1	1	1	1	1	1

## TRANSIENT DATA

ITEM	TIME	CTMP	ITER.	TRNS	TEMPX	FMAX	VIBL1K	VDPP	VIBULK	VDTDF	XIDEP	XIDFP	ALFATN	S
1	.500-07	.550-07	1	.991+01	.332+03	.318+06	.140+01	.666+02	.344+02	.102+03	.198-02	.240-02	.964+00	2
2	.110-06	.550-07	1	.920+01	.325+06	.325+06	.144+01	.695+02	.378+02	.109+03	.198-02	.241-02	.106+01	2
3	.195-06	.550-07	1	.763+01	.369+03	.325+06	.149+01	.695+02	.420+02	.113+03	.198-02	.241-02	.975+01	2
4	.220-06	.550-07	1	.774+01	.382+03	.325+06	.151+01	.695+02	.471+02	.118+03	.198-02	.241-02	.975+01	2
5	.275-06	.550-07	1	.674+01	.405+03	.325+06	.159+01	.726+02	.536+02	.125+03	.198-02	.241-02	.940+00	2
6	.350-06	.550-07	1	.674+01	.405+03	.325+06	.159+01	.726+02	.622+02	.136+03	.198-02	.241-02	.105+01	2





TRANSIENT DATA

ITEM	TIME	OTIME	ITEM	TRNS	TEMPX	EMAX	VLRUK	VJFP	VURUK	VOTCF	XI JFP	XI JFP	AI FATJ	S
7	.365-06	.550-07	1	.721+01	.417+03	.332+06	.163+01	.726+02	.734+02	.148+03	.198-02	.241-02	.101+01	2
8	.440-06	.550-07	1	.750+01	.420+03	.332+06	.167+01	.726+02	.806+02	.159+03	.198-02	.241-02	.978+00	2
9	.495-06	.550-07	1	.774+01	.439+03	.339+06	.171+01	.757+02	.913+02	.169+03	.198-02	.242-02	.104+01	2
10	.550-06	.550-07	1	.808+01	.460+03	.339+06	.175+01	.757+02	.110+03	.178+03	.198-02	.242-02	.107+01	2
11	.600-06	.550-07	1	.863+01	.469+03	.339+06	.179+01	.757+02	.110+03	.187+03	.198-02	.242-02	.107+01	2
12	.715-06	.550-07	1	.767+01	.478+03	.339+06	.183+01	.757+02	.127+03	.194+03	.198-02	.242-02	.977+00	2
13	.825-06	.550-07	1	.731+01	.486+03	.339+06	.191+01	.757+02	.127+03	.200+03	.198-02	.242-02	.945+00	2
14	.880-06	.550-07	1	.638+01	.494+03	.346+06	.195+01	.788+02	.131+03	.205+03	.198-02	.243-02	.102+01	2
15	.935-06	.550-07	1	.605+01	.509+03	.353+06	.199+01	.788+02	.134+03	.212+03	.198-02	.243-02	.983+00	2
16			1	.605+01			.203+01	.821+02	.137+03	.221+03	.198-02	.244-02	.100+01	2





TRANSIENT DATA

ITSA	TIME	I-TIME	ITEM	TRMS	TEMPK	FMAX	VRHJK	VDFP	VRHJLK	VRTOJF	XIDFP	XIDFF	ALFATN	S
18	990-06	550-07	1	571+01	517+03	353+06	206+01	A21+02	138+03	223+03	198-02	248-02	105+01	2
19	104-05	550-07	1	524+01	544+03	353+06	213+01	A21+02	140+03	224+03	198-02	248-02	102+01	2
20	110-05	550-07	1	436+01	545+03	353+06	217+01	A21+02	142+03	225+03	198-02	248-02	984+00	2
21	115-05	550-07	1	398+01	541+03	353+06	220+01	A21+02	143+03	227+03	198-02	248-02	974+00	2
22	121-05	550-07	1	359+01	545+03	353+06	223+01	A21+02	144+03	228+03	198-02	248-02	973+00	2
23	126-05	550-07	1	327+01	545+03	360+06	226+01	A54+02	144+03	233+03	197-02	245-02	101+01	2
24	132-05	550-07	1	31+01	555+03	360+06	229+01	A54+02	145+03	233+03	197-02	245-02	984+00	2
25	143-05	550-07	1	26+01	559+03	367+06	232+01	AAA+02	145+03	236+03	197-02	246-02	105+01	2
26	148-05	550-07	1	287+01	564+03	367+06	235+01	AAA+02	145+03	236+03	197-02	246-02	105+01	2
27	154-05	550-07	1	240+01	568+03	367+06	237+01	AAA+02	145+03	237+03	197-02	246-02	100+01	2
28	159-05	550-07	1	220+01	572+03	367+06	240+01	AAA+02	146+03	237+03	197-02	246-02	980+00	2
29	170-05	550-07	1	207+01	578+03	367+06	242+01	AAA+02	146+03	237+03	197-02	246-02	981+00	2
30	176-05	550-07	1	181+01	581+03	367+06	247+01	AAA+02	146+03	237+03	197-02	246-02	977+00	2
31	181-05	550-07	1	171+01	583+03	367+06	249+01	AAA+02	146+03	237+03	197-02	246-02	972+00	2
32	187-05	550-07	1	157+01	586+03	374+06	251+01	AAA+02	146+03	237+03	197-02	247-02	101+01	2
33	192-05	550-07	1	147+01	588+03	374+06	253+01	922+02	142+03	237+03	197-02	247-02	984+00	2
34	198-05	550-07	1	14+01	591+03	381+06	255+01	957+02	142+03	240+03	197-02	248-02	106+01	2
35	203-05	550-07	1	15+01	593+03	381+06	257+01	957+02	142+03	241+03	197-02	248-02	106+01	2
36	208-05	550-07	1	132+01	596+03	381+06	263+01	957+02	142+03	241+03	197-02	248-02	102+01	2
37	214-05	550-07	1	122+01	593+03	381+06	264+01	957+02	142+03	241+03	197-02	248-02	100+01	2



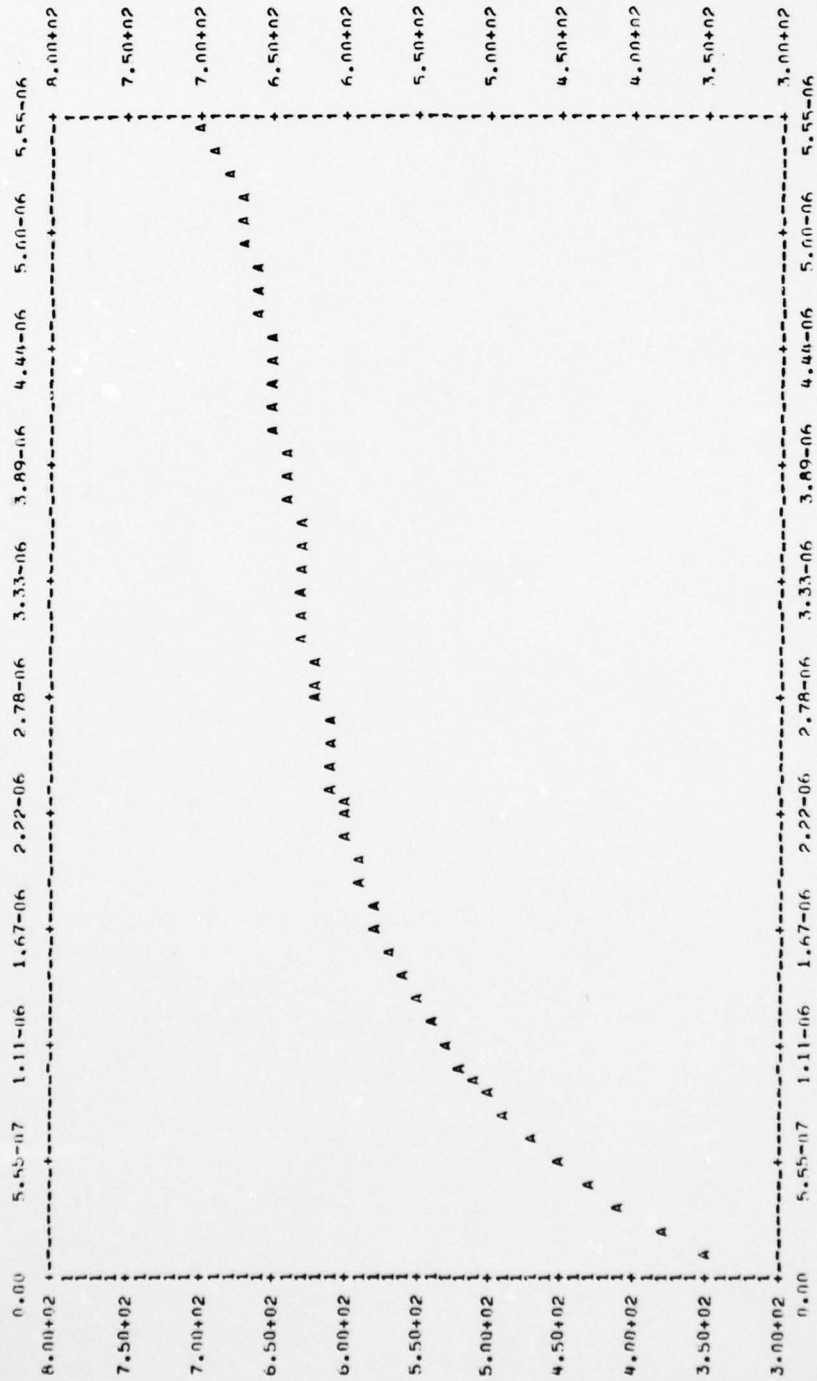








PLOT OF MAXIMUM TEMPERATURE VERSUS TIME



MAXIMUM TEMPERATURE VERSUS TIME

AD-A057 598

MISSISSIPPI STATE UNIV MISSISSIPPI STATE DEPT OF ELEC--ETC F/G 9/3  
A NUMERICAL MODEL FOR THERMAL SECOND BREAKDOWN.(U)

MAY 78 W H CAUSEY

DAAG29-77-G-0190

UNCLASSIFIED

MSSU-EIRS-EE-78-3

ARO-15304.1-A-EL

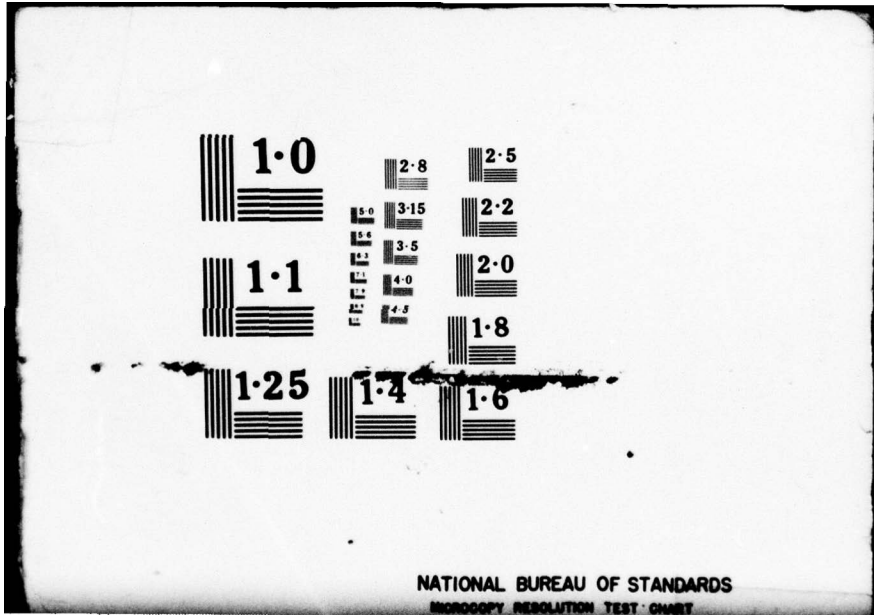
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2 of 2  
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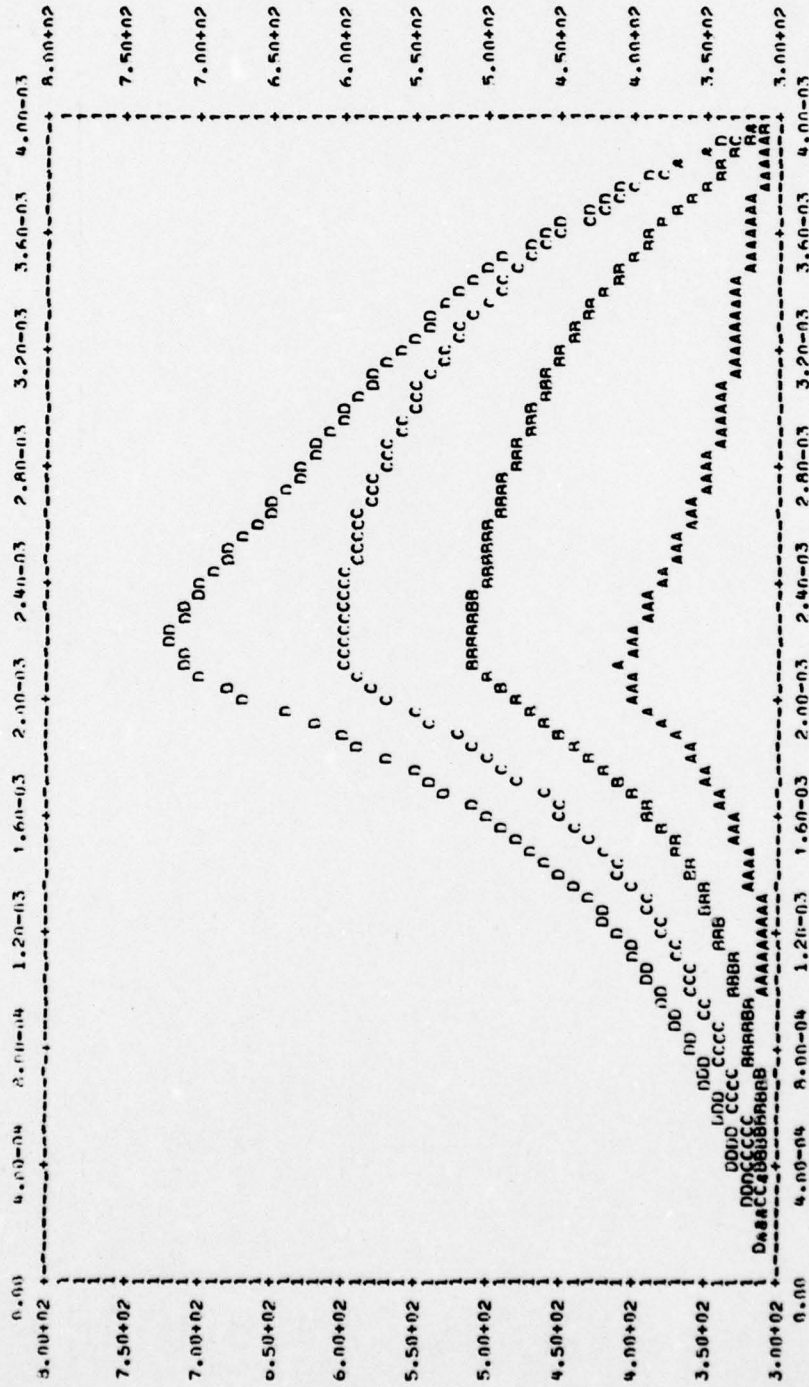
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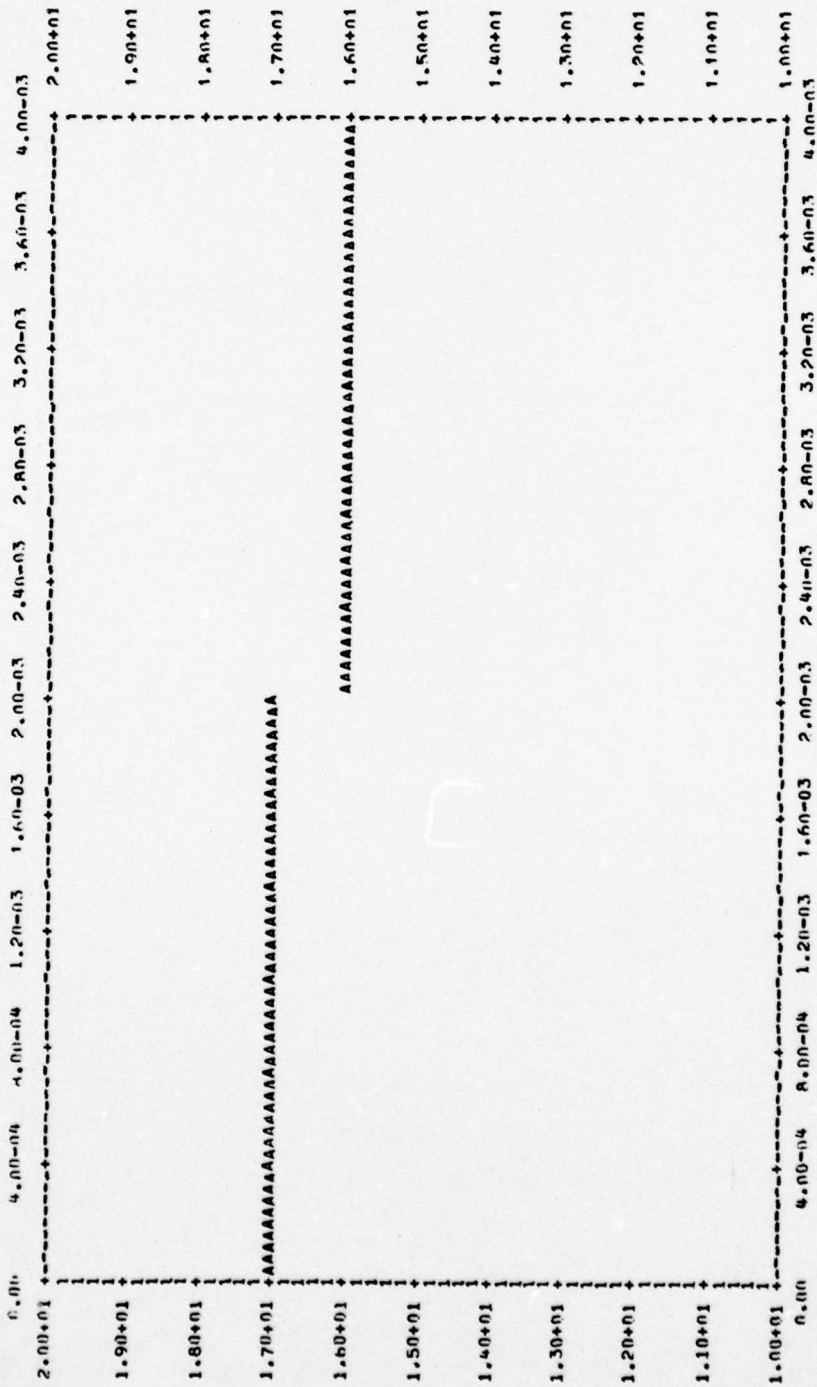


PLOT OF DIODE TEMPERATURE PROFILES



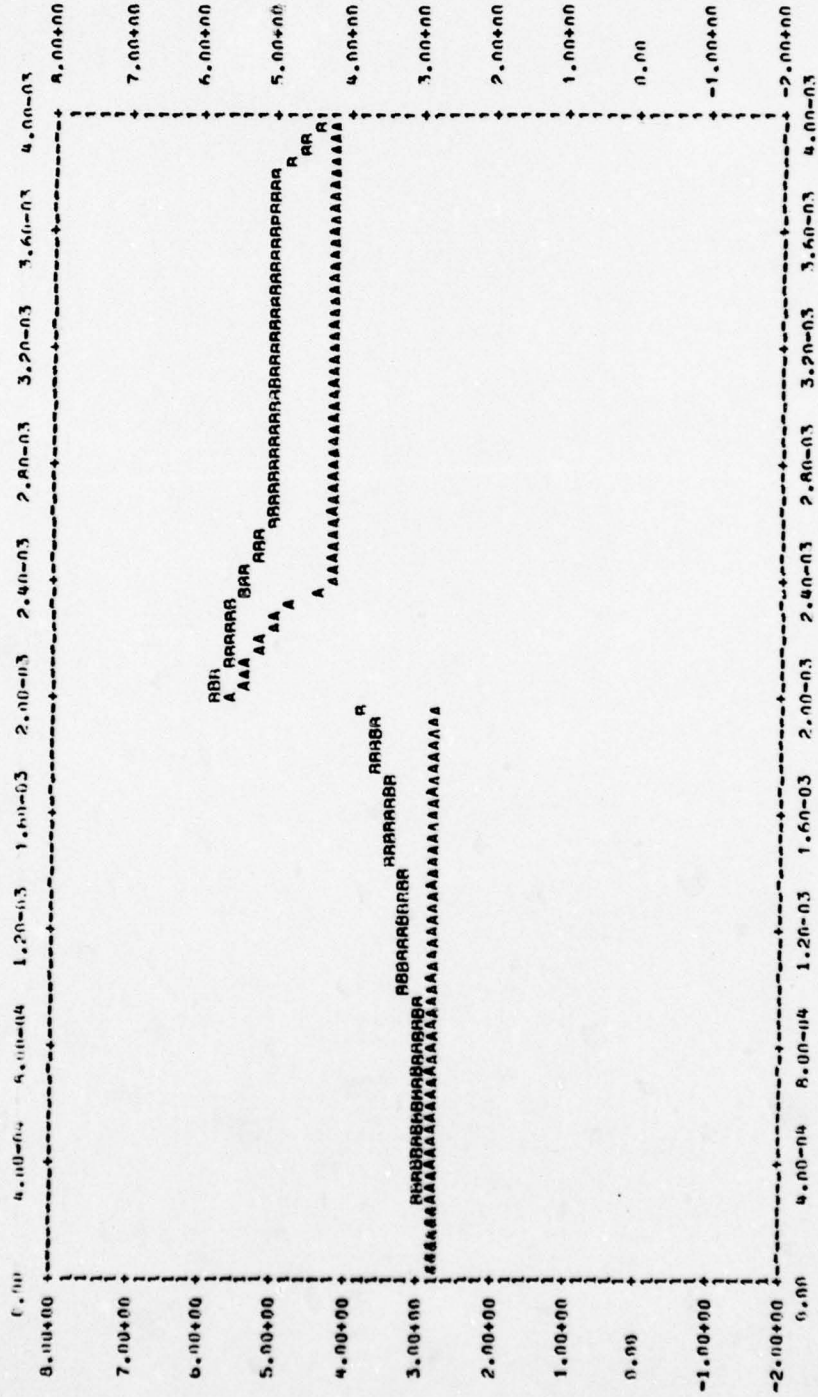
DIODE TEMPERATURE VERSUS POSITION

PLOT OF IMPURITY PROFILE



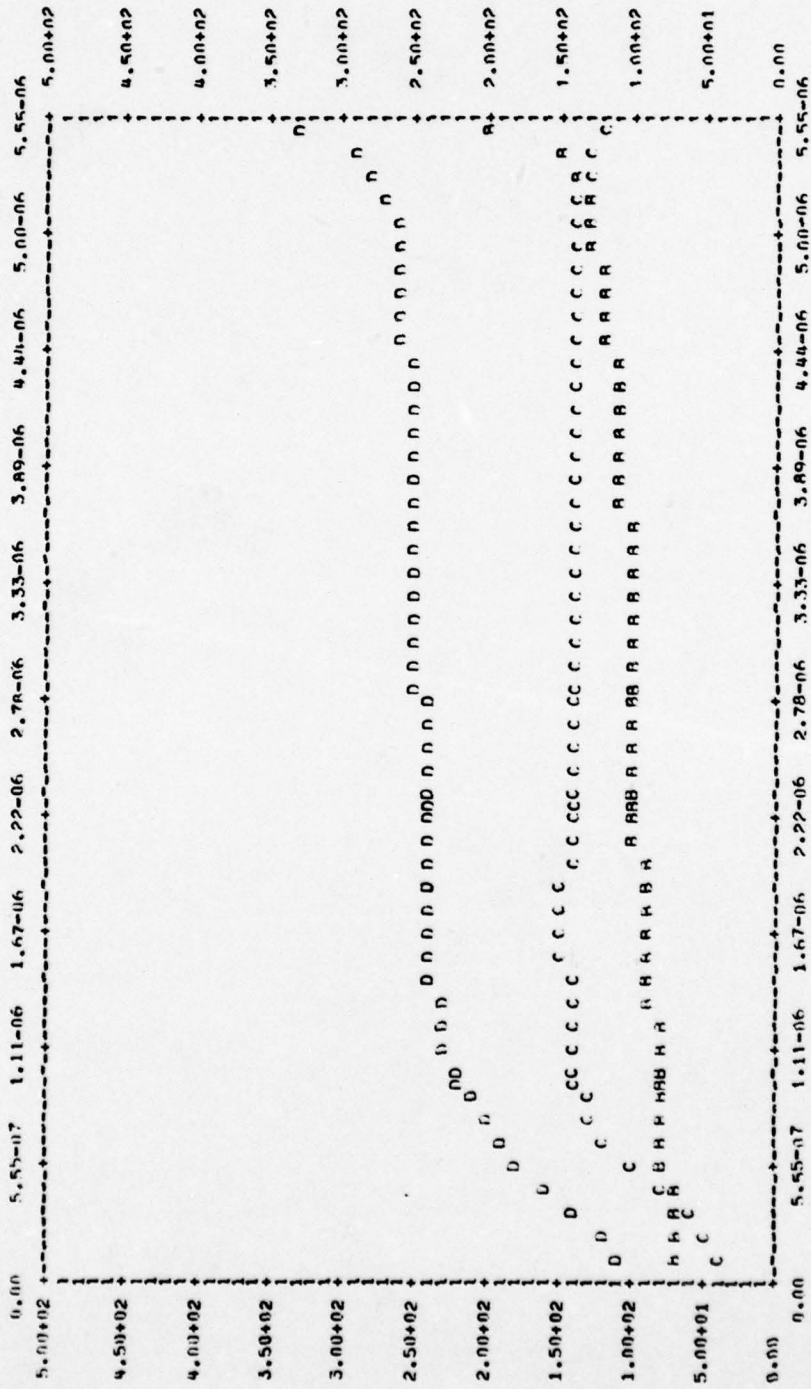
LOG OF DIODE IMPURITY CONCENTRATION VERSUS POSITION

PLOT OF INITIAL AND FINAL ELECTRIC FIELD PROFILES



LOG OF ELECTRIC FIELD VERSUS POSITION

PLOT OF DIODE VOLTAGE TRANSIENT



DIODE VOLTAGES VERSUS TIME

## APPENDIX B

## COMPUTER LISTINGS FOR DIODE MODEL

ALGORITHM	Page
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Subroutine BKDEPL . . . . .	B3
Subroutine DEPV . . . . .	B5
Subroutine DHTEMP . . . . .	B6
Subroutine DHT2D . . . . .	B8
Subroutine DHT2D1 . . . . .	B13
Subroutine DHT2D2 . . . . .	B18
Subroutine DOPLG . . . . .	B24
Subroutine EFIELD . . . . .	B25
Subroutine EMOBS . . . . .	B28
Subroutine EPROF . . . . .	B29
Subroutine HMOBS . . . . .	B31
Subroutine INALFA . . . . .	B32
Subroutine IONCOF . . . . .	B34
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## SUBROUTINE BANDA6

\*TEMP(1).BANDA6

```

SUBROUTINE BANDA6(LRMAX,NCD,NHD,LXROW,LAROW,LACOL,A,
&X,NBNDTX,PIVMIN)

```

```

SUB. 'BANDA6' EVALUATES THE SOLUTION OF A BANDED
(OR DIAGONAL) SYSTEM OF (LRMAX) LINEAR SIMULTANEOUS
EQUATIONS THROUGH THE GAUSSIAN ELIMINATION TECHNIQUE.
THE COEFFICIENT ARRAY 'A' IS DESTROYED.

```

```

LRMAX - NUMBER OF EQUATIONS TO BE SOLVED SIMULTANEOUSLY
LXROW - SOLUTION ARRAY LENGTH, INCLUDES UNKNOWN AND
        BOUNDARY VALUES
NCD - COLUMN NUMBER OF CENTRAL DIAGONAL IN 'A'
NHD - COLUMN NUMBER FOR EQUATION CONSTANTS IN 'A'
A - COEFFICIENT AND CONSTANT ARRAY
X - SOLUTION ARRAY
NBNDTX - NUMBER OF POSITIONS RESERVED FOR BND VALUES AT TOP
        OF 'X' ARRAY
NDB - NUMBER OF COEFFICIENT DIAGONALS BELOW CENTRAL
      (OR MAIN) DIAGONAL
NDA - NUMBER OF COEFFICIENT DIAGONALS ABOVE CENTRAL
      (OR MAIN) DIAGONAL
PIVMIN - MINIMUM PIVOT
LAROW - COEFFICIENT AND CONSTANT ARRAY ROW DIMENSION
LACOL - COEFFICIENT AND CONSTANT ARRAY COLUMN DIMENSION

```

```

DIMENSION X(LXROW),A(LAROW,LACOL)

```

```

NDB=NCD-1
NDA=NHD-NCD-1
PIVMIN=1.0E35

```

```

UPPER TRIANGULATION OF ROWS (2)-(NDB)

```

```

IF(NDB.EQ.1) GO TO 20
DO 5 LR=2,NDB
  LCOF=NDB+2-LR
  DO 10 LCO=LCOF,NDB
    ALFA=A(LR,LCO)/A(LR+LCO-NCD,NCD)
    DO 15 LC=1,NDA
      A(LR,LC+LCO)=A(LR,LC+LCO)-ALFA*A(LR+LCO-NCD,LC+NCD)
    CONTINUE
    A(LR,NHD)=A(LR,NHD)-ALFA*A(LR+LCO-NCD,NHD)
  CONTINUE
CONTINUE

```

```

CONTINUE

```

```

UPPER TRIANGULARIZATION OF ROWS (NDB+1)-(LRMAX)
DO 25 LR=NCD,LRMAX

```

```

SEARCH FOR MINIMUM DIAGONAL PIVOT ELEMENT

```

```

TA=A(LR-NDB,NCD)
IF(DABS(TA).LT.DABS(PIVMIN)) PIVMIN=TA
DO 30 LCO=1,NDB

```

```

ALFA=A(LR,LCO)/A(LR+LCO-NCD,NCD)
DO 32 LC=1,NDA
  A(LR,LC+LCO)=A(LR,LC+LCO)-ALFA*A(LR+LCO-NCD,LC+NCD)
CONTINUE
A(LR,NHD)=A(LR,NHD)-ALFA*A(LR+LCO-NCD,NHD)
CONTINUE
CONTINUE

```

```

BACK SUBSTITUTION FOR X(LRMAX)-X(LRMAX-NDA+1)

```

```

LRSTOP=LRMAX-NDA+1
DO 45 LR=LRMAX,LRSTOP,-1
  TA=A(LR,NHD)
  KK=LR+NBNDTX
  KSTOP=LRMAX-LR
  IF(KSTOP.EQ.0) GO TO 40
  DO 35 K=1,KSTOP
    TA=TA-X(K+KK)*A(LR,K+NCD)
  CONTINUE
CONTINUE
X(KK)=TA/A(LR,NCD)
CONTINUE

```

```

BACK SUBSTITUTION FOR X(LRMAX-NDA)-X(NDB+1)

```

```

LRST=LRMAX-NDA
DO 55 LR=LRST,1,-1

```

## SUBROUTINE BANDA6 (Continued)

```
80      KK=LR+NBNDTX
81      TA=A(LR,NHD)
82      DO 50 K=1,NDA
83      TA=TA-X(K+KK)*A(LR,K+NCD)
84      CONTINUE
85      X(KK)=TA/A(LR,NCD)
86      CONTINUE
87      C
88      RETURN
89      END
```

## SUBROUTINE BKDEPL

\*TEMP(1).BKDEPL

```

SUBROUTINE BKDEPL(NND,XDEPL,XMET,XDEPEP,XDEPU,XL,DX,DOPL,DOPEP,
&DOPU,ALFATD,EMAX,AERMAX,EMAXL,EMAXU,E,T,ALFAIN,VDEP,
&ITCMAX,IDB1,IDB2,IDB3,NP1,SDOPL,SDOPEP,SDOPU)

```

```

SUB BKDEPL DETERMINES THE DEPLETION REGION WIDTH SUCH THAT THE
AVALANCHE BREAKDOWN INTEGRAL IS APPROXIMATELY EQUAL TO ONE.
MAXIMUM ELECTRIC FIELD ESTIMATIONS ARE ITERATED UNTIL THE
INTEGRAL IS WITH IN A SPECIFIED ERROR OR A MAXIMUM NUMBER OF
ITERATIONS ARE PERFORMED.

```

```

NND      - NUMBER OF NODES ALONG AXIS OF DIODE
XDEPL   - DEPLETION REGION LOWER BOUNDARY
XMET    - POSITION OF METALLURGICAL JUNCTION
XDEPEP  - EPITAXIAL LAYER BOUNDARY
XL      - DIODE LENGTH
DX      - NODE SPACING ALONG DIODE AXIS
DOPL    - LOWER DOPING CONC.
DOPEP   - EPITAXIAL DOPING CONC.
DOPU    - UPPER DOPING CONC.
ALFATD  - AVALANCHE IONIZATION COEFFICIENT TEMPERATURE DEPENDENCE
PARAMETER
EMAX    - MAXIMUM DEPLETION REGION ELECTRIC FIELD
AERMAX  - MAXIMUM AVALANCHE BREAKDOWN INTEGRAL ERROR
EMAXL   - LOWER BOUND FOR EMAX
EMAXU   - UPPER BOUND FOR EMAX
E       - ELECTRIC FIELD ARRAY
T       - TEMPERATURE ARRAY
ALFAIN  - AVALANCHE BREAKDOWN INTEGRAL
VDEP    - DEPLETION REGION VOLTAGE
ITCMAX  - MAXIMUM NUMBER OF ITERATIONS ON EMAX
IDB1    - DEBUG SENTINEL FOR SUB INALFA
IDB2    - DEBUG SENTINEL FOR SUB BKDEPL
IDB3    - DEBUG SENTINEL FOR SUB FPROF
NP1     - JUNCTION ORIENTATION, 1 - NP, 0 - PN
SDOPL   - LOWER DEPLETION REGION SPACE CHARGE
SDOPEP  - EPITAXIAL DEPLETION REGION SPACE CHARGE
SDOPU   - UPPER DEPLETION REGION SPACE CHARGE

```

```

DEBUG NAMELIST
NAMELIST /DEBUG/NND,XDEPL,XMET,XDEPEP,XDEPU,XL,DX,DOPL,DOPEP,DOPU,
&ALFATD,ALFAIN,EMAX,AERMAX,EMAXL,EMAXU,VDEP,VDEPL,VDEPEP,VDEPU,
&ITCMAX,NP1

```

```

DIMENSION E(NND),T(NND)

```

```

INTEGER FLAGEB

```

```

INITIALIZATION COMPUTATIONS

```

```

SET THE MAXIMUM ELECTRIC FIELD ITERATION COUNTER
ITC=0

```

```

INITIALIZE ELECTRIC FIELD SEARCH BOUNDARIES
TEMAXU=EMAXU
TEMAXL=EMAXL

```

```

200 CONTINUE

```

```

BEGIN ITERATION ON MAXIMUM ELECTRIC FIELD
INCREMENT ITERATION COUNTER
ITC=ITC+1

```

```

CALCULATE TRIAL EMAX
EMAX=(TEMAXU+TEMAXL)/2.0

```

```

GENERATE NEW ELECTRIC FIELD PROFILE FOR EMAX
CALL EPROF(NND,DX,XDEPL,XMET,XDEPEP,XDEPU,XL,SDOPL,
&SDOPEP,SDOPU,EMAX,E,IDB3,FLAGEB)

```

```

EVALUATE THE AVALANCHE IONIZATION INTEGRAL FOR THE NEW ELECTRIC
FIELD PROFILE
CALL INALFA(NND,XDEPL,XMET,XDEPEP,XDEPU,DX,DOPL,DOPEP,
&DOPU,ALFATD,E,T,ALFAIN,IDB1,NP1)

```

```

CHECK FOR A DEPLETED BULK REGION. SUB FPROF SETS 'FLAGEB'
EQUAL TO ONE FOR A DEPLETED BULK REGION.
IF(FLAGEB.LE.0) GO TO 300

```

```

A BULK REGION HAS BEEN DEPLETED. IF ALFAIN IS GREATER THAN ONE

```

## SUBROUTINE BKDEPL (Continued)

```

80 C A VALID SOLUTION MAY EXIST. PERFORM ANOTHER ITERATION!
81 IF(ALFAIN.GT.1.0) GO TO 300
82 C
83 C BAD DIODE DESIGN. THE REQUIRED EMAX CAN NOT BE ACHIEVED
84 WITHOUT DEPLETING A BULK REGION. TERMINATE XQT.
85 C WRITE(6,290) FLAGEB,ALFAIN,EMAX
86 290 FORMAT(/,40H A BULK REGION HAS BEEN DEPLETED WITHOUT,
87 &44H SATISFYING THE AVALANCHE BREAKDOWN INTEGRAL,/,
88 &32H XQT IS TERMINATED IN SUB BKDEPL,/,
89 &8H FLAGEB=,I2,5X,7HALFAIN=,E10.3,5X,5HEMAX=,F10.3)
90 STOP
91 C
92 C
93 C 300 CONTINUE
94 C
95 C UPDATE ELECTRIC FIELD SEARCH BOUNDARIES
96 IF(ALFAIN.GT.1.0) GO TO 310
97 C
98 C INCREASE ELECTRIC FIELD TRIAL EMAX
99 TEMAXL=EMAX
100 GO TO 320
101 C
102 C 310 CONTINUE
103 C
104 C DECREASE ELECTRIC FIELD TRIAL VALUE
105 TEMAXU=EMAX
106 C
107 C 320 CONTINUE
108 C
109 C EVALUATE AVALANCHE IONIZATION INTEGRAL ERROR
110 IF(ALFAIN.GE.1.0) AERROR=ALFAIN-1.0
111 IF(ALFAIN.LT.1.0) AERROR=1.0/ALFAIN-1.0
112 C
113 C DEBUG LIST OPTION
114 IF(IOB2.EQ.1) WRITE(6,505) ITC,TEMAXL,TEMAXU,
115 &EMAX,ALFAIN,AERROR,XDEPL,XDEPU
116 505 FORMAT(I10,7E10.3)
117 C
118 C HAS THE AVALANCHE IONIZATION INTEGRAL BEEN DETERMINED TO THE
119 SPECIFIED ERROR?
120 IF(AERROR.LE.AERMAX) GO TO 600
121 C
122 C THE REQUIRED ACCURACY HAS NOT BEEN ACHIEVED. IF THE MAXIMUM
123 NUMBER OF ITERATIONS HAS NOT BEEN PERFORMED, MAKE ANOTHER!
124 IF(ITC.LT.ITCMAX) GO TO 200
125 C
126 C THE MAXIMUM NUMBER OF ITERATIONS HAS BEEN PERFORMED WITHOUT
127 ACHIEVING THE SPECIFIED ACCURACY. WRITE AN ERROR MESSAGE
128 AND TERMINATE XQT.
129 C WRITE(6,510) EMAX,ALFAIN,AERROR
130 510 FORMAT(/,45H THE MAXIMUM NUMBER OF ITERATIONS ON EMAX HAS,
131 &48H BEEN PERFORMED WITHOUT ACHIEVING THE SPECIFIED,
132 &27H ACCURACY FOR THE AVALANCHE,/,
133 &55H BREAKDOWN INTEGRAL. EITHER THE ACCURACY 'AERMAX', THE,
134 &41H NUMBER OF ITERATIONS 'ITCMAX', OR ONE OF,
135 &19H THE ELECTRIC FIELD,/,
136 &49H BOUNDARIES 'EMAXL OR EMAXU', SHOULD BE MODIFIED./,
137 &/,6H EMAX=,E10.3,5X,7HALFAIN=,E10.3,5X,7HAERROR=,E10.3)
138 C
139 C 600 CONTINUE
140 C
141 C EVALUATE DEPLETION VOLTAGE, VDEP
142 CALL DEPV(SDOPL,SDOPEP,SDOPU,XDFPL,XMET,XDEPFP,XDEPU,
143 &VDEPL,VDEPEP,VDEPU,VDEP)
144 C
145 C DEBUG OUTPUT
146 IF(IOB2.NE.1) RETURN
147 C WRITE(6,1000)
148 1000 FORMAT(/,29H DEBUG OUTPUT FROM SUB BKDEPL)
149 C WRITE(6,DEBUG)
150 C
151 RETURN
152 END

```

## SUBROUTINE DEPV

\*TEMP(1).DEPV

```

1  SUBROUTINE DEPV(SDOPL,SDOPEP,SDOPU,XDEPL,XMET,XDEPEP,XDEPU,
2  &VDEPL,VDEPEP,VDEPU,VDEP)
3
4  C
5  C
6  C   SUB DEPV EVALUATES ANALYTICALLY THE VOLTAGE ACROSS THE LOWER,
7  C   EPITAXIAL, AND UPPER DEPLETION REGIONS.
8  C
9  C   VARIABLE DEFINITIONS:
10 C   SDOPL - LOWER DEPLETION REGION SPACE CHARGE
11 C   SDOPEP - EPITAXIAL DEPLETION REGION SPACE CHARGE
12 C   SDOPU - UPPER DEPLETION REGION SPACE CHARGE
13 C   XDEPL - LOWER DEPLETION REGION BOUNDARY
14 C   XMET - METALLURGICAL JUNCTION
15 C   XDEPEP - EPITAXIAL LAYER BOUNDARY
16 C   XDEPU - UPPER DEPLETION REGION BOUNDARY
17 C   VDEPL - LOWER DEPLETION REGION VOLTAGE
18 C   VDEPEP - EPITAXIAL DEPLETION REGION VOLTAGE
19 C   VDEPU - UPPER DEPLETION REGION VOLTAGE
20 C   VDEP  - TOTAL DEPLETION REGION JUNCTION VOLTAGE
21 C
22 C   CONSTANT ASSIGNMENTS
23 C   DATA Q/1.6E-19/
24 C   DATA PERM/1.06E-12/
25 C   PERM - FARADS/CM
26 C
27 C   EVALUATE LOWER DEPLETION REGION VOLTAGE
28 C   VDEPL=Q/2.0/PERM*SDOPL*(XMET-XDEPL)**2
29 C
30 C   DOES UPPER DEPLETION REGION BND LIE WITHIN EPITAXIAL REG.
31 C   IF(XDEPU.LE.XDEPEP) GO TO 100
32 C
33 C   UPPER DEP. REG. BND LIES OUTSIDE EPITAXIAL REG.
34 C   VDEPEP=Q/PERM*(SDOPL*(XMET-XDEPL)-SDOPEP/2.0*(XDEPEP-XMET))*
35 C   *(XDEPEP-XMET)
36 C   VDEPU=Q/2.0/PERM*SDOPU*(XDEPU-XDEPEP)**2
37 C   GO TO 200
38 C
39 C   100 CONTINUE
40 C
41 C   DEPLETION REG. BND LIES WITHIN EPITAXIAL REG.
42 C   VDEPEP=Q/2.0/PERM*SDOPEP*(XDEPU-XMET)**2
43 C   VDEPU=0.0
44 C
45 C   200 CONTINUE
46 C
47 C   EVALUATE TOTAL DEPLETION REGION VOLTAGE
48 C   VDEP=VDEPL+VDEPEP+VDEPU
49 C
50 C   RETURN
51 C   END

```

## SUBROUTINE DHTEMP

\*TEMP(1),DHTEMP

```

SUBROUTINE DHTEMP(IFLAG,NND,NNH,XDH,THKH,HSPEC,HDEN,DTIME,
&TEMPD,TEMPH)

```

```

A QUASI-TWO-DIMENSIONAL THERMAL MODEL COMPOSED OF 'NNH' UNCOUPLED
ONE DIMENSIONAL MODELS IS FORMULATED. THERMAL CONDUCTION OCCURS
PERPENDICULAR TO THE DIODE AXIS THROUGH A PARALLEL
COMBINATION OF ONE DIMENSIONAL CONDUCTORS.

```

## VARIABLE DEFINITIONS

```

IFLAG - NEW SIMULATION SENTINEL WHICH PROVIDES FOR SUCCESSIVE
SIMULATIONS IN ONE RUN STREAM. IFLAG IS RESET IN MAIN
PROGRAM FOR NEW SIMULATION AND SET IN SUB DHTEMP DURING
FIRST REFERENCE

```

```

NND - NUMBER OF NODE POINTS ALONG DIODE AXIS
NNH - NUMBER OF NODE POINTS ALONG Y-AXIS (PERPENDICULAR TO
DIODE AXIS) WITH IN SUBSTRATE MATERIAL

```

```

XDH - HEADER MATERIAL THICKNESS

```

```

THKH - HEADER MATERIAL THERMAL CONDUCTIVITY

```

```

HSPEC - HEADER MATERIAL SPECIFIC HEAT

```

```

HDEN - HEADER MATERIAL DENSITY

```

```

DTIME - TIME STEP INCREMENT

```

```

TEMPD - LINEAR ARRAY FOR TEMPERATURES ALONG DIODE AXIS. VALUES
SUPPLIED BY CALLING PROGRAM AND USED AS BND BY SUB

```

```

TEMPH - TWO DIMENSIONAL HEADER TEMPERATURE ARRAY FOR RETURNING
HEADER TEMPERATURES TO CALLING PROGRAM

```

```

NBNCTX - COLUMN POINTER FOR LOCATING THE RESPECTIVE ONE
DIMENSIONAL HEADER TEMPERATURE PROFILES WITH IN THE
TWO DIMENSIONAL HEADER TEMPERATURE ARRAY FOR SUB
BANDA6. SUB BANDA6 SOLVES THE INDIVIDUAL HEADER
TEMPERATURE PROFILES AND STORES THEM IN ARRAY TEMPH

```

```

DIMENSION TEMPD(101),TEMPH(12,101),A(12,4)

```

```

THE MAIN PROGRAM SETS IFLAG EQUAL TO ZERO AT THE BEGINNING OF EACH
NEW SIMULATION TO QUE INITIALIZATION CALCULATIONS. IF IFLAG EQUAL
ONE SKIP INITIALIZATION CALCULATIONS
IF(IFLAG.EQ.1) GO TO 25

```

## INITIALIZE SUBSTRATE TEMP ARRAY

```

DO 20 K=1,NNH
DO 15 J=1,NND
TEMPH(K,J)=300.0

```

```

15 CONTINUE
20 CONTINUE

```

```

NNHM1=NNH-1
NNDM1=NND-1
DXH=XDH/NNH
DXDXH=DXH*DXH
AA=THKH/HSPEC/HDEN

```

```

SET FLAG TO SKIP INITIALIZATION CALCULATIONS
IFLAG=1

```

```

25 CONTINUE

```

## INTERMEDIATE COEFFICIENT EVALUATION

```

A1=DTIME*AA
A2=- (DXDXH+2.0*DTIME*AA)
A3=A1
A4=-DXDXH

```

```

INITIALAZE TEMPERATURE COLUMN POINTER
NBNCTX=0

```

```

EVALUATION OF 'NND' ONE DIMENSIONAL TEMPERATURE PROFILES
DO 50 J=1,NND

```

## COEFFICIENT EVALUATION

```

DO 55 N=1,NNHM1
A(N,1)=A1
A(N,2)=A2
A(N,3)=A3
A(N,4)=A4*TEMPH(N,J)

```

```

55 CONTINUE

```

```

INCLUDE BOUNDARY CONDITIONS
A(1,4)=A(1,4)-A1*TEMPD(J)

```

## SUBROUTINE DHTEMP (Continued)

```
80      A(NNHM1,4)=A(NNHM1,4)-300.0*A(NNHM1,3)
81      C
82      C      EVALUATE ONE DIMENSIONAL TEMPERATURE PROFILE
83      C      CALL BANDA6(NNHM1,2,4,1212,12,4,A,TEMPH,NBNDTX,PIVMIN)
84      C
85      C      INCREMENT TEMPERATURE COLUMN POINTER
86      C      NBNDTX=NBNDTX+12
87      50  CONTINUE
88      C
89      C      RETURN
90      C      END
```

## SUBROUTINE DHT2D

\*TEMP(1).DHT2D

1 SUBROUTINE DHT2D(IFLAG,NND,NNH,XL,XDH,THKHX,THKHY,HSPEC,  
 2 &HDEN,DTIME,TEMPD,TEMPH,SMAX,DTHMAX,ITPRH,IBND,S)

3  
 4 A TWO DIMENSIONAL THERMAL MODEL FOR SIMULATING THERMAL CONDUCTION  
 5 THROUGH THE DIODE SUBSTRATE OR HEADER MATERIAL. THE THERMAL  
 6 CONDUCTIVITY, SPECIFIC HEAT AND DENSITY OF THE SUBSTRATE MATERIAL  
 7 ARE ASSUMED TEMPERATURE INDEPENDENT. THERE IS NO JOULE DISSIPATION  
 8 WITH IN THE SUBSTRATE. THE TEMPERATURE PROFILES FOR THE NEXT  
 9 POINT IN TIME (TIME+DTIME) ARE CALCULATED EACH TIME THE  
 10 SUBROUTINE IS CALLED. AN ITERATIVE SOLUTION PROCEDURE SIMILAR  
 11 TO THE SOR TECHNIQUE IS USED TO EVALUATE THE NEW TEMPERATURES  
 12 PROFILES.  
 13

## DECLARATIVE STATEMENTS

14 DIMENSION TEMPD(101),TEMPH(12,101),TEMPS(12,101)  
 15 DIMENSION TEMPS1(12,101),AA(12,4)

16  
 17 INTEGER S,SMAX

## VARIABLE DEFINITIONS

18 IFLAG = NEW SIMULATION SENTINEL WHICH PERMITS SUCCESSIVE  
 19 SIMULATIONS IN ONE RUN STREAM BY QUEING SIMULATION INITIALIZATION  
 20 COMPUTATIONS.  
 21

22 NND = NUMBER OF GRID OR NODE POINTS ALONG DIODE AXIS (X-AXIS)

23 NNH = NUMBER OF GRID OR NODE POINTS ALONG Y-AXIS (PERPENDICULAR  
 24 TO DIODE AXIS) WITH IN HEADER MATERIAL.  
 25

26 XL = DIODE LENGTH. (X-AXIS)

27 XDH = HEADER MATERIAL THICKNESS

28 THKHY = HEADER MATERIAL THERMAL CONDUCTIVITY ALONG Y-AXIS  
 29 (ASSUMED CONSTANT)

30 THKHX = HEADER MATERIAL THERMAL CONDUCTIVITY ALONG X-AXIS  
 31 (ASSUMED CONSTANT). NORMALLY THKHX=THKHY. THKHX=0.0 FOR  
 32 QUASI-TWO-DIMENSIONAL HEADER THERMAL MODEL. FOR THIS REDUCED  
 33 MODEL ONLY ONE ITERATION IS REQUIRED. INORDER TO OVRIDE  
 34 THE CONVERGENCE CHECK FOR THIS CASE SET SMAX=1 AND DTHMAX=100.0  
 35

36 HSPEC = HEADER MATERIAL SPECIFIC HEAT (ASSUMED CONSTANT)

37 HDEN = HEADER MATERIAL DENSITY (ASSUMED CONSTANT)

38 DTIME = TIME STEP INCREMENT FOR NEXT TIME STEP

39 TEMPD = LINEAR ARRAY FOR TEMPERATURES ALONG DIODE AXIS. VALUES  
 40 SUPPLIED BY CALLING PROGRAM AND USED AS BND BY SUB DHT2D

41 TEMPH = TWO DIMENSIONAL HEADER TEMPERATURE ARRAY FOR RETURNING  
 42 HEADER TEMPERATURES TO CALLING PROGRAM. DURING ITERATIONS TEMPH  
 43 REPRESENTS TEMPERATURES AT PREVIOUS POINT IN TIME BUT IS  
 44 REDEFINED AS NEW TEMPERATURE VALUES BEFORE RETURNING  
 45 TO THE CALLING PROGRAM

46 SMAX = MAXIMUM NUMBER OF ITERATIONS FOR HEADER TEMPERATURE.

47 DTHMAX = CONVERGENCE CRITERIA FOR HEADER TEMPERATURES ALGORITHM.  
 48 MAXIMUM ACCEPTABLE NORMALIZED CHANGE IN TEMPERATURE BETWEEN  
 49 ITERATIONS S AND S+1.  
 50

51 ITPRH = HEADER TEMPERATURE ITERATION PRINT SENTINEL. WHEN  
 52 ITPRH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION

53 IBND = INDICATES THE TYPE BND AT X=0 AND X=XL. 0 = CONSTANT  
 54 TEMPERATURE, 1 = BLOCKING

55 TEMPS = TWO DIMENSIONAL HEADER TEMPERATURES FROM PREVIOUS  
 56 ITERATION (S).

57 TEMPS1 = TWO DIMENSIONAL HEADER TEMPERATURES FOR NEW  
 58 ITERATION (S+1).

59 AA = COEFFICIENT ARRAY FOR ONE DIMENSIONAL TEMPERATURE PROFILES.

60 NND = NUMBER OF TEMPERATURE NODES ALONG DIODE AXIS  
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 79

## SUBROUTINE DHT2D (Continued)

```

80      NNH - NUMBER OF TEMPERATURE NODES ALONG Y-AXIS (PERPENDICULAR TO
81      DIODE AXIS) IN SUBSTRATE.  MAXIMUM VALUE OF NNHMX
82
83      NNHMAX - NNH MAXIMUM VALUE WHICH IS THE SAME AS THE 'ROW DIMENSION'
84      FOR ARRAYS TEMPH, TEMPS, AND TEMPS1.
85
86      NNHEND - COLUMN POINTER FOR LOCATING THE RESPECTIVE ONE DIMENSIONAL
87      TEMPERATURE PROFILES WITH IN THE TWO DIMENSIONAL TEMPERATURE ARRAY
88      TEMPS1 FOR SUBROUTINE BANDA6 WHICH SOLVES THE INDIVIDUAL ONE
89      DIMENSIONAL TEMPERATURE PROFILES.
90
91      S - ITERATION COUNTER
92
93      DTHS - NORMALIZED CHANGE IN HEADER TEMPERATURE AT NODE (J,I)
94      BETWEEN THE S AND S+1 ITERATIONS.
95
96      DTHSMX - MAXIMUM NORMALIZED CHANGED IN HEADER TEMPERATURE
97      BETWEEN THE S AND S+1 ITERATIONS.
98
99      ITPRDH - HEADER TEMPERATURE ITERATION PRINT SINTINEL.  WHEN
100     ITPRDH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION
101
102     -----
103     100 CONTINUE
104     -----
105
106     SIMULATION INITIALIZATION CALCULATIONS
107
108     IFLAG=0 IMPLIES FIRST TIME STEP FOR NEW SIMULATION AND THAT
109     SIMULATION INITIALIZATION CALCULATIONS SHOULD BE PERFORMED.
110     IF(IFLAG.NE.0) GO TO 200
111
112     SET IFLAG TO INDICATE THAT THE SIMULATION HAS BEEN INITIALIZED
113     IFLAG=1
114
115     INITIALIZE TEMPERATURE ARRAYS
116     DO 110 I=1,101
117     DO 110 J=1,12
118     TEMPH(J,I)=300.0
119     TEMPS(J,I)=300.0
120     TEMPS1(J,I)=300.0
121     110 CONTINUE
122
123     EVALUATE GRID INCREMENTS
124     DX=XL/(NND-1)
125
126     THE NUMBER OF HEADER GRID POINTS ALONG Y-AXIS IS (NNH+1)
127     DY=XDH/NNH
128
129     EVALUATE MODIFIED GRID COUNTS
130     NNDM1=NND-1
131     NNDM2=NND-2
132     NNHM1=NNH-1
133     NNHM2=NNH-2
134
135     INITIALIZE COLUMN POINTER INCREMENT
136     NNHMAX=12
137
138     -----
139     200 CONTINUE
140     -----
141
142     PRE-ITERATION COMPUTATIONS
143
144     PARTIAL COEFFICIENT EVALUATION WHICH WILL ACCOMMODATE A VARILABLE
145     TIME STEP CONTROLLED BY THE CALLING PROGRAM
146     A=-THKH*DTIME*DX*DX
147     B=-2.0*A+DY*DY*DX*DX*HDEN*HSPEC
148     C=A
149     D1=DX*DX*DY*DY*HDEN*HSPEC
150     D2=THKH*DY*DY*DTIME
151
152     INITIALIZE ITERATION COUNTER
153     S=0
154
155     INITIALIZE TEMPS1 WITH TEMPH FROM PREVIOUS TIME STEP
156     DO 210 I=1,NND
157     DO 210 J=1,NNH
158     TEMPS1(J,I)=TEMPH(J,I)

```

## SUBROUTINE DHT2D (Continued)

```

160      210 CONTINUE
161      C
162      C-----
163      300 CONTINUE
164      C-----
165      C
166      C
167      C      ITERATION LOOP
168      C      TRANSFER TEMPS1 TO TEMPS SO THAT NEW TEMPS1 VALUE MAY BE CALCULATED
169      DO 305 I=1,NND
170      DO 305 J=1,NNH
171      TEMPS(J,I)=TEMPS1(J,I)
172      305 CONTINUE
173      C
174      C      INCREMENT ITERATION COUNTER
175      S=S+1
176      C
177      C      EVALUATE NND ONE DIMENSIONAL TEMPERATURE PROFILES ALONG Y-AXIS
178      C      WITH COUPLING WITH ADJACENT COLUMNS.
179      C
180      C      INITIALIZE COLUMN POINTER FOR THE FIRST ONE DIMENSIONAL
181      C      TEMPERATURE PROFILE.
182      NNHBND=NNHMAX
183      C
184      C-----
185      400 CONTINUE
186      C-----
187      C
188      C      IF BLOCKING BND SPECIFIED FOR X=0, EVALUATE TEMPS1(J,1) AND
189      C      TEMPS(J,2)
190      C      IF(IBND.NE.1) GO TO 500
191      C
192      C      COEFFICIENT EVALUATION FOR TEMPS1(J,2) WITH BLOCKING BND
193      DO 410 J=1,NNHM1
194      AA(J,1)=A
195      AA(J,2)=B
196      AA(J,3)=C
197      AA(J,4)=D1*TEMPH(J,2)+D2*(TEMPS(J,3)-TEMPS(J,2))
198      410 CONTINUE
199      C
200      C      INCLUDE BND FOR TEMPS1(J,2)
201      AA(1,4)=AA(1,4)-A*TEMPD(2)
202      AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
203      C
204      C      EVALUATE TEMPS1(J,2)
205      CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
206      C
207      C      INCREMENT COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
208      NNHBND=NNHBND+NNHMAX
209      C
210      C      EQUATE TEMPS1(J,2) AND TEMPS1(J,1) FOR BLOCKING BND
211      DO 420 J=1,NNH
212      TEMPS1(J,1)=TEMPS1(J,2)
213      420 CONTINUE
214      C
215      C-----
216      500 CONTINUE
217      C-----
218      C
219      C      IF CONSTANT TEMPERATURE BND SPECIFIED FOR X=0, EVALUATE TEMPS1(J,2)
220      C      IF(IBND.NE.0) GO TO 600
221      C
222      C      COEFFICIENT EVALUATION FOR TEMPS1(J,2) AND CONSTANT TEMP BND
223      DO 510 J=1,NNHM1
224      AA(J,1)=A
225      AA(J,2)=B
226      AA(J,3)=C
227      AA(J,4)=D1*TEMPH(J,2)+D2*(300.0+TEMPS(J,3)-2.0*TEMPS(J,2))
228      510 CONTINUE
229      C
230      C      INCLUDE BND
231      AA(1,4)=AA(1,4)-A*TEMPD(2)
232      AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
233      C
234      C      EVALUATE TEMPS1(J,2)
235      CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
236      C
237      C      INCREMENT COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
238      NNHBND=NNHBND+NNHMAX
239      C

```

## SUBROUTINE DHT2D (Continued)

```

240 C-----
241 C 600 CONTINUE
242 C-----
243 C
244 C EVALUATE TEMPERATURE PROFILES FOR TEMPS1(J,3) - TEMPS1(J,NNDM2)
245 C DO 620 I=3,NNDM2
246 C
247 C EVALUATE COEFFICIENTS FOR TEMPS1(J,I)
248 C DO 610 J=1,NNHM1
249 C   AA(J,1)=A
250 C   AA(J,2)=B
251 C   AA(J,3)=C
252 C   AA(J,4)=D1*TEMPH(J,I)+D2*(TEMPS(J,I-1)+TEMPS(J,I+1)
253 C     &-2.0*TEMPS(J,I))
254 C 610 CONTINUE
255 C
256 C INCLUDE BND FOR TEMPS1(J,I)
257 C AA(1,4)=AA(1,4)-A*TEMPD(I)
258 C AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
259 C
260 C EVALUATE TEMPS1(J,I)
261 C CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
262 C
263 C INCRFMET COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
264 C NNHBND=NNHBND+NNHMAX
265 C
266 C 620 CONTINUE
267 C
268 C-----
269 C 700 CONTINUE
270 C-----
271 C
272 C IF BLOCKING BND SPECIFIED EVALUATE TEMPS1(J,NNDM1) AND
273 C TEMPS1(J,NND)
274 C IF(IBND.NE.1) GO TO 800
275 C
276 C COEFFICIENT EVALUATION FOR TEMPS1(J,NNDM1) WITH BLOCKING BND
277 C DO 710 J=1,NNHM1
278 C   AA(J,1)=A
279 C   AA(J,2)=B
280 C   AA(J,3)=C
281 C   AA(J,4)=D1*TEMPH(J,NNDM1)+D2*(TEMPS(J,NNDM2)-TEMPS(J,NNDM1))
282 C 710 CONTINUE
283 C
284 C INCLUDE BND
285 C AA(1,4)=AA(1,4)-A*TEMPD(NNDM1)
286 C AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
287 C
288 C EVALUATE TEMPS1(J,NNDM1)
289 C CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
290 C
291 C EQUATE TEMPS1(J,NNDM1) AND TEMPS1(J,NND) FOR BLOCKING BND
292 C DO 720 J=1,NNH
293 C   TEMPS1(J,NND)=TEMPS1(J,NNDM1)
294 C 720 CONTINUE
295 C
296 C-----
297 C 800 CONTINUE
298 C-----
299 C
300 C IF CONSTANT TEMPERATURE BND SPECIFIED FOR X=XL, EVALUATE
301 C TEMPS1(J,NNDM1)
302 C IF(IBND.NE.0) GO TO 900
303 C
304 C COEFFICIENT EVALUATION FOR TEMPS1(J,NNDM1) AND CONSTANT TEMP BND
305 C DO 810 J=1,NNHM1
306 C   AA(J,1)=A
307 C   AA(J,2)=B
308 C   AA(J,3)=C
309 C   AA(J,4)=D1*TEMPH(J,NNDM1)+D2*(TEMPS(J,NNDM2)+300.0
310 C     &-2.0*TEMPS(J,NNDM1))
311 C 810 CONTINUE
312 C
313 C INCLUDE BND FOR TEMPS1(J,NNDM1)
314 C AA(1,4)=AA(1,4)-A*TEMPD(NNDM1)
315 C AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
316 C
317 C EVALUATE TEMPS1(J,NNDM1)
318 C CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
319 C

```

## SUBROUTINE DHT2D (Continued)

```

320 C-----
321 900 CONTINUE
322 C-----
323 C
324 C      CONVERGENCE CHECK
325 C
326 C      EVALUATE MAXIMUM NORMALIZED CHANGE IN TEMPERATURE FOR THIS
327 C      ITERATION
328 C      DTHSMX=0.0
329 C      DO 910 I=2,NNDM1
330 C      DO 910 J=1,NNHM1
331 C      DTHS=(TEMPS1(J,I)-TEMPS(J,I))/TEMPS1(J,I)
332 C      IF(DTHS.GT.DTHSMX) DTHSMX=DTHS
333 C
334 C 910 CONTINUE
335 C
336 C      PRINT ITERATION SUMMARY
337 C 920 IF(ITPRH.EQ.1) WRITE(6,920) S,DTHSMX
338 C      FORMAT(3H S=,I2,5X,7HDTHSMX=,E8.3)
339 C
340 C      IF DTHSMX .LE. DTHMAX THE SPECIFIED CONVERGENCE HAS BEEN ACHIEVED
341 C      IF(DTHSMX.LE.DTHMAX) GO TO 1000
342 C
343 C      CONVERGENCE HAS NOT BEEN ACHIEVED. IF THE ITERATION COUNT
344 C      IS LESS THAN THE MAXIMUM SPECIFIED START ANOTHER ITERATION
345 C      IF(S.LT.SMAX) GO TO 300
346 C
347 C      THE MAXIMUM NUMBER OF ITERATION HAS BEEN PERFORMED WITHOUT
348 C      ACHIEVING CONVERGENCE. WRITE ERROR MESSAGE AND TERMINATE XOT
349 C 930 WRITE(6,930) S,DTHSMX
350 C      &/,27H ***** EXECUTION TERMINATED./,
351 C      &9H ***** S=,I2,5X,7HDTHSMX=,E8.3./,
352 C      &34H ***** INCREASE SMAX AND/OR DTHMAX)
353 C
354 C      STOP *****
355 C-----
356 C
357 C 1000 CONTINUE
358 C-----
359 C
360 C      TRANSFER NEW SUBSTRATE TEMPERATURE VALUES TO ARRAY TEMPH
361 C      DO 1010 I=1,NND
362 C      DO 1010 J=1,NNH
363 C      TEMPH(J,I)=TEMPS1(J,I)
364 C 1010 CONTINUE
365 C
366 C      RETURN TO CALLING PROGRAM WITH NEW HEADER TEMPERATURES
367 C      RETURN
368 C      END

```

SUBROUTINE DHT2D1

\*TEMP(1).DHT2D1

SUBROUTINE DHT2D1(IFLAG,NND,NNH,XL,XDH,THKH,THKY,HSPEC,  
&HDEN,DTIME,TEMPO,TEMPH,SMAX,DTHMAX,ITPRH,IBND,S)

A TWO DIMENSIONAL THERMAL MODEL FOR SIMULATING THERMAL CONDUCTION THROUGH THE DIODE SUBSTRATE OR HEADER MATERIAL. THE THERMAL CONDUCTIVITY, SPECIFIC HEAT AND DENSITY OF THE SUBSTRATE MATERIAL ARE ASSUMED TEMPERATURE INDEPENDENT. THERE IS NO JOULE DISSIPATION WITH IN THE SUBSTRATE. THE TEMPERATURE PROFILES FOR THE NEXT POINT IN TIME (TIME+DTIME) ARE CALCULATED EACH TIME THE SUBROUTINE IS CALLED. AN ITERATIVE SOLUTION PROCEDURE SIMILAR TO THE SOR TECHNIQUE IS USED TO EVALUATE THE NEW TEMPERATURES PROFILES. DHT2D1 DIFFERS FROM DHT2D IN THAT THE VERY LATEST VALUES OF TEMP ARE USED IN THE ITERATIVE PROCEDURE.

DECLARATIVE STATEMENTS

DIMENSION TEMPO(101),TEMPH(12,101),TEMPS(12,101)  
DIMENSION TEMPS1(12,101),AA(12,4)

INTEGER S,SMAX

VARIABLE DEFINITIONS

IFLAG - NEW SIMULATION SENTINEL WHICH PERMITS SUCCESSIVE SIMULATIONS IN ONE RUN STREAM BY QUEING SIMULATION INITIALIZATION COMPUTATIONS.

NND - NUMBER OF GRID OR NODE POINTS ALONG DIODE AXIS (X-AXIS)

NNH - NUMBER OF GRID OR NODE POINTS ALONG Y-AXIS (PERPENDICULAR TO DIODE AXIS) WITH IN HEADER MATERIAL.

XL - DIODE LENGTH, (X-AXIS)

XDH - HEADER MATERIAL THICKNESS

THKY - HEADER MATERIAL THERMAL CONDUCTIVITY ALONG Y-AXIS (ASSUMED CONSTANT)

THKH - HEADER MATERIAL THERMAL CONDUCTIVITY ALONG X-AXIS (ASSUMED CONSTANT). NORMALLY THKH=THKY. THKH=0.0 FOR QUASI-TWO-DIMENSIONAL HEADER THERMAL MODEL. FOR THIS REDUCED MODEL ONLY ONE ITERATION IS REQUIRED. INORDER TO OVRIDE THE CONVERGENCE CHECK FOR THIS CASE SET SMAX=1 AND DTHMAX=100.0

HSPEC - HEADER MATERIAL SPECIFIC HEAT (ASSUMED CONSTANT)

HDEN - HEADER MATERIAL DENSITY (ASSUMED CONSTANT)

DTIME - TIME STEP INCREMENT FOR NEXT TIME STEP

TEMPO - LINEAR ARRAY FOR TEMPERATURES ALONG DIODE AXIS. VALUES SUPPLIED BY CALLING PROGRAM AND USED AS BND BY SUB DHT2D

TEMPH - TWO DIMENSIONAL HEADER TEMPERATURE ARRAY FOR RETURNING HEADER TEMPERATURES TO CALLING PROGRAM. DURING ITERATIONS TEMPH REPRESENTS TEMPERATURES AT PREVIOUS POINT IN TIME BUT IS REDEFINED AS NEW TEMPERATURE VALUES BEFORE RETURNING TO THE CALLING PROGRAM

SMAX - MAXIMUM NUMBER OF ITERATIONS FOR HEADER TEMPERATURE.

DTHMAX - CONVERGENCE CRITERIA FOR HEADER TEMPERATURES ALGORITHM. MAXIMUM ACCEPTABLE NORMALIZED CHANGE IN TEMPERATURE BETWEEN ITERATIONS S AND S+1.

ITPRH - HEADER TEMPERATURE ITERATION PRINT SENTINEL. WHEN ITPRH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION

IBND - INDICATES THE TYPE BND AT X=0 AND X=XL. 0 - CONSTANT TEMPERATURE, 1 - BLOCKING

TEMPS - TWO DIMENSIONAL HEADER TEMPERATURES FROM PREVIOUS ITERATION (S).

TEMPS1 - TWO DIMENSIONAL HEADER TEMPERATURES FOR NEW ITERATION (S+1).

AA - COEFFICIENT ARRAY FOR ONE DIMENSIONAL TEMPERATURE PROFILES.

NND - NUMBER OF TEMPERATURE NODES ALONG DIODE AXIS

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## SUBROUTINE DHT2D1 (Continued)

```

80      C
81      C
82      C      NNH - NUMBER OF TEMPERATURE NODES ALONG Y-AXIS (PERPENDICULAR TO
83      C      DIODE AXIS) IN SUBSTRATE.  MAXIMUM VALUE OF NNHMX
84      C
85      C      NNHMAX - NNH MAXIMUM VALUE WHICH IS THE SAME AS THE 'ROW DIMENSION'
86      C      FOR ARRAYS TEMPH, TEMPS, AND TEMPS1.
87      C
88      C      NNHEND - COLUMN POINTER FOR LOCATING THE RESPECTIVE ONE DIMENSIONAL
89      C      TEMPERATURE PROFILES WITH IN THE TWO DIMENSIONAL TEMPERATURE ARRAY
90      C      TEMPS1 FOR SUBROUTINE BANDA6 WHICH SOLVES THE INDIVIDUAL ONE
91      C      DIMENSIONAL TEMPERATURE PROFILES.
92      C
93      C      S - ITERATION COUNTER
94      C
95      C      DTHS - NORMALIZED CHANGE IN HEADER TEMPERATURE AT NODE (J,I)
96      C      BETWEEN THE S AND S+1 ITERATIONS.
97      C
98      C      DTHSMX - MAXIMUM NORMALIZED CHANGED IN HEADER TEMPERATURE
99      C      BETWEEN THE S AND S+1 ITERATIONS.
100     C
101     C      ITPRDH - HEADER TEMPERATURE ITERATION PRINT SENTINEL.  WHEN
102     C      ITPRDH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION
103     C
104     C-----
105     C      100 CONTINUE
106     C-----
107     C
108     C      SIMULATION INITIALIZATION CALCULATIONS
109     C
110     C      IFLAG=0 IMPLIES FIRST TIME STEP FOR NEW SIMULATION AND THAT
111     C      SIMULATION INITIALIZATION CALCULATIONS SHOULD BE PERFORMED.
112     C      IF(IFLAG.NE.0) GO TO 200
113     C
114     C      SET IFLAG TO INDICATE THAT THE SIMULATION HAS BEEN INITIALIZED
115     C      IFLAG=1
116     C
117     C      INITIALIZE TEMPERATURE ARRAYS
118     C      DO 110 I=1,101
119     C      DO 110 J=1,12
120     C      TEMPH(J,I)=300.0
121     C      TEMPS(J,I)=300.0
122     C      TEMPS1(J,I)=300.0
123     C      110 CONTINUE
124     C
125     C      EVALUATE GRID INCREMENTS
126     C      DX=XL/(NND-1)
127     C
128     C      THE NUMBER OF HEADER GRID POINTS ALONG Y-AXIS IS (NNH+1)
129     C      DY=XDH/NNH
130     C
131     C      EVALUATE MODIFIED GRID COUNTS
132     C      NNDM1=NND-1
133     C      NNDM2=NND-2
134     C      NNHM1=NNH-1
135     C      NNHM2=NNH-2
136     C
137     C      INITIALIZE COLUMN POINTER INCREMENT
138     C      NNHMAX=12
139     C
140     C-----
141     C      200 CONTINUE
142     C-----
143     C
144     C      PRE-ITERATION COMPUTATIONS
145     C
146     C      PARTIAL COEFFICIENT EVALUATION WHICH WILL ACCOMMODATE A VARILABLE
147     C      TIME STEP CONTROLLED BY THE CALLING PROGRAM
148     C      A=-THKHY*DTIME*DX*DX
149     C      B=-2.0*A+DY*DY*DX*DX*HDEN*HSPEC
150     C      C=A
151     C      D1=DX*DX*DY*DY*HDEN*HSPEC
152     C      D2=THKH*DY*DY*DTIME
153     C
154     C      INITIALIZE ITERATION COUNTER
155     C      S=0
156     C
157     C      INITIALIZE TEMPS1 WITH TEMPH FROM PREVIOUS TIME STEP
158     C      DO 210 I=1,NND
159     C      DO 210 J=1,NNH

```

## SUBROUTINE DHT2D1 (Continued)

```

160     TEMPS1(J,I)=TEMPH(J,I)
161     210 CONTINUE
162     C
163     C-----
164     300 CONTINUE
165     C-----
166     C
167     C     ITERATION LOOP
168     C
169     C     TRANSFER TEMPS1 TO TEMPS SO THAT NEW TEMPS1 VALUE MAY BE CALCULATED
170     C     DO 305 I=1,NNH
171     C     DO 305 J=1,NNH
172     C     TEMPS(J,I)=TEMPS1(J,I)
173     C     305 CONTINUE
174     C
175     C     INCREMENT ITERATION COUNTER
176     C     S=S+1
177     C
178     C     EVALUATE NNH ONE DIMENSIONAL TEMPERATURE PROFILES ALONG Y-AXIS
179     C     WITH COUPLING WITH ADJACENT COLUMNS.
180     C
181     C     INITIALIZE COLUMN POINTER FOR THE FIRST ONE DIMENSIONAL
182     C     TEMPERATURE PROFILE.
183     C     NNHBND=NNHMAX
184     C
185     C-----
186     400 CONTINUE
187     C-----
188     C
189     C     IF BLOCKING BND SPECIFIED FOR X=0, EVALUATE TEMPS1(J,1) AND
190     C     TEMPS(J,2)
191     C     IF(IRND.NE.1) GO TO 500
192     C
193     C     COEFFICIENT EVALUATION FOR TEMPS1(J,2) WITH BLOCKING BND
194     C     DO 410 J=1,NNHM1
195     C     AA(J,1)=A
196     C     AA(J,2)=B
197     C     AA(J,3)=C
198     C     AA(J,4)=D1*TEMPH(J,2)+D2*(TEMPS(J,3)-TEMPS(J,2))
199     C     410 CONTINUE
200     C
201     C     INCLUDE BND FOR TEMPS1(J,2)
202     C     AA(1,4)=AA(1,4)-A*TEMPD(2)
203     C     AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
204     C
205     C     EVALUATE TEMPS1(J,2)
206     C     CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
207     C
208     C     INCREMENT COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
209     C     NNHBND=NNHBND+NNHMAX
210     C
211     C     EQUATE TEMPS1(J,2) AND TEMPS1(J,1) FOR BLOCKING BND
212     C     DO 420 J=1,NNH
213     C     TEMPS1(J,1)=TEMPS1(J,2)
214     C     420 CONTINUE
215     C
216     C-----
217     500 CONTINUE
218     C-----
219     C
220     C     IF CONSTANT TEMPERATURE BND SPECIFIED FOR X=0, EVALUATE TEMPS1(J,2)
221     C     IF(IRND.NE.0) GO TO 600
222     C
223     C     COEFFICIENT EVALUATION FOR TEMPS1(J,2) AND CONSTANT TEMP BND
224     C     DO 510 J=1,NNHM1
225     C     AA(J,1)=A
226     C     AA(J,2)=B
227     C     AA(J,3)=C
228     C     AA(J,4)=D1*TEMPH(J,2)+D2*(300.0+TEMPS(J,3)-2.0*TEMPS(J,2))
229     C     510 CONTINUE
230     C
231     C     INCLUDE BND
232     C     AA(1,4)=AA(1,4)-A*TEMPD(2)
233     C     AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
234     C
235     C     EVALUATE TEMPS1(J,2)
236     C     CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
237     C
238     C     INCREMENT COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
239     C     NNHBND=NNHBND+NNHMAX

```

## SUBROUTINE DHT2D1 (Continued)

```

240 C
241 C-----
242 600 CONTINUE
243 C-----
244 C
245 C   EVALUATE TEMPERATURE PROFILES FOR TEMPS1(J,3) - TEMPS1(J,NNDM2)
246 DO 620 I=3,NNDM2
247 C
248 C   EVALUATE COEFFICIENTS FOR TEMPS1(J,I)
249 DO 610 J=1,NNHM1
250 AA(J,1)=A
251 AA(J,2)=B
252 AA(J,3)=C
253 AA(J,4)=D1*TEMPH(J,I)+D2*(TEMPS1(J,I-1)+TEMPS(J,I+1)
254 &-2.0*TEMPS(J,I))
255 610 CONTINUE
256 C
257 C   INCLUDE BND FOR TEMPS1(J,I)
258 AA(1,4)=AA(1,4)-A*TEMPD(I)
259 AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
260 C
261 C   EVALUATE TEMPS1(J,I)
262 CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
263 C
264 C   INCREMENT COLUMN POINTER FOR NEXT TEMPERATURE PROFILE
265 NNHBND=NNHBND+NNHMAX
266 C
267 620 CONTINUE
268 C
269 C-----
270 700 CONTINUE
271 C-----
272 C
273 C   IF BLOCKING BND SPECIFIED EVALUATE TEMPS1(J,NNDM1) AND
274 TEMPS1(J,NND)
275 IF(IRND.NE.1) GO TO 800
276 C
277 C   COEFFICIENT EVALUATION FOR TEMPS1(J,NNDM1) WITH BLOCKING BND
278 DO 710 J=1,NNHM1
279 AA(J,1)=A
280 AA(J,2)=B
281 AA(J,3)=C
282 AA(J,4)=D1*TEMPH(J,NNDM1)+D2*(TEMPS1(J,NNDM2)-TEMPS(J,NNDM1))
283 710 CONTINUE
284 C
285 C   INCLUDE BND
286 AA(1,4)=AA(1,4)-A*TEMPD(NNDM1)
287 AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
288 C
289 C   EVALUATE TEMPS1(J,NNDM1)
290 CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)
291 C
292 C   EQUATE TEMPS1(J,NNDM1) AND TEMPS1(J,NND) FOR BLOCKING BND
293 DO 720 J=1,NNH
294 TEMPS1(J,NND)=TEMPS1(J,NNDM1)
295 720 CONTINUE
296 C
297 C-----
298 800 CONTINUE
299 C-----
300 C
301 C   IF CONSTANT TEMPERATURE BND SPECIFIED FOR X=XL, EVALUATE
302 TEMPS1(J,NNDM1)
303 IF(IRND.NE.0) GO TO 900
304 C
305 C   COEFFICIENT EVALUATION FOR TEMPS1(J,NNDM1) AND CONSTANT TEMP BND
306 DO 810 J=1,NNHM1
307 AA(J,1)=A
308 AA(J,2)=B
309 AA(J,3)=C
310 AA(J,4)=D1*TEMPH(J,NNDM1)+D2*(TEMPS1(J,NNDM2)+300.0
311 &-2.0*TEMPS(J,NNDM1))
312 810 CONTINUE
313 C
314 C   INCLUDE BND FOR TEMPS1(J,NNDM1)
315 AA(1,4)=AA(1,4)-A*TEMPD(NNDM1)
316 AA(NNHM1,4)=AA(NNHM1,4)-C*300.0
317 C
318 C   EVALUATE TEMPS1(J,NNDM1)
319 CALL BANDA6(NNHM1,2,4,1212,12,4,AA,TEMPS1,NNHBND,PIVMIN)

```

## SUBROUTINE DHT2D1 (Continued)

```

320 C
321 C -----
322 C 900 CONTINUE
323 C -----
324 C
325 C CONVERGENCE CHECK
326 C
327 C EVALUATE MAXIMUM NORMALIZED CHANGE IN TEMPERATURE FOR THIS
328 C ITERATION
329 C DTHSMX=0.0
330 C DO 910 I=2,NNDM1
331 C DO 910 J=1,NNHM1
332 C DTHS=(TEMPS1(J,I)-TEMPS(J,I))/TEMPS1(J,I)
333 C IF(DTHS.GT.DTHSMX) DTHSMX=DTHS
334 C 910 CONTINUE
335 C
336 C PRINT ITERATION SUMMARY
337 C IF(ITPRH.EQ.1) WRITE(6,920) S,DTHSMX
338 C 920 FORMAT(3H S=,I2,5X,7HDTHSMX=,E8.3)
339 C
340 C IF DTHSMX .LE. DTHMAX THE SPECIFIED CONVERGENCE HAS BEEN ACHIEVED
341 C IF(DTHSMX.LE.DTHMAX) GO TO 1000
342 C
343 C CONVERGENCE HAS NOT BEEN ACHIEVED. IF THE ITERATION COUNT
344 C IS LESS THAN THE MAXIMUM SPECIFIED START ANOTHER ITERATION
345 C IF(S.LT.SMAX) GO TO 300
346 C
347 C THE MAXIMUM NUMBER OF ITERATION HAS BEEN PERFORMED WITHOUT
348 C ACHIEVING CONVERGENCE. WRITE ERROR MESSAGE AND TERMINATE XQT
349 C WRITE(6,930) S,DTHSMX
350 C 930 FORMAT(///,46H ***** CONVERGENCE FAILURE IN SUBROUTINE DHT2D,
351 C &/,27H ***** EXECUTION TERMINATED,/,
352 C &9H ***** S=,I2,5X,7HDTHSMX=,E8.3,/,
353 C &34H ***** INCREASE SMAX AND/OR DTHMAX)
354 C
355 C STOP *****
356 C -----
357 C
358 C 1000 CONTINUE
359 C -----
360 C
361 C TRANSFER NEW SUBSTRATE TEMPERATURE VALUES TO ARRAY TEMPH
362 C DO 1010 I=1,NND
363 C DO 1010 J=1,NNH
364 C TEMPH(J,I)=TEMPS1(J,I)
365 C 1010 CONTINUE
366 C
367 C RETURN TO CALLING PROGRAM WITH NEW HEADER TEMPERATURES
368 C RETURN
369 C END

```

## SUBROUTINE DHT2D2

\*TEMP(1),DHT2D2

SUBROUTINE DHT2D2(IFLAG,NND,NNH,XL,XDH,THKH,THKY,HSPEC,  
HDEN,DTIME,TEMPD,TEMPH,SMAX,DTHMAX,ITPRH,IBND,S)

A TWO DIMENSIONAL THERMAL MODEL FOR SIMULATING THERMAL CONDUCTION THROUGH THE DIODE SUBSTRATE OR HEADER MATERIAL. THE THERMAL CONDUCTIVITY, SPECIFIC HEAT AND DENSITY OF THE SUBSTRATE MATERIAL ARE ASSUMED TEMPERATURE INDEPENDENT. THERE IS NO JOULE DISSIPATION WITH IN THE SUBSTRATE. THE TEMPERATURE PROFILES FOR THE NEXT POINT IN TIME (TIME+DTIME) ARE CALCULATED EACH TIME THE SUBROUTINE IS CALLED. AN ITERATIVE SOLUTION PROCEDURE SIMILAR TO THE SOR TECHNIQUE IS USED TO EVALUATE THE NEW TEMPERATURE PROFILES. FOR DHT2D2 THE HEADER TEMPERATURE IS EVALUATED ROW WISE (ALONG X-AXIS) RATHER THAN COLUMN WISE AS IN DHT2D1. THE VERY LATEST VALUES OF TEMP ARE USED IN THE ITERATIVE PROCEDURE.

## DECLARATIVE STATEMENTS

DIMENSION TEMPD(101),TEMPH(12,101),TEMPS(12,101)  
DIMENSION TEMPS1(12,101),AA(101,4),TEMP(101)

INTEGER S,SMAX

## VARIABLE DEFINITIONS

IFLAG = NEW SIMULATION SENTINEL WHICH PERMITS SUCCESSIVE SIMULATIONS IN ONE RUN STREAM BY QUEING SIMULATION INITIALIZATION COMPUTATIONS.

NND = NUMBER OF GRID OR NODE POINTS ALONG DIODE AXIS (X-AXIS)

NNH = NUMBER OF GRID OR NODE POINTS ALONG Y-AXIS (PERPENDICULAR TO DIODE AXIS) WITH IN HEADER MATERIAL.

XL = DIODE LENGTH, (X-AXIS)

XDH = HEADER MATERIAL THICKNESS

THKY = HEADER MATERIAL THERMAL CONDUCTIVITY ALONG Y-AXIS (ASSUMED CONSTANT)

THKH = HEADER MATERIAL THERMAL CONDUCTIVITY ALONG X-AXIS (ASSUMED CONSTANT). NORMALLY THKH=THKY. THKH=0.0 FOR QUASI-TWO-DIMENSIONAL HEADER THERMAL MODEL. FOR THIS REDUCED MODEL ONLY ONE ITERATION IS REQUIRED. INORDER TO OVERRIDE THE CONVERGENCE CHECK FOR THIS CASE SET SMAX=1 AND DTHMAX=100.0

HSPEC = HEADER MATERIAL SPECIFIC HEAT (ASSUMED CONSTANT)

HDEN = HEADER MATERIAL DENSITY (ASSUMED CONSTANT)

DTIME = TIME STEP INCREMENT FOR NEXT TIME STP

TEMPD = LINEAR ARRAY FOR TEMPERATURES ALONG DIODE AXIS. VALUES SUPPLIED BY CALLING PROGRAM AND USED AS BND BY SUB DHT2D

TEMPH = TWO DIMENSIONAL HEADER TEMPERATURE ARRAY FOR RETURNING HEADER TEMPERATURES TO CALLING PROGRAM. DURING ITERATIONS TEMPH REPRESENTS TEMPERATURES AT PREVIOUS POINT IN TIME BUT IS REDEFINED AS NEW TEMPERATURE VALUES BEFORE RETURNING TO THE CALLING PROGRAM

SMAX = MAXIMUM NUMBER OF ITERATIONS FOR HEADER TEMPERATURE.

DTHMAX = CONVERGENCE CRITERIA FOR HEADER TEMPERATURES ALGORITHM. MAXIMUM ACCEPTABLE NORMALIZED CHANGE IN TEMPERATURE BETWEEN ITERATIONS S AND S+1.

ITPRH = HEADER TEMPERATURE ITERATION PRINT SENTINEL. WHEN ITPRH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION

IBND = INDICATES THE TYPE BND AT X=0 AND X=XL. 0 - CONSTANT TEMPERATURE, 1 - BLOCKING

TEMPS = TWO DIMENSIONAL HEADER TEMPERATURES FROM PREVIOUS ITERATION (S).

TEMPS1 = TWO DIMENSIONAL HEADER TEMPERATURES FOR NEW ITERATION (S+1).

AA = COEFFICIENT ARRAY FOR ONE DIMENSIONAL TEMPERATURE PROFILES.

## SUBROUTINE DHT2D2 (Continued)

```

80      C
81      C C C C C
82      C C C C C
83      C C C C C
84      C C C C C
85      C C C C C
86      C C C C C
87      C C C C C
88      C C C C C
89      C C C C C
90      C C C C C
91      C C C C C
92      C C C C C
93      C C C C C
94      C C C C C
95      C C C C C
96      C C C C C
97      C C C C C
98      C C C C C
99      C C C C C
100     C C C C C
101     C C C C C
102     C C C C C
103     C C C C C
104     C C C C C
105     C C C C C
106     C C C C C
107     C C C C C
108     C C C C C
109     C C C C C
110     C C C C C
111     C C C C C
112     C C C C C
113     C C C C C
114     C C C C C
115     C C C C C
116     C C C C C
117     C C C C C
118     C C C C C
119     C C C C C
120     C C C C C
121     C C C C C
122     C C C C C
123     C C C C C
124     C C C C C
125     C C C C C
126     C C C C C
127     C C C C C
128     C C C C C
129     C C C C C
130     C C C C C
131     C C C C C
132     C C C C C
133     C C C C C
134     C C C C C
135     C C C C C
136     C C C C C
137     C C C C C
138     C C C C C
139     C C C C C
140     C C C C C
141     C C C C C
142     C C C C C
143     C C C C C
144     C C C C C
145     C C C C C
146     C C C C C
147     C C C C C
148     C C C C C
149     C C C C C
150     C C C C C
151     C C C C C
152     C C C C C
153     C C C C C
154     C C C C C
155     C C C C C
156     C C C C C
157     C C C C C
158     C C C C C
159     C C C C C

```

NND - NUMBER OF TEMPERATURE NODES ALONG DIODE AXIS  
NNH - NUMBER OF TEMPERATURE NODES ALONG Y-AXIS (PERPENDICULAR TO DIODE AXIS) IN SUBSTRATE. MAXIMUM VALUE OF NNHMX  
NNHMAX - NNH MAXIMUM VALUE WHICH IS THE SAME AS THE 'ROW DIMENSION' FOR ARRAYS TEMPH, TEMPS, AND TEMPS1.  
NNHBND - COLUMN POINTER FOR LOCATING THE RESPECTIVE ONE DIMENSIONAL TEMPERATURE PROFILES WITH IN THE TWO DIMENSIONAL TEMPERATURE ARRAY TEMPS1 FOR SUBROUTINE BANDA6 WHICH SOLVES THE INDIVIDUAL ONE DIMENSIONAL TEMPERATURE PROFILES.  
S - ITERATION COUNTER  
DTHS - NORMALIZED CHANGE IN HEADER TEMPERATURE AT NODE (J,I) BETWEEN THE S AND S+1 ITERATIONS.  
DTHSMX - MAXIMUM NORMALIZED CHANGED IN HEADER TEMPERATURE BETWEEN THE S AND S+1 ITERATIONS.  
ITPRDH - HEADER TEMPERATURE ITERATION PRINT SENTINEL. WHEN ITPRDH=1 S AND DTHSMX ARE PRINTED FOR EACH ITERATION

-----  
100 CONTINUE  
-----

SIMULATION INITIALIZATION CALCULATIONS  
IFLAG=0 IMPLIES FIRST TIME STEP FOR NEW SIMULATION AND THAT SIMULATION INITIALIZATION CALCULATIONS SHOULD BE PERFORMED. IF(IFLAG.NE.0) GO TO 200  
SET IFLAG TO INDICATE THAT THE SIMULATION HAS BEEN INITIALIZED  
IFLAG=1  
INITIALIZE TEMPERATURE ARRAYS  
DO 110 I=1,NND  
DO 110 J=1,NNH  
TEMPH(J,I)=300.0  
TEMPS(J,I)=300.0  
TEMPS1(J,I)=300.0  
110 CONTINUE

EVALUATE GRID INCREMENTS  
DX=XL/(NND-1)  
THE NUMBER OF HEADER GRID POINTS ALONG Y-AXIS IS (NNH+1)  
DY=XDH/NNH  
EVALUATE MODIFIED GRID COUNTS  
NNDM1=NND-1  
NNDM2=NND-2  
NNHM1=NNH-1  
NNHM2=NNH-2

-----  
200 CONTINUE  
-----

PRE-ITERATION COMPUTATIONS  
PARTIAL COEFFICIENT EVALUATION WHICH WILL ACCOMMODATE A VARILABLE TIME STEP CONTROLLED BY THE CALLING PROGRAM  
A=-THKH\*DTIME\*DY\*DY  
B=-2.0\*A+DY\*DY\*DX\*DX\*HDEN\*HSPEC  
C=A  
D1=DX\*DX\*DY\*DY\*HDEN\*HSPEC  
D2=THKHY\*DX\*DX\*DTIME  
INITIALIZE ITERATION COUNTER  
S=0  
INITIALIZE TEMPS1 WITH TEMPH FROM PREVIOUS TIME STEP  
DO 210 I=1,NND  
DO 210 J=1,NNH  
TEMPS1(J,I)=TEMPH(J,I)

```

160      210 CONTINUE
161      C
162      C-----
163      300 CONTINUE
164      C-----
165      C
166      C      ITERATION LOOP
167      C
168      C      TRANSFER TEMPS1 TO TEMPS SO THAT NEW TEMPS1 VALUE MAY BE CALCULATED
169      DO 305 I=1,NND
170      DO 305 J=1,NNH
171      TEMPS(J,I)=TEMPS1(J,I)
172      305 CONTINUE
173      C
174      C      INCREMENT ITERATION COUNTER
175      S=S+1
176      C
177      C      EVALUATE NNHM1 ONE DIMENSIONAL TEMPERATURE PROFILES ALONG X-AXIS
178      C      WITH COUPLING WITH ADJACENT ROWS.
179      C-----
180      C
181      400 CONTINUE
182      C-----
183      C
184      C      IF BLOCKING BND SPECIFIED FOR X=0 AND X=XL, EVALUATE TEMPS1(1,I)
185      IF (IBND.NE.1) GO TO 500
186      C
187      C      COEFFICIENT EVALUATION FOR TEMPS1(1,I) WITH BLOCKING BND
188      DO 410 I=2,NNDM1
189      II=I-1
190      AA(II,1)=A
191      AA(II,2)=B
192      AA(II,3)=C
193      AA(II,4)=D1*TEMPH(1,I)+D2*(TEMPD(I)+TEMPS(2,I))-2.0*TEMPS(1,I)
194      410 CONTINUE
195      C
196      C      INCLUDE BLOCKING BND FOR TEMPS1(1,I)
197      AA(1,2)=AA(1,2)+AA(1,1)
198      AA(NNDM2,2)=AA(NNDM2,2)+AA(NNDM2,3)
199      C
200      C      EVALUATE TEMPS1(1,I)
201      CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)
202      C
203      C      EQUATE TEMP(1) AND TEMP(2), AND TEMP(NND) AND TEMP(NNDM1)
204      FOR BLOCKING BND
205      TEMP(1)=TEMP(2)
206      TEMP(NND)=TEMP(NNDM1)
207      C
208      C      TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY
209      DO 420 I=1,NND
210      TEMPS1(1,I)=TEMP(I)
211      420 CONTINUE
212      C
213      C-----
214      500 CONTINUE
215      C-----
216      C
217      C      IF CONSTANT TEMPERATURE BND SPECIFIED FOR X=0 AND X=XL,
218      C      EVALUATE TEMPS1(1,I)
219      IF (IBND.NE.0) GO TO 600
220      C
221      C      COEFFICIENT EVALUATION FOR TEMPS1(1,I) AND CONSTANT TEMP BND
222      DO 510 I=2,NNDM1
223      II=I-1
224      AA(II,1)=A
225      AA(II,2)=B
226      AA(II,3)=C
227      AA(II,4)=D1*TEMPH(1,I)+D2*(TEMPD(I)+TEMPS(2,I))-2.0*TEMPS(1,I)
228      510 CONTINUE
229      C
230      C      INCLUDE CONSTANT TEMPERATURE BND FOR TEMPS1(1,I)
231      AA(1,4)=AA(1,4)-AA(1,1)*300.0
232      AA(NNDM2,4)=AA(NNDM2,4)-AA(NNDM2,3)*300.0
233      C
234      C      EVALUATE TEMPS1(1,I)
235      CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)
236      C
237      C      TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY
238      DO 520 I=2,NNDM1
239      TEMPS1(1,I)=TEMP(I)

```

## SUBROUTINE DHT2D2 (Continued)

```

240      520 CONTINUE
241      C-----
242      C-----
243      600 CONTINUE
244      C-----
245      C-----
246      C-----
247      C-----
248      C-----
249      C-----
250      C-----
251      C-----
252      C-----
253      C-----
254      C-----
255      C-----
256      C-----
257      C-----
258      C-----
259      C-----
260      C-----
261      C-----
262      C-----
263      C-----
264      C-----
265      C-----
266      C-----
267      C-----
268      C-----
269      C-----
270      C-----
271      C-----
272      C-----
273      C-----
274      C-----
275      C-----
276      C-----
277      C-----
278      C-----
279      C-----
280      C-----
281      C-----
282      C-----
283      C-----
284      C-----
285      C-----
286      C-----
287      C-----
288      C-----
289      C-----
290      C-----
291      C-----
292      C-----
293      C-----
294      C-----
295      C-----
296      C-----
297      C-----
298      C-----
299      C-----
300      C-----
301      C-----
302      C-----
303      C-----
304      C-----
305      C-----
306      C-----
307      C-----
308      C-----
309      C-----
310      C-----
311      C-----
312      C-----
313      C-----
314      C-----
315      C-----
316      C-----
317      C-----
318      C-----
319      C-----

```

EVALUATE TEMPERATURE PROFILES FOR TEMPS1(2,I) - TEMPS1(NNHM2,I)  
WITH BLOCKING BND  
DO 630 J=2,NNHM2  
EVALUATE COEFFICIENTS FOR TEMPS1(J,I)  
DO 610 I=2,NNDM1  
II=I-1  
AA(II,1)=A  
AA(II,2)=B  
AA(II,3)=C  
AA(II,4)=D1\*TEMPH(J,I)+D2\*(TEMPS1(J-1,I)+TEMPS(J+1,I)  
&-2.0\*TEMPS(J,I))  
610 CONTINUE  
INCLUDE BLOCKING BND FOR TEMPS1(J,I)  
AA(1,2)=AA(1,1)+AA(1,2)  
AA(NNDM2,2)=AA(NNDM2,2)+AA(NNDM2,3)  
EVALUATE TEMP(J,I)  
CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)  
EQUATE TEMP(1) AND TEMP(2), AND TEMP(NNDM1) AND AND TEMP(NND)  
FOR BLOCKING BND  
TEMP(1)=TEMP(2)  
TEMP(NND)=TEMP(NNDM1)  
TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY  
DO 620 I=1,NND  
TEMPS1(J,I)=TEMP(I)  
620 CONTINUE  
630 CONTINUE  
C-----  
C-----  
700 CONTINUE  
C-----  
C-----  
EVALUATE TEMPERATURE PROFILES FOR TEMPS1(2,I) - TEMPS1(NNHM2,I)  
WITH CONSTANT TEMPERATURE BND  
DO 730 J=2,NNHM2  
EVALUATE COEFFICIENTS FOR TEMPS1(J,I)  
DO 710 I=2,NNDM1  
II=I-1  
AA(II,1)=A  
AA(II,2)=B  
AA(II,3)=C  
AA(II,4)=D1\*TEMPH(J,I)+D2\*(TEMPS1(J-1,I)+TEMPS(J+1,I)  
&-2.0\*TEMPS(J,I))  
710 CONTINUE  
INCLUDE CONSTANT TEMPERATURE BND FOR TEMPS1(J,I)  
AA(1,4)=AA(1,4)-AA(1,1)\*300.0  
AA(NNDM2,4)=AA(NNDM2,4)-AA(NNDM2,3)\*300.0  
EVALUATE TEMP(J,I)  
CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)  
TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY  
DO 720 I=2,NNDM1  
TEMPS1(J,I)=TEMP(I)  
720 CONTINUE  
730 CONTINUE  
C-----  
C-----  
800 CONTINUE  
C-----  
C-----  
IF BLOCKING BND SPECIFIED EVALUATE TEMPS1(NNHM1,I)  
IF(IRND.NE.1) GO TO 900  
COEFFICIENT EVALUATION FOR TEMPS1(NNHM1,I) WITH BLOCKING BND  
DO 810 I=2,NNDM1  
II=I-1

## SUBROUTINE DHT2D2 (Continued)

```

320      AA(II,1)=A
321      AA(II,2)=B
322      AA(II,3)=C
323      AA(II,4)=D1*TEMPH(NNHM1,I)+D2*(TEMPS1(NNHM2,I)+300.0
324      &-2.0*TEMPS(NNHM1,I))
325 810 CONTINUE
326
327      C      INCLUDE BLOCKING BND FOR TEMPS1(NNHM1,I)
328      AA(1,2)=AA(1,2)+AA(1,1)
329      AA(NNDM2,2)=AA(NNDM2,2)+AA(NNDM2,3)
330
331      C      EVALUATE TEMPS1(NNHM1,I)
332      CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)
333
334      C      EQUATE TEMP(1) AND TEMP(2), AND TEMP(NNDM1) AND
335      TEMP(NND) FOR BLOCKING BND
336      TEMP(1)=TEMP(2)
337      TEMP(NND)=TEMP(NNDM1)
338
339      C      TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY
340      DO 820 I=1,NND
341      TEMPS1(NNHM1,I)=TEMP(I)
342 820 CONTINUE
343
344      C-----
345      C 900 CONTINUE
346      C-----
347
348      C      IF CONSTANT TEMPERATURE BND SPECIFIED, EVALUATE
349      TEMPS1(NNHM1,I)
350      IF(IRND.NE.0) GO TO 1000
351
352      C      COEFFICIENT EVALUATION FOR TEMPS1(NNHM1,I) WITH CONSTANT
353      TEMPERATURE BND
354      DO 910 I=2,NNDM1
355      II=I-1
356      AA(II,1)=A
357      AA(II,2)=B
358      AA(II,3)=C
359      AA(II,4)=D1*TEMPH(NNHM1,I)+D2*(TEMPS1(NNHM2,I)+300.0
360      &-2.0*TEMPS(NNHM1,I))
361 910 CONTINUE
362
363      C      INCLUDE CONSTANT TEMPERATURE BND FOR TEMPS1(NNHM1,I)
364      AA(1,4)=AA(1,4)-300.0*AA(1,1)
365      AA(NNDM2,4)=AA(NNDM2,4)-300.0*AA(NNDM2,3)
366
367      C      EVALUATE TEMPS1(NNHM1,I)
368      CALL BANDA6(NNDM2,2,4,101,101,4,AA,TEMP,1,PIVMIN)
369
370      C      TRANSFER HEADER ROW TEMPERATURE TO THE HEADER TEMPERATURE ARRAY
371      DO 920 I=2,NNDM1
372      TEMPS1(NNHM1,I)=TEMP(I)
373 920 CONTINUE
374
375      C-----
376      C 1000 CONTINUE
377      C-----
378
379      C      CONVERGENCE CHECK
380
381      C      EVALUATE MAXIMUM NORMALIZED CHANGE IN TEMPERATURE FOR THIS
382      ITERATION
383      DTHSMX=0.0
384      DO 1010 I=2,NNDM1
385      DO 1010 J=1,NNHM1
386      DTHS=(TEMPS1(J,I)-TEMPS(J,I))/TEMPS1(J,I)
387      IF(DTHS.GT.DTHSMX) DTHSMX=DTHS
388 1010 CONTINUE
389
390      C      PRINT ITERATION SUMMARY
391      IF(ITPRH.EQ.1) WRITE(6,1020) S,DTHSMX
392 1020 FORMAT(3H S=,I2,5X,7HDTHSMX=,E8,3)
393
394      C      IF DTHSMX .LE. DTHMAX THE SPECIFIED CONVERGENCE HAS BEEN ACHIEVED
395      IF(DTHSMX.LE.DTHMAX) GO TO 2000
396
397      C      CONVERGENCE HAS NOT BEEN ACHIEVED. IF THE ITERATION COUNT
398
399

```

## SUBROUTINE DHT2D2 (Continued)

```

400 C      IS LESS THAN THE MAXIMUM SPECIFIED START ANOTHER ITERATION
401     IF(S.LT.SMAX) GO TO 300
402 C
403 C      THE MAXIMUM NUMBER OF ITERATION HAS BEEN PERFORMED WITHOUT
404 C      ACHIEVING CONVERGENCE.  WRITE ERROR MESSAGE AND TERMINATE XQT
405     WRITE(6,1030) S,DTHSMX
406     1030 FORMAT(///,46H ***** CONVERGENCE FAILURE IN SUBROUTINE DHT2D,
407            &/,27H ***** EXECUTION TERMINATED,/,
408            &9H ***** S=,I2,5X,7HDTHSMX=E,8.3,/,
409            &34H ***** INCREASE SMAX AND/OR DTHMAX)
410 C
411 C      STOP *****
412 C-----
413 C-----
414     2000 CONTINUE
415 C-----
416 C-----
417 C      TRANSFER NEW SUBSTRATE TEMPERATURE VALUES TO ARRAY TEMPH
418     DO 2020 I=1,NND
419     DO 2020 J=1,NNH
420     TEMPH(J,I)=TEMPS1(J,I)
421     2020 CONTINUE
422 C
423 C      RETURN TO CALLING PROGRAM WITH NEW HEADER TEMPERATURES
424     RETURN
425     END

```

\*TEMP(1).DOPLG

```

1      SUBROUTINE DOPLG(NND,DX,XMET,XDEPEP,DOPL,DOPU,DOPEP,DOPLOG,IDB4)
2
3      SUB DOPLG GENERATES A LOGARITHMIC DOPING PROFILE IN ARRAY DOPLOG
4
5      NND      - NUMBER OF NODES ALONG DIODE AXIS
6      DX      - NODE SPACING ALONG DIODE AXIS
7      XMET    - METALLURGICAL JUNCTION LOCATION
8      XDEPEP  - EPITAXIAL LAYER BOUNDARY
9      DOPL    - LOWER DOPING CONCENTRATION
10     DOPEP   - EPITAXIAL LAYER DOPING CONCENTRATION
11     DOPU    - UPPER DOPING CONCENTRATION
12     DOPLOG  - LOGARITHMIC DOPING PROFILE
13     IDB4    - DEBUG PRINT SENTINEL
14
15     DIMENSION DOPLOG(NND)
16
17     DOPLGL=ALOG10(DOPL)
18     DOPLGE=ALOG10(DOPEP)
19     DOPLGU=ALOG10(DOPU)
20
21     GENERATE IMPURITY PROFILE
22     DO 10 I=1,NND
23     X=(I-1)*DX
24     IF(X.LE.XMET)DOPLOG(I)=DOPLGL
25     IF((X.GT.XMET).AND.(X.LE.XDEPEP))DOPLOG(I)=DOPLGE
26     IF(X.GT.XDEPEP)DOPLOG(I)=DOPLGU
27
28     IF(IDB4.NE.0)WRITE(6,11)I,DOPLOG(I)
29     11 FORMAT(1X,7HDOPLOG(,I3,2H)=,F6.3)
30
31     10 CONTINUE
32
33     RETURN
34     END

```

\*TEMP(1),EFIELD

```

1 SUBROUTINE EFIELD(TEMP,XL,NND,ITER,RAC,XLDEP,XUDEP,CUR,DOPL,DOPU,D
2 &OPEP,XMET,XDEPEP,NP1,VLBR,VRBR,VTOT,ECRIN,EMAXB,IDB4,EINIT)
3
4 C
5 C
6 C
7 C
8 C
9 C
10 C
11 C
12 C
13 C
14 C
15 C
16 C
17 C
18 C
19 C
20 C
21 C
22 C
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67 C
68 C
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70 C
71 C
72 C
73 C
74 C
75 C
76 C
77 C
78 C
79 C

```

SUBROUTINE EFIELD(TEMP,XL,NND,ITER,RAC,XLDEP,XUDEP,CUR,DOPL,DOPU,D  
&OPEP,XMET,XDEPEP,NP1,VLBR,VRBR,VTOT,ECRIN,EMAXB,IDB4,EINIT)

SUB EFIELD EVALUATES THE DIODE ELECTRIC FIELD FROM CONTACT TO  
CONTACT ASSUMING THAT THE DIODE CURRENT CONSIST TOTALLY  
OF A DRIFT CURRENT. THE RESULTING E FIELD IS TEMPERATURE  
AND DOPING CONCENTRATION DEPENDENT. THERMAL EQUILIBRIUM  
MAJORITY AND MINORITY CARRIER CONCENTRATIONS ARE ASSUMED.

VARIABLE DEFINITIONS

ECRIN(I)-ELECTRIC FIELD INTENSITY AT NODE I  
TEMP(I) -TEMPERATURE AT NODE I  
ITER -NO. OF ITERATIONS USED IN CALCULATING E FIELD  
XL -TOTAL LENGTH OF DIODE  
NND -NO. OF NODES ON DIODE AXIS  
RAC -DESIRED ACCURACY IN COMPUTATION OF ECRIN(I)  
XLDEP -LEFT DEPLETION REGION BOUNDARY  
XUDEP -RIGHT DEPLETION REGION BOUNDARY  
DOPL -DOPING CONCENTRATION OF LEFT BULK REGION  
DOPU -DOPING CONCENTRATION OF RIGHT BULK REGION  
CUR -DIODE CURRENT DENSITY  
VLBR -VOLTAGE ACROSS LEFT BULK REGION  
VRBR -VOLTAGE ACROSS RIGHT BULK REGION  
VTOT -TOTAL VOLTAGE ACROSS DIODE  
XN -CONCENTRATION OF ELECTRONS  
P -CONCENTRATION OF HOLES  
XNI -INTRINSIC CARRIER CONCENTRATION  
XMET -METALLURGICAL JUNCTION  
XDEPEP -EPITAXIAL BOUNDARY  
DOPEP -EPITAXIAL IMPURITY CONCENTRATION  
NP1 -1 FOR NP CONFIG.,0 FOR PN CONFIG.  
IDB4 -DEBUG PARAMETER  
EINIT -INITIAL VALUE FOR CALCULATING ELECTRIC FIELD  
Q -UNIT CHARGE ON AN ELECTRON,IN COULOMBS  
XK -BOLTZMANN CONSTANT,ELECTRON VOLTS/DEGREE KELVIN  
F -TOTAL CURRENT DENSITY EQUATION  
PF -DERIVATIVE OF F WITH RESPECT TO ELECTRIC FIELD

DIMENSION ECRIN(NND),TEMP(NND)  
DATA Q/1.6E-19/XK/8.62E-5/

CALCULATE DEPLETION REGION BOUNDARIES TO NEAREST NODE  
DX=XL/(NND-1)  
N=XLDEP/DX +1.5  
M=XUDEP/DX +1.5

DEBUG OUTPUT  
IF(IDB4.EQ.1)WRITE(6,50)DX,N,M,NND  
50 FORMAT(1X,3HDX=,F10.5,1X,2HN=,I3,1X,2HM=,I3,1X,4HNND=,I3)

DO LOOP FOR CALCULATING ELECTRIC FIELD AT EACH NODE L  
10 DO 20 L=1,NND

CALCULATE XNV,XNC,EFFECTIVE DENSITY OF STATE  
XNV=1.02E19\*(TEMP(L)/300.0)\*\*1.5  
XNC=2.8E19\*(TEMP(L)/300.0)\*\*1.5

CALCULATE INTRINSIC CARRIER CONCENTRATION XNI  
XNI=(XNV\*\*.5)\*(XNC\*\*.5)\*EXP(-(1.1/(2\*XK\*TEMP(L))))

CALCULATE HOLE AND ELECTRON CONCENTRATIONS  
LL=L-1

IF N-P DIODE CONFIG.(NP1=1)GO TO 18  
IF(NP1.EQ.1)GO TO 18

FOR P-N DIODE CONFIG.  
IF(LL\*DX.LE.XMET)GO TO 11  
IF((LL\*DX.GT.XMET).AND.(LL\*DX.LE.XDEPEP))GO TO 12  
IF(LL\*DX.GT.XDEPEP)GO TO 13

FOR LOWER (P) SIDE  
11 HOL=.5\*DOPL+.5\*((DOPL\*\*2)+4\*(XNI\*\*2))\*\*.5)  
ELE=(XNI\*\*2)/HOL

## SUBROUTINE EFIELD (Continued)

```

80      GO TO 16
81      C
82      C
83      12 FOR FPITAXIAL LAYER(N-TYPE)
84      ELE=.5*DOPEP+.5*(((DOPEP**2)+4*(XNI**2))**.5)
85      HOL=(XNI**2)/ELE
86      GO TO 16
87      C
88      C
89      13 FOR UPPER (N) SIDE
90      ELE=.5*DOPU+.5*(((DOPU**2)+4*(XNI**2))**.5)
91      HOL=(XNI**2)/ELE
92      GO TO 16
93      C
94      C
95      C
96      18 FOR N-P DIODE CONFIG.
97      IF(LL*DX .LE. XMET)GO TO 14
98      IF((LL*DX .GT. XMET).AND.(LL*DX .LE. XDEPEP))GO TO 15
99      IF(LL*DX .GT. XDEPEP)GO TO 21
100     C
101     C
102     14 FOR LOWER (N) SIDE
103     ELE=.5*DOPL+.5*(((DOPL**2)+4*(XNI**2))**.5)
104     HOL=(XNI**2)/ELE
105     GO TO 16
106     C
107     C
108     15 FOR FPITAXIAL LAYER(P-TYPE)
109     HOL=.5*DOPEP+.5*(((DOPEP**2)+4*(XNI**2))**.5)
110     ELE=(XNI**2)/HOL
111     GO TO 16
112     C
113     C
114     21 FOR UPPER (P) SIDE
115     HOL=.5*DOPU+.5*(((DOPU**2)+4*(XNI**2))**.5)
116     ELE=(XNI**2)/HOL
117     C
118     C
119     16 INITIALIZE ELECTRIC FIELD
120     E=EINIT
121     C
122     C
123     DETERMINE DOPING FOR POSITION ALONG DIODE AXIS
124     IF(LL*DX .LT. XMET)DOP1=DOPL
125     IF((LL*DX .GT. XMET).AND.(LL*DX .LE. XDEPEP))DOP1=DOPEP
126     IF(LL*DX .GT. XDEPEP)DOP1=DOPU
127     C
128     C
129     DEBUG OUTPUT
130     IF(IDB4 .EQ. 1)WRITE(6,95)ELE,HOL,TEMP(L)
131     95 FORMAT(/,1X,4HELF=,F10.5,1X,4HHOL=,F10.5,1X,5HTEMP=,F6.1)
132     C
133     C
134     CHECK FOR CONVERGENCE OF NEWTON-RAPHSON METHOD
135     CALL EMOBS(DOP1,EMAXB,TEMP(L),EMO,EMOE,FMOT)
136     CALL HMOBS(DOP1,EMAXB,TEMP(L),HMO,HMOE,HMOT)
137     CURPR=Q*(ELE*EMO+HOL*HMO)*EMAXB
138     IF(CURPR.GE.CUR)GO TO 40
139     C
140     C
141     SET ELECTRIC FIELD TO DEFAULT VALUE
142     E=EMAXB
143     GO TO 19
144     C
145     C
146     40 DO LOOP FOR CALCULATING ELECTRIC FIELD
147     DO 17 I=1,ITER
148     C
149     C
150     CALL SUBROUTINES FOR FINDING MOBILITIES
151     CALL EMOBS(DOP1,E,TEMP(L),EMO,EMOE,FMOT)
152     CALL HMOBS(DOP1,E,TEMP(L),HMO,HMOE,HMOT)
153     C
154     C
155     CALCULATE F(E),TOTAL CURRENT DENSITY EQUATION
156     F=(Q*ELE*EMO*E)+(Q*HOL*HMO*E)
157     C
158     C
159     CALCULATE PF(E),DERIVATIVE OF TOTAL CURRENT DENSITY
160     WITH RESPECT TO ELECTRIC FIELD
161     PF=(Q*ELE*EMO)+(Q*HOL*HMO)+(Q*ELE*E*EMOE)+(Q*HOL*E*HMOE)
162     C
163     C
164     CALCULATE DELTA E
165     DE=(CUR-F)/PF
166     C
167     C
168     DEBUG OUTPUT
169     IF(IDB4 .EQ. 1)WRITE(6,45)E,F,PF,DE,EMO,HMO,FMOE,HMOE
170     45 FORMAT(1X,2HE=,E9.4,1X,2HF=,E9.4,1X,3HPF=,E9.4,1X,3HDE=,E9.4,1X,4H
171     REMO=,E9.4,1X,4HHMO=,E9.4,1X,5HEMOE=,E9.4,1X,5HHMOE=,E9.4)

```

## SUBROUTINE EFIELD (Continued)

```

160 C
161 C   CALCULATE NEW VALUE OF E
162 E=E+DE
163 C
164 C
165 C   CHECK FOR DESIRED ACCURACY
166 17 IF (ABS(DE/E).LE. RAC)GO TO 19
167 C
168 C   DEBUG OUTPUT
169 19 IF (IDB4 .EQ. 1)WRITE(6,47)E
170 47 FORMAT(1X,7HEFIELD=,E10.5,/)
171 C
172 C   SET ELECTRIC   FIELD(ECRIN(L)) EQUAL TO FINAL VALUE OF E
173 20 ECRIN(L)=E
174 C
175 C   CALCULATE VOLTAGE ACROSS LEFT BULK REGION
176 VLBR=ECRIN(1)*.5*DX
177 DO 25 J=2,N
178 25 VLBR=VLBR+ECRIN(J)*DX
179 C
180 C   CALCULATE VOLTAGE ACROSS RIGHT BULK REGION
181 VRBR=ECRIN(NND)*.5*DX
182 NL=NND-1
183 DO 30 J=M,NL
184 30 VRBR=VRBR+ECRIN(J)*DX
185 C
186 C   CALCULATE DEPLETION REGION VOLTAGE
187 NXL=N+1
188 NUL=M-1
189 VDEP=0
190 DO 35 LL=NXL,NUL
191 35 VDEP=VDEP+ECRIN(LL)*DX
192 C
193 C   CALCULATE TOTAL VOLTAGE
194 VTOT=VLBR+VRBR+VDEP
195 C
196 RETURN
197 END

```

\*TEMP(1),EMOBS

```

1 SUBROUTINE EMOBS(DOP1,E1,TEMP,EMO,EMOE,EMOT)
2
3 C
4 C
5 C
6 C
7 C
8 C
9 C
10 C
11 C
12 C
13 C
14 C
15 C
16 C
17 C
18 C
19 C
20 C
21 C
22 C
23 C
24 C
25 C
26 C
27 C
28 C
29 C
30 C
31 C
32 C
33 C
34 C
35 C
36 C
37 C
38 C
39 C
40 C
41 C
42 C
43 C
44 C
45 C
46 C
47 C
48 C
49 C
50 C
51 C
52 C
53 C
54 C
55 C
56 C
57 C
58 C
59 C

```

EMOBS EVALUATES ELECTRON MOBILITY, DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO THE ELECTRIC FIELD AND THE DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO TEMPERATURE.

DOP1 - DOPING CONCENTRATION  
E1 - ELECTRIC FIELD  
TEMP - TEMPERATURE  
EMO - ELECTRON MOBILITY  
EMOE - DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO ELECTRIC FIELD  
EMOT - DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO TEMPERATURE  
IFLAG - SENTINEL FOR INITIALIZATION CALCULATIONS

ASSIGN CONSTANTS FOR ELECTRON MOBILITY CALCULATIONS  
DATA EM00,EN,ES,FA,EF,ER,ALFA,IFLAG/1400.0,3.0E16,350.0,3.5E3,  
#8.8,7.4E3,2.5,0/

INITIALIZATION CALCULATIONS  
IF(IFLAG.NE.0)GO TO 10  
TB= FF\*EA\*EA  
TC=ER\*\*(-2)  
TE= 1.0/(EM00\*300.0\*\*ALFA)

SET SENTINEL TO SKIP INITIALIZATION CALCULATIONS  
IFLAG=1

10 CONTINUE

E=ABS(E1)  
DOP=ABS(DOP1)

EVALUATE REMAINING PARAMETERS  
TA=DOP/(DOP/ES+EN)  
TD=EA\*E+TB

EVALUATE INTERMEDIATE FUNCTION  
H=1.0+TA+(1.0/TD+TC)\*E\*E

DERIVATIVE OF H WITH RESPECT TO F  
HE=((2.0\*TD-EA\*E)/(TD\*TD)+2.0\*TC)\*E

G=TE\*TEMP\*\*ALFA  
DERIVATIVE OF G WITH RESPECT TO T  
GT=ALFA\*G/TEMP

EVALUATE ELECTRON MOBILITY  
EMO=1.0/(G\*SQRT(H))

EVALUATE DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO E  
EMOE=-HE/(2.0\*G\*H\*\*1.5)

EVALUATE DERIVATIVE OF ELECTRON MOBILITY WITH RESPECT TO T  
EMOT=-GT/(SQRT(H)\*G\*G)

RETURN  
END

## SUBROUTINE EPROF

\*TEMP(1).EPROF

```

1 SUBROUTINE EPROF(NND,DX,XDEPL,XMFT,XDEPEP,XDFPU,XL,SDOPL,
2 &SDOPEP,SDOPU,EMAX,E,IDB3,FLAGEB)
3
4 C
5 C SUB FPROF ANALYTICALLY GENERATES THE DEPLETION REGION ELECTRIC
6 C FIELD PROFILE BASED ON THE E FIELD VALUE SPECIFIED AT THE
7 C METALLURGICAL JUNCTION, (EMAX). IF A BULK REGION IS DEPLETED,
8 C FLAGEB IS SET EQUAL TO ONE AND THE ERRONEOUS DEPLETION REGION
9 C BOUNDARY IS SET EQUAL TO THE RESPECTIVE BULK REGION BOUNDARY.
10
11 C
12 C VARIABLE DEFINITIONS
13 C NND - NUMBER OF NODES ALONG DIODE AXIS
14 C DX - NODE SPACING ALONG DIODE AXIS
15 C XDEPL - LOWER DEPLETION REGION BOUNDARY
16 C XMFT - METALLURGICAL JUNCTION LOCATION
17 C XDEPU - UPPER DEPLETION REGION BOUNDARY
18 C XL - DIODE LENGTH
19 C SDOPL - LOWER DEPLETION REGION SPACE CHARGE
20 C SDOPEP - EPITAXIAL DEPLETION REGION SPACE CHARGE
21 C SDOPU - UPPER DEPLETION REGION SPACE CHARGE
22 C EMAX - ELECTRIC FIELD AT METALLURGICAL JUNCTION
23 C E - ELECTRIC FIELD ARRAY
24 C IDB3 - SUB EPROF DEBUG PRINT SENTINEL
25 C FLAGEB - DEPLETED BULK REGION SENTINEL
26
27 C
28 C NAMELIST /DEBUG/NND,DX,XDEPL,XMFT,XDEPEP,XDFPU,XL,SDOPL,
29 C &SDOPEP,SDOPU,EMAX,Q,PERM,FEP
30
31 C
32 C DIMENSION E(NND)
33 C
34 C INTEGER FLAGEB
35 C
36 C DATA Q/1.6E-19/
37 C DATA PERM/1.06E-12/
38 C
39 C
40 C EVALUATE LOWER DEPLETION REGION EDGE
41 C XDEPL=XMFT-PERM/Q*EMAX/SDOPL
42 C
43 C
44 C EVALUATE UPPER DEPLETION REGION WIDTH
45 C XDEPU=XMFT+PERM/Q*EMAX/SDOPEP
46 C
47 C
48 C DOES UPPER DEP REG EDGE FALL WITHIN EPIT REG?
49 C IF(XDEPU.LE.XDEPEP) GO TO 100
50 C
51 C
52 C UPPER DEP REG EDGE OCCURS WITHIN BACKGROUND DOPING
53 C EVALUATE ELECTRIC FIELD AT EPIT RDN
54 C EEP=EMAX-Q/PERM*SDOPEP*(XDEPEP-XMET)
55 C
56 C
57 C EVALUATE UPPER DEP REG EDGE WITHIN BACKGROUND DOPING
58 C XDEPU=XDEPEP+PERM/Q*EEP/SDOPU
59 C
60 C 100 CONTINUE
61 C
62 C NEW XDEPL AND XDEPU HAVE BEEN EVALUATED
63 C ARE DEP REG EDGES VALID?
64 C
65 C
66 C RESET FLAGEB
67 C FLAGEB=0
68 C
69 C
70 C IF(XDEPL.GE.0.0.AND.XDEPU.LE.XL) GO TO 200
71 C
72 C
73 C A BULK REG HAS BEEN DEPLETED, SET FLAGEB=1 AND SET
74 C THE ERRONEOUS DEP REG BND EQUAL TO THE RESPECTIVE BULK
75 C BND. IF THIS CONDITION YIELDS ALFAIN.LT.AFRMAX
76 C THE DIODE DESIGN IS BAD AND XQT WILL BE TERMINATED
77 C IN SUB BKDEPL
78 C FLAGEB=1
79 C IF(XDEPL.LT.0.0) XDEPL=0.0
80 C IF(XDEPU.GT.XL) XDEPU=XL
81 C
82 C
83 C 200 CONTINUE
84 C
85 C GENERATE ELECTRIC FIELD PROFILES
86 C DO 290 N=1,NND
87 C
88 C
89 C DETERMINE NODE POSITION
90 C X=(N-1)*DX
91 C
92 C
93 C EVALUATE E FIELD AT NODE I OR X
94 C IF(X.GE.XDEPL) GO TO 210

```

```
80      C
81      C      SET F FIELD IN LOWER BULK EQUAL TO ZERO
82      E(N)=0.0
83      GO TO 290
84      C
85      210 CONTINUE
86      C
87      IF(X.GT.XMET) GO TO 220
88      C
89      EVALUATE E WITHIN LOWER DEP REG
90      E(N)=Q/PERM*SDOPL*(X-XDFPL)
91      C
92      GO TO 290
93      C
94      220 CONTINUE
95      C
96      IF(X.GT.XDEPEP) GO TO 230
97      C
98      EVALUATE E WITHIN EPIT DEP REG
99      E(N)=EMAX-Q/PERM*SDOPEP*(X-XMET)
100     C
101     GO TO 290
102     C
103     230 CONTINUE
104     C
105     IF(X.GT.XDEPU) GO TO 240
106     C
107     EVALUATE E WITHIN UPPER DEP REG
108     E(N)=EMAX-Q/PERM*(SDOPEP*(XDEPEP-XMET)+SDOPU*(X-XDFPEP))
109     C
110     GO TO 290
111     C
112     240 CONTINUE
113     C
114     SET F FIELD IN UPPER BULK EQUAL TO ZERO
115     E(N)=0.0
116     C
117     290 CONTINUE
118     C
119     DEBUG PRINT OPTION
120     IF(IDB3.NE.1) RETURN
121     WRITE(6,DEBUG)
122     C
123     RETURN
124     END
```



\*TEMP(1).INALFA

```

1      SUBROUTINE INALFA(NND,XDEPL,XMET,XDEPEP,XDEPU,DX,DOPL,DOPEP,
2      &DOPU,ALFATD,E,T,ALFAIN,IDB1,NP1)
3
4      SUB INALFA EVALUATES THE INTEGRAL OF ALFA OR THE AVALANCHE
5      BREAKDOWN INTEGRAL FROM THE FIRST GRID POINT PASS XDEPL TO
6      THE LAST GRID POINT BEFORE XDEPU.
7
8      NND      - NUMBER OF NODES ALONG DIODE AXIS
9      XDEPL   - LOWER DEP REGION BND
10     XMET    - POSITION OF METALLURGICAL JUNCTION
11     XDEPEP  - EPITAXIAL LAYER BOUNDARY
12     XDEPU   - UPPER DEP REGION BND
13     DX      - NODE SPACING ALONG DIODE AXIS
14     DOPL    - LOWER DOPING CONCENTRATION
15     DOPEP   - EPITAXIAL DOPING CONCENTRATION
16     DOPU    - UPPER DOPING CONCENTRATION
17     ALFATD  - AVALANCHE IONIZATION COEFFICIENT TEMPERATURE
18             DEPENDENCE PARAMETER
19     E       - ELECTRIC FIELD ARRAY
20     T       - TEMPERATURE ARRAY
21     ALFAIN  - SPACIAL INTEGRAL OF ALFA
22     IDB1    - DEBUG PRINT SENTINEL
23     NP1     - JUNCTION ORIENTATION, 1 - NP, 0 - PN
24
25     DEBUG NAMELIST
26     NAMELIST /DEBUG/NND,XDEPL,XMET,XDEPEP,XDEPU,DX,DOPL,DOPEP,DOPU,
27     &ALFATD,ALFAIN,NDEPL,NDEPU
28
29     DIMENSION E(NND),T(NND)
30
31     DETERMINE THE INSIDE DEPLETION REGION GRID POINT LIMITS
32     NDEPL=XDEPL/DX+2
33     NDEPU=XDEPU/DX+1
34
35     INITIALIZE GRID POINTER
36     N=NDEPL-1
37
38     INITIALIZE THE ALFA INTEGRAL
39     ALFAIN=0.0
40
41     -----
42     100 CONTINUE
43     -----
44
45     INTEGRATE ALFA FROM N=NDEPL TO N=NDEPU
46
47     N=N+1
48     X=(N-1)*DX
49     IF(X.GE.XMET) GO TO 14
50
51     EVALUATE ALFA IN LOWER DEPLETION REGION
52     CALL IONCOF(T(N),E(N),DOPL,NP1,ALFA,ALFATD)
53     GO TO 19
54
55     14 CONTINUE
56     IF(X.GT.XDEPEP) GO TO 15
57
58     EVALUATE ALFA IN THE EPITAXIAL LAYER
59     CALL IONCOF(T(N),E(N),DOPEP,NP1,ALFA,ALFATD)
60     GO TO 19
61
62     15 CONTINUE
63
64     EVALUATE ALFA IN UPPER DEPLETION REGION
65     CALL IONCOF(T(N),E(N),DOPU,NP1,ALFA,ALFATD)
66
67     19 CONTINUE
68
69     SUM NEW ALFA
70     ALFAIN=ALFAIN+ALFA
71
72     SUBSTRACT HALF OF FIRST ALFA
73     IF(N.EQ.NDEPL) ALFAIN=ALFAIN-ALFA/2.0
74
75     SUBSTRACT HALF OF LAST ALFA
76     IF(N.EQ.NDEPU) ALFAIN=ALFAIN-ALFA/2.0
77
78     HAVE ALL ALFAS BEEN SUMMED?
79     IF(N.LT.NDEPU) GO TO 100

```

```
80      C
81      C      MULTIPLY ALFAIN BY GRID SPACING TO YIELD THE INTEGRAL OF ALFA
82      C      ALFAIN=ALFAIN*DX
83      C
84      C      DEBUG OUTPUT
85      C      IF(IDB1.NE.1) RETURN
86      C      WRITE(6,200)
87      C      200 FORMAT(/,30H DEBUG LISTING FROM SUB INALFA,/)
88      C      WRITE(6,DEBUG)
89      C
90      C      RETURN
91      C      END
```

## SUBROUTINE IONCOF

\*TEMP(1).IONCOF

```

1      SUBROUTINE IONCOF(T,EE,DOP,NP1,ALFA,ALFATD)
2
3      IONCOF - EVALUATES AVALANCHE IONIZATION COEFFICIENT AS A FUNCTION
4      OF TEMPERATURE AND ELECTRIC FIELD. THE TEMPERATURE DEPENDENCE IS
5      LINEAR IN PARAMETER ALFATD. THE AVALANCHE COEFFICIENT EVALUATED
6      CORRESPONDS TO THE MINORITY CARRIER CONC FOR EPITAXIAL LAYER
7      MATERIAL.
8
9      T      - TEMPERATURE, DEG K
10     EE     - ELECTRIC FIELD, VOLTS/CM
11     DOP    - DOPING CONCENTRATION
12     ALFA   - AVALANCHE IONIZATION COEFFICIENT
13     ALFATD - AVALANCHE IONIZATION COEFFICIENT TEMPERATURE DEPENDENCE
14             PARAMETER, 1/DEG K
15     NP1    - DIODE ORIENTATION: 1 - NP, 0 - PN
16
17     INITIALIZE PARAMETERS FOR IONIZATION COEFFICIENT FORMULATION
18     DATA EA,EB/3.8E6,1.7E6/
19     DATA HA,HB/2.25E7,3.26E6/
20
21     N-TYPE OR P-TYPE?
22     IF(NP1.NE.1) GO TO 10
23
24     CAL. N-TYPE COEFF.
25     ALFA=0.0
26     E=ABS(EE)
27
28     N-TYPE COEFF. = 0?
29     IF(E.LT.1.12E5) RETURN
30
31     CAL. COEFF. FOR N-TYPE
32     ALFA=EA*(1.0-ALFATD*(T-300.0))*EXP(-EB/E)
33
34     ENFORCE MINIMUM VALUE FOR ALFA
35     IF(ALFA.LT.1.0) ALFA=1.0
36
37     RETURN
38
39 10 CONTINUE
40
41     EVALUATE P-TYPE COEFF
42     ALFA=0.0
43     E=ABS(EE)
44
45     P-TYPE COEFF. = 0?
46     IF(E.LT.1.93E5) RETURN
47
48     CAL P-TYPE COEFF.
49     ALFA=HA*(1.0-ALFATD*(T-300.0))*EXP(-HB/E)
50
51     ENFORCE MINIMUM VALUE FOR ALFA
52     IF(ALFA.LT.1.0) ALFA=1.0
53
54     RETURN
55
56     END

```



## SUBROUTINE L PLOT (Continued)

```

80      25 CONTINUE
81      C
82      26 CONTINUE
83      C
84      C      BLANK OUT GRAPH ARRAY
85      DO 28 J=2,100
86      DO 27 K=2,50
87      ARRAY(K,J)=BLANK
88      27 CONTINUE
89      28 CONTINUE
90      C
91      C      GENERATE GRID
92      IF (IGRID.EQ.0) GO TO 29
93      DO 31 J=6,46,5
94      DO 31 K=2,100
95      ARRAY(J,K)=PERIOD
96      31 CONTINUE
97      DO 32 J=11,91,10
98      DO 32 K=2,50
99      ARRAY(K,J)=PERIOD
100     32 CONTINUE
101     C
102     29 CONTINUE
103     C
104     C      EVALUATE X AND Y AXIS SCALE VALUES
105     DDX=(XMAX-XMIN)/10
106     DDY=(YMAX-YMIN)/10
107     DO 30 J=1,11
108     XAXIS(J)=XMIN+DDX*(J-1)
109     YAXIS(J)=YMIN + DDY * (J-1)
110     30 CONTINUE
111     C
112     C      EVALUATE X AND Y INCREMENTS
113     DX= (XMAX-XMIN)/100
114     DY= (YMAX-YMIN)/50
115     C
116     C      GENERATE GRAPH ARRAY
117     IF(NYCOR1.NE.0) GO TO 40
118     C
119     C      ORDINATE VALUES STORED COLUMN WISE IN CALLING PROGRAM
120     DO 38 J=1,NPTS
121     NX=(X(J)-XMIN)/DX+1.4999
122     DO 37 K=J,MPLPT,MPTS
123     KK=(K-J)/MPTS+1
124     NY=(Y(K)-YMIN)/DY+1.4999
125     IF (NX.LT.2.OR.NX.GT.100.OR.NY.LT.2.OR.NY.GT.50) GO TO 37
126     IF (ARRAY (NY,NX).EQ.CHAR(KK)) GO TO 37
127     IF (ARRAY(NY,NX).EQ.BLANK.OR.ARRAY(NY,NX).EQ.PERIOD) GO TO 35
128     ARRAY(NY,NX)=ASTR
129     GO TO 37
130     35 ARRAY(NY,NX)=CHAR(KK)
131     37 CONTINUE
132     38 CONTINUE
133     GO TO 49
134     C
135     40 CONTINUE
136     C
137     C      ORDINATE VALUES STORED ROW WISE IN CALLING PROGRAM
138     DO 48 J=1,MPLPT,MPLTS
139     JJ=(J-1)/MPLTS+1
140     NX=(X(JJ)-XMIN)/DX + 1.4999
141     KMAX=J+NPLTS-1
142     DO 47 K=J,KMAX
143     KK=K-J+1
144     NY=(Y(K)-YMIN)/DY + 1.4999
145     IF (NX.LT.2.OR.NX.GT.100.OR.NY.LT.2.OR.NY.GT.50) GO TO 47
146     IF (ARRAY (NY,NX).EQ.CHAR(KK)) GO TO 47
147     IF (ARRAY(NY,NX).EQ.BLANK.OR.ARRAY(NY,NX).EQ.PERIOD) GO TO 45
148     ARRAY(NY,NX)=ASTR
149     GO TO 47
150     45 ARRAY(NY,NX)=CHAR(KK)
151     47 CONTINUE
152     48 CONTINUE
153     C
154     49 CONTINUE
155     C
156     C      WRITE GRAPH ARRAY
157     WRITE(6,50) (XAXIS(I),I=1,11)
158     50 FORMAT('1'//////,7X,11(1PE10.2),/)
159     NNY=11

```

```
160      DO 70 J=51,6,-5
161      WRITE(6,55) YAXIS(NNY),(ARRAY(J,I),I=1,101),YAXIS(NNY)
162      55 FORMAT(4X,1PE8.2,1X,101A1,1X,1PE8.2)
163      NNY=NNY-1
164      DO 65 K=1,4
165      WRITE(6,60)(ARRAY (J-K,I),I=1,101)
166      60 FORMAT(13X,101A1)
167      65 CONTINUE
168      70 CONTINUE
169      WRITE(6,55)YAXIS(1),(ARRAY(51,I),I=1,101),YAXIS(1)
170      WRITE(6,75)(XAXIS(I),I=1,11)
171      75 FORMAT(/,7X,11(1PE10.2))
172      C
173      WRITE GRAPH TITLE
174      J=1
175      80 CONTINUE
176      IF(TITLE(J).EQ.BLANK.OR.TITLE(J).EQ.ZERO.OR.J.GE.22)GO TO 85
177      J=J+1
178      GO TO 80
179      85 CONTINUE
180      JJ=J-1
181      II=(22-J)/2
182      IF(JJ.LT.1) GO TO 95
183      WRITE(6,90) (BLANK,I=1,II),(TITLE(J),J=1,JJ)
184      90 FORMAT(/,22A6,/)
185      95 CONTINUE
186      WRITE(6,105)
187      105 FORMAT('1')
188      IFLAG=1
189      C
190      RETURN
191      END
```

\*TEMP(1).TEMPTR10

```

1 C ***** TEMPTR10 *****
2 C
3 C
4 C DIMENSION X(101),TEMP(101),TTEMP(101),TEMPL(101),TEMPAR(10,101)
5 C DIMENSION C(101),E(101),EE(101),PE(2,101),DOPLOG(101),TITLE5(22)
6 C DIMENSION PLTIME(10),A(101,4),THKDPF(101),THKHPPF(101)
7 C DIMENSION PTEMPX(500),PTIMEX(500),TITLE1(22),TITLE2(22),TITLE3(22)
8 C DIMENSION PVOLT(4,500),TITLE4(22)
9 C DIMENSION TEMPH(12,101),XXDH(14)
10 C
11 C INTEGER UPE,FLAGEB,PLOT,PDTP,PDIP,PDEP,PDVP,TFLAG,SCFLAG,SMAX,S
12 C
13 C NAMEDLIST /DPARMR/THKD,THKHx,THKHy,DDEN,HDEN,DSPEC,HSPEC,XDT,
14 C &XDH,XLDEP,XMET,XEPDEP,XUDEP,XL,DOPL,DOPEP,DOPU,VEL,ALFATD,NP1,
15 C &THKDPF,THKHPPF
16 C
17 C NAMEDLIST /DPARW/THKD,THKHx,THKHy,DDEN,HDEN,DSPEC,HSPEC,XDT,
18 C &XDH,XLDEP,XMET,XEPDEP,XUDEP,XL,
19 C &DOPL,DOPEP,DOPU,SCONC,SDOPL,SDOPEP,SDOPU,VEL,ALFATD,NP1
20 C
21 C NAMEDLIST /SPARM/CUR,NND,NNH,IBND,TIMEMX,TMAX,TPMAX,ITSNMX,DTIME,
22 C &LTRNIN,LTEMP,LDHTEM,PLOT,PVOLT,X,IGRID,TRMSMI,ITERMX,ITLST,
23 C &IDHTMO,SMAX,DTHMAX,ITPRH,
24 C &PLTIME,EMAXL,EMAXU,EMAXR,FINT,UPF,AERMAX,EERMAX,ITCMAX,
25 C &IDB0,IDB1,IDB2,IDB3,IDB4,PDTP,PDIP,PDEP,PDVP
26 C
27 C DATA TITLE1/6HMAXIMU,6HM TEMP,6HERATUR,6HE VFRS,6HUS TIM,
28 C &6HE ,16*1H /
29 C
30 C DATA TITLE2/6HDIODE ,6HTEMPER,6HATURE ,6HVERSUS,6H POSIT,
31 C &6HION ,16*1H /
32 C
33 C DATA TITLE3/6HLOG OF,6H ELECT,6HRIC FI,6HELD VE,6HRSUS P,
34 C &6HOSITIO,6HN ,15*1H /
35 C
36 C DATA TITLE4/6HDIODE ,6HVOLTAG,6HES VER,6HSUS TI,
37 C &2HME,17*1H /
38 C
39 C DATA TITLE5/6HLOG OF,6H DIODE,6H IMPUR,6HITY CO,6HNCENTR,6HATION ,
40 C &6HVERSUS,6H POSIT,6HION ,13*1H /
41 C
42 C ASSIGN CONSTANTS
43 C Q=1.6E-19
44 C PERM=1.04E-12
45 C
46 C C
47 C C DEFINE DIODE AND SIMULATION PARAMETERS
48 C C
49 C C ASSIGN DEFAULT DIODE PARAMETER VALUES
50 C THKD=1.0 THKD - WATTS/CM-K
51 C THKHx=0.46 THKHx - WATTS/CM-K
52 C THKHy=0.46 THKHy - WATTS/CM-K
53 C DDEN=2.3 DDEN - GM/CM3
54 C HDEN=4.0 HDEN - GM/CM3
55 C DSPEC=0.7 DSPEC - J/GM-K
56 C HSPEC=0.79 HSPEC - J/GM-K
57 C XDT=1.0E-4 XDT - CM
58 C XDH=250E-4 XDH - CM
59 C XLDEP=0.0 XLDEP - CM
60 C XMET=20.0E-4 XMET - CM
61 C XEPDEP=40.0E-4 XEPDEP - CM
62 C XUDEP=0.0 XUDEP - CM
63 C XL=40.0E-4 XL - CM
64 C DOPL=1.0E17 DOPL - CM-3
65 C DOPEP=1.0E16 DOPEP - CM-3
66 C DOPU=1.0E16

```

## PROGRAM TEMPTR10 (Continued)

```

80      C          DOPU - CM-3
81      VEL=1.0E7
82      C          VEL - CM/SEC
83      ALFATD=2.5E-3
84      C          ALFATD -
85      NP1=1
86      C          NP1 - 1 FOR NP, 0 FOR PN
87      C
88      C          INITIALIZE THERMAL CONDUCTIVITY PERTURBATION ARRAY
89      DO 5 K=1,101
90      THKDPF(K)=1.0
91      THKHPPF(K)=1.0
92      5 CONTINUE
93      C
94      C          ASSIGN DEFAULT SIMULATION PARAMETERS, SPARM
95      CUR=1.25E4
96      C          CUR - AMPS/CM2
97      NND=101
98      NNH=0
99      IBND=0
100     TIMEMX=1.0
101     C          TIMEMX - SEC
102     TMAX= 700.0
103     C          TMAX - DEG K
104     TPMAX=800.0
105     C          TPMAX - DEG K
106     ITSNMX=200
107     DTIMF=1.0E-9
108     C          DTIME - SEC
109     LTRNIN=2
110     LTEMP=0
111     LDHTEM=0
112     PLOT=0
113     PDTP=1
114     PDIP=1
115     PDEP=1
116     PDVP=1
117     PVOLTX=250.0
118     IGRID=0
119     TRMSMI=1000.0
120     ITERMX=10
121     ITLST=10000
122     IDHTMO=1
123     SMAX=10
124     DTHMAX=1.0E-4
125     ITPRH=0
126     EMAXL=1.0E5
127     EMAXU=1.0E6
128     EMAXB=1.0E5
129     EINT=100.0
130     UPE=0
131     ITCMAX=10
132     AERMAX=0.1
133     EERMAX=1.0E-4
134     IDB0=0
135     IDB1=0
136     IDB2=0
137     IDB3=0
138     IDB4=0
139     DO 40 J=1,10
140     PLTIME(J)=100
141     40 CONTINUE
142     PLTIME(1)=25.0E-9
143     PLTIME(2)=50.0E-9
144     PLTIME(3)=75.0E-9
145     PLTIME(4)=100.0E-9
146     PLTIME(5)=125.0E-9
147     PLTIME(6)=150.0E-9
148     C
149     C          BEGIN NEW SIMULATION
150     C
151     13 CONTINUE
152     C
153     C          SKIP TO TOP OF NEXT PAGE TO BEGIN NEW SIMULATION
154     WRITE(6,9)
155     9 FORMAT(1H1)
156     C
157     C          READ/WRITE SIMULATION PARAMETERS
158     READ(5,SPARM,END=1000)
159     WRITE(6,SPARM)

```

```

160 C
161 C READ DIODE PARAMETERS
162 C READ(5,DPARMR)
163 C
164 C EVALUATE MOBILE SPACE CHARGE ASSUMING LIMITING VELOCITY
165 C IN DEPLETION REGION
166 C SCONC=CUR/Q/VEL
167 C
168 C IF EXCESSIVE MOBILE SPACE CHARGE SET SCFLAG TO OMIT THIS SIMULATION
169 C SCFLAG=0
170 C IF(SCONC.GE.DOPL) SCFLAG=1
171 C IF(SCONC.GE.DOPEP) SCFLAG=1
172 C IF(SCONC.GE.DOPU) SCFLAG=1
173 C
174 C EVALUATE NET SPACE CHARGE
175 C SDOPL=DOPL-SCONC
176 C SDOPEP=DOPEP-SCONC
177 C SDOPU=DOPU-SCONC
178 C
179 C WRITE DIODE PARAMETERS
180 C WRITE(6,DPARMW)
181 C
182 C IF(SCFLAG.EQ.1) WRITE(6,30)
183 C 30 FORMAT(///,5X,45H***** DRIVING CURRENT YIELDS EXCESSIVE MOBILE
184 C &39H SPACE CHARGE, SIMULATION OMITTED *****)
185 C
186 C IF SCFLAG.EQ.1 SKIP TO NEXT SIMULATION
187 C IF(SCFLAG.EQ.1) GO TO 13
188 C
189 C RESET FLAG FOR HEADER THERMAL MODEL TO SIGNAL NEW DATA SET
190 C IFLAG=0
191 C
192 C SET FLAG TO WRITE TRANSIENT DATA HEADER
193 C TFLAG=1
194 C
195 C INITIALIZE PROGRAM PARAMETERS
196 C NNDM1=NND-1
197 C NNDM2=NND-2
198 C NNHP1=NNH+1
199 C IOCONT=0
200 C ITSN=0
201 C TIME=0.0
202 C KPLOT=1
203 C IPTIME=1
204 C IPTINC=ITSNMX/101+1
205 C PTEMPX(IPTIME)=0.0
206 C PTIMFX(IPTIME)=0.0
207 C DX=XL/NNDM1
208 C DXDX=DX*DX
209 C EFXDH=XDH
210 C IF(NNH.LT.3) GO TO 12
211 C EFXDH=XDH/NNH
212 C DO 11 N=1,NNHP1
213 C XXDH(N)=(N-1)*EFXDH
214 C 11 CONTINUE
215 C 12 CONTINUE
216 C
217 C GENERATE POSITION ARRAY AND INITIALIZE TEMPERATURE ARRAY
218 C DO 15 I=1,NND
219 C X(I)=DX*(I-1)
220 C TEMP(I)=300.0
221 C TEMPL(I)=300.0
222 C TTEMP(I)=300.0
223 C TEMPH(1,I)=300.0
224 C 15 CONTINUE
225 C
226 C CALL EPROF TO INITIALIZE THE DEPLETION REG BNDS. ASSUME
227 C THE MAX E-FIELD TO EQUAL THE MINIMUM SEARCH VALUE EMAXL
228 C REQUIRED BY SUB BKDEP
229 C CALL EPROF(NND,DX,XLDEP,XMET,XEPDEP,XUDEP,XL,
230 C &SDOPL,SDOPEP,SDOPU,EMAXL,E,IDB3,FLAGEB)
231 C
232 C CALL DOPLG TO GENERATE LOG OF IMPURITY CONCENTRATION PROFILE
233 C FOR PLOTTING
234 C CALL DOPLG(NND,DX,XMET,XEPDEP,DOPL,DOPU,DOPEP,DOPLG,IDB4)
235 C
236 C CALL BKDEP TO EVALUATE DEPLETION REGION WIDTH AND E-FIELD
237 C PROFILE FOR THE INITIAL TEMPERATURE PROFILE
238 C CALL BKDEPL(NND,XLDEP,XMET,XEPDEP,XUDEP,XL,DX,
239 C &DOPL,DOPEP,DOPU,ALFATD,FMAX,AERMAX,EMAXL,

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## PROGRAM TEMPTR10 (Continued)

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240      &EMAX1),E,TEMP,ALFAIN,VDEP,ITCMAX,
241      &IDB1, IDB2, IDB3, NP1, SDOPL, SDOPEP, SDOPU)
242  C
243  C      CALL EFIELD TO EVALUATE THE BULK REGION E-FIELD PROFILES
244  C      FOR THE INITIAL TEMPERATURE PROFILE
245  C      CALL EFIELD(TEMP, XL, NND, ITCMAX, FFRMAX, XLDEP, XUDEF, CUR, DOPL, DOPU,
246  C      &DOPEP, XMET, XEPDEP, NP1, VLBULK, VUBULK, VOIODE, FF, EMAXB, IOB4, EINT)
247  C
248  C      EVALUATE TOTAL DIODE VOLTAGE
249  C      VDIODE=VLBULK+VDEP+VUBULK
250  C
251  C      COMBINE BULK AND DEPLETION E-FIELD
252  C      DO 18 N=1, NND
253  C      E(N)=AMAX1(E(N), EE(N))
254  C
255  C      STORE INITIAL E FIELD FOR PLOTTING
256  C      PE(1,N)=E(N)
257  C      18 CONTINUE
258  C
259  C      CHECK FOR THERMAL CONDUCTIVITY PERTURBATIONS
260  C      DO 20 KK=1, NND
261  C      IF((THKDPF(KK).NE.1.0).OR.(THKHPP(KK).NE.1.0))GO TO 22
262  C      20 CONTINUE
263  C      GO TO 100
264  C
265  C      OUTPUT THERMAL CONDUCTIVITY PERTURBATIONS
266  C      22 CONTINUE
267  C      WRITE(6,23)
268  C      23 FORMAT(1H1,///,2X,4HNODF,6X,6HPOSITI,2HON,8X,6HDOPING,9X,
269  C      &6HE FIEL,2HD,7X,6HTHKDPF,9X,6HTHKHPP,/)
270  C
271  C      DETERMINE DOPING CONCENTRATIONS
272  C      DO 24 KKK=1, NND
273  C      IF(X(KKK).LE.XMET)DOP=DOPL
274  C      IF((X(KKK).GT.XMET).AND.(X(KKK).LE.XEPDEP))DOP=DOPEP
275  C      IF(X(KKK).GT.XEPDEP)DOP=DOPU
276  C      WRITE(6,26)KKK,X(KKK),DOP,E(KKK),THKDPF(KKK),THKHPP(KKK)
277  C      26 FORMAT(1X,I4,5X,E10.5,5X,E10.5,5X,E10.5,5X,F10.4,5X,F10.4)
278  C      24 CONTINUE
279  C
280  C
281  C      100 CONTINUE
282  C
283  C      WRITE TRANSIENT DATA HEADER
284  C      IF(TFLAG.NE.1) GO TO 110
285  C      WRITE(6,80)
286  C      80 FORMAT(1H1,///,T2,4HITSN,T9,4HTIME,T18,5HDTIME,T25
287  C      &5HITERN,T33,4HTRMS,T41,6HTEMPMX,T51,4HEMAX,T59,6HVLBULK,
288  C      &T69,4HVDEP,T77,6HVUBULK,T86,6HVDIODE,T95,5HXLDEP,
289  C      &T104,5HXUDEF,T113,6HALFAIN,T121,1HS,/)
290  C
291  C      RESET TRANSIENT DATA HEADER FLAG
292  C      TFLAG=0
293  C
294  C      TIME STEP LOOP
295  C      110 CONTINUE
296  C      TIME=TIME+DTIME
297  C      ITSN=ITSN+1
298  C      ITERN=0
299  C
300  C      EVALUATE POWER DENSITY
301  C      DO 115 N=2, NNDM1
302  C      C(N)=CUR*E(N)
303  C      115 CONTINUE
304  C
305  C      ITERATION LOOP
306  C      120 CONTINUE
307  C      ITERN=ITERN+1
308  C
309  C
310  C      COEFFICIENT EVALUATION
311  C      AA=THKD/ODEN/DSPEC
312  C      BB=-THKHY/(DDEN*DSPEC*XDT*EFXDH)
313  C      DXDTBB=DXDX*DTIME*BB
314  C
315  C      A1=DTIME*AA
316  C      A2=DTIME*DXDX*BB
317  C      A3=DXDTBB*300.0
318  C
319  C      DO 130 N=1, NNDM2

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## PROGRAM TEMPTR10 (Continued)

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320      A(N,1)=A1*THKDPF(N)
321      A(N,2)=THKHPF(N)*A2-(DXDX+2.0*A(N,1))
322      A(N,3)=A(N,1)
323      A(N,4)=-DXDX*(TEMPL(N+1)+DTIME*C(N+1)/(DDEN*DSPEC))
324      IF(NNH.GE.3) A(N,4)=A(N,4)+DXDTRR*TEMPH(1,N+1)
325      IF(NNH.LT.3) A(N,4)=A(N,4)+A3
326      CONTINUE
130  C
327  C
328  C      EVALUATE BOUNDARY CONDITIONS
329  C
330  C      IBND=0, CONSTANT BOUNDARY TEMPERATURES
331  C
332  C      IF(IRND.NE.0) GO TO 133
333  C      A(1,4)=A(1,4)-TEMP(1)*A(1,1)
334  C      A(NNDM2,4)=A(NNDM2,4)-TEMP(NND)*A(NNDM2,3)
335  C
336  C      133 CONTINUE
337  C
338  C      IF(IRND.NE.1) GO TO 135
339  C
340  C      IBND=1, BLOCKING BOUNDARY CONDITIONS
341  C      A(1,2)=A(1,2)+A(1,1)
342  C      A(NNDM2,2)=A(NNDM2,2)+A(NNDM2,3)
343  C      135 CONTINUE
344  C
345  C      SOLVE SYSTEM OF LINEAR EQUATIONS
346  C
347  C      CALL BANDA6(NNDM2,2,4,101,101,4,A,TEMP,1,PIVMIN)
348  C
349  C      IF(IRND.NE.1) GO TO 138
350  C
351  C      UPDATE END POINT TEMPS FOR BLOCKING BND
352  C      TEMP(1)=TEMP(2)
353  C      TEMP(NND)=TEMP(NNDM1)
354  C
355  C      138 CONTINUE
356  C
357  C      EVALUATE MAXIMUM TEMPERATURE AND RMS TEMPERATURE CHANGE
358  C      TRMS=0.0D0
359  C      TEMPMX=TEMP(1)
360  C      DO 140 N=2,NNDM1
361  C      TRMS=TRMS+(TEMP(N)-TEMP(N))**2
362  C      TTEMP(N)=TEMP(N)
363  C      TEMPMX=DMAX1(TEMPMX,TEMP(N))
364  C      140 CONTINUE
365  C      TRMS=SQRT(TRMS/NNDM2)
366  C
367  C      IF(ITLST.EQ.1) WRITE(6,150)ITSN,TIME,DTIME,ITFRN,TRMS,TEMPMX,
368  C      &EMAX,VLBULK,VDEP,VUBULK,VDIODE,XLDEP,XUDEP,ALFAIN,S
369  C      150  FORMAT(I5,2E9.3,I5,10E9.3,I3)
370  C
371  C      IF(TRMS.LE.TRMSMI) GO TO 170
372  C      IF(ITERN.LT.ITERMX) GO TO 120
373  C      WRITE(6,160)ITSN
374  C      160  FORMAT(29H ***** CONVERGENCE FAILURE AT,
375  C      &17H TIME STEP NUMBER,I5,7H *****)
376  C      170 CONTINUE
377  C
378  C      ITERATION LOOP COMPLETE, ADVANCE TO NEXT TIME STEP
379  C
380  C      EVALUATE SUBSTRATE OR HEADER TEMPERATURE PROFILES
381  C
382  C      QUASI-TWO DIMENSIONAL HEADER THERMAL MODEL
383  C      IF(NNH.GT.3.AND.IDHTMO.EQ.1) CALL DHTEMP(IFLAG,NND,NNH,
384  C      &XDH,THKH,HSPEC,HDEN,DTIME,TEMP,TEMPH)
385  C
386  C      TWO-DIMENSIONAL HEADER THERMAL MODEL. HEADER TEMPERATURES
387  C      EVALUATED COLUMN WISE (PROFILES PERPENDICULAR TO DIODE AXIS)
388  C      WITH NEWLY COMPUTED TEMPERATURES INCORPORATED AFTER EACH
389  C      HEADER TEMPERATURE ITERATION IS COMPLETED.
390  C      IF(NNH.GT.3.AND.IDHTMO.EQ.2) CALL DHT2D(IFLAG,NND,NNH,XL,
391  C      &XDH,THKH,THKH,HSPEC,HDEN,DTIME,TEMP,TEMPH,SMAX,DTHMAX,
392  C      &ITPRH,IBND,S)
393  C
394  C      TWO-DIMENSIONAL HEADER THERMAL MODEL. HEADER TEMPERATURES
395  C      EVALUATED COLUMN WISE (PROFILES PERPENDICULAR TO DIODE AXIS)
396  C      WITH NEWLY COMPUTED TEMPERATURES INCORPORATED AS THEY
397  C      ARE EVALUATED.
398  C      IF(NNH.GT.3.AND.IDHTMO.EQ.3) CALL DHT2D1(IFLAG,NND,NNH,
399  C      &XL,XDH,THKH,THKH,HSPEC,HDEN,DTIME,TEMP,TEMPH,SMAX,

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## PROGRAM TEMPTR10 (Continued)

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400      &DTHMAX,ITPRH,IBND,S)
401      C
402      C      TWO-DIMENSIONAL HEADER THERMAL MODEL. HEADER TEMPERATURES
403      C      EVALUATED ROW WISE (PROFILES PARALLEL TO DIODE AXIS)
404      C      WITH NEWLY COMPUTED TEMPERATURES INCORPORATED AS THEY
405      C      ARE EVALUATED.
406      C      IF(NNH.GT.3.AND.IDHTMO.FQ.4) CALL DHT2D2(IFLAG,NND,NNH,
407      C      &XL,XDH,THKH,THKY,HSPEC,HDEN,DTIME,TEMP,TEMPH,SMAX,
408      C      &DTHMAX,ITPRH,IBND,S)
409      C
410      C      STORE PRESENT DIODE TEMPERATURE PROFILE FOR NEXT SET
411      C      OF ITERATIONS
412      C      DO 175 N=2,NNDM1
413      C      TEMPL(N)=TEMP(N)
414      C      175 CONTINUE
415      C
416      C
417      C      IF(UPE.LE.0) GO TO 185
418      C
419      C      UPDATE DEP REG BNDS AND E-FIELD FOR NEXT TIME STEP
420      C      CALL BKDEPL(NND,XLDEP,XMET,XEPDF,
421      C      &XUDEP,XL,DX,DOPL,DOPEP,DOPU,ALFATD,EMAX,AERMAX,
422      C      &EMAXL,EMAXU,E,TEMP,ALFATN,VDEP,ITCMAX,
423      C      &IDB1,IDB2,IDB3,NP1,SDOPL,SDOPEP,SDOPU)
424      C
425      C      UPDATE BULK REG E-FIELD FOR NEXT TIME STEP
426      C      CALL EFIELD(TEMP,XL,NND,ITCMAX,EFMAX,XLDEP,XUDEP,CUR,DOPL,DOPU,
427      C      &DOPEP,XMET,XEPDF,NP1,VLBULK,VUBULK,VDIODE,FE,EMAXR,IDB4,EINT)
428      C
429      C      EVALUATE TOTAL DIODE VOLTAGE
430      C      VDIODE=VLBULK+VDEP+VUBULK
431      C
432      C      COMBINE BULK AND DEPLETION REGION E-FIELDS
433      C      DO 179 N=1,NND
434      C      E(N)=AMAX1(E(N),FE(N))
435      C      179 CONTINUE
436      C
437      C      185 CONTINUE
438      C
439      C      SAVE MAXIMUM TEMPERATURE AND DIODE VOLTAGES VERSUS TIME
440      C      IFTSI=0
441      C      IF(ITSN-ITSN/IPTINC*IPTINC.NE.0) GO TO 178
442      C      IPTIME=IPTIME+1
443      C      PTEMPX(IPTIME)=TEMPMX
444      C      PVOLT(1,IPTIME)=VLBULK
445      C      PVOLT(2,IPTIME)=VDEP
446      C      PVOLT(3,IPTIME)=VUBULK
447      C      PVOLT(4,IPTIME)=VDIODE
448      C      PTIMFX(IPTIME)=TIME
449      C      IFTSI=1
450      C      178 CONTINUE
451      C      OUTPUT SECTION.
452      C
453      C      LIST TRANSIENT DATA
454      C      ICONSN=0
455      C      IF(ITSN-ITSN/LTRNIN*LTRNIN.NE.0) GO TO 180
456      C      WRITE(6,150)ITSN,TIME,DTIME,ITERN,TRMS,TEMPMX,
457      C      &EMAX,VLBULK,VDEP,VUBULK,VDIODE,XLDEP,XUDEP,ALFATN,S
458      C      ICONSN=1
459      C      180 CONTINUE
460      C
461      C      TERMINATE EXECUTION IF EITHER MAX TIME, MAX TIME STEP
462      C      COUNT OR MAX TEMP IS EXCEEDED.
463      C      IF(TIME.GE.TIMEMX.OR.ITSN.GE.ITSNMX.OR.TEMPMX.GE.TMAX) GO TO 190
464      C
465      C      IF(TIME.LT.PLTIME(KPLOT)) GO TO 230
466      C
467      C      STORE TEMPERATURE PROFILES
468      C      190 CONTINUE
469      C      KPLOT=KPLOT+1
470      C      IF(KPLOT.LE.11) GO TO 210
471      C      WRITE(6,200)
472      C      200 FORMAT(/,40H ***** MORE THAN 10 TEMPERATURE PROFILES,
473      C      &16H REQUESTED *****/,28H ***** SIMULATION TERMINATED,
474      C      &27H *****/)
475      C      KPLOT=KPLOT-1
476      C      GO TO 240
477      C
478      C      210 CONTINUE
479      C

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## PROGRAM TEMPTR10 (Continued)

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480 C   DEFINE PLOT TIME FOR EXTRA PLOT
481 C   IF (TIME.LT.PLTIME(KPLOT-1)) PLTIME(KPLOT-1)=TIME
482 C
483 C   WRITE TIME STEP DATA FOR PLOT TIME
484 C   IF (ICONS.NE.1) WRITE(6,150) ITSN,TIME,DTIME,ITERN,TRMS,TEMPMX,
485 C   &EMAX,VLBULK,VDEP,VUBULK,VDIODE,XLDEP,XUDEP,ALFATN,S
486 C
487 C   STORE MAX TEMP, DIODE VOLTAGES AND TIME FOR PLOTTING
488 C   IF (IFTSI.EQ.1) VALUES ALREADY STORED FOR LAST TIME STEP
489 C   IF (IFTSI.EQ.1) GO TO 215
490 C   IPTIME=IPTIME+1
491 C   PTEMPX(IPTIME)=TEMPMX
492 C   PVOLT(1,IPTIME)=VLBULK
493 C   PVOLT(2,IPTIME)=VDEP
494 C   PVOLT(3,IPTIME)=VUBULK
495 C   PVOLT(4,IPTIME)=VDIODE
496 C   PTIMEX(IPTIME)=TIME
497 C 215 CONTINUE
498 C
499 C   STORE DIODE TEMPERATURE PROFILES
500 C   DO 220 J=1,NND
501 C   TEMPAR(KPLOT-1,J)=TEMP(J)
502 C 220 CONTINUE
503 C
504 C   IF (NNH.LT.3.OR.LDHTM.NE.1) GO TO 230
505 C
506 C   WRITE DIODE AND HEADER TEMPERATURE PROFILES
507 C   WRITE(6,223) ITSN,TIME,(XXDH(N),N=1,NNHP1)
508 C 223 FORMAT(9H1 ITSN = ,I5.5X,7HTIME = ,E8.3,/,
509 C   &T12,5HXH = ,14E8.3)
510 C   WRITE(6,224)
511 C 224 FORMAT(/,T7,1HN,T12,2HXD,T18,5HDTEMP,T26,5HHTEMP,/)
512 C   DO 228 J=1,NND
513 C   WRITE(6,226) J,X(J),TEMP(J),(TEMPH(K,J),K=1,NNH)
514 C 226 FORMAT(I8,15E8.3)
515 C 228 CONTINUE
516 C
517 C   SET TFLAG FOR NEW TRANSIENT DATA HEADER
518 C   TFLAG=1
519 C
520 C 230 CONTINUE
521 C
522 C   TERMINATE EXECUTION IF EITHER MAX TIME, MAX TIME STEP
523 C   COUNT OR MAX TEMP IS EXCEEDED
524 C   IF (TIME.LT.TIMEMX.AND.ITSN.LT.ITSNMX.AND.TEMPMX.LT.TMAX) GO TO 100
525 C
526 C 240 CONTINUE
527 C
528 C   TERMINATE EXECUTION AND OUTPUT SIMULATION RESULTS
529 C
530 C   PLOT MAXIMUM TEMPERATURE VERSUS TIME
531 C   CALL LPLOT(IPTIME,500,1,1,500,0,PTIMEX,0.0,PTIMEX(IPTIME),PTEMPX
532 C   &,300.0,TPMAX,TITLE1,IGRID)
533 C
534 C   LIST AND/OR PLOT TEMPERATURE PROFILES
535 C
536 C   KPLOT=KPLOT-1
537 C   IF (LTEMP.NE.1) GO TO 280
538 C
539 C   LIST DIODE TEMPERATURE PROFILES
540 C   WRITE(6,250) (PLTIME(J),J=1,KPLOT)
541 C 250 FORMAT(1H1,T8,1HN,T13,1HX,T19,5HTIME1,T27,5HTIME2
542 C   &,T35,5HTIME3,T43,5HTIME4,T51,5HTIME5,T59,5HTIME6
543 C   &,T67,5HTIME7,T75,5HTIME8,T83,5HTIME9,T91,6HTIME10
544 C   &,T99,6HTIME11,T107,6HTIME12,T115,6HTIME13,T123
545 C   &,6HTIME14,/,16X,14E8.3)
546 C   WRITE(6,251)
547 C 251 FORMAT()
548 C
549 C   DO 270 K=1,NND
550 C   WRITE(6,260) K,X(K),(TEMPAR(J,K),J=1,KPLOT)
551 C 260 FORMAT(1X,I7,15E8.3)
552 C 270 CONTINUE
553 C
554 C 280 CONTINUE
555 C
556 C   IF ((PLOT.NE.1).AND.(PDTP.NE.1)) GO TO 283
557 C
558 C   PLOT DIODE TEMPERATURE PROFILES
559 C   CALL LPLOT(NND,101,KPLOT,10,1010,1,X,0.0,XL,

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## PROGRAM TEMPTR10 (Continued)

```
560      &TEMPAR,300.0,TPMAX,TITLE2,IGRID)
561 C
562 283 IF((PLOT.NE.1).AND.(PDIP.NE.1))GO TO 287
563 C   PLOT DIODE IMPURITY PROFILE
564   CALL LPLOT(NND,101,1,1,101,0,X,0.0,XL,DOPL0G,10.0,20.0,TITLE5,IGRI
565   &D)
566 C
567 287 IF((PLOT.NE.1).AND.(PDEP.NE.1))GO TO 350
568 C   STORE FINAL E FIELD PROFILE FOR PLOTTING
569   DO 290 N=1,NND
570   PE(2,N)=E(N)
571 290 CONTINUE
572 C
573   GENERATE LOG OF E FIELD PLOTTING ARRAY
574   DO 310 M=1,2
575   DO 320 N=1,NND
576   IF(PE(M,N).GE.1.0E-2) TPE =ALOG10(PE(M,N))
577   IF(PE(M,N).LT.1.0E-2) TPE =-2.0
578   PE(M,N)=TPE
579 320 CONTINUE
580 310 CONTINUE
581 C
582   PLOT LOG OF FIRST AND LAST E FIELD PROFILES VERSUS POSITION
583   CALL LPLOT(NND,101,2,2,202,1,X,0.0,XL,PE,-2.0,8.0,
584   &TITLE3,IGRID)
585 350 IF((PLOT.NE.1).AND.(PDVP.NE.1))GO TO 500
586 C
587   PLOT DIODE VOLTAGES VERSUS TIME
588   CALL LPLOT(IPTIME,500,4,4,404,1,PTIMEX,0.0,
589   &PTIMFX(IPTIME),PVOLT,0.0,PVOLTX,TITLE4,IGRID)
590 C
591 500 CONTINUE
592 C
593   GO TO 13
594 C
595 1000 STOP
596   END
```