Implementation of Arithmetic Mean Method on Determination of Peak Junction Temperature of Semiconductor Device on Printed Circuit Board

by

Guwanch Mashadov

Dissertation submitted in partial fulfillment of the
requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Universiti Teknologi PETRONAS

Tronoh, Perak

December 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Guwanch Mashadov

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ABSTRACT

High reliability users of microelectronic devices have been derating junction temperature and other critical stress parameters to improve device reliability and extend operating life. The junction temperature is what really matters for component functionality and reliability. This study presents a useful analysis on mathematical approach which can be implemented to predict thermal behavior in Integrated Circuit (IC). The problem could be modeled as heat conduction equation. In this study, numerical approaches based on implicit scheme and Arithmetic Mean (AM) iterative method will be applied to solve the governing heat conduction equation. From the numerical results obtained, it shows that AM method solves the governing heat conduction equation with minimum number of iterations and fastest computational time compared to the Gauss-Seidel (GS) method. It is in design phase when simulations and modeling are carried out to ensure high performance and reliability. The availability of thermal analysis tool for maximum temperature prediction would be of great value to designers of power device ICs.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In a power device application, high power is usually encountered. It is engineers' job to make power devices reliable for their intended application. In order to achieve this goal, considerations have to be taken regarding reliability and performance. During the design phase, especially when a new platform for new technology is involved, thorough calculations and simulations are carried out to ensure the designed electrical parameters and other reliability characteristics are optimized. High reliability users of microelectronic devices have been derating junction temperature and other critical stress parameters for decades to improve device reliability and extend operating life [1]. It is in the first phase, i.e., design phase where semiconductor devices are stressed for reliability and performance [2]. It is of important concern to predict junction temperature at this phase.

Generally, electronic systems are made of various components attached on Printed Circuit Board (PCB). PCB provides electrical connection and mechanical support for electronic components by means of pathways. Typical PCB assembly may be seen in Figure 1.1, including IC components with several resistors and capacitors. With the evolution of ICs, there have been many types of IC packages. In a standard construction (refer Figure 1.2), the IC die is attached to a metal support (die paddle) and wire bonded to a metal leadframe. In this structure, epoxy resin is used as a component body [3].

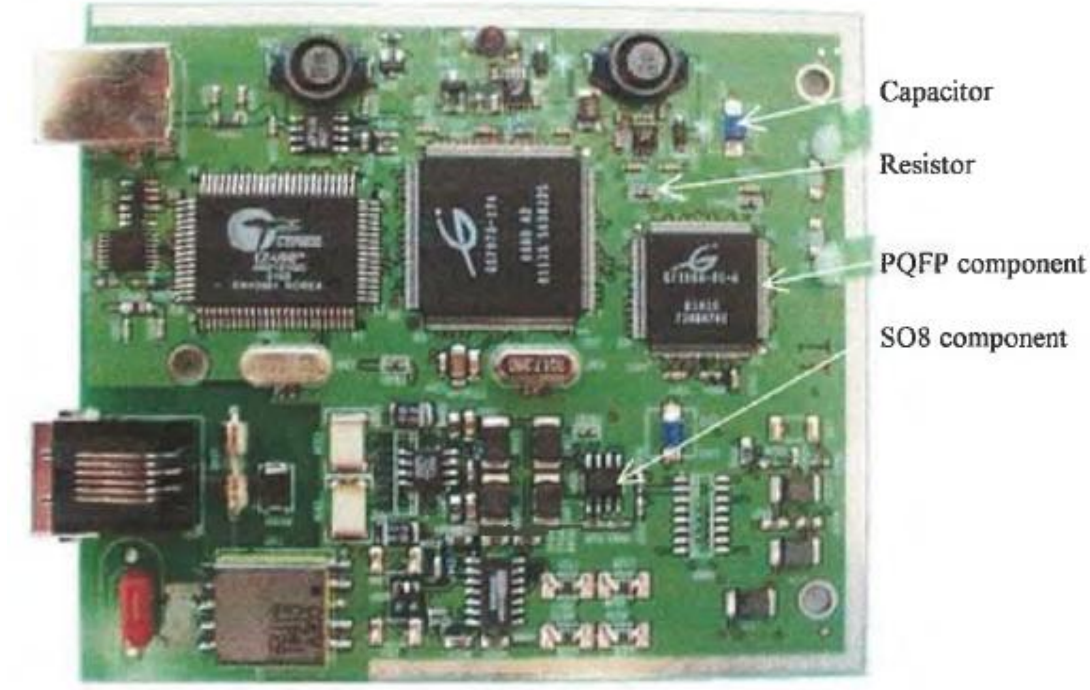

Figure 1.1 Printed Circuit Board

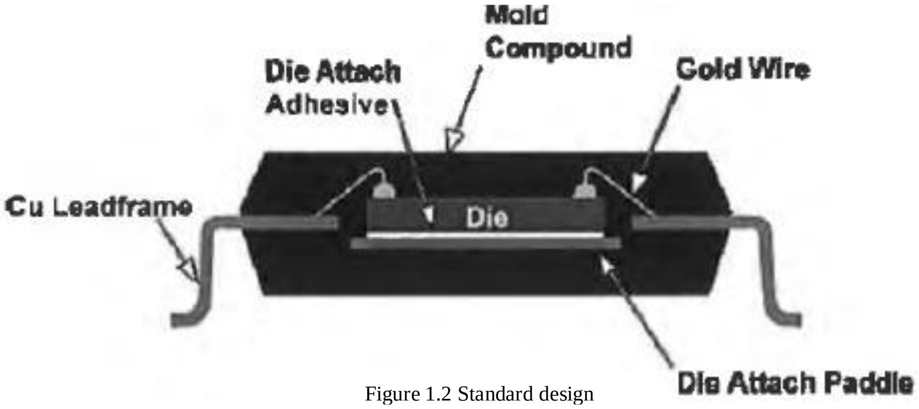

Figure 1.2 Standard design

To improve thermal performance, packages might contain high-thermally conductive metal or heat slug, as shown in Figure 1.3, which will dissipate excessive thermal heat from IC.

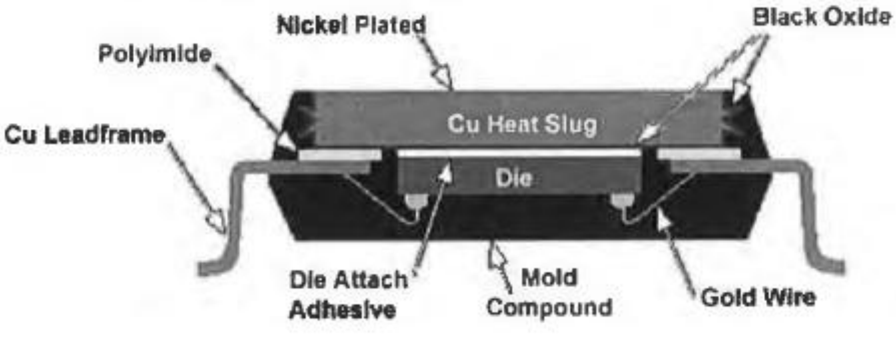

Figure 1.3 Thermally enhanced with heat slug

Figure 1.4 provides basic illustration of IC die mounted on PCB, while Figures 1.5 and 1.6 give detailed view of IC silicon die with its package. There is no heat slug as shown in Figure 1.5, where leadframe provides electrical connection to the external leads and PCB. The die paddle is not required when there is heat slug as illustrated in Figure 1.6, in that case, die can be directly attached to the heat slug. In Figure 1.6, heat slug is exposed at the base of package body.

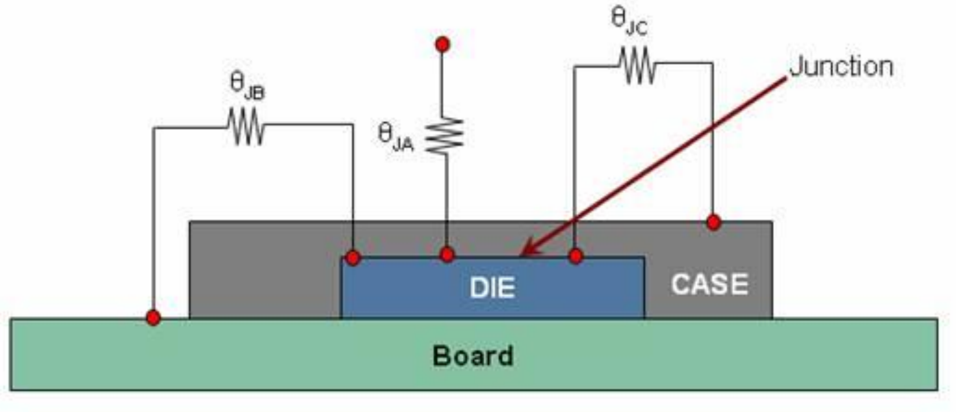

Figure 1.4 PCB mounted silicon die

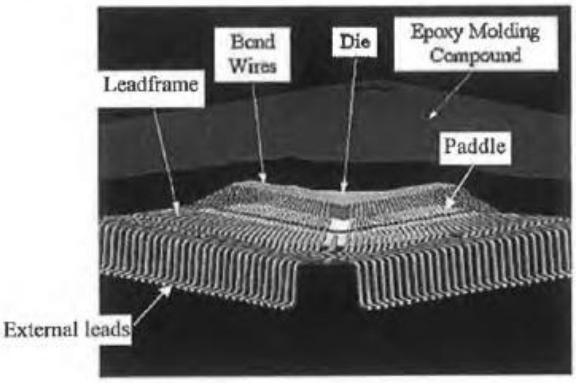

Figure 1.5 Internal architecture of an IC

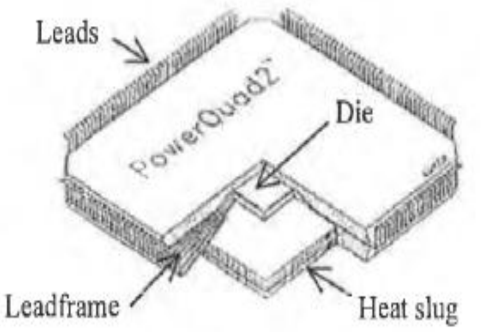

Figure 1.6 IC view from package base

Designing good performance and reliable power electronic system requires careful consideration of the thermal and electrical domain. Over designing the system adds unnecessary cost and weight; under designing the system may lead to overheating and even system failure. Finding an optimized solution requires a good understanding to predict the operating temperatures of the system’s power components and heat generated by those components affects neighboring devices, such as capacitors and microcontrollers. The generated heat from semiconductor device can affect nearby devices thus reducing overall performance of the system. The maximum allowable junction temperature is one of the key factors that limit the power dissipation capability of a device. It is defined by the manufacturer and usually depends on the reliability of the die used in the manufacturing process [4].

To ensure that a device is operated within its defined temperature limits, power dissipation must be well understood. When a device is running, it consumes electrical energy that is transformed into heat. Thermal response curves were traditional methods used to calculate peak junction temperature of a device. The model is not suitable for large surges of short time duration, as they are faced in present day power electronic systems [5].

Design of a cooling system is highly dependent on junction temperature and its influence on neighboring devices [4]. In order to develop thermal control system, one needs to estimate temperature profile of a component, in our case semiconductor device. This in turn will improve system’s reliability and performance. As stated in [6], appropriate cooling strategy highly depends on prediction of component junction temperature.

1.2 Problem Statement

Using the concept of junction temperature, it is assumed that the die's temperature is uniform across its top surface, i.e., uniform power dissipation [7]. Most of the die's thickness is to provide mechanical support for the very thin layer of active components on its surface. For many thermal analyses, electrical components on the die lay at the chip's surface. Therefore, junction temperature is actual die or device temperature. Study presented in [8] gives important ideas of IC die temperature distribution, which can be seen from Figure 1.7. Note that the hottest temperature is actual die or junction temperature.

In this study one-dimensional heat conduction equation will be used as a basis for junction temperature prediction. One-dimensional heat conduction equation in itself is second-order linear parabolic partial differential equation.

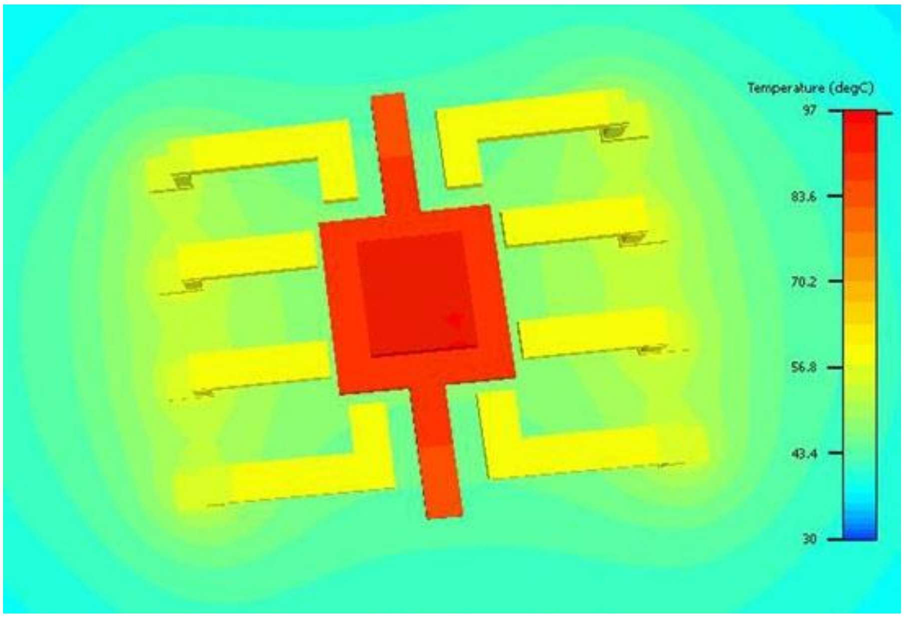

Figure 1.7 IC die temperature

The heat conduction equation models the flow of heat in a rod that is insulated everywhere except at the two ends [9]. Solutions of this equation are functions of two variables, i.e., one spatial variable (position along the rod) and time. The one-dimensional in the description of the differential equation refers to the fact that we are considering only one spatial dimension. Imagine a thin rod that is given an initial temperature distribution, and then insulated on the sides, as shown in Figure 1.8.

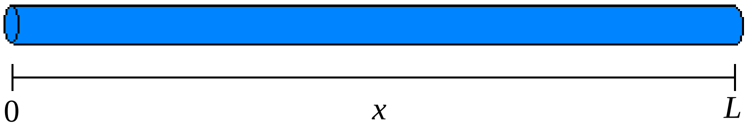

Figure 1.8 Thin rod

The temperature variation with time along the rod can be investigated. Suppose that the rod has a length L, and we establish a coordinate system along the rod as illustrated in Figure 1.8. This modeling is basis for heat conduction equation along silicon die.

The one-dimensional heat conduction equation that represents the problem is written as follows

$$K \frac{\partial^2 T}{(\partial x)^2} = \rho c \frac{\partial T}{\partial t} \tag{1}$$

with boundary conditions [11]

$$\left.\begin{aligned} & SK \frac{\partial T}{\partial x}\Big|_{x=0} = -P_{in} \\ & T(L,t) = T_{in} \qquad t > 0 \end{aligned}\right\} \tag{2}$$

The equation holds for domain $0<x<L$ and time $t \geq 0$ where L and T are the thickness of device and temperature of semiconductor device (IC die) respectively. Meanwhile K, ρ, c are silicon's thermal conductivity, mass density, specific heat capacity and S, P_{in}, T_{in} represent the area of semiconductor, input dissipated power and input temperature respectively. The equation (1) is derived from Fourier's Law of Heat Conductivity and conservation of energy [10].

Throughout this study, convection and radiation will be assumed negligible. Thermal properties of silicon die will be assumed to be constant and not depend on junction temperature. In this study, the performance of AM iterative method with implicit discretization scheme will be investigated in determining the peak junction temperature of semiconductor device.

1.3 Objective of Study

The main objectives are:

- To formulate and implement the AM method with implicit scheme for solving the governing heat conduction equation.
- To develop the algorithm for AM method with implicit scheme for solving the governing heat conduction equation.
- To determine the peak junction temperature of semiconductor device

1.4 Significance and Feasibility of Study

The delivered results of the study, i.e. peak junction temperature of the semiconductor device may be used in design phase of a semiconductor device. The prediction can be very useful in calculating the junction temperature, especially to identify if IC die temperature exceeds predefined limits. It is of important issue as performance and reliability depends on temperature prediction. Thermal engineers and/or researchers may benefit from the produced deliverables.

CHAPTER 2

LITERATURE REVIEW

2.1 Traditional Methods

The following traditional method is used to calculate the junction temperature, T_J

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \tag{3}$$

where θ_{JA}, T_A and P_D represent thermal resistance, ambient temperature and power dissipation respectively [4].

However, there are drawbacks using traditional method. First of all as mentioned by Clemente [5] the model developed many years ago, is inappropriate for large surges of short time duration, as they are encountered in present day power conditioning systems. It normally does not include pulse widths in the order of few microseconds, as required by the reaction times of modern power conditioning systems. The difficulty of using peak temperature measurements for pulse widths of this duration further compounds the problem. This is an important issue in the design of power electronic equipment. Attempts to calculate the junction temperature using traditional θ_{JA} calculations are not recommended. Traditional method can produce large errors because important parameters are not always acknowledged for, like airflow, proximity of other components, and PCB thickness and layers [13].

In [8], some methods of IC die temperature prediction are provided. It states that the most accurate way to determine junction temperature is to measure IC die temperature itself while component operates. This can only be done by component supplier. It can be achieved by installing temperature sensors and integrating them with IC die. Although, the method is most accurate it is very costly for both supplier and user. Another method subject to discussion is to measure case temperature. Case temperature or top package temperature is the closest to the IC die. Thus, by measuring case temperature and knowing heat flow profile junction temperature can be predicted. One of the ways to measure case temperature is to use an Infrared (IR) camera or IR gun. Figure 2.1 shows case temperature measured by IR camera.

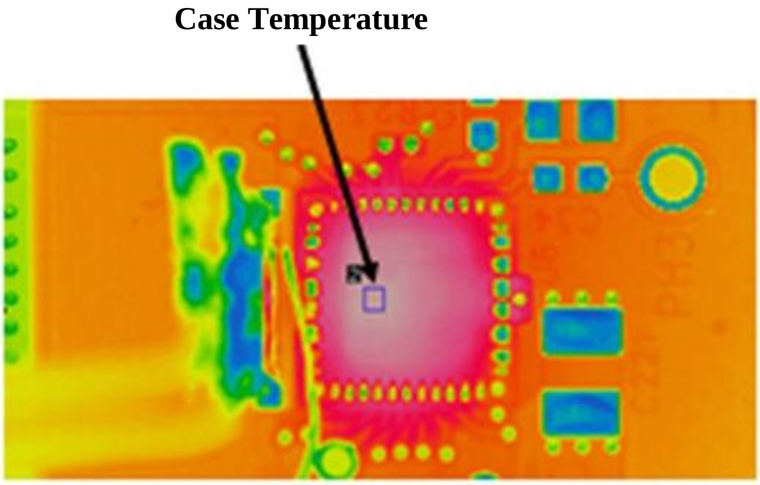

Figure 2.1 Case temperature measured by an IR camera

2.2 Numerical Approaches

Large extent of works was done on determination of junction temperature of semiconductor devices. Literatures used different kinds of mathematical modeling for solving heat conduction equation of thermal control system on PCB. All of the studies use heat conduction equation as stated in [10]. Ammous *et al*. [12] proposed thermal models needed for the electrothermal simulation of power electronic systems. It gives a useful analysis about the choice the thermal model circuit networks, equivalent to a discretization of heat conduction equation by the finite-difference method (FDM). In [12], it gives ideas about boundary conditions representations. FDM and Finite Element Method (FEM) were used to discretize heat conduction equation. It also assumes convection and radiation as negligible. Clemente [5] supports these ideas in a case of vertical power transistor (silicon die).

Many numerical approaches were implemented for solving heat conduction equations of thermal control systems on printed circuit board. In [14], multigrid method was implemented as a mathematical approach to solve problem (1). It is relevant to mention that Zarith *et al*. [14] used FDM to transform equation (1) into a system of linear equations. It states that iterative method is suitable to implement compared to direct method. It also mentions that multigrid method is able to solve system of linear equations faster. In [11], sequential algorithm of parabolic equation is used in solving thermal control process on PCB. The aim is to simulate parabolic equation by implementing sequential algorithm in solving thermal control systems. Numerical results obtained have proved that it is available to predict the thermal behavior using numerical approaches.

Many studies involving AM and its variants have been conducted in solving various scientific problems. In [15], AM method has been applied in solving large sparse system of linear equations. It states that, the AM method converges for systems with coefficient matrices that are symmetric positive definite or positive real or irreducible L-matrices with a strong diagonal dominance. It clearly mentioned that, the method is very suitable for parallel implementation on a multiprocessor system. It also states that the conditions which guarantee the convergence of AM iterative method. In [15], some numerical examples, where AM method is applied for solving an elliptic boundary value problem and initial-boundary value problem for the diffusion-convection equation are presented. In [18], new variant of AM method for solving large block tridiagonal linear systems have been introduced. The main concern of this study is to derive new variant of AM method that having a higher degree of parallelism within its structure. The performance of AM method was studied by solving algebraic systems which arise from the discretization of elliptic boundary value problems.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

First phase of the study is to understand the concept of heat conduction equation and derivation of it. Applying initial and boundary conditions are necessary in this phase. The next phase is to integrate heat conduction equation into silicon die. Here basic model of silicon die on PBC is needed to analyze. The next steps are to formulate and implement the AM method in solving finite-difference approximation equation generated from the heat conduction equation. After possessing working algorithm, final task will be to determine peak junction temperature of semiconductor device (IC die). Throughout this study, MatLab programming software will be used for the development of numerical algorithm and computer simulations. Overall it can be summarized briefly as in Figure 3.1.

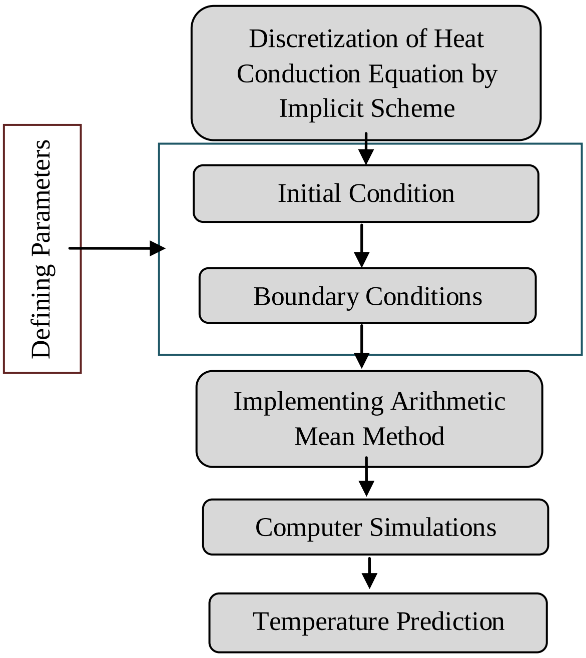

Figure 3.1 Methodology chart

3.2 Implicit Method (Backward Time Central Difference Space)

FDM proceeds by replacing derivatives in the differential equations by finite difference approximations. FDM is easy and efficient for implementation for lower orders and faster compared to FEM. It is suitable for analysis framework for this study. FDM can be extended to arbitrarily high order of accuracy. There are two sources of error in FDM i.e. round-off error (computer rounding of decimal quantities) and truncation error (difference between approximation and exact analytical solution). FDM can be used to discretize in space and/or in time.

In this study, FDM based on implicit scheme will be used to discretize the domain of problem (1). The domain in space is partitioned using a mesh $x_i=i\Delta x$ and domain in time $t_j=j\Delta t$. Uniform partition is considered both in space and time. Δx, Δt are the size of space and time subintervals, and x_i, t_j mesh points (endpoints) of the subintervals. The values of i and j are $0\leq i\leq n$ and $0\leq j\leq m$ respectively. The values of n and m will define the solution matrix. The following notation is used for simplicity:

$$T(x_i,t_j)=T_i^j \tag{4}$$

The grid spacing is:

$$\Delta x=\frac{L}{n}; \qquad \Delta t=\frac{t}{m} \tag{5}$$

where t is final elapsed time.

In implicit method for space derivative at position x_i second-order central difference is used. When at time t_{j+1} backward difference is used. The scheme is always convergent and stable [19]. The expected equation after discretizing problem (1) is:

$$\frac{T_i^{j+1}-T_i^j}{\Delta t}=\alpha\left(\frac{T_{i+1}^{j+1}-2T_i^{j+1}+T_{i-1}^{j+1}}{(\Delta x)^2}\right) \tag{6}$$

$$(1+2s)T_i^{j+1}-sT_{i-1}^{j+1}-sT_{i+1}^{j+1}=T_i^j \tag{7}$$

where $\alpha = \frac{K}{\rho c}$ (thermal diffusivity) and $s = \alpha \frac{\Delta t}{(\Delta x)^2}$

Applying forward finite difference for the LHS of temperature gradient in Eq. (2) we get

$$\frac{\partial T_0^j}{\partial x} = \frac{T_1^j - T_0^j}{\Delta x} \tag{8}$$

This yields to:

$$T_1^j = T_0^j + a\Delta x \tag{9}$$

where $a = -{P_{in}}/{SK}$

By using Equations (7) and (9) we get a system of linear equations which can be represented in matrix form as follows:

$$\begin{bmatrix} 1+s & -s & & & \\ -s & 1+2s & -s & & \\ & \ddots & \ddots & \ddots & \\ & & -s & 1+2s & -s \\ & & & -s & 1+2s \end{bmatrix} \begin{bmatrix} T_1^{j+1} \\ T_2^{j+1} \\ \vdots \\ T_{n-2}^{j+1} \\ T_{n-1}^{j+1} \end{bmatrix} = \begin{bmatrix} T_1^j - sa\Delta x \\ T_2^j \\ \vdots \\ T_{n-2}^j \\ T_{n-1}^j + ST_{in} \end{bmatrix} \tag{10}$$

or

$$AT = b \tag{11}$$

where A is a tridiagonal matrix, b is a given vector, and T denotes the unknown vector which needs to be determined.

One can use direct methods like explicit forward Euler method, implicit backward Euler method to solve Eq. (10). But there are drawbacks in terms of accuracy and computational time. Iterative methods improve the solution of Eq. (10) and are very useful for solving large and sparse systems. Iterative methods begin with an initial guess for the solution to the matrix equation. Each iteration updates the new k^{th} estimate T^k which converges on the exact solution T.

3.3 Arithmetic Mean method

To obtain accurate results, numerical methods have to use finest mesh grid. Hence, it will lead to large linear systems and can be problematic to solve as *n*, the order of linear systems increases. Thus, iterative AM method is one of the options for efficient solutions. This method has been proposed widely to be one of the feasible and successful types of numerical algorithms for solving any linear systems [15], [16]. The rate of convergence of AM method is relatively insensitive to the exact choice of the parameter ω [17]. The value of ω will be determined by implementing computer program (source code) and then choose one value of ω, where it's number of iterations is the smallest.

In this study, one of the two-stage methods, i.e., AM will be applied to solve the generated linear system (11). This will give a solution to problem (1). Essentially, each iteration of the AM method consists of solving two independent systems $T^{(1)}$and $T^{(2)}$. Now, let us consider matrix *A* that split into the form:

$$A = D + L + U \tag{12}$$

where *D, L* and *U* are diagonal, strictly lower triangular and strictly upper triangular matrices. Thus, the general scheme for AM method to solve linear system (11) is defined as [15], [16], [17]:

$$\left.\begin{aligned} &(D+\omega L)T^{(1)} = ((1-\omega)D-\omega U)T^{(k)} + \omega b \\ &(D+\omega U)T^{(2)} = ((1-\omega)D-\omega L)T^{(k)} + \omega b \\ &T^{(k+1)} = \frac{1}{2}(T^{(1)} + T^{(2)}) \end{aligned}\right\} \tag{13}$$

where *k* (*k=0,1,2,...,*) is the number of iterations, $T^{(0)}$ is an initial vector approximation to *T*, ω is an acceleration (relaxation) parameter, which is used to increase the convergence rate. Equation (13) is characterized by having within its overall mathematical structure certain well-defined substructures that can be executed simultaneously. This feature makes it ideally suited for implementation on a multiprocessor system with two or more vector processors; the lower triangular system and the upper triangular system in Equation (13) can be solved simultaneously on two different processors. The conditions for convergence of AM method are clearly stated in [15], [18].

CHAPTER 4

RESULTS & DISCUSSION

In this chapter, comparison between iterative methods, i.e., GS and AM is presented. Performance criteria such as computational time (CPU time), number of iterations and maximum junction temperature will be analyzed in both methods. MatLab R2012b has a built-in function 'pdepe' which can be used to solve initial-boundary value problems for parabolic-elliptic partial differential equations in one dimension. Both GS method and 'pdepe' function will act as control methods.

It is important to define initial-boundary conditions properly, as they affect the outcomes significantly. Initial condition corresponds to the case at time $t=0$. It is assumed to be $294K$, which is just room temperature. It is the temperature before component starts operating. Boundary conditions define the values of the problem at $x=0$ and $x=L$. Boundary conditions were defined in Eq. (2). $T(L,t)=T_{in}$ corresponds to the case at $x=L$, which is upper boundary of semiconductor device. The upper surface is considered to be the cooling boundary, where input temperature is assumed to be constant, $T_{in}=300.15K$. In this study, upper surface has Dirichlet boundary conditions. Power dissipation starts from the active IC die layer and flows up linearly along the x axes perpendicular to the silicon surface S. The lower boundary at $x=0$ is considered to be Neumann boundary conditions, where temperature gradient exists. Therefore, this study presents mixed boundary conditions.

The value of initial datum, $T^{(0)}$ is set to be zero for both GS and AM methods and experimental values of ω for AM method are chosen within ±0.1 to be an optimal value by a trial and error process. All simulations described in this study are performed using on a PC with Intel(R) Core(TM) i3-2328M CPU @ (2.20 GHz 2.20 GHz.) and with a system type of 32-bit, 2.60GB RAM.

Input parameters *L=550e-4cm*, *S=0.1cm*^{2}, *pc=1.63J/(Kcm*^{3}*)*, *K(thermal conductivity)=1.54 W/(cm K)* and *Pin=200 W* respectively. To get a better idea of temperature prediction, several values for elapsed time were used, *t=2e-3*, *t=6e-3* and *t=10e-3* seconds.

Results of numerical simulations, which were obtained from implementations of iterative methods, have been recorded in Tables 1, 2 and 3 respectively. Each table is recorded for each value of elapsed time. The stopping criterion used for GS and AM methods was ε, such that

$$\left|T^{(k+1)} - T^{(k)}\right| \le \varepsilon \qquad (14)$$

where ε*=1.0e-10*.

Table 1a. Number of iterations for *t=2ms*

Number of iterations					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	12155	45725	99891	173960	211122
AM	4322 (ω=1.6)	10462 (ω=1.8)	18881 (ω=1.8)	27746 (ω=1.9)	36920 (ω=1.9)

Table 1b. Computational time for *t=2ms*

CPU time (seconds)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	0.873	1.848	4.676	10.138	12.376
AM	0.493	1.293	2.334	3.587	4.848

Table 1c. Maximum temperature at *t=2ms*

Maximum temperature (K)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	355.7851	356.5180	356.7612	356.8826	356.9554
AM	355.7851	356.5180	356.7612	356.8826	356.9554
'pdepe'	357.5525	357.5523	357.5435	357.5460	357.5539

Table 2a. Number of iterations for *t=6ms*

Number of iterations					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	31506	120789	264487	388332	573252
AM	8915 (ω=1.7)	22635 (ω=1.9)	37943 (ω=1.9)	55476 (ω=1.9)	75428 (ω=1.9)

Table 2b. Computational time for *t=6ms*

CPU time (seconds)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	1.103	4.642	12.875	21.242	27.356
AM	1.094	2.564	4.636	6.740	9.767

Table 2c. Maximum temperature at $t=6ms$

Maximum temperature (K)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	368.5538	369.6896	370.0674	370.2562	370.3694
AM	368.5538	369.6896	370.0674	370.2562	370.3694
'pdepe'	370.9317	370.9455	370.9221	370.9241	370.9451

Table 3a. Number of iterations for $t=10ms$

Number of iterations					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	46424	178336	329889	450078	506660
AM	11457 (ω=1.8)	29839 (ω=1.9)	50575 (ω=1.9)	75013 (ω=1.9)	103400 (ω=1.9)

Table 3b. Computational time for $t=10ms$

CPU time (seconds)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	1.545	6.948	18.318	22.347	27.012
AM	1.271	3.328	6.147	9.164	13.342

Table 3c. Maximum temperature at *t=10ms*

Maximum temperature (K)					
Method	***n***				
	30	**60**	**90**	**120**	**150**
GS	369.1622	370.3479	370.7430	370.9406	371.0591
AM	369.1622	370.3479	370.7430	370.9406	371.0591
'pdepe'	371.5474	371.5452	371.5507	371.5497	371.5454

Figures below show temperature profile for each value of elapsed time, with *n=30; 60; 90; 120; 150*.

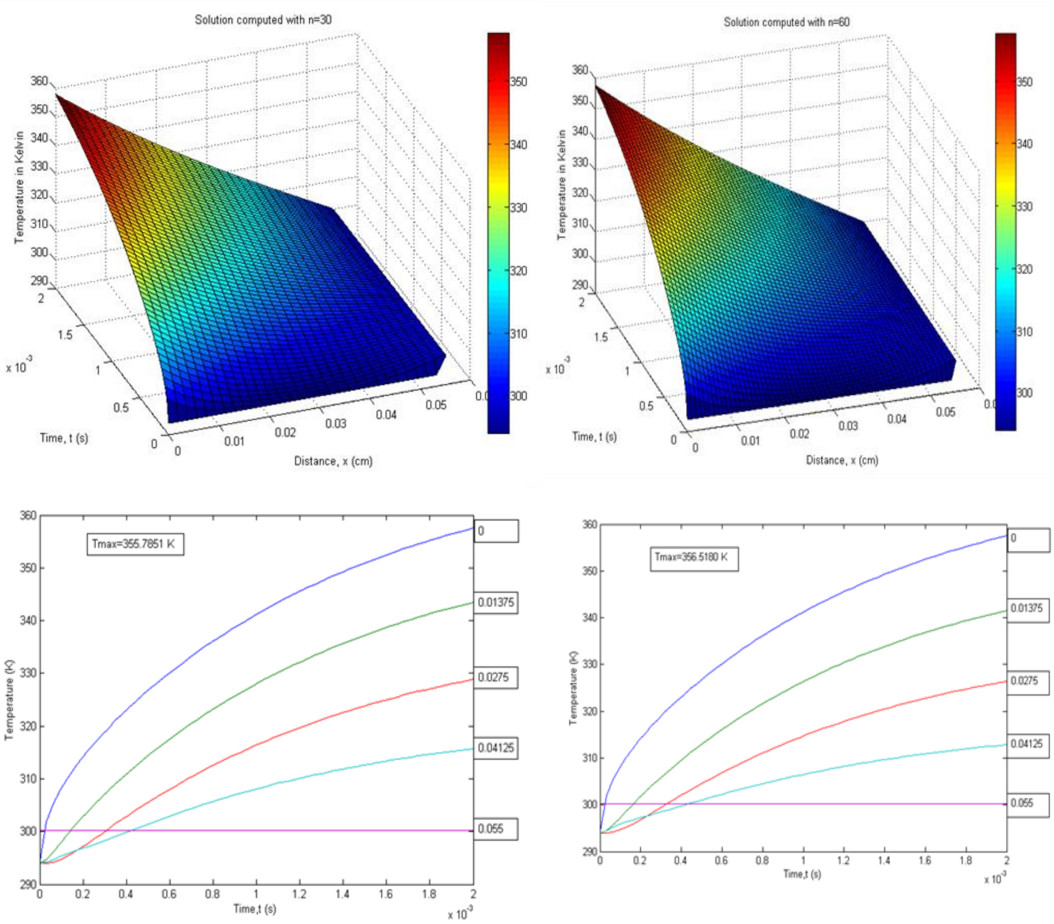

Figure 4.1 Temperature profile for *n*=30 and 60, at *t*=2ms

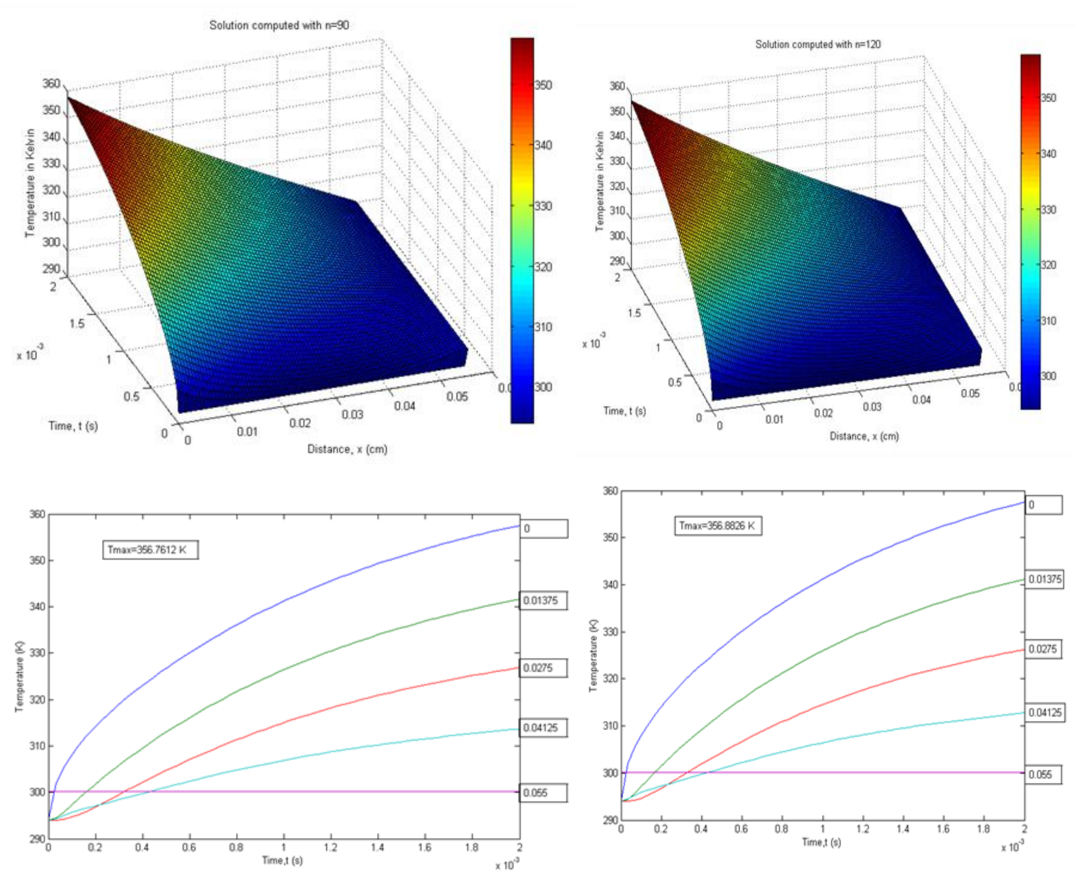

Figure 4.2 Temperature profile for *n*=90 and 120, at *t*=2ms

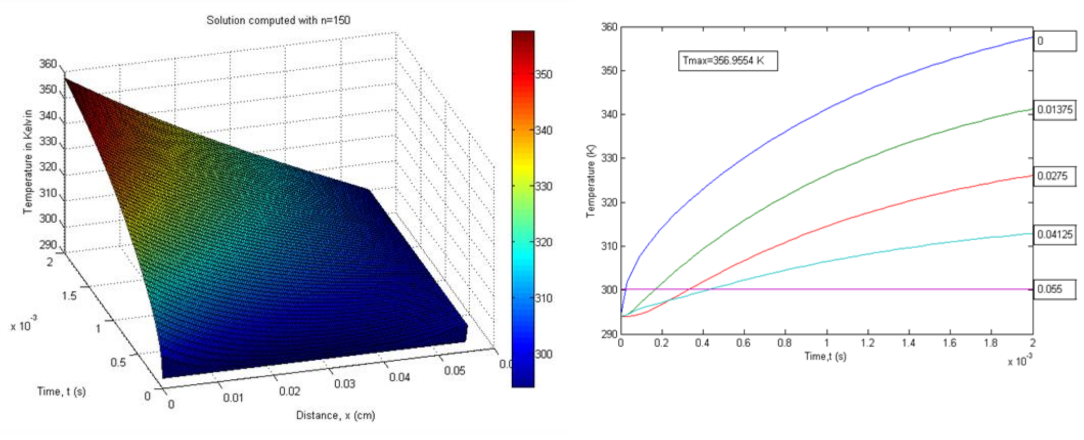

Figure 4.3 Temperature profile for *n*=150, at *t*=2ms

One can observe the thermal behavior within a semiconductor device (IC die). Note that the red region is the hottest temperature along a die. Temperature with respect to time graphs clearly shows that the temperature is still rising for *t=2ms*. These graphs follow parabolic pattern. Observe that for a case when $x=L$ temperature is constant, whereas within semiconductor for specified distances temperature is rising.

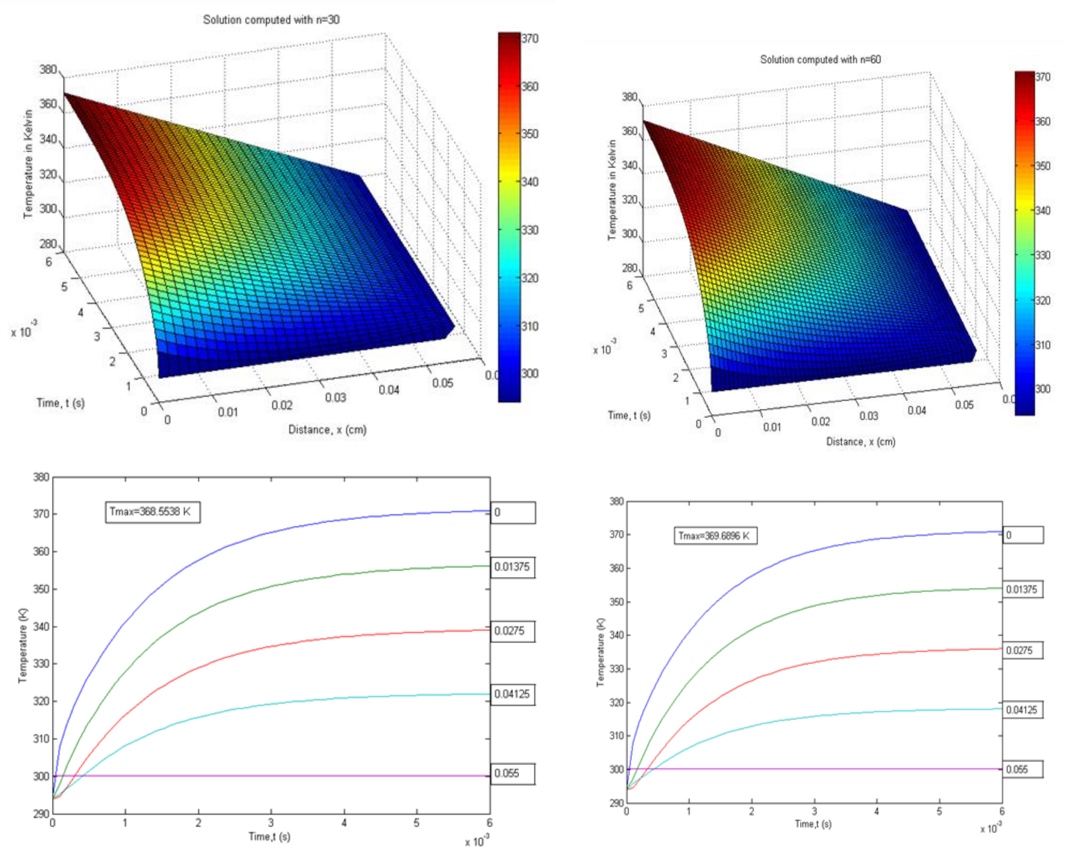

Figure 4.4 Temperature profile for *n*=30 and 60, at *t*=6ms

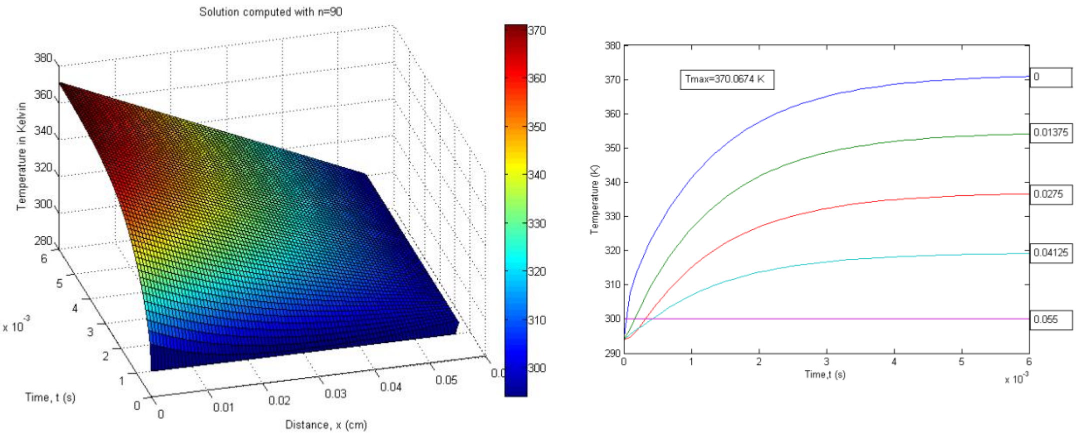

Figure 4.5 Temperature profile for *n*=90, at *t*=6ms

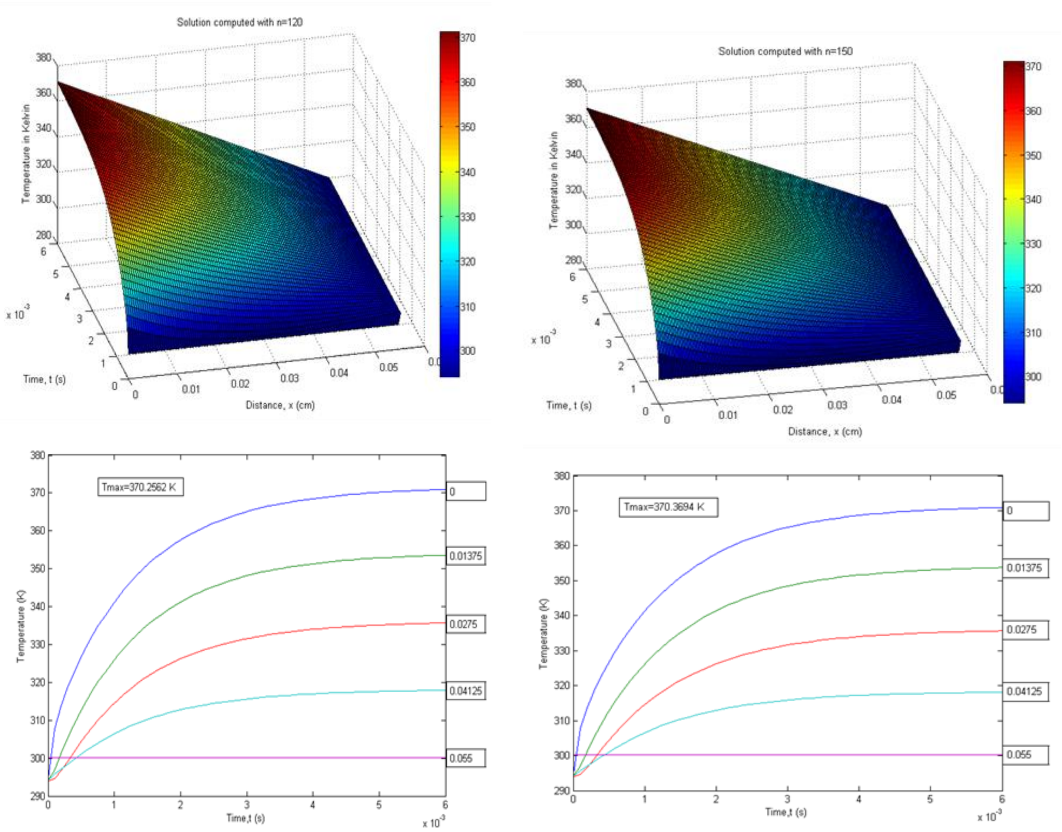

Figure 4.6 Temperature profile for *n*=120 and 150, at *t*=6ms

As an elapsed time increases (*t=6ms*) temperature within a semiconductor starts to be constant. The value of maximum temperature and the area of hot region are bigger compared to the case at *t=2ms*.

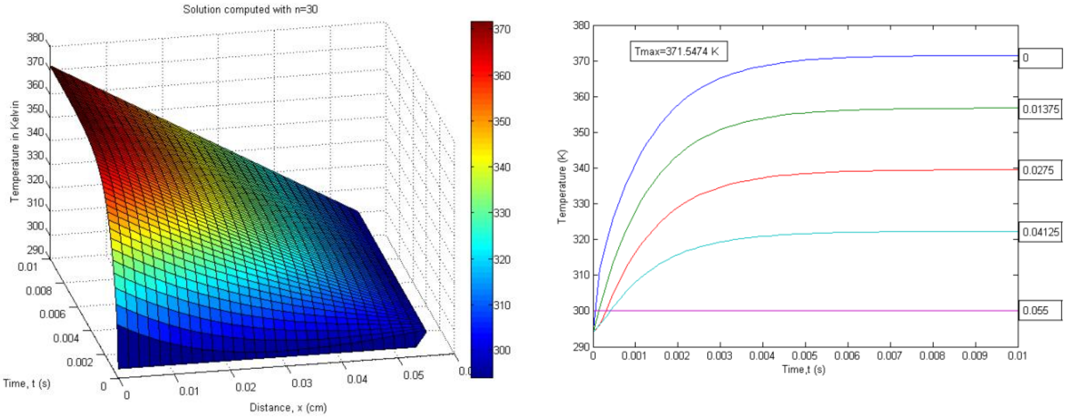

Figure 4.7 Temperature profile for *n*=30, at *t*=10ms

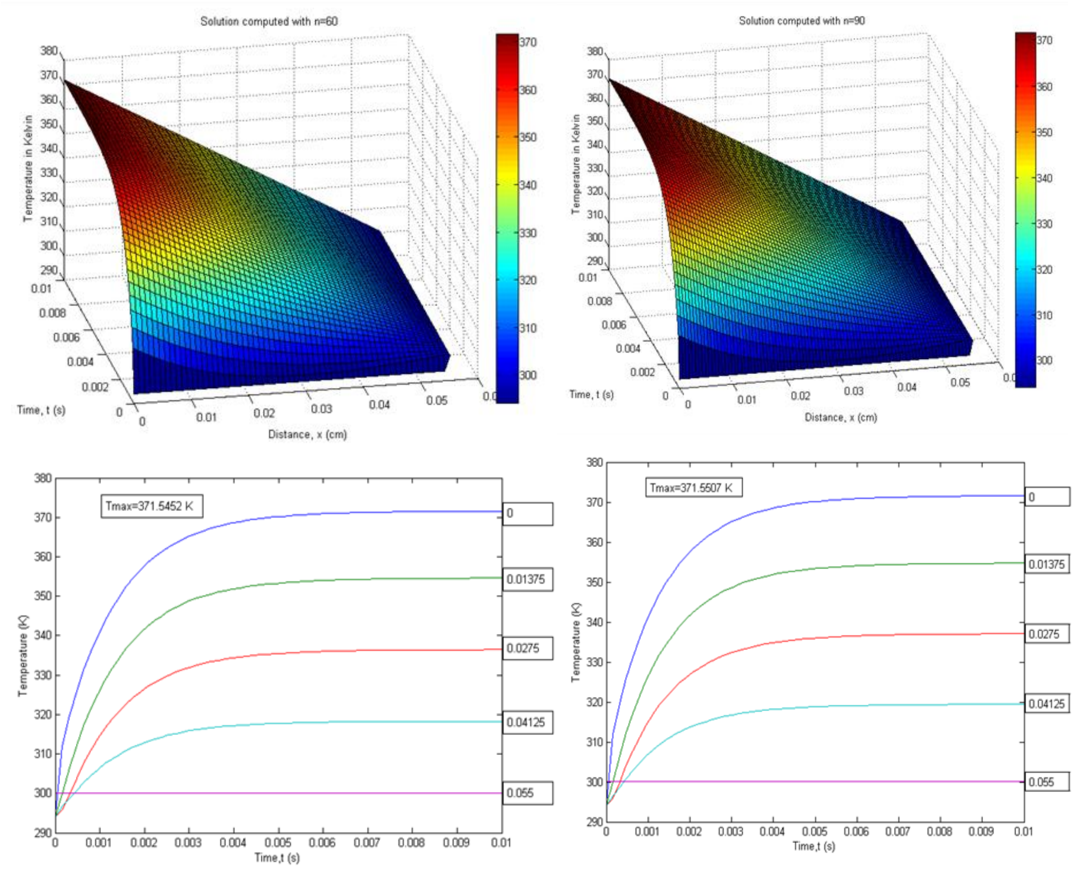

Figure 4.8 Temperature profile for *n*=60 and 90, at *t*=10ms

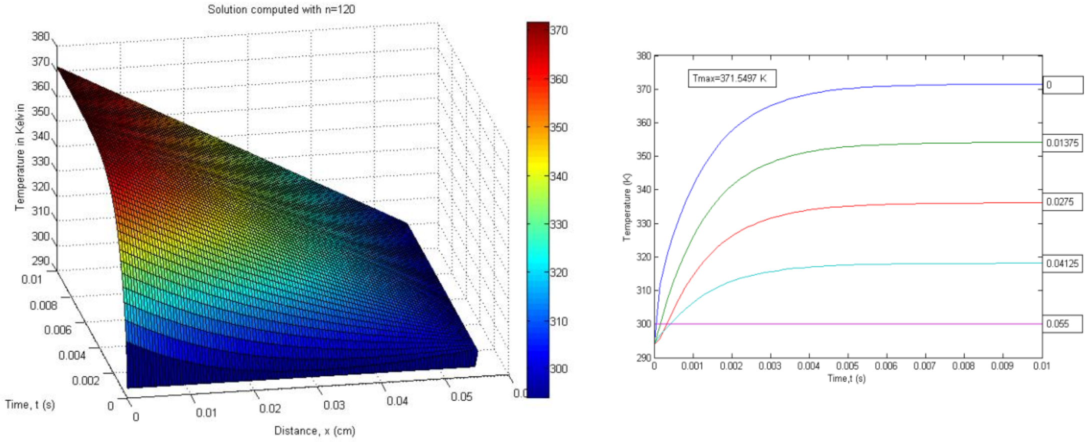

Figure 4.9 Temperature profile for *n*=120, at *t*=10ms

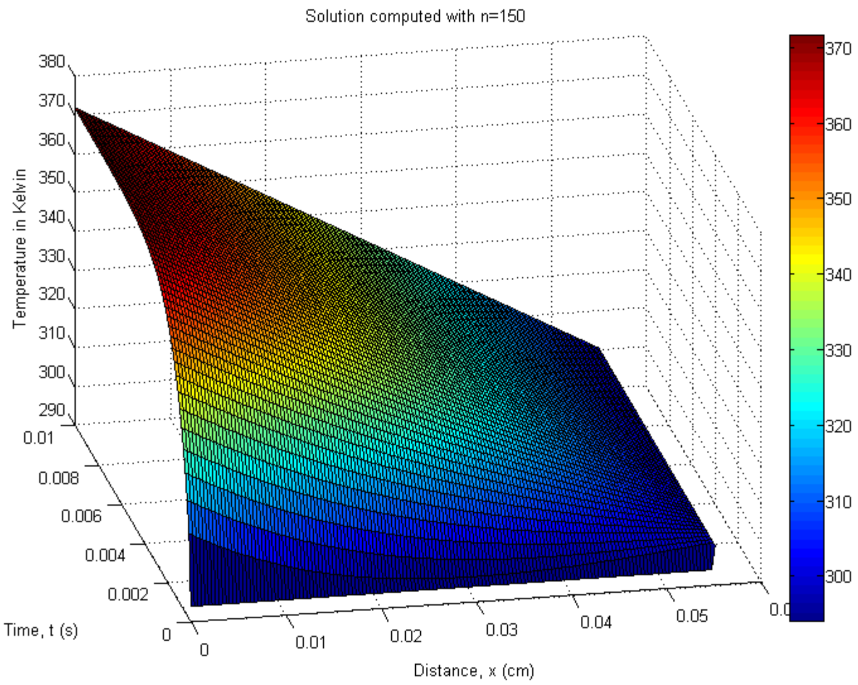

Figure 4.10 Temperature distribution for *n*=150, at *t*=10ms

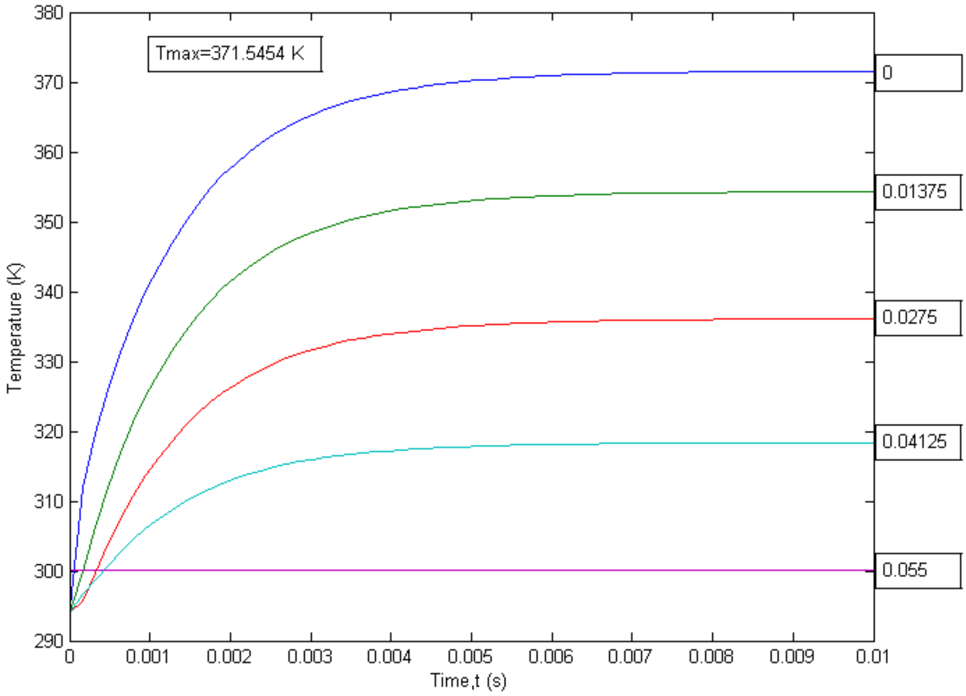

Figure 4.11 Temperature with respect to time for *n*=150,
with defined distance along IC die, at *t*=10ms

By observing Figure 4.11, note that after elapsed time *t=10ms* the temperature remains constant; the maximum temperature has been achieved. Hence, computed maximum junction or IC die temperature is:

Tmax=371.5454 Kelvin or *Tmax=97.9091 Celsius*

From Tables 1, 2, 3 it is clear to see that as the size of mesh grid *n* increases we get closer values to the exact solution. Through the observation in Table 1, by using AM method number of iterations are decreased by *64.44-84.05%* and computational time is decreased by *43.52-60.83%* respectively compared to GS method. For the Table 2, number of iterations are decreased by *71.7-85.7%* and computational time is decreased by *0.82-69%*. Lastly for the Table 3, number of iterations and computational time are decreased by *75-84%* and *17.7-66.4%* respectively. The decrement percentages of the number of iterations and execution time for AM method compared with the GS method are summarized in Table 4.

Table 4. Decrement percentages of the number of iterations and execution time for AM method compared with the GS method

Elapsed time (milliseconds)	**Method**	**Number of iterations (%)**	**CPU time (%)**
t=2	AM	64.44-84.05	43.52-60.83
t=6	AM	71.7-85.7	0.82-69
t=10	AM	75-84	17.7-66.4

To sum up AM method is more superior in terms of number of iterations and computational time compared to the GS method.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this study numerical techniques were used to present temperature behavior of semiconductor device, more precisely temperature of IC die. Implicit method was used for discretization of heat conduction equation. Two iterative techniques, i.e., GS and AM were studied and implemented to get the solution of temperature profile arisen from system of linear equations. Numerical results of computational time, number of iterations and maximum junction temperature were recorded. The results are identified to be acceptable since average operating junction temperature of component IC die is between *80* and *120* Celsius. Through numerical results obtained from Tables 1, 2, 3 and 4, it clearly shows that by applying AM method can reduce number of iterations and execution time. Overall, AM method is more superior compared to GS method. The purpose of this study was to improve the confidence level of the design, and at the same time reduce time and energy consumed for real experimental procedures in actual process. One dimensional parabolic partial heat conduction equation had been proved that it can be applied in predicting the temperature profile for electronic devices.

For the future works, this study can be extended to investigate the actual IC die temperature of semiconductor device. This can be achieved by measuring case temperature of a component and get a close approximate value to the actual junction temperature. The actual die temperature can be compared with the results obtained from AM method, and maximum absolute error values can be presented.

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