Bulletin of Faculty of Science, Zagazig University (BFSZU)
e-ISSN: 1110-1555
Volume-2023, Issue-2, pp-147-163
https://bfszu.journals.ekb.eg/journal
Research Paper DOI:10.21608/bfszu.2022.173023.1200

Photomechanical and Thermal Wave Responses of a Two-Temperature Semiconductor Model with Moisture Diffusivity Process

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ABSTRACT : **In the context of the two-temperature thermoelasticity theory, a novel mathematical-physical model is introduced that describes the influence of moisture diffusivity in the semiconductor material. The Two-dimensional (2D) Cartesian coordinate is used to study the coupled between the thermo-elastic, plasma waves, and Moisture Diffusivity. Dimensionless quantities are the main physical fields in the Laplace transform domain. For the unknown variables, some conditions are applied at the free surface of the medium according to two temperature theory, to get the main quantities analytically. The Laplace transform technique has been applied with some numerical approximations in the time domain to obtain the exact expressions of the main physical fields. Due to the effects of the two temperature parameter, numerical results of silicon material have been introduced. The impacts of thermoelectric, thermoelastic, and reference moisture parameters have been discussed graphically.**

Date of Submission: 08-11-2022 Date of acceptance:01-12-2022

Keywords: Photothermal theory; Two temperature; moisture diffusivity; Thermoelasticity; Harmonic Wave; reference moisture.

1. Introduction

The spread of particles of one substance through those of another is called diffusion. Diffusion is the process by which concentrated liquids disperse when placed in water and by which odors disperse through the air. When particles disperse from places of high concentration, where there are many, to areas of low concentration, where there are fewer, diffusion occurs naturally.

The interdependence of moisture, heat, and deformation can be visualised in many engineering problems of practical interest.. Mechanically applied additional stresses can significantly alter temperature and moisture distribution. As a result, there is a need to shed light on the connection between mechanical deformation and diffusion caused by temperature and moisture.

Lord and Shulman [1] suggested a generalised thermoelasticity theory that replaces the classical Fourier law with a modified Fourier law that includes relaxation time parameters and heat flux vectors. Green and Lindsay [2] proposed another generalisation of thermoelasticity in which governing equations were restricted using the entropy inequality. Sherief et al. [3] derived the equations for generalised thermoelasticity in an anisotropic medium as well as the variational principle for governing equations. Green and Nagdhi [4-6] proposed a new theory for thermal wave propagation that includes energy dissipation. P.Chen [7–9] developed the two-temperature theory of thermoelasticity depending upon conductive temperature (φ) and thermodynamic temperature (T) involving two temperature parameter (a). If (a) tends to zero, this theory transformed into the classical theory of heat conduction. . Youssef [11] has developed a new model of generalized thermoelasticity that depends on two temperatures, T and φ , where the difference between the two temperatures is proportional to the heat supply $\ddot{\varphi}_{ii}$ with a nonnegative constant a. Within the Dual Phase Lag (DPL) model framework, Ezzat et al [12] built a two-temperature magneto thermoelastic fractional order model. The temperature rate dependent two temperature thermoelastic theory was developed by Shivay and Mukhopahyay [13]. (TRDTT). This theory is based on the temperature rate dependence of conductive and thermodynamic temperature. [14] investigated the effect of two temperatures on wave thermomechanical loading to derive the thermodynamic and conductive temperature expressions. Abouelregal et al [15] Introduce A new thermoelasticity model based on fractional calculus in combination with Fourier's law of heat, and dual temperature theory is presented, including the Moore-Gibson-Thomson equation.

Sharma et al. [16] investigated the Rayleigh wave propagation in an isotropic thermo-diffusive elastic half-plane.Aouadi [17] investigated the stability implications of a non-simple thermoelastic diffusive problem.

Lotfy and Hassan [18] used normal mode analysis to studying the two temperature theory in generalized thermoelasticity with rotation under thermal shock problem. Kumar and Gupta [19] used the harmonic wave solution to generate three coupled dilatational waves in the context of the Dual Phase Lag Diffusion (DPLD) model. Kumar and Kansal [20-22] investigated the Rayleigh wave progression in a thermoelastic half-plane with mass diffusion. The frequency equation of Rayleigh surface waves with mass diffusion in an isotropic thermodiffusive half-plane was developed by Kumar and Gupta [23]. We will obtain a solution in the Fourier-transformed domain using the normal mode analysis technique. To use the normal mode analysis, we must first assume that all of the relationships are sufficiently smooth on the real axis for the normal mode analysis of all of these functions to be possible. The exact expression for the temperature distribution, thermal stresses, and displacement components was obtained using the normal mode analysis [24-30]. Youssef and El-Bary [31] investigated various problems using two-temperature thermoelasticity with relaxation times and demonstrated that the results obtained are qualitatively different from those obtained using one temperature thermoelasticity.

This article uses a moisture diffusivity model In the context of Two Temperature theory, to investigate wave propagation in a photo-thermoelasticity semiconductor medium under the influence of moisture. The problem is solved in two dimensions using thermo-elasticity and moisture diffusivity during a photothermal transport process at the semi-infinite semiconducting medium's free surface

Finally, numerical computations of carrier density, normal force stress, moisture concentration, normal displacement, and temperature distribution were created and graphically depicted

2. Basic Equations

Assuming thermo-elastic semiconductor material has linear elastic properties and is transversely anisotropic homogeneous. The medium is examined during the photothermal transport phase, considering the overlap between plasma-thermal and moisture diffusion.

In this problem, the main four distributions are the carrier density (intensity) $N(r_i,t)$, moisture concentration $m(r_i,t)$, the temperature change of a material particle $T(r_i,t)$, and the displacement vector $u(r_i,t)$ (r_i represents the position vector and t represents the time).

The connection between plasma-thermal-elastic wave and moisture diffusion equations can be expressed in tensor form [32–34]:

$$\frac{\partial N(r_i,t)}{\partial t} = D_E N_{,ii}(r_i,t) - \frac{N(r_i,t)}{\tau} + \kappa\, T(r_i,t), \tag{1}$$

$$\rho C_e\left(D_T \phi_{,ii}(r_i,t) + D_T^m m_{,ii}(r_i,t)\right) = \rho C_e \frac{\partial \mathrm{T}(r_i,t)}{\partial t} - \frac{E_g}{\tau} N(r_i,t) + \gamma_t T_0 \frac{\partial u_{i,j}(r_i,t)}{\partial t}, \tag{2}$$

$$k_m\left(D_m\, m_{,ii}(r_i,t) + D_m^T T_{,ii}(r_i,t)\right) = k_m \frac{\partial m(r_i,t)}{\partial t} - \frac{E_g}{\tau} N(r_i,t) + \gamma_m m_0 D_m \frac{\partial u_{i,j}(r_i,t)}{\partial t}, \tag{3}$$

The motion equation as follow:

$$\rho \frac{\partial^2 u_i(r_i,t)}{\partial t^2} = \sigma_{ij,j} \,. \tag{4}$$

The equation for the tensor of displacement and strain can be written as follows:

$$\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}) \,. \tag{5}$$

According to two-temperature theory, the relationship between the heat conduction temperature and the thermodynamical heat temperature can be written as follows.:

$$\phi - T = a\,\phi_{,ii} \,. \tag{6}$$

Where a is a positive constant (selected), it is known as the two-temperature parameter.
The tensor form of stress-displacement-plasma-temperature with moisture concentration is as follows:

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl} - \beta_{ij}(\alpha_t T + d_n N) - \beta_{ij}^m\, m, \quad i,j,k,l = 1,2,3 \,. \tag{7}$$

Where D_T expresses temperature diffusivity D_m is the diffusion coefficient of moisture, D_T^m and D_m^T are coupled diffusivities, D_E is the carrier diffusion coefficient, m_0 reference moisture, k_m moisture diffusivity, C_{ijkl} represents the isothermal parameters tensor of an elastic medium, ε_{kl} is the strain tensor, β_{ij} and β_{ij}^m are the isothermal thermo-elastic coupling tensor material coefficient of moisture concentration respectively. The parameter of non-zero thermal activation coupling $\kappa = \frac{\partial N_0}{\partial T}\frac{T}{\tau}$, N_0 represents the equilibrium carrier concentration [33, 35]. In the case of relatively low Temperatures κ is neglected. On the other hand, in the general case, the problem is discussed when the thermal activation coupling parameter is zero.

The constants $E_g, \rho., \tau, \lambda, \mu,$ and T_0 are known as the energy gap of the semiconductor, the photogenerated carrier lifetime, the density, Lame's elastic constants, and the absolute temperature, respectively.

Also, $\gamma_t = (3\lambda + 2\mu)\alpha_T$ is the volume thermal expansion, α_T the linear thermal expansion coefficient, C_e the solid plate specific heat coefficient at constant strain, and δ_n the difference between conductive deformation potential and valence band.
The physical quantities can be defined in 2D as follows:

$$\frac{\partial N}{\partial t} = D_E \nabla^2 N - \frac{N}{\tau} + \kappa\, T \,, \tag{8}$$

$$\rho C_e \left(D_T \nabla^2 \phi + D_T^m \nabla^2 m \right) = \rho C_e \frac{\partial \mathrm{T}}{\partial t} - \frac{E_g}{\tau} N + \gamma_t T_0 \frac{\partial}{\partial t}\left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \right), \tag{9}$$

$$k_m \left(D_m \nabla^2 m + D_m^T \nabla^2 T \right) = k_m \frac{\partial m}{\partial t} - \frac{E_g}{\tau} N + \gamma_m m_0 D_m \frac{\partial}{\partial t}\left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \right). \tag{10}$$

The equation (4) became

$$\rho \frac{\partial^2 u}{\partial t^2} = (2\mu + \lambda)\frac{\partial^2 u}{\partial x^2} + \mu \frac{\partial^2 u}{\partial z^2} - \gamma_t \frac{\partial T}{\partial x} - \delta_n \frac{\partial N}{\partial x} - \gamma_m \frac{\partial m}{\partial x}, \tag{11}$$

$$\rho \frac{\partial^2 w}{\partial t^2} = (2\mu + \lambda)\frac{\partial^2 w}{\partial z^2} + \mu \frac{\partial^2 w}{\partial x^2} - \gamma_t \frac{\partial T}{\partial z} - \delta_n \frac{\partial N}{\partial z} - \gamma_m \frac{\partial m}{\partial z} \tag{12}$$

Where $\gamma_{t,m} = \beta\, \alpha_{m,T}$ and $\delta_n = \beta d_n, \beta = 3\mu + 2\lambda, \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}$.

The two-temperature equation (7) takes as follows:

$$\phi - T = a \nabla^2 \phi \,. \tag{13}$$

The constitutive equation in 2D takes the following form:

$$\sigma_{xx}=(2\mu+\lambda)\frac{\partial u}{\partial x}+\lambda\frac{\partial w}{\partial z}-\beta(\alpha_t T+d_n N)-\gamma_m m\ , \tag{14}$$

$$\sigma_{zz}=(2\mu+\lambda)\frac{\partial w}{\partial z}+\lambda\frac{\partial u}{\partial x}-\beta(\alpha_t T+d_n N)-\gamma_m m\ , \tag{15}$$

$$\sigma_{xz}=\mu(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x})-\gamma_m m\ . \tag{16}$$

3. Mathematical Formulation of the Problem

We can insert, in the non-dimensional form, two scalar potential functions $u=\frac{\partial \Pi}{\partial x}+\frac{\partial \Psi}{\partial z}$ and $w=\frac{\partial \Pi}{\partial z}-\frac{\partial \Psi}{\partial x}$

For more simplicity, the following non-dimensional variants are introduced:

$$(x',z',u',w')=\frac{(x,z,u,w)}{C_T t^*},t'=\frac{t}{t^*},((T',\phi'),N')=\frac{(\gamma_t(T,\phi),\delta_n N)}{2\mu+\lambda},\sigma'=\frac{\sigma}{\mu},e'=e,m'=m. \tag{17}$$

The dashed is dropped for convenience in equations (8)- (15)and (16) by using (17), then we have:

$$(\nabla^2-q_1-q_2\frac{\partial}{\partial t})N+\varepsilon_3 T=0\ , \tag{18}$$

$$\nabla^2\phi-a_1\frac{\partial}{\partial t}T+a_2\nabla^2 m+a_3 N-\varepsilon_1\frac{\partial}{\partial t}\nabla^2\Pi=0\ , \tag{19}$$

$$\left(\nabla^2-a_4\frac{\partial}{\partial t}\right)m+a_5\nabla^2 T+a_6 N-a_7\nabla^2\Pi=0\ , \tag{20}$$

$$\left(\nabla^2-\frac{\partial^2}{\partial t^2}\right)\Pi-T-N-a_8 m=0, \tag{21}$$

$$\left\{\nabla^2-\alpha\frac{\partial^2}{\partial t^2}\right\}\Psi=0, \tag{22}$$

$$\phi-T=\alpha_6\nabla^2\phi. \tag{23}$$

in the non-dimensional ,The stress component takes the following form:

$$\sigma_{xx}=a_9\frac{\partial^2\Pi}{\partial x^2}+a_{10}\frac{\partial^2\Pi}{\partial z^2}+2\frac{\partial^2\Psi}{\partial z\partial x}-a_9\left(T+N\right)-a_{11}m, \tag{24}$$

$$\sigma_{zz}=a_9\frac{\partial^2\Pi}{\partial z^2}+a_{10}\frac{\partial^2\Pi}{\partial x^2}-2\frac{\partial^2\Psi}{\partial z\partial x}-a_9\left(T+N\right)-a_{11}m, \tag{25}$$

$$\sigma_{xz}=\frac{\partial^2\Psi}{\partial z^2}+2\frac{\partial^2\Pi}{\partial x\partial z}-\frac{\partial^2\Psi}{\partial x^2}. \tag{26}$$

Where

$$q_1=\frac{kt^*}{D_E\rho\tau C_e}\ ,\quad q_2=\frac{k}{D_E\rho C_e},\ a_1=\frac{C_T^2 t^*}{D_T}\ ,$$

$$a_2=\frac{D_T^m\gamma_t}{D_T(2\mu+\lambda)},\ \varepsilon_2=\frac{\alpha_T E_g t^*}{\tau d_n\rho C_e},\ a_3=\varepsilon_2 a_1\ \ \varepsilon_1=\frac{\gamma_t^2 T_0 t^*}{k\rho}$$

$$,\ a_4=\frac{C_T^2 t^*}{D_m},\ a_5=\frac{D_m^T(2\mu+\lambda)}{D_m\gamma_t},\ a_6=\frac{E_g(2\mu+\lambda)t^* a_4}{k_m\delta_n\tau},\ a_7=\frac{\gamma_m m_0 C_T^2 t^*}{k_m},\ a_8=\frac{\gamma_m}{2\mu+\lambda}$$

$$\varepsilon_3 = \frac{d_n k\kappa t^*}{\alpha_T \rho C_e D_E}$$

$$, \; a_9 = \frac{2\mu+\lambda}{\mu}, \; a_{10} = \frac{\lambda}{\mu}, C_T^2 = \frac{2\mu+\lambda}{\rho}, \; \delta_n = (2\mu+3\lambda)d_n, \; t^* = \frac{k}{\rho C_e C_T^2} \; a_{11} = \frac{\gamma_m}{\mu},$$

$$\alpha_6 = \frac{a}{t^{*2}C_T^2}, \alpha = \frac{K}{\mu C_e} \; .$$

where ε_1, ε_2 ,and ε_3 can be called the thermoelastic coupling parameter, the thermo-energy coupling parameter, and the thermoelectric coupling parameter, respectively.

4. Harmonic wave analysis

The main physical fields' 2D solutions, which can be formed for any function, are decomposed using the harmonic wave technique (normal mode analysis). In the following form:

$$G(x,z,t) = \bar{G}(x)\exp(\omega t + ibz) \; . \tag{27}$$

Where the quantity $\bar{G}(x)$ is the amplitude of the main physical field $G(x,z,t)$, $i = \sqrt{1}$ ω presents the complex time frequency, and expresses b the wave number in the z-direction. Using the normal mode method, which is defined in equation (27) and applied to equations(18)-(26), yields:

$$(D^2 - \alpha_1)\bar{N} + \varepsilon_3 \bar{T} = 0, \tag{28}$$

$$(D^2 - b^2)\bar{\phi} - \alpha_2 \bar{T} + a_2(D^2 - b^2)\bar{m} + a_3 \bar{N} - \alpha_3 (D^2 - b^2)\bar{\Pi} = 0, \tag{29}$$

$$\left(D^2 - \alpha_4\right)\bar{m} + a_5(D^2 - b^2)\bar{T} + a_6 \bar{N} - \alpha_5 (D^2 - b^2)\bar{\Pi} = 0, \tag{30}$$

$$(D^2 - \alpha_6)\bar{\Pi} - \bar{T} - \bar{N} - a_8 \bar{m} = 0, \tag{31}$$

$$(D^2 - \alpha_7)\bar{\phi} + \beta\bar{T} = 0, \tag{32}$$

$$\left\{D^2 - \alpha_8\right\}\bar{\Psi} = 0, \tag{33}$$

$$\bar{\sigma}_{xx} = \left(a_9 D^2 - a_{10} b^2\right)\bar{\Pi} + 2ibD\bar{\Psi} - a_9\left(\bar{T} + \bar{N}\right) - a_{11}\bar{m}, \tag{34}$$

$$\bar{\sigma}_{zz} = \left(a_{10} D^2 - a_9 b^2\right)\bar{\Pi} - 2ibD\bar{\Psi} - a_9\left(\bar{T} + \bar{N}\right) - a_{11}\bar{m}, \tag{35}$$

$$\bar{\sigma}_{xz} = -(D^2 - b^2)\bar{\Psi} + 2ibD\bar{\Pi} \; . \tag{36}$$

Where, $D = \frac{d}{dx}$, $\alpha_1 = b^2 + q_1 + q_2\omega$, $\alpha_2 = a_1\omega$, $\alpha_3 = \omega\varepsilon_1$, $\alpha_4 = a_4\omega + b^2$, $\alpha_5 = a_7\omega, \alpha_6 = b^2 + \omega^2, \alpha_7 = b^2 + \beta \; \beta = \frac{1}{a^*}$.

Eliminating $\bar{\phi}, \bar{T}, \bar{\Pi}, \bar{N}$ and $\bar{m}$ between equations (28)-(31), and (32) yields:

$$(D^{10} - \Theta_1 D^8 + \Theta_2 D^6 - \Theta_3 D^4 + \Theta_4 D^2 - \Theta_5)\left\{\bar{\phi}, \bar{m}, \bar{N}, \bar{T}, \bar{\Pi}\right\}(x)e^{(\omega t + ibz)} = 0 \; . \tag{37}$$

Where,

$$\Theta_1 = \frac{(-2b^2 a_2 a_5 - a_2 a_5 \alpha_1 - a_2 a_5 \alpha_6 - a_2 a_5 \alpha_7 - a_5 a_8 \alpha_3 - a_2 \alpha_5 + \beta + \alpha_2 + \alpha_3)}{(-a_2 a_5)},$$

$$\Theta_2=\frac{1}{(a_2a_5)}\left\{\begin{array}{l} b^4a_2a_5+2b^2a_2a_5\alpha_1+2b^2a_2a_5\alpha_6+2b^2a_2a_5\alpha_7+2b^2a_5a_8\alpha_3+2b^2a_2\alpha_5+\\ a_2a_5\alpha_1\alpha_6+a_2a_5\alpha_1\alpha_7+a_2a_5\alpha_6\alpha_7+a_5a_8\alpha_1\alpha_3+a_5a_8\alpha_3\alpha_7\\ -b^2\beta-b^2\alpha_3-\beta a_8\alpha_5-a_2a_7\varepsilon_3+a_2\alpha_1\alpha_5+a_2\alpha_5\alpha_7+a_2\alpha_5\varepsilon_3-a_8\alpha_2\alpha_5\\ -\beta\alpha_1-\beta\alpha_4-\beta\alpha_6+a_3\varepsilon_3-\alpha_1\alpha_2-\alpha_1\alpha_3-\alpha_2\alpha_4-\alpha_2\alpha_6-\alpha_2\alpha_7-\alpha_3\alpha_4-\alpha_3\alpha_7-\alpha_3\varepsilon_3 \end{array}\right\},$$

$$\Theta_3=\frac{-1}{(a_2a_5)}\left\{\begin{array}{l} -b^4a_2a_5\alpha_1-b^4a_2a_5\alpha_6-b^4a_2a_5\alpha_7-b^4a_5a_8\alpha_3-b^4a_2\alpha_5-2b^2a_2a_5\alpha_1\alpha_6-\\ 2b^2a_2a_5\alpha_1\alpha_7-2b^2a_2a_5\alpha_6\alpha_7-2b^2a_5a_8\alpha_1\alpha_3-2b^2a_5a_8\alpha_3\alpha_7+2b^2\beta a_8\alpha_5\\ +b^2a_2a_7\varepsilon_3-2b^2a_2\alpha_1\alpha_5-2b^2a_2\alpha_5\alpha_7-2b^2a_2\alpha_5\varepsilon_3+b^2a_8\alpha_2\alpha_5-a_2a_5\alpha_1\alpha_6\alpha_7\\ -a_5a_8\alpha_1\alpha_3\alpha_7+b^2\beta\alpha_1+b^2\beta\alpha_4+b^2\beta\alpha_6+b^2\alpha_1\alpha_3+b^2\alpha_3\alpha_4+b^2\alpha_3\alpha_7+\\ b^2\alpha_3\varepsilon_3+\beta a_8\alpha_1\alpha_5+a_2a_7\alpha_6\varepsilon_3+a_2a_7\alpha_7\varepsilon_3-a_2\alpha_1\alpha_5\alpha_7-a_2\alpha_5\alpha_7\varepsilon_3-a_2a_8\alpha_5\varepsilon_3+\\ a_7a_8\alpha_3\varepsilon_3+a_8\alpha_1\alpha_2\alpha_5+a_8\alpha_2\alpha_5\alpha_7+\beta\alpha_1\alpha_4+\beta\alpha_1\alpha_6+\beta\alpha_4\alpha_6-a_3\alpha_4\varepsilon_3-a_3\alpha_6\varepsilon_3-\\ a_3\alpha_7\varepsilon_3+\alpha_1\alpha_2\alpha_4+\alpha_1\alpha_2\alpha_6+\alpha_1\alpha_2\alpha_7+\alpha_1\alpha_3\alpha_4+\alpha_1\alpha_3\alpha_7+\alpha_2\alpha_4\alpha_6+\alpha_2\alpha_4\alpha_7\\ +\alpha_2\alpha_6\alpha_7+\alpha_3\alpha_4\alpha_7+\alpha_3\alpha_4\varepsilon_3+\alpha_3\alpha_7\varepsilon_3 \end{array}\right\},$$

$$\Theta_4=\frac{1}{(a_2a_5)}\left\{\begin{array}{l} b^4a_2a_5\alpha_1\alpha_6+b^4a_2a_5\alpha_1\alpha_7+b^4a_2a_5\alpha_6\alpha_7+b^4a_5a_8\alpha_1\alpha_3+b^4a_5a_8\alpha_3\alpha_7-b^4\beta a_8\alpha_5+\\ b^4a_2\alpha_1\alpha_5+b^4a_2\alpha_5\alpha_7+b^4a_2\alpha_5\varepsilon_3+2b^2a_2a_5\alpha_1\alpha_6\alpha_7+2b^2a_5a_8\alpha_1\alpha_3\alpha_7-2b^2\beta a_8\alpha_1\alpha_5\\ -b^2a_2a_7\alpha_6\varepsilon_3-b^2a_2a_7\alpha_7\varepsilon_3+2b^2a_2\alpha_1\alpha_5\alpha_7+2b^2a_2\alpha_5\alpha_7\varepsilon_3+b^2a_3a_8\alpha_5\varepsilon_3-b^2a_7a_8\alpha_3\varepsilon_3\\ -b^2a_8\alpha_1a_2\alpha_5-b^2a_8\alpha_2\alpha_5\alpha_7-b^2\beta\alpha_1\alpha_4-b^2\beta\alpha_1\alpha_6-b^2\beta\alpha_4\alpha_6-b^2\alpha_1\alpha_3\alpha_4-b^2\alpha_1\alpha_3\alpha_7\\ -b^2\alpha_3\alpha_4\alpha_7-b^2\alpha_3\alpha_4\varepsilon_3-b^2\alpha_3\alpha_7\varepsilon_3-a_2a_7\alpha_6\alpha_7\varepsilon_3+a_3a_8\alpha_5\alpha_7\varepsilon_3-a_7a_8\alpha_3\alpha_7\varepsilon_3-\\ a_8\alpha_1\alpha_2\alpha_5\alpha_7-\beta\alpha_1\alpha_4\alpha_6+a_3\alpha_4\alpha_6\varepsilon_3+a_3\alpha_4\alpha_7\varepsilon_3+a_3\alpha_6\alpha_7\varepsilon_3-\alpha_1\alpha_2\alpha_4\alpha_6-\alpha_1\alpha_2\alpha_4\alpha_7\\ -\alpha_1\alpha_2\alpha_6\alpha_7-\alpha_1\alpha_3\alpha_4\alpha_7-\alpha_2\alpha_4\alpha_6\alpha_7-\alpha_3\alpha_4\alpha_7\varepsilon_3 \end{array}\right\},$$

$$\Theta_5=\frac{-1}{(a_2a_5)}\left\{\begin{array}{l} -b^2\alpha_1\alpha_3\alpha_7-b^2\alpha_3\alpha_4\alpha_7-b^2\alpha_3\alpha_4\varepsilon_3-b^2\alpha_3\alpha_7\varepsilon_3-a_2a_7\alpha_6\alpha_7\varepsilon_3+a_3a_8\alpha_5\alpha_7\varepsilon_3\\ -a_7a_8\alpha_3\alpha_7\varepsilon_3-a_8\alpha_1\alpha_2\alpha_5\alpha_7-\beta\alpha_1\alpha_4\alpha_6+a_3\alpha_4\alpha_6\varepsilon_3+a_3\alpha_4\alpha_7\varepsilon_3+a_3\alpha_6\alpha_7\varepsilon_3\\ -\alpha_1\alpha_2\alpha_4\alpha_6-\alpha_1\alpha_2\alpha_4\alpha_7-\alpha_1\alpha_2\alpha_6\alpha_7-\alpha_1\alpha_3\alpha_4\alpha_7-\alpha_2\alpha_4\alpha_6\alpha_7-\alpha_3\alpha_4\alpha_7\varepsilon_3 \end{array}\right\}. \quad (38)$$

The factorization method was used to remedy the principle ordinary differential equation (ODE) (37) as follows:

$$\left(D^2-m_1^2\right)\left(D^2-m_2^2\right)\left(D^2-m_3^2\right)\left(D^2-m_4^2\right)\left(D^2-m_5^2\right)\{\bar{\phi},\bar{T},\bar{\Pi},\bar{N},\bar{m}\}(x)e^{(\omega t+ibz)}=0. \quad (39)$$

Where $m_n^2\,(n=1,2,3,4,5)$ represent the roots that may be taken in the positive real part $x\to\infty$. The solution of equation (ODE) (39) takes the following form (according to the linearity of the problem) :

$$\bar{T}(x)=\sum_{n=1}^{5}D_n(b,\omega)\,e^{-m_nx}. \quad (40)$$

In the same way, the solutions of the other quantities can be expressed as:

$$\bar{N}(x)=\sum_{n=1}^{5}D_n'(b,\omega)\,e^{-m_nx}=\sum_{n=1}^{5}H_{1n}D_n(b,\omega)\,e^{-m_nx}, \quad (41)$$

$$\bar{\Pi}(x)=\sum_{n=1}^{5}D_n''(b,\omega)\exp(-m_nx)=\sum_{n=1}^{5}H_{2n}\,D_n(b,\omega)\exp(-m_nx), \quad (42)$$

$$\bar{m}(x)=\sum_{n=1}^{5}D_n'''(b,\omega)\exp(-m_nx)=\sum_{n=1}^{5}H_{3n}\,D_n(b,\omega)\exp(-m_nx), \quad (43)$$

$$\bar{\phi}(x)=\sum_{n=1}^{5} D_n^{(4)}(b,\omega)\exp(-m_n x)=\sum_{n=1}^{5} H_{4n}\, D_n(b,\omega)\exp(-m_n x). \tag{44}$$

The solution to equation (33) can be written in the following form:

$$\bar{\psi}(x)=D_6(b,\omega)\,e^{-m_6 x}. \tag{45}$$

Where $m_6=\pm\sqrt{\alpha_8}$ are the real roots of equation (33).

To obtain the stress components, first write the displacement components in terms of parameters according to equation (18):

$$\bar{\sigma}_{xx}=\sum_{n=1}^{5} H_{5n}\, D_n(b,\omega)\exp(-m_n x)-2ibm_6 D_6\exp(-m_6 x), \tag{46}$$

$$\bar{\sigma}_{zz}=\sum_{n=1}^{5} H_{6n}\, D_n(b,\omega)\exp(-m_n x)+2ibm_6 D_6\exp(-m_6 x) \tag{47}$$

$$\bar{\sigma}_{xz}=\sum_{n=1}^{5} H_{7n} D_n(b,\omega)\exp(-m_n x)-(m_6^2+b^2)D_6\exp(-m_6 x) \tag{48}$$

Since
$$\bar{u}(x)=D\bar{\Pi}+ib\bar{\psi}, \tag{49}$$
$$\bar{w}(x)=ib\bar{\Pi}-D\bar{\psi}. \tag{50}$$

Then,

$$\bar{u}(x)=\sum_{n=1}^{5} D_n''(b,\omega)\, m_n e^{-m_n x}+ibD_6(b,\omega)\exp(-m_6 x), \tag{51}$$

$$\bar{w}(x)=ib\sum_{n=1}^{5} D_n''(b,\omega)\, e^{-m_n x}+D_6(b,\omega)\, m_6\exp(-m_6 x). \tag{52}$$

Where D_n, D_n', D_n'', D_n''', and $D_n^{(4)}$ $, n=1,2,3,4,5$ are unknown parameters depending on the parameter b,ω. The relationship between the unknown parameters D_n, D_n', D_n'', D_n''', and $D_n^{(4)}$ $, n=1,2,3,4,5$ can be obtained when using the main equations (28)-(35) and (36), which take the following relationship:

$$H_{1n}=\frac{-\varepsilon_3}{m_n{}^2-\alpha_1},$$

$$H_{2n}=\frac{(a_5a_8-1)m_n^4+(-b^2a_5a_8-a_5a_8\alpha_1+\alpha_1+\alpha_4+\varepsilon_3)m_n^2+b^2a_5a_8\alpha_1-a_7a_8\varepsilon_3-\alpha_1\alpha_4-\alpha_4\varepsilon_3}{m_n^6+(-a_8\alpha_5-\alpha_1-\alpha_4-\alpha_6)m_n^4+(b^2a_8\alpha_5+a_8\alpha_1\alpha_5+\alpha_1\alpha_4+\alpha_1\alpha_6+\alpha_6\alpha_4)m_n^2-b^2a_8\alpha_1\alpha_5-\alpha_1\alpha_4\alpha_6}$$
,

$$H_{3n}=-\frac{(m_n^6+(-s^2-\alpha_1-\alpha_2-\alpha_3)m_n^4+(s^2\alpha_1+s^2\alpha_2-a_3\varepsilon_3+\alpha_1\alpha_2+\alpha_1\alpha_3+\alpha_3\varepsilon_3)m_n^2+s^2a_3\varepsilon_3-s^2\alpha_1\alpha_2)}{((m_n^2-\alpha_1)(m_n^2a_2-s^2a_2-a_8\alpha_3)m_n^2)}$$

$$,H_{4n}=\frac{-\beta}{(m_n{}^2-\alpha_7)},\, H_{5n}=\left(a_9m_n^2-a_{10}b^2\right)H_{2n}-a_9\left((1+H_{1n})\right)-a_{11}H_{3n},$$

$$H_{6n}=\left(a_9m_n^2-a_{10}b^2\right)H_{2n}-a_9\left((1+H_{1n})\right)-a_{11}H_{3n}\;\; H_{6n}=2I\,b\,m_i\,H_{3i}. \tag{53}$$

5. Applications

In this section, we determine the parameters $D_n(n=1,2,3,4,5,6)$. We should suppress the unbounded positive exponentials at infinity in the physical problem. The constants $D_1, D_2, D_3, D_4, D_5, D_6$ have to be chosen such that the boundary conditions on the surface $x=0$ (suppose the boundary $x=0$ is adjacent to the vacuum) take the form:

i) Mechanical boundary condition that the surface of the half-space is traction load.

$$\sigma_{xx}(0,z,t) = -p_1 \exp(\omega t + ibz) \quad (54)$$

ii) the displacement boundary condition that the surface of the half-space is traction free

$$u(0,z,t) = 0. \quad (55)$$

iii) Assuming that the boundary $x = 0$ is thermally insulated, we have

$$\frac{\partial T(0,z,t)}{\partial x} = 0. \quad (56)$$

vi) the boundary condition for the carrier density can be given below:

$$\frac{\partial N(0,z,t)}{\partial x} = \frac{s}{D_e} N. \quad (57)$$

vii) The moisture diffusion boundary condition at the free surface $x = 0$ when

$$m(0,z,t) = 0. \quad (58)$$

viii) The conductive temperature boundary condition at the free surface $x = 0$ when

$$\phi(0,z,t) = \phi_0. \quad (59)$$

6. Numerical results and discussions

The numerical values of the physical quantity (Temperature, displacement, carrier density, moisture concentration, conductive temperature, and normal distribution of stress) of this problem are carried out for a short period. The numerical simulation is done using materials. In S.I., the constants have used The unit, and the MATLAB software is used to plot. The physical constants of Si and Ge for the lower medium are given in table 1 as follows [35]:

Table (1): physical constants of Si and Ge materials

Name (unit)	Symbol	Si	Ge
Lamé's constants (N/m^2)	λ , μ	6.4×10^{10} , 6.5×10^{10}	$0.48\text{x}10^{11}$ $0.53\text{x}10^{11}$
Density (kg/m^3)	ρ	2330	5300
Absolute Temperature (K)	T_0	800	723
The photogenerated Carrier lifetime (s)	τ	$5\text{x}10^{-5}$	$1.4\text{x}10^{-6}$
The carrier diffusion coefficient (m^2/s)	D_E	2.5×10^{-3}	10^{-2}
the coefficient of electronic deformation (m^3)	d_n	$-9\text{x}10^{-31}$	$-6\text{x}10^{-31}$
The energy gap (eV)	E_g	1.11	0.72
The coefficient of linear thermal expansion (K^{-1})	α_t	$4.14\text{x}10^{-6}$	$3.4\text{x}10^{-3}$
The thermal conductivity of the sample ($Wm^{-1}K^{-1}$)	k	150	60
Specific heat at constant strain ($J/(kg\,K)$)	C_e	695	310
The recombination velocities (m/s)	s	2	2
The pulse rise time (ps)	t_0	9	9
the radius of the beam (μm)	r	100	100

the absorption depth of heating energy (m^{-1})	γ'	10^{-3}	10^{-3}
The absorbed energy (J)	I_0	10^5	10^5
temperature diffusivity	D_T	$\frac{k}{\rho C_e}$	$\frac{k}{\rho C_e}$
coupled diffusivities $(m^2(\%H_2O)/s(K))$,	D_T^m	2.1×10^{-7}	2.1×10^{-7}
$(m^2 s(K)/(\%H_2O))$	D_m^T	0.648×10^{-6}	0.648×10^{-6}
reference moisture	m_0	10%	10%
the diffusion constants of moisture (m^2s^{-1})	D_m	0.35×10^{-2}	0.35×10^{-2}
thermodiffusive constant of moisture ($cm/cm(\%H_2o)$)	α_m	2.68×10^{-3}	2.68×10^{-3}
moisture diffusivity (kg/msM)	k_m	2.2×10^{-8}	2.2×10^{-8}

6.1. The effect of Two-temperature parameter

The first group (figure 1) represents the variations of main fields in this phenomenon according to the different values of the two-temperature parameter against the horizontal distance x in the context of moisture diffusivity. Two cases are considered in this category, the first when the two-temperature parameter does not vanish $a \neq 0$. In this case, the thermodynamic T and the conductive φ temperatures are equal, which describes the one-temperature case. in comparison, $a > 0$ the two-temperature theory is obtained. From figure 1, the wave propagation according to one temperature case takes the same behavior as the two-temperature case of carrier density. In the other distributions (thermodynamic Temperature, displacement, stress, and conductive Temperature), the wave propagations take a different behavior. From this category, the two-temperature parameter significantly affects the magnitude of all field distributions. The physical fields satisfy the boundary conditions at the surface in two cases of a two-temperature parameter.

6.2. The effect of thermoelastic coupling parameters

Figure 2 (in the second category) depicts the major physical fields versus horizontal distance. x in the context of PT theory with moisture diffusivity under the two temperature theory. All calculations are carried out under moisture diffusivity $\varepsilon_3 = -7.8\times10^{-36}$ and $m_0 = 10\%$ for silicon (Si) material. All subfigures discuss three cases of the thermoelastic coupling parameter. The solid lines (————) represent the case when $\varepsilon_1 = 0.001$ the dashed lines (— — —) express the case at $\varepsilon_1 = 0.002$, and the dotted lines (…………) show the case at $\varepsilon_1 = 0.003$. The first subfigure represents (T) distribution with the variation of the dimensionless thermoelastic coupling parameters with the distance x. The thermo-dynamical temperature T starts from the positive minimum value, which satisfies the thermally insulated condition with sharp increases in the first range until it reaches the maximum peak value near the surface due to the photo-excitation and moisture diffusivity. On the other hand, the T distribution decreases in the second range to reach the minimum value far from the surface.

The second subfigure displays the carrier density distribution against the distance in variation values of thermoelastic parameters. However, a small change in thermoelastic coupling parameters has no significant effect on the carrier density, which has a similar quality behavior. The third subfigure shows the conductive temperature, which has the same behavior as the first subfigure, and The fourth subfigure describes the moisture concentration m distribution against the horizontal distance x. The moisture concentration distribution starts from zero value for all three cases. In the case of $\varepsilon_1 = 0.001$ the distribution takes the exponential behavior with smooth decreasing. Still, on the other hand, when $\varepsilon_1 = 0.002$ $\varepsilon_1 = 0.003$ the distribution of moisture concentration decreases sharply in the first range, it takes exponential propagation behavior until it reaches a minimum value near the zero line due to moisture diffusivity. The fifth subfigure displays the increasing stress force σ amplitude due to the mechanical loads tending to increase the value of thermoelastic coupling parameters. The sixth subfigure displays the displacement distribution u with the horizontal distance x due to moisture diffusivity and the thermal effect of photothermal excitation for the rough surface. The displacement distribution starts from zero value and increases to maximum values near the surface for all three cases of the thermoelastic coupling parameter when and decreases in exponential propagation behavior until it reaches a minimum value near the zero line.

6.3 The effect of the thermoelectric coupling parameter

Figure 3 (which represents in the third category) shows the main physical fields against the horizontal distance x in the context of photo-thermoelasticity theory with moisture diffusivity under the two temperature theory. All calculations are carried out under the effect of moisture diffusivity when $\varepsilon_1 = .001 \text{ and } m_0 = 10\%$ for silicon (Si) materiel. All subfigures discus three cases of the thermoelectric coupling parameter. The solid lines (———) represent the case when $\varepsilon_3 = -7.8\times10^{-36}$, the dashed lines (— — —) express the case at $\varepsilon_3 = -8.8\times10^{-36}$ and the dotted lines (··········) show the case at $\varepsilon_3 = -9.8\times10^{-36}$.The first subfigure represents (T) distribution with the variation of the dimensionless of the thermoelectric coupling parameters with the distance x. The thermo-dynamical temperature T starts from positive minimum value, which it satisfies the thermally insulated condition with sharply increases in the first range until reach the peak maximum value near the surface due to the photo-excitation and moisture diffusivity. On other hand, the T distribution decreases in the second range to reach the minimum value far away from the surface .The second subfigure displays the carrier density distribution against the distance in variation values of thermoelastic parameters. However, a small change in thermoelastic coupling parameters has no significant effect on the carrier density, which has a similar quality behavior. The third subfigure shows the conductive temperature, which behaves similarly to the dynamical temperature. The fourth subfigure describes the moisture concentration m distribution against the horizontal distance x. The moisture concentration distribution starts from a positive value for all three cases. In the case of $\varepsilon_1 = 0.001$ the distribution takes the exponential behavior with smooth decreasing. Still, on the other hand, when $\varepsilon_1 = 0.002$ $\varepsilon_1 = 0.003$ the distribution of moisture concentration decreases sharply in the first range, it takes exponential propagation behavior until it reaches a minimum value near the zero line due to moisture diffusivity. The fifth subfigure displays the increase of stress force σ amplitude due to the mechanical loads tending to increase the value of thermoelectric coupling parameters. The sixth subfigure displays the displacement distribution u with the horizontal distance x due to moisture diffusivity and the thermal effect of photothermal excitation for the rough surface. The displacement distribution starts from zero value and increases to maximum values near the surface for all three cases of the thermoelectric coupling parameter when and decreases in exponential propagation behavior until it reaches a minimum value near the zero line.

6.4. Influence of reference moisture

Figure 4(the fourth category) shows the main physical fields against the horizontal distance x with moisture constants. All calculations are carried out under the thermoelastic couples $\varepsilon_1 = 0.001, \varepsilon_3 = -7.8\times10^{-36}$ for Silicon (Si) material. Figure 3 (the third category) exhibits the variation of the physical fields relative to the distance x in three cases of reference moisture m_0. The first represents the case of reference moisture when $m_0 = 10\%$ (———), the second case of reference moisture field when $m_0 = 20\%$ (— — —), and the third case of reference moisture field when $m_0 = 30\%$ (··········). All evaluations are made in the moisture field when $\varepsilon_1 = 0.001$ and $\varepsilon_3 = -7.8\times10^{-36}$. From this figure, it is clear that the moisture field affects the wave propagation behavior of displacement, moisture concentration, stress force , temperature distributions, and carrier density distribution, but carrier density doesn't affect it.

6.5. The comparison between Si and Ge materials

Figure 5 (the fifth category) illustrates the comparison between elastic semiconductor materials, silicon (Si) and germanium (Ge). In this category, the values of the physical fields under studying have been evaluated numerically when $\varepsilon_1 = 0.001$ and $\varepsilon_3 = -7.8 \times 10^{-36}$ under the influence of moisture field under the two temperature theory. From this figure, it is the difference of physical constants of Ge and Si materials have a great effect on all the wave propagation of the dimensionless distributions for T , m , u , σ , and ϕ

7.Conclusion

The novel model is studied in 2D is taken into account during the theories of two-temperature and photo-thermoelasticity. The complex governing equations are taken in dimensionless with some initial and boundary conditions. The difference of photo-thermoelasticity theories according to thermal relaxation times is considered. The effects of moisture diffusivity appear clearly on the distributions of wave propagation for the basic quantities under study. On the other hand, the two-temperature parameter has a great impact on the all wave propagations also. The wave propagations of silicon semiconductor is noticed to be significantly affected by the variation in two-temperature parameter. On the other hand, the model used is very useful for scientists and engineers of renewable energy in improving the capacity of photovoltaic cells, as well as electrical circuits and computer processors.

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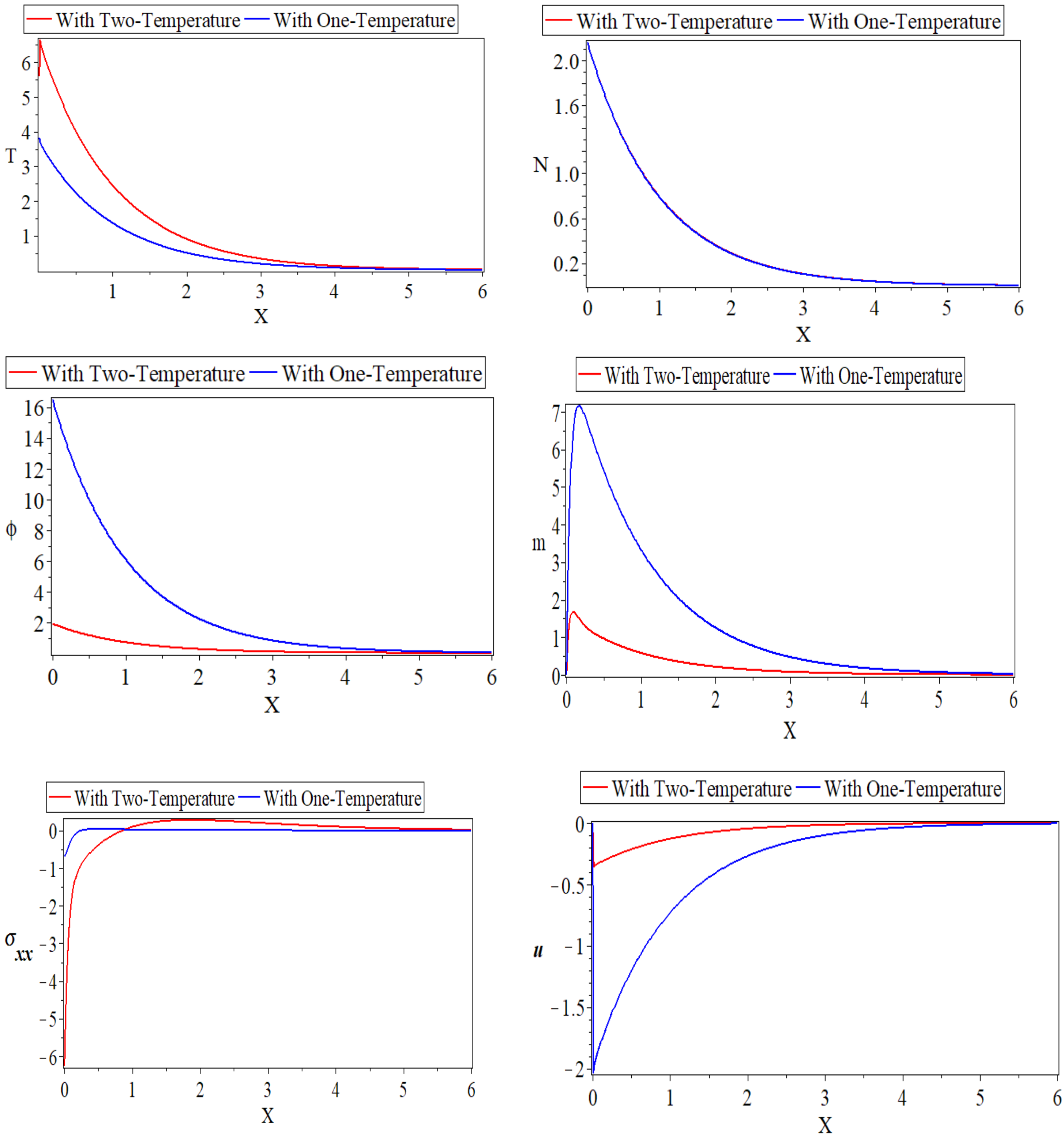
With Two-Temperature
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Figure 1

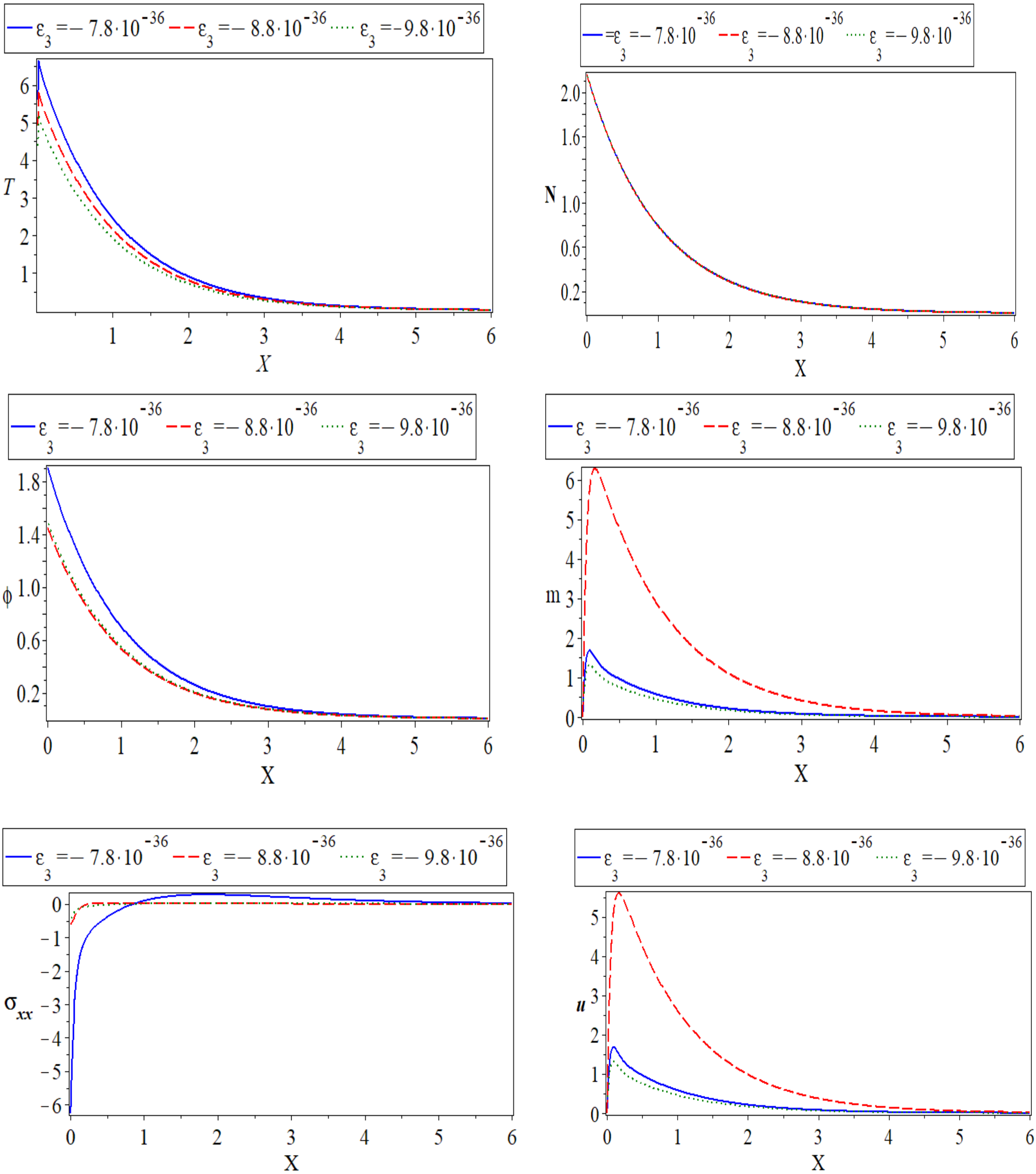

Figure 2

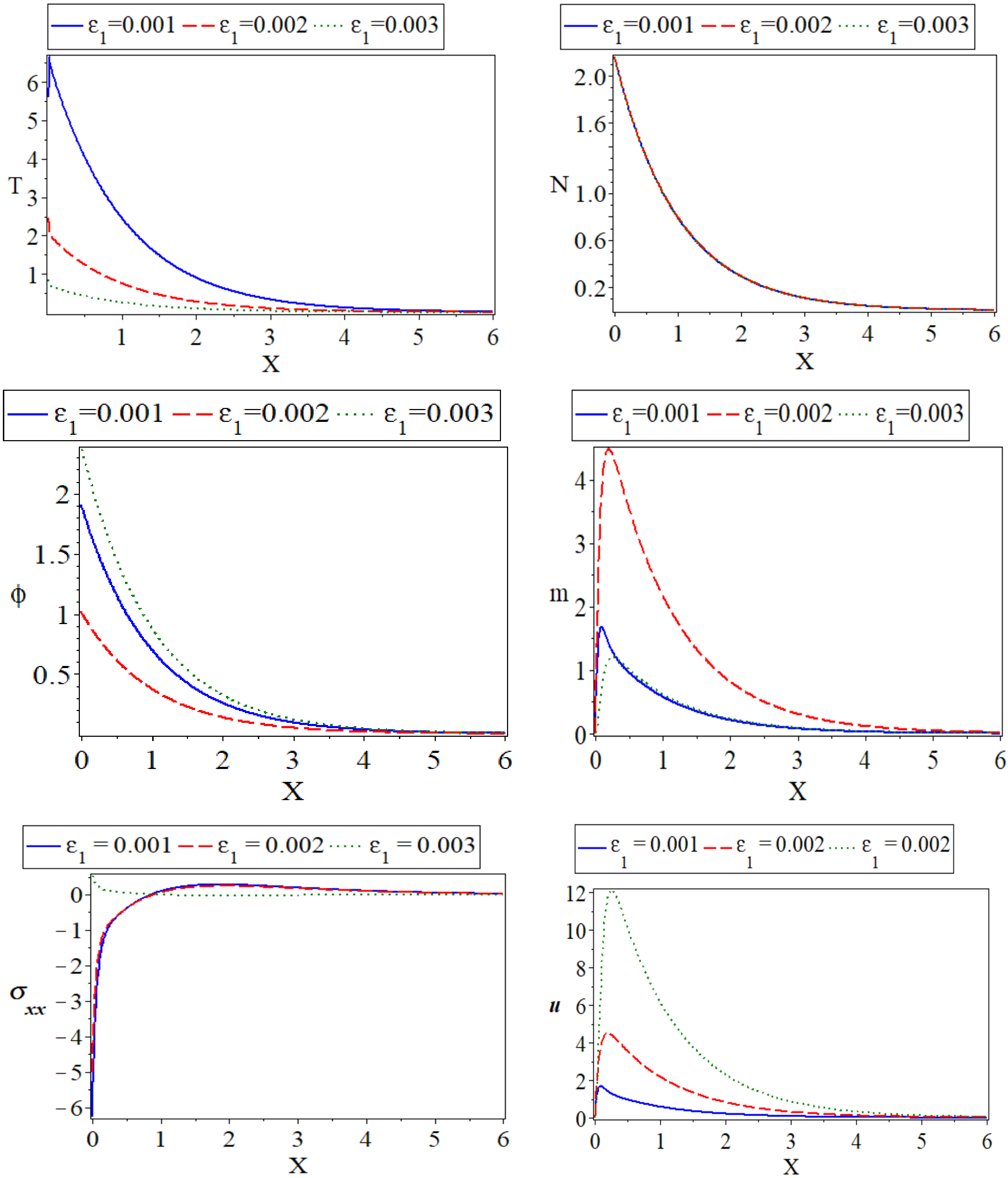

Figure 3

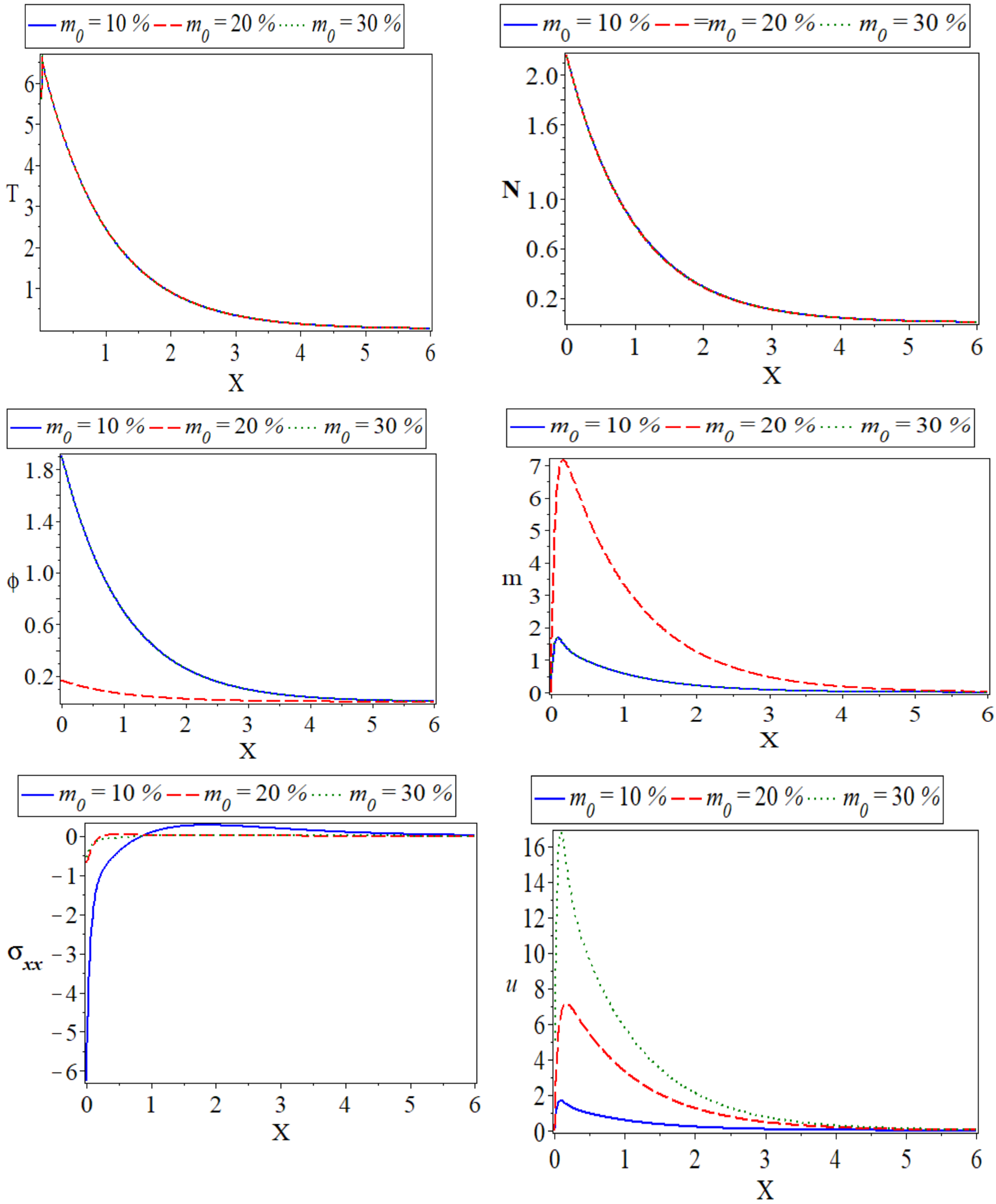

Figure 4

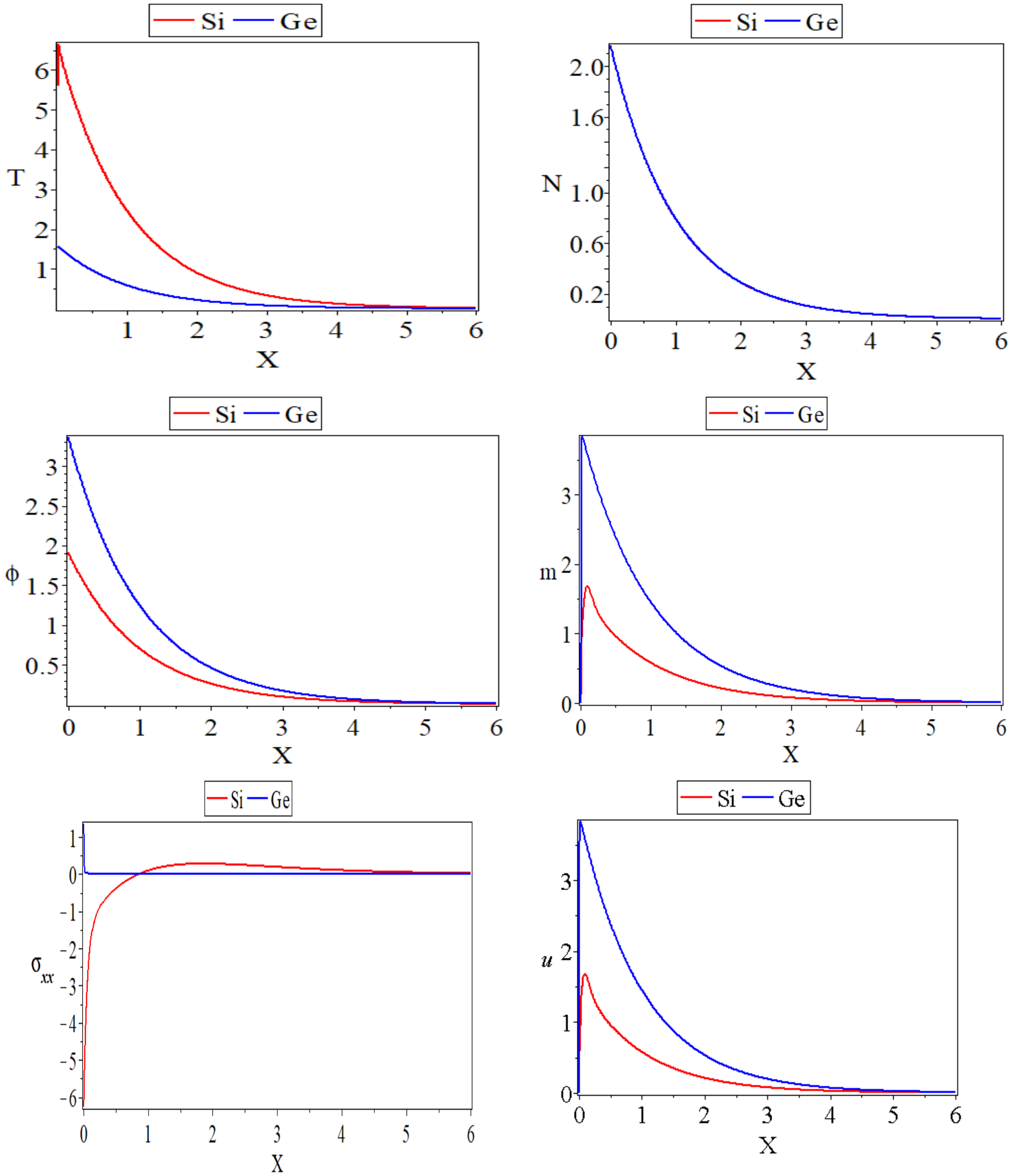

Figure 5