

Article

The Effects of Variable Thermal Conductivity in Semiconductor Materials Photogenerated by a Focused Thermal Shock

Faris Alzahrani 

Nonlinear Analysis and Applied Mathematics Research Group (NAAM), Department of Mathematics,
King Abdulaziz University, Jeddah 21521, Saudi Arabia; falzahrani1@kau.edu.sa

Received: 14 July 2020; Accepted: 23 July 2020; Published: 27 July 2020



Abstract: In this work, the generalized photo-thermo-elastic model with variable thermal conductivity is presented to estimate the variations of temperature, the carrier density, the stress and the displacement in a semiconductor material. The effects of variable thermal conductivity under photo-thermal transport process is investigated by using the coupled model of thermoelastic and plasma wave. The surface of medium is loaded by uniform unit step temperature. Easily, the analytical solutions in the domain of Laplace are obtained. By using Laplace transforms with the eigenvalue scheme, the fields studied are obtained analytically and presented graphically.

Keywords: variable thermal conductivity; semiconductor medium; Laplace transforms; eigenvalues approach

1. Introduction

The theory of bodies explains the properties of the inner structure of some materials when the second law of thermodynamics is used. The conduction of thermal energy in thermo-elastic materials with internal structures is investigated. The laws of the balance of a continuum medium are used from the first moment (heat flux) the heat energy equations with microstructure when are added to the governing equation. With the development of semiconductor integrated circuit technologies and solid-state sensor technologies, MEMS has been widely used in many fields; it has the characteristics of small volume, lightweight and low energy consumption.

To understand the internal structural properties of elastic media—especially in semiconductor media—the electrical properties of these media must be investigated in such a way that considers of their mechanical-thermal properties. The importance of semiconducting materials is due to their recent uses in many beneficial applications—especially in modern technologies based on new energy alternatives. Many of these applications depend on studying the effects of the fall of the sunlight or a beam of laser on the outer surface of the semiconducting material, without taking into account the internal structure of the medium.

Semiconductor materials have only been studied as elastic materials without taking into consideration the influence of light beams on them. However, semiconducting materials are considered nanomaterials in modern technology that have many uses, e.g., industrial photovoltaic solar cells. Electronic and elastic deformations occur when a laser beam strikes the surface of a semiconductor medium. In this case, some surface electrons will be excited and photo-excited free carriers will be generated. In modern technology, the relationship between the uses of photothermal (PT) theory and semiconductors is close. Many scientists have used the PT theory to obtain the values of the temperature. The thermal diffusion of nanocomposite semiconductor materials has also been measured.

Todorovic [1,2] studied thermoelastic and plasma waves in a semiconductor materials. Ailawalia and Kumar [3] investigated the photo-thermo-elastic interactions in semiconducting media caused by

the ramp-type heating. Lotfy et al. [4] studied Thomson and electromagnetic effects under photothermal transport process in semiconducting media. Lotfy et al. [5] studied the responses of electromagnetic and Thomson impacts of semiconductor media due to laser pulses during photo-thermal excitations. Lotfy et al. [6] used fractional-order magnetophotothermal models to study the influences of variable thermal conductivity of a semiconductor medium with cavity. Hobiny and Abbas [7] investigated the photo-thermal interactions in a two-dimensional semiconducting half-spaces under the Green–Naghdi model. Othman and Marin [8] studied using the Green–Naghdi model to investigate the effects of thermal load due to laser pulse on thermo-elastic porous media. Alzahrani and Abbas [9] studied the photo-thermoelastic interaction in a two-dimensional semiconductor media without energy dissipations. Jahangir et al. [10] studied photo-thermoelastic interactions in a semiconductor media with two thermal relaxation times. Mondal and Sur [11] investigated the propagations of the photo-thermo-elastic waves in an orthotropic semiconductor media with a spherical hole and memory response. Several authors [12–25] have presented solutions to many problems by using generalized thermoelastic models.

The purpose of this paper is to study the effects of the variability of thermal conductive in a semiconductor material using the eigenvalues approach. By using the eigenvalue scheme and Laplace transforms based on analytic-numeric approaches, the basic equations are derived. The numeric results of the main physical fields in different cases is studied and shown graphically and discussed.

2. Mathematical Model

The basic equations in the context of photothermal model for a homogeneous and isotropic semiconducting material in the absences of body force and thermal sources are given as in [26–28]:

The equations of motion:

$$\mu u_{i,jj} + (\lambda + \mu) u_{j,ij} - \gamma_n N_{,i} - \gamma_t T_{,i} = \rho \frac{\partial^2 u_i}{\partial t^2} \quad (1)$$

The coupling between plasma and thermoelastic waves can be given by:

$$D_e N_{,jj} - \frac{N}{\tau} + \frac{k}{\tau} T - \frac{\partial N}{\partial t} = 0.0 \quad (2)$$

The equation of heat conduction:

$$(KT_{,j})_j + \frac{E_g}{\tau} N - \rho c_e \frac{\partial T}{\partial t} - \gamma_t T_o \frac{\partial u_{j,j}}{\partial t} = 0.0, \quad (3)$$

The stress–strain relations:

$$\sigma_{ij} = (\lambda u_{k,k} - \gamma_n N - \gamma_t T) \delta_{ij} + \mu (u_{i,j} + u_{j,i}) \quad (4)$$

where ρ is the density of material, $N = n - n_o$, n_o is the carrier concentration at equilibrium, $i, j, k = 1, 2, 3$, τ is the lifetime of photo-generated carrier, $T = T^* - T_o$, T^* is the variations of temperature, u_i are the displacement components, T_o is the reference temperature, $k = \frac{\partial n_o}{\partial T}$ is the coupling parameter of thermal activation [27], σ_{ij} are the components of stresses, $\gamma_t = (3\lambda + 2\mu)\alpha_t$ and α_t is the linear thermal expansion coefficients, D_e is the carrier diffusion coefficient, t is the time, $\gamma_n = (3\lambda + 2\mu)d_n$, d_n is the electronic deformation coefficient, λ, μ are the Lamé's constants, c_e is the heat specific at constant strain and K is the thermal conductivity, which is considered to be temperature-dependent. We will consider the thermal conductivity has the following linear form [29]

$$K(T) = K_o(1 + K_1 T) \quad (5)$$

where K_1 is a non-positive small parameter and K_o is the thermal conductivity at the initial temperature T_o . The following mapping [29] can be used

$$\phi = \frac{1}{K_0} \int_0^T K(T) dT \quad (6)$$

where the new function ϕ expressing the heat conduction. Substituting from Equation (5) into Equation (6) and integrating, we can obtain [29]

$$\phi = T + \frac{1}{2} K_1 T^2, \quad (7)$$

From Equations (6) and (7), we can deduce the following

$$K_0 \phi_{,i} = K(T) T_{,i}, \quad (8)$$

$$K_0 \phi_{,ii} = (K(T) T_{,i})_{,i}, \quad (9)$$

$$K_0 \frac{\partial \phi}{\partial t} = K(T) \frac{\partial T}{\partial t}, \quad (10)$$

Thus, the basic Equations (1)–(4) can be rewritten in the form:

$$\mu u_{i,jj} + (\lambda + \mu) u_{j,ij} - \gamma_n N_{,i} - \gamma_t \phi_{,i} = \rho \frac{\partial^2 u_i}{\partial t^2}, \quad (11)$$

$$D_e N_{,jj} - \frac{N}{\tau} + \frac{k}{\tau} \phi = \frac{\partial N}{\partial t}, \quad (12)$$

$$K_0 \phi_{,jj} + \frac{E_g}{\tau} N = \rho c_e \frac{\partial \phi}{\partial t} + \gamma_t T_0 \frac{\partial u_{j,j}}{\partial t}, \quad (13)$$

$$\sigma_{ij} = \mu (u_{i,j} + u_{j,i}) + \left(\lambda u_{k,k} - \gamma_n N - \frac{\gamma_t}{K_1} (-1 + \sqrt{1 + 2K_1 \phi}) \right) \delta_{ij}, \quad (14)$$

Let us consider a homogeneous, isotropic infinite semiconductor material, whose states can be written in terms of the time t and the space variable x , therefore the Equations (11)–(14) are expressed by:

$$(\lambda + 2\mu) \frac{\partial^2 u}{\partial x^2} - \gamma_n \frac{\partial N}{\partial x} - \gamma_t \frac{\partial \phi}{\partial x} = \rho \frac{\partial^2 u}{\partial t^2}, \quad (15)$$

$$D_e \frac{\partial^2 N}{\partial x^2} - \frac{N}{\tau} + \frac{k}{\tau} \phi = \frac{\partial N}{\partial t}, \quad (16)$$

$$K_0 \frac{\partial^2 \phi}{\partial x^2} + \frac{E_g}{\tau} N = \rho c_e \frac{\partial \phi}{\partial t} + \gamma_t T_0 \frac{\partial^2 u}{\partial t \partial x}, \quad (17)$$

$$\sigma_{xx} = (\lambda + 2\mu) \frac{\partial u}{\partial x} - \gamma_n N - \frac{\gamma_t}{K_1} (-1 + \sqrt{1 + 2K_1 \phi}), \quad (18)$$

3. Application

We shall also assume that the initial state of the medium is quiescent and are completed by consider the boundary conditions at $x = 0$ as

$$u(0, t) = 0, \quad (19)$$

The surface $x = 0.0$ is due to the with thermal shock varying heat:

$$T(0, t) = T_1 H(t), \quad (20)$$

From Equation (7), then boundary condition (20) is expressed by

$$\phi(0, t) = T_1 H(t) + \frac{1}{2} K_1 (T_1 H(t))^2, \quad (21)$$

where $H(t)$ is the Heaviside unit function and T_1 is a constant temperature. The carrier density boundary condition are defined by

$$D_e \left. \frac{\partial N(x, t)}{\partial x} \right|_{x=0} = s_0 N(0, t), \quad (22)$$

where s_0 is the velocity of recombination on the surface. Now, for conveniences, the nondimensional physical variables are given by

$$\phi^* = \frac{\phi}{T_0}, N^* = \frac{N}{n_0}, K_1^* = T_0 K_1, \sigma_{xx}^* = \frac{\sigma_{xx}}{\lambda + 2\mu}, (x^*, u^*) = \eta c(x, u), (t^*, \tau^*) = \eta c^2(t, \tau), \quad (23)$$

where $c^2 = \frac{\lambda + 2\mu}{\rho}$ and $\eta = \frac{\rho c_e}{K}$.

By using the parameters of dimensionless (23), rewrite the basic equations with neglecting the primes one obtains:

$$\frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2} - x_1 \frac{\partial N}{\partial x} - x_2 \frac{\partial \phi}{\partial x}, \quad (24)$$

$$x_3 \frac{\partial N}{\partial t} = \frac{\partial^2 N}{\partial x^2} - \frac{x_3}{\tau} N + \frac{\beta}{\tau} \phi, \quad (25)$$

$$\frac{\partial \phi}{\partial t} = \frac{\partial^2 \phi}{\partial x^2} + \frac{x_4}{\tau} N - x_5 \frac{\partial^2 u}{\partial t \partial x}, \quad (26)$$

$$\sigma_{xx} = \frac{\partial u}{\partial x} - x_1 N - x_2 (-1 + \sqrt{1 + 2K_1 \phi}), \quad (27)$$

$$(0, t) = 0, \left. \frac{\partial N(x, t)}{\partial x} \right|_{x=0} = x_6 N(0, t), \phi(0, t) = T_1 H(t) + \frac{1}{2} K_1 (T_1 H(t))^2, \quad (28)$$

where $x_1 = \frac{n_0 \gamma_n}{\lambda + 2\mu}$, $x_2 = \frac{T_0 \gamma_t}{\lambda + 2\mu}$, $x_3 = \frac{1}{\eta D_e}$, $\beta = \frac{k T_0}{n_0 \eta^2 c^2 D_e}$, $x_4 = \frac{n_0 E_g}{\rho c_e T_0}$, $x_5 = \frac{\gamma_t}{\rho c_e}$ and $x_6 = \frac{s_0}{\eta c D_e}$.

For $f(x, t)$ function Laplace transforms was written as

$$\bar{f}(x, p) = L[f(x, t)] = \int_0^\infty f(x, t) e^{-pt} dt, \quad p > 0, \quad (29)$$

where p is the Laplace transforms parameters. Hence, the basic equations can be rewritten by forms as follow

$$\frac{d^2 \bar{u}}{dx^2} = p^2 \bar{u} + x_1 \frac{d\bar{N}}{dx} + x_2 \frac{d\bar{\phi}}{dx}, \quad (30)$$

$$\frac{d^2 \bar{N}}{dx^2} = x_3 \left(p + \frac{1}{\tau} \right) \bar{N} - \frac{\beta}{\tau} \bar{\phi}, \quad (31)$$

$$\frac{d^2 \bar{\phi}}{dx^2} = p \bar{\phi} - \frac{x_4}{\tau} \bar{N} + x_5 p \frac{d\bar{u}}{dx}, \quad (32)$$

$$\bar{\sigma}_{xx} = \frac{d\bar{u}}{dx} - x_1 \bar{N} - x_2 \left(-1 + \sqrt{1 + 2K_1 \bar{\phi}} \right), \quad (33)$$

$$\bar{u}(0, t) = 0, \left. \frac{d\bar{N}(x, t)}{dx} \right|_{x=0} = x_6 \bar{N}(0, t), \bar{\phi}(0, t) = \frac{T_1}{p} \left(1 + \frac{1}{2p} T_1 K_1 \right), \quad (34)$$

We will now get the solutions of coupled differential system (30)–(32) with the boundary conditions (34) by using the eigenvalues method proposed [30–35]. From Equations (30)–(32), the matrices–vectors can be given by

$$\frac{dV}{dx} = AV, \quad (35)$$

$$\text{where } V = \begin{bmatrix} \bar{u} & \bar{N} & \bar{\phi} & \frac{d\bar{u}}{dx} & \frac{d\bar{N}}{dx} & \frac{d\bar{\phi}}{dx} \end{bmatrix}^T \text{ and } A = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ a_{41} & 0 & 0 & 0 & a_{45} & a_{46} \\ 0 & a_{52} & a_{53} & 0 & 0 & 0 \\ 0 & a_{62} & a_{63} & a_{64} & 0 & 0 \end{bmatrix}, \text{ with}$$

$$a_{41} = p^2, a_{45} = x_1, a_{46} = x_2, a_{52} = x_3\left(p + \frac{1}{\tau}\right), a_{53} = -\frac{\beta}{\tau}, a_{62} = -\frac{x_4}{\tau}, a_{63} = p, a_{64} = px_5$$

Thus, the characteristic equation of matrix A are presented by:

$$\xi^6 - r_3\xi^4 + r_2\xi^2 + r_1 = 0, \quad (36)$$

where:

$$r_1 = a_{62}a_{53}a_{41} - a_{41}a_{63}a_{52}$$

$$r_2 = a_{46}a_{52}a_{64} + a_{41}a_{52} - a_{45}a_{53}a_{64} + a_{41}a_{63} - a_{53}a_{62} + a_{52}a_{63}$$

$$r_3 = a_{46}a_{64} + a_{52} + a_{41} + a_{63}$$

The matrix eigenvalue of A are the six roots of Equation (36) which define by the forms $\pm\xi_1, \pm\xi_2, \pm\xi_3$. Thus, the eigenvectors Y are computed as:

$$\begin{aligned} Y_1 &= a_{46}(a_{52} - \xi^2)\xi - \xi a_{53}a_{45}, Y_2 = (a_{41} - \xi^2)a_{53} \\ Y_3 &= -(a_{41} - \xi^2)(a_{52} - \xi^2), Y_4 = \xi Y_1, Y_5 = \xi Y_2, Y_6 = \xi Y_3 \end{aligned} \quad (37)$$

The solutions of Equation (35) have the following from:

$$V(x, p) = \sum_{i=1}^3 (B_i Y_i e^{-\xi_i x} + B_{i+1} Y_{i+1} e^{\xi_i x}), \quad (38)$$

Due to the regularity condition of the solution, the increasing exponential nature with the variable x has been eliminated to infinity, so the general solutions (34) can be presented as:

$$V(x, p) = \sum_{i=1}^3 B_i Y_i e^{-\xi_i x}, \quad (39)$$

where B_1, B_2 and B_3 are constants which can be determined by using the boundary conditions of the problem. Thus, the general solutions of physical quantities can be taken the forms:

$$\bar{u}(x, p) = \sum_{i=1}^3 B_i U_i e^{-\xi_i x}, \quad (40)$$

$$\bar{N}(x, p) = \sum_{i=1}^3 B_i N_i e^{-\xi_i x}, \quad (41)$$

$$\bar{\phi}(x, p) = \sum_{i=1}^3 B_i T_i e^{-\xi_i x}, \quad (42)$$

The numeric inversions scheme adopted the general solutions of the carrier density, the displacement, the temperature and the stress distribution. The Stehfest method [36] was taken

as a numeric inversions scheme. In this method, the Laplace transforms inverses for $\bar{f}(x, p)$ are approximated as:

$$f(x, t) = \frac{\ln(2)}{t} \sum_{n=1}^N V_n \bar{f}\left(x, n \frac{\ln(2)}{t}\right), \quad (43)$$

where:

$$V_n = (-1)^{\left(\frac{N}{2}+1\right)} \sum_{p=\frac{n+1}{2}}^{\min(n, \frac{N}{2})} \frac{(2p)! p^{\left(\frac{N}{2}+1\right)}}{p!(n-p)! \left(\frac{N}{2}-p\right)! (2n-1)!}$$

where N is the term numbers.

4. Numeric Results and Discussion

For numeric computations, silicon medium was selection for purposes of numeric estimation. The parameters values for silicon (Si) medium are given by [37]:

$$d_n = -9 \times 10^{-31} (\text{m}^3), \lambda = 3.64 \times 10^{10} (\text{N})(\text{m}^{-2}), \mu = 5.46 \times 10^{10} (\text{N})(\text{m}^{-2}), T_0 = 300 (\text{k})$$

$$c_e = 695 (\text{J})(\text{kg}^{-1})(\text{k}^{-1}), \rho = 2330 (\text{kg})(\text{m}^{-3}), E_g = 1.11 (\text{eV}), \alpha_t = 3 \times 10^{-6} (\text{k}^{-1})$$

$$s_0 = 2 (\text{m})(\text{s}^{-1}), n_0 = 10^{20} (\text{m}^{-3}), \tau = 5 \times 10^{-5} (\text{s}), D_e = 2.5 \times 10^{-3} (\text{m}^2)(\text{s}^{-1}), T_1 = 1$$

The numeric computations are carried out for the time $t = 1.5$. Based on the above values of parameters, the values of physical quantities (numeral) with respect to the distances x with the coupled theory of plasma and thermoelastic wave are presented in Figures 1–5. The variations of carrier density, the variations of temperature, the variations of displacement and the variation of stress along the distances x in the context of the coupled photo-thermo-elastic model are computed numerically. Figure 1 shows the variations of temperature versus x . It is observed that the temperature has maximum values ($T_1 = 1$) which satisfy the problem boundary conditions when $x = 0$ after that it gradually reduces with the rising of the distance x until it reached to zero. Otherwise, Figure 2 exhibits the variations of the heat conduction along the distance x . Figure 3 displays the variation of carrier density with respect to the distance x . It is observed that it begins with its ultimate value at the surface $x = 0$ then it gradually reduces with the rising of the distances x until it close to zeros. Figure 4 depicts the variation of displacement along the distance x . It is clear that the displacement begin from zero which satisfy boundary conditions of the problem when $x = 0$ then it is rising gradually up to peak values then reduces to zero. Figure 5 demonstrates the variations of stress versus the distance x . It is observed that it attains maximum negative value after that it increases gradually to zeros.

Finally, in the compressions between the solutions, it can be concluded that considering the coupling photo-thermoelastic models with variable thermal conductivity is significant phenomenon and have important effects on the distributions of the studding fields.

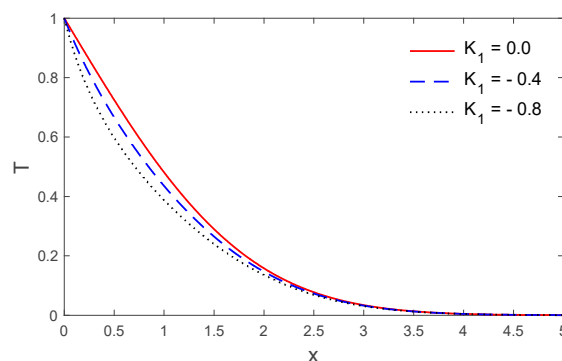


Figure 1. Variations of temperature with respect to the distance for various values of K_1 .

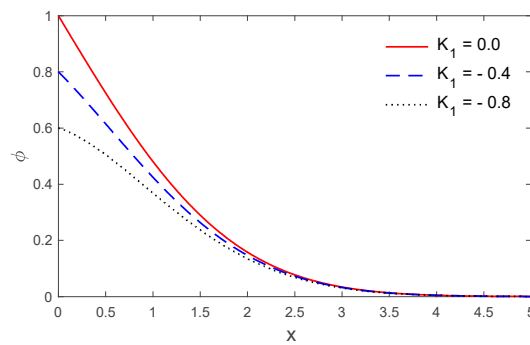


Figure 2. Variations of heat conduction with respect to the distance for various values of K_1 .

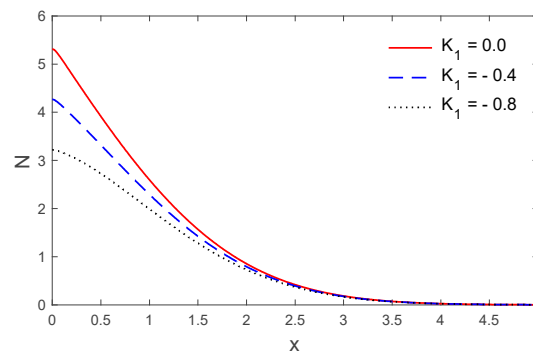


Figure 3. Variations of carrier density with respect to the distance for various values of K_1 .

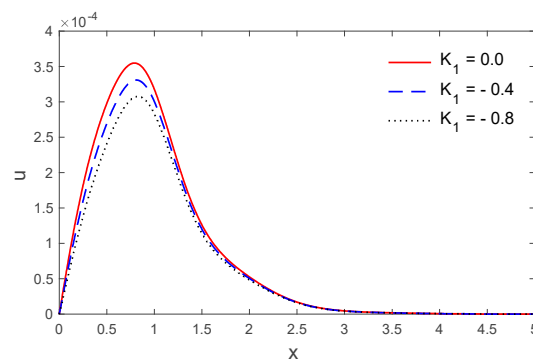


Figure 4. Variations of displacement with respect to the distance for various values of K_1 .

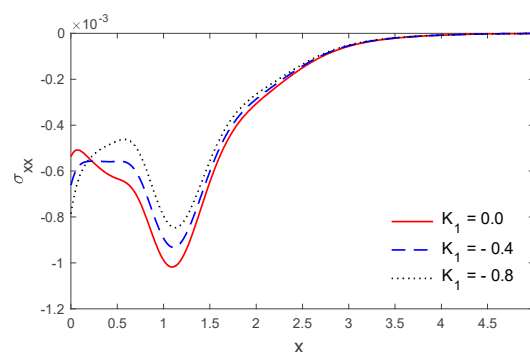


Figure 5. Variation of stress with respect to the distance for various values of K_1 .

5. Conclusions

In the present work, I study the effects of variable thermal conductivity in semiconductor materials photogenerated by a focused thermal shock. The resulting nondimensional equations were solved employing the Laplace transforms techniques and were solved using the eigenvalues approach.

The significant effects of the variable thermal conductivity are discussed for all physical quantities. The results carried out in this work can be used to design various semiconductor elements to meet special engineering requirements.

Funding: This project was funded by the Deanship of Scientific Research (DSR), King Abdulaziz University, Jeddah, under Grant No (DF-417-130-1441). The authors, therefore, gratefully acknowledge the DSR technical and financial support.

Acknowledgments: This may include administrative and technical support or donations in kind.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Todorović, D. Plasma, thermal, and elastic waves in semiconductors. *Rev. Sci. Instrum.* **2003**, *74*, 582–585. [\[CrossRef\]](#)
2. Todorović, D. Photothermal and electronic elastic effects in microelectromechanical structures. *Rev. Sci. Instrum.* **2003**, *74*, 578–581. [\[CrossRef\]](#)
3. Ailawalia, P.; Kumar, A. Ramp Type Heating in a Semiconductor Medium under Photothermal Theory. *Silicon* **2019**, *12*, 347–356. [\[CrossRef\]](#)
4. Lotfy, K.; El-Bary, A.; Hassan, W.; Alharbi, A.; Almatrafi, M. Electromagnetic and Thomson effects during photothermal transport process of a rotator semiconductor medium under hydrostatic initial stress. *Results Phys.* **2020**, *16*, 102983. [\[CrossRef\]](#)
5. Lotfy, K.; Hassan, W.; El-Bary, A.; Kadry, M.A. Response of electromagnetic and Thomson effect of semiconductor medium due to laser pulses and thermal memories during photothermal excitation. *Results Phys.* **2020**, *16*, 102877. [\[CrossRef\]](#)
6. Lotfy, K.; El-Bary, A.; Tantawi, R. Effects of variable thermal conductivity of a small semiconductor cavity through the fractional order heat-magneto-photothermal theory. *Eur. Phys. J. Plus* **2019**, *134*, 280. [\[CrossRef\]](#)
7. Hobiny, A.; Abbas, I. A GN model on photothermal interactions in a two-dimensions semiconductor half space. *Results Phys.* **2019**, *15*, 102588. [\[CrossRef\]](#)
8. Othman, M.I.; Marin, M. Effect of thermal loading due to laser pulse on thermoelastic porous medium under GN theory. *Results Phys.* **2017**, *7*, 3863–3872. [\[CrossRef\]](#)
9. Alzahrani, F.S.; Abbas, I.A. Photo-thermo-elastic interactions without energy dissipation in a semiconductor half-space. *Results Phys.* **2019**, *15*, 102805. [\[CrossRef\]](#)
10. Jahangir, A.; Tanvir, F.; Zenkour, A. Photo-thermo-elastic interaction in a semiconductor material with two relaxation times by a focused laser beam. *Adv. Astron. Spacecr. Sci. Int. J.* **2020**, *7*, 41–52.
11. Mondal, S.; Sur, A. Photo-thermo-elastic wave propagation in an orthotropic semiconductor with a spherical cavity and memory responses. *Waves Random Complex Media* **2020**, 12–14. [\[CrossRef\]](#)
12. Abbas, I.A. The effects of relaxation times and a moving heat source on a two-temperature generalized thermoelastic thin slim strip. *Can. J. Phys.* **2014**, *93*, 585–590. [\[CrossRef\]](#)
13. Zenkour, A.M.; Abbas, I.A. A generalized thermoelasticity problem of an annular cylinder with temperature-dependent density and material properties. *Int. J. Mech. Sci.* **2014**, *84*, 54–60. [\[CrossRef\]](#)
14. Abbas, I.A. Nonlinear transient thermal stress analysis of thick-walled FGM cylinder with temperature-dependent material properties. *Meccanica* **2014**, *49*, 1697–1708. [\[CrossRef\]](#)
15. Lotfy, K. Effect of variable thermal conductivity during the photothermal diffusion process of semiconductor medium. *Silicon* **2019**, *11*, 1863–1873. [\[CrossRef\]](#)
16. Lotfy, K.; Abo-Dahab, S.; Tantawy, R.; Anwar, N. Thermomechanical Response Model. on a Reflection Photothermal Diffusion Waves (RPTD) for Semiconductor Medium. *Silicon* **2019**, *12*, 199–209. [\[CrossRef\]](#)
17. Hobiny, A.; Abbas, I. Fractional Order GN Model. on Photo-Thermal Interaction in a Semiconductor Plane. *Silicon* **2020**, *12*, 1957–1964. [\[CrossRef\]](#)
18. Abbas, I.A.; Marin, M. Analytical solution of thermoelastic interaction in a half-space by pulsed laser heating. *Phys. E Low-dimensional Syst. Nanostructures* **2017**, *87*, 254–260. [\[CrossRef\]](#)
19. Riaz, A.; Ellahi, R.; Bhatti, M.M.; Marin, M. Study of heat and mass transfer in the Eyring–Powell model of fluid propagating peristaltically through a rectangular compliant channel. *Heat Transf. Res.* **2019**, *50*, 1539–1560. [\[CrossRef\]](#)

20. Bhatti, M.; Ellahi, R.; Zeeshan, A.; Marin, M.; Ijaz, N. Numerical study of heat transfer and Hall current impact on peristaltic propulsion of particle-fluid suspension with compliant wall properties. *Mod. Phys. Lett. B* **2019**, *33*, 1950439. [[CrossRef](#)]
21. Marin, M.; Vlase, S.; Ellahi, R.; Bhatti, M. On the partition of energies for the backward in time problem of thermoelastic materials with a dipolar structure. *Symmetry* **2019**, *11*, 863. [[CrossRef](#)]
22. Marin, M.; Ellahi, R.; Chirilă, A. On solutions of Saint-Venant's problem for elastic dipolar bodies with voids. *Carpathian J. Math.* **2017**, *33*, 219–232.
23. Marin, M.; Nicaise, S. Existence and stability results for thermoelastic dipolar bodies with double porosity. *Contin. Mech. Thermodyn.* **2016**, *28*, 1645–1657. [[CrossRef](#)]
24. Marin, M.; Craciun, E.-M.; Pop, N. Considerations on mixed initial-boundary value problems for micropolar porous bodies. *Dyn. Syst. Appl.* **2016**, *25*, 175–196.
25. Ghiță, C.; Pop, N.; Popescu, I.N. Existence result of an effective stress for an isotropic visco-plastic composite. *Comput. Mater. Sci.* **2012**, *64*, 52–56. [[CrossRef](#)]
26. Song, Y.; Bai, J.; Ren, Z. Study on the reflection of photothermal waves in a semiconducting medium under generalized thermoelastic theory. *Acta Mech.* **2012**, *223*, 1545–1557. [[CrossRef](#)]
27. Mandelis, A.; Nestoros, M.; Christofides, C. Thermoelectronic-wave coupling in laser photothermal theory of semiconductors at elevated temperatures. *Opt. Eng.* **1997**, *36*, 459–468. [[CrossRef](#)]
28. Youssef, H.M.; El-Bary, A.A. Theory of hyperbolic two-temperature generalized thermoelasticity. *Mater. Phys. Mech.* **2018**, *40*, 158–171.
29. Youssef, H. State-space approach on generalized thermoelasticity for an infinite material with a spherical cavity and variable thermal conductivity subjected to ramp-type heating. *Can. Appl. Math. Q.* **2005**, *13*, 4.
30. Das, N.C.; Lahiri, A.; Giri, R.R. Eigenvalue approach to generalized thermoelasticity. *Indian J. Pure Appl. Math.* **1997**, *28*, 1573–1594.
31. Abbas, I.A. Eigenvalue approach in a three-dimensional generalized thermoelastic interactions with temperature-dependent material properties. *Comput. Math. Appl.* **2014**, *68*, 2036–2056. [[CrossRef](#)]
32. Abbas, I.A. Eigenvalue approach for an unbounded medium with a spherical cavity based upon two-temperature generalized thermoelastic theory. *J. Mech. Sci. Technol.* **2014**, *28*, 4193–4198. [[CrossRef](#)]
33. Abbas, I.A. A dual phase lag model on thermoelastic interaction in an infinite fiber-reinforced anisotropic medium with a circular hole. *Mech. Based Des. Struc. Mach.* **2015**, *43*, 501–513. [[CrossRef](#)]
34. Lahiri, A.; Das, B.; Sarkar, S. Eigenvalue approach to thermoelastic interactions in an unbounded body with a spherical cavity. In Proceedings of the World Congress on Engineering, London, UK, 30 June–2 July 2010.
35. Hobiny, A.D.; Abbas, I.A. A study on photothermal waves in an unbounded semiconductor medium with cylindrical cavity. *Mech. Time-Depend. Mater.* **2017**, *21*, 61–72. [[CrossRef](#)]
36. Stehfest, H. Algorithm 368: Numerical inversion of Laplace transforms [D5]. *Commun. ACM* **1970**, *13*, 47–49. [[CrossRef](#)]
37. Song, Y.; Todorovic, D.M.; Cretin, B.; Vairac, P.; Xu, J.; Bai, J. Bending of Semiconducting Cantilevers Under Photothermal Excitation. *Int. J. Thermophys.* **2014**, *35*, 305–319. [[CrossRef](#)]

