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Photo-thermoelastic Investigation of Semiconductor Material Due to Distributed Loads

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ABSTRACT

A dynamic mathematical model of photo-thermoelastic (semiconductor) medium is developed to analyze the deformation due to inclined loads. The governing equations for photo-thermoelastic with dual phase lag model are framed for two-dimensional case and are further simplified by using potential function. Appropriate transforms w.r.t time (Laplace) and w.r.t space variables (Fourier) are employed on the resulting equations which convert the system of equations into differential equation. The problem is examined by deploying suitable mechanical boundary conditions. Specific types of distributed loads as uniformly distributed force and Linearly distributed force are taken to examine the utility of the model. The analytic expressions like displacements, stresses, temperature distribution and carrier density are obtained in the new domain (transformed).To recover the quantities in the physical domain, numerical inversion technique is employed. Numerical computed results with different angle of inclination vs distance are analyzed with and without dual phase lag theories of thermoelasticity in the form of visual representations. It is seen that physical field quantities are sensitive towards photo-thermoelastic and phase lag parameters.

Keywords: Photo-thermal; Semiconductor; Inclined load; Laplace and Fourier transforms.

1 INTRODUCTION

THE Generalized thermoelasticity have many applications in various fields of engineering including soil dynamics, oil extraction, mineral exploration, earthquake prediction and many more. With the advancement in the technologies, semiconducting materials (as silicon (Si)) were used in various branches of engineering and material science. Over the past few years, the study of semiconductor materials through both photoacoustic and photothermal technologies [1,2] are regarded as accepted approach. Mandelis and Hess [3] explored the effective personification in the analysis of photoacoustic and photothermal technologies. The new law of heat conduction take the place of the classical Fourier law and was established as the generalized thermoelastic theory with one relaxation time suggested by Lord and Shulman [4]. Green and Lindsay [5] popularized another generalized thermoelasticity

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theory with two relaxation times. For an anisotropic body the theories of generalized thermoelasticity were continued by Sherief and Dhaliwal [6]. Tzou [7] examined the heat conduction from imperceptible to perceptible extend. The analytical and empirical sense of the Dual phase lag model have been supported in Tzou [8]. Abbas and Zenkor [9] explored the deformation problem with special function applied on temperature in dual phase lag model. Many authors [10-12] studied the effects of electronic deformation in photo-thermoelastic materials. Zenkor, Abouelregal and Aifantis[13] discussed the deformation problem in two-temperature dual-phase-lags theory due to inclined load . By applying fractional order photo-thermoelasticity, Hobiny and Abbas [14] studied problem of wave propagation in photo-thermoelastic medium. Photothermal interactions with dual phase lag in a semiconductor medium containing a sphere with a hole using spherical polar coordinates was discussed by Hobiny and Abbas [15]. Lotfy [16] studied photo-thermal elastic waves in semiconductor medium with pluse heat flux. The study of Photo-thermal-elastic waves in a functionally graded material was investigated by Lotfy and Tantawi [17]. Different authors [18-22] discussed different problems in various mediums such as elastic, thermoelastic and micropolar elastic by applying inclined load. Numerous investigations done on different thermoelasticity theories by various authors[23-29].

Regardless of this, the problem of photo-thermoelastic medium due to inclined load was not done before.

2 BASIC EQUATIONS

The governing equations in the context of the dual phase lag model for heat conduction equations, the plasma and equation of motion can be written as [4, 7, 30, 31]

$$K\left(1+\tau_T\frac{\partial}{\partial t}\right)\theta_{,jj}=-\frac{E_g}{\tau}N+\left(1+\tau_q\frac{\partial}{\partial t}+m\frac{\tau_q^2}{2}\frac{\partial^2}{\partial t^2}\right)\left(\rho C_e\frac{\partial\theta}{\partial t}+\gamma_t T_0\frac{\partial u_{j,j}}{\partial t}\right) \tag{1}$$

$$D_e N_{,jj}=\frac{\partial N}{\partial t}+\frac{N}{\tau}-k\frac{\theta}{\tau} \tag{2}$$

$$(\lambda+\mu)u_{j,ij}+\mu u_{i,jj}-\gamma_n N_{,i}-\gamma_t\theta_{,i}=\rho\ddot{u}_i \tag{3}$$

$$\sigma_{ij}=\left(\lambda u_{j,j}-\gamma_n N-\gamma_t\theta\right)\delta_{ij}+\mu\left(u_{i,j}+u_{j,i}\right) \tag{4}$$

There are three cases: $0\prec\tau_T\prec\tau_q$, $m=1$ (DPL model), $\tau_q=\tau_0\succ 0$, $\tau_T=m=0$ (LS theory), $\tau_q=\tau_T=m=0$ (CT theory), where $N=n-n_0$, n_0 - initial carrier concentration, $\theta=T-T_0$, T_0 -initial temperature, u_i - displacement components, τ_q and τ_T - times , τ_0 -thermal relaxation time, C_e - specific heat , K - thermal conductivity, ρ -density, σ_{ij} -stress tensors, $\gamma_t=(3\lambda+2\mu)\alpha_t$, α_t - linear thermal expansion coefficient, D_e - carrier diffusion coefficient, λ and μ - Lame's constants, τ - photo-generated carrier lifetime, E_g - semiconductor energy gap, E -excitation energy, $\gamma_n=(3\lambda+2\mu)d_n$, d_n - electronic deformation coefficient and $k=\dfrac{\partial n_0}{\partial\theta}$ [32], t -time. A superposed dot represents differentiation with respect to time variable t . δ_{ij} - kronecker delta.

3 MATHEMATICAL MODEL

3.1 Structure

A semiconductor medium with reference temperature T_0 permeated by an inclined line load F_0 acting on the *y*-axis is considered.

For two dimensional problem, The components of displacement vector $\vec{u}$ as:

$$u_1 = u_1(x, z, t) \text{ and}, u_3 = u_3(x, z, t) \tag{5}$$

Carrier density $N = N(x, z, t)$, Temperature $\theta = \theta(x, z, t)$.
Initially the medium is considered at rest. The elementary and consistency conditions are

$$\begin{aligned} &u_1(x, z, 0) = 0 = \dot{u}_1(x, z, 0), \\ &u_3(x, z, 0) = 0 = \dot{u}_3(x, z, 0), \\ &\theta(x, z, 0) = 0 = \dot{\theta}(x, z, 0), \\ &N(x, z, 0) = 0 = \dot{N}(x, z, 0) \; for \; z \geq 0, \; -\infty < x < \infty, \end{aligned} \tag{6}$$

$$u_1(x, z, t) = u_3(x, z, t) = \theta(x, z, t) = N(x, z, t) = 0 \quad \text{for } t > 0 \quad \text{when } z \to \infty . \tag{7}$$

4 SOLUTION METHODOLOGY

To smoothen the solution, the non-dimensional variables are proposed

$$\begin{aligned} &\left(x', z', u_1', u_3'\right) = \eta c\left(x, z, u_1, u_3\right), \; \left(t_{11}', t_{31}', t_{33}'\right) = \frac{1}{\mu}\left(t_{11}, t_{31}, t_{33}\right), \theta' = \frac{\theta}{T_0}, \\ &\left(t', \tau', \tau_0'\right) = \eta c^2\left(t, \tau, \tau_0\right), \; N' = \frac{N}{n_0}, \; F_n' = \frac{F_n}{\mu}, \; F_t' = \frac{F_t}{\mu}, \end{aligned} \tag{8}$$

where $c^2 = \dfrac{\lambda + 2\mu}{\rho}$, $\eta = \dfrac{\rho C_E}{K}$.

Using the Helmholtz equation (dimensionless form)

$$u_1 = \frac{\partial \phi}{\partial x} - \frac{\partial \psi}{\partial z} \quad , \; u_3 = \frac{\partial \phi}{\partial z} + \frac{\partial \psi}{\partial x} \tag{9}$$

Laplace and Fourier transforms determined as:

$$\bar{f}(x, z, s) = \int_0^\infty f(x, z, t)\, e^{-st} dt \; , \tag{10}$$

$$\hat{f}(\xi, z, s) = \int_{-\infty}^\infty \bar{f}(x, z, s)\, e^{i\xi x} dx . \tag{11}$$

and using on (1)-(3) , with (9)-(10) after simplification gives

$$\left(\frac{d^6}{dz^6} + Q\frac{d^4}{dz^4} + N\frac{d^2}{dz^2} + I\right)(\hat{\phi}, \hat{\theta}, \hat{N}) = 0, \tag{12}$$

$$\left(\frac{d^2}{dz^2} - \lambda_4^2\right)\hat{\psi} = 0 , \tag{13}$$

where

$$Q = \frac{1}{A}[B - 3\xi^2 A], N = \frac{1}{A}[C - 2B\xi^2 + 3\xi^4 A],$$
$$I = \frac{1}{A}[B\xi^4 - C\xi^2 + D - A\xi^6], \lambda_4^2 = \xi^2 + \frac{s^2}{g_2},$$

and

$$A = n_1, \ B = n_2 s\left(-1 + \varepsilon_1 \beta_t\right) + n_1\left(\frac{\alpha}{\tau} - \alpha s + s^2\right),$$
$$C = \frac{\beta}{\tau}\left(-\varepsilon_2 + \varepsilon_1 s n_2 \beta_n\right) - \alpha n_2\left(s + \frac{1}{\tau}\right) + n_2 s^3 + n_1 \alpha s^2\left(s - \frac{1}{\tau}\right) + \varepsilon_1 s n_2 \beta_t\left(1 - \alpha s + \frac{1}{\tau}\right),$$
$$D = \frac{\beta \varepsilon_2 s^2}{\tau^2} + \frac{\alpha n_2 s^2}{\tau} + \alpha s^3 n_2,$$

where

$$g_1 = \frac{\lambda + \mu}{\lambda + 2\mu}, \quad g_2 = \frac{\mu}{\lambda + 2\mu}, \quad \beta_n = \frac{\gamma_n n_0}{(\lambda + 2\mu)}, \quad \beta_t = \frac{\gamma_t T_0}{(\lambda + 2\mu)}, \quad \alpha = \frac{1}{D_e \eta},$$
$$\beta = \frac{k T_0}{D_e n_0 \eta}, \ \varepsilon_1 = \frac{\gamma_t}{K\eta}, \quad \varepsilon_2 = \frac{E_g n_0}{T_0 \eta K}, \ n_1 = \left(1 + \tau_T s\right), \ n_2 = \left(1 + \tau_q s + m s^2 \frac{\tau_q^2}{2}\right)$$

$\pm\lambda_j \ (j = 1,2,3)$ specifies roots of (12) whereas $\pm\lambda_4$ give roots of (13). Using the radiation condition, the solution of (12) and (13) takes the form

$$\hat{\phi} = A_1 e^{-\lambda_1 z} + A_2 e^{-\lambda_2 z} + A_3 e^{-\lambda_3 z}, \tag{14}$$

$$\hat{\theta} = d_1 A_1 e^{-\lambda_1 z} + d_2 A_2 e^{-\lambda_2 z} + d_3 A_3 e^{-\lambda_3 z}, \tag{15}$$

$$\hat{N} = e_1 A_1 e^{-\lambda_1 z} + e_2 A_2 e^{-\lambda_2 z} + e_3 A_3 e^{-\lambda_3 z}, \tag{16}$$

$$\hat{\psi} = A_4 e^{-\lambda_4 z} \tag{17}$$

where

$$d_i = \frac{P^* \lambda_i^2 + Q^*}{R^* \lambda_i^2 + S^*}, \ e_i = \frac{U^* \lambda_i^2 + V^*}{X^* \lambda_i^2 + T^*}, \qquad i = 1,2,3,$$
$$P^* = \frac{1}{\beta_t}, Q^* = \frac{-\xi^2 - s^2}{\beta_t}, R^* = \frac{z}{\beta}, S^* = -\frac{\alpha\tau}{\beta} + \frac{\alpha}{\beta} + \frac{\beta_n}{\beta_t} - \frac{\xi^2 z}{\beta}$$

where $A_i \ (i = 1,2,3,4)$ being arbitrary constants.

5 BOUNBARY CONDITIONS

To evaluate the unknown parameters, we intended at $z = 0$

(a) F_n applied in the positive z-axis

(b) F_t applied in the positive *x*-axis

$$(i)\ t_{33}(x,z,t)=-F_n\psi_1(x)H(t)\ ,\quad (ii)\ t_{31}(x,z,t)=-F_t\psi_2(x)H(t)\ ,\quad (iii)\ \theta=0,\quad (iv)\ N=0\ ,\quad \text{at } z=0 \tag{18}$$

where F_n and F_t are the magnitude of forces , $H(t)$ - Heaviside unit step function, $\psi_1(x)$ - vertical load distribution, $\psi_2(x)$ - horizontal load distribution. Making use of (4)-(9) in (18) by applying (10)-(11) and $\hat{\phi},\hat{\theta},\hat{N}$ and $\hat{\psi}$ from (14)-(17)in the emerging equations, we obtain the expressions for components of displacement, stress, temperature distribution and carrier density

$$\hat{u}_1=\frac{1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[(-i\,\xi)(\Delta_1e^{-\lambda_1 z}-\Delta_3e^{-\lambda_2 z}+\Delta_5e^{-\lambda_3 z})+\lambda_4\Delta_7e^{-\lambda_4 z}] \\ +F_t\hat{\psi}_2(\xi)[(-i\,\xi)(\Delta_2e^{-\lambda_1 z}-\Delta_4e^{-\lambda_2 z}+\Delta_6e^{-\lambda_3 z})-\lambda_4\Delta_8e^{-\lambda_4 z}]\}\ , \tag{19}$$

$$\hat{u}_3=\frac{-1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[\lambda_1\Delta_1e^{-\lambda_1 z}-\lambda_2\Delta_3e^{-\lambda_2 z}+\lambda_3\Delta_5e^{-\lambda_3 z})+i\,\xi\Delta_7e^{-\lambda_4 z}] \\ +F_t\hat{\psi}_2(\xi)[\lambda_1\Delta_2e^{-\lambda_1 z}-\lambda_2\Delta_4e^{-\lambda_2 z}+\lambda_3\Delta_6e^{-\lambda_3 z})-i\,\xi\Delta_8e^{-\lambda_4 z}]\}, \tag{20}$$

$$\hat{t}_{33}=\frac{1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[s_1\Delta_1e^{-\lambda_1 z}-s_2\Delta_3e^{-\lambda_2 z}+s_3\Delta_5e^{-\lambda_3 z}+s_4\Delta_7e^{-\lambda_4 z}] \\ +F_t\hat{\psi}_2(\xi)[s_1\Delta_2e^{-\lambda_1 z}-s_2\Delta_4e^{-\lambda_2 z}+s_3\Delta_6e^{-\lambda_3 z}-s_4\Delta_8e^{-\lambda_4 z}]\}\ , \tag{21}$$

$$\hat{t}_{31}=\frac{1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[\lambda_1\Delta_1e^{-\lambda_1 z}-\lambda_2\Delta_3e^{-\lambda_2 z}+\lambda_3\Delta_5e^{-\lambda_3 z}-m_1\Delta_7e^{-\lambda_4 z}] \\ +F_t\hat{\psi}_2(\xi)[\lambda_1\Delta_2e^{-\lambda_1 z}-\lambda_2\Delta_4e^{-\lambda_2 z}+\lambda_3\Delta_6e^{-\lambda_3 z}+m_1\Delta_8e^{-\lambda_4 z}]\}\ , \tag{22}$$

$$\hat{\theta}=\frac{1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[d_1\Delta_1e^{-\lambda_1 z}-d_2\Delta_3e^{-\lambda_2 z}+d_3\Delta_5e^{-\lambda_3 z}] \\ +F_t\hat{\psi}_2(\xi)[d_1\Delta_2e^{-\lambda_1 z}-d_2\Delta_4e^{-\lambda_2 z}+d_3\Delta_6e^{-\lambda_3 z}]\}\ , \tag{23}$$

$$\hat{N}=\frac{1}{\Delta s}\{F_n\hat{\psi}_1(\xi)[t_1\Delta_1e^{-\lambda_1 z}-t_2\Delta_3e^{-\lambda_2 z}+t_3\Delta_5e^{-\lambda_3 z}] \\ +F_t\hat{\psi}_2(\xi)[t_1\Delta_2e^{-\lambda_1 z}-t_2\Delta_4e^{-\lambda_2 z}+t_3\Delta_6e^{-\lambda_3 z}]\}\ , \tag{24}$$

where

$$\Delta=\mu\{[-s_4\lambda_1-m_1s_1]\,\Delta_{10}+[s_4\lambda_2+m_1s_2]\,\Delta_{20}+[-s_4\lambda_3-m_1s_3]\,\Delta_{30}\},$$
$$\Delta_{1,2}=(\mu\lambda_3,s_4)\Delta_{10}\ ,\qquad \Delta_{3,4}=(\mu\lambda_4,s_4)\Delta_{20}\ ,\qquad \Delta_{5,6}=(\mu\lambda_4,s_4)\Delta_{30}\ ,$$
$$\Delta_7=\mu[\lambda_1\Delta_{10}-\lambda_2\Delta_{20}+\lambda_3\Delta_{30}]\ ,$$
$$s_i=b_5\lambda_i^2-b_6i\,\xi-b_3e_i-b_4d_i\ ,\qquad (i=1,2,3),$$
$$s_4=(i\,\xi b_5+b_6)\lambda_4,$$
$$\Delta_{10}=d_2e_3-d_3e_2$$
$$\Delta_{20}=d_1e_3-d_3e_1$$
$$\Delta_{30}=d_1e_2-d_2e_1$$
$$\Delta_8=S_1\Delta_{10}-S_2\Delta_{20}-S_3\Delta_{30}$$

$$b_1 = \frac{(\lambda + 2\mu)}{\mu},\ b_2 = \frac{\lambda}{\mu},\quad b_3 = \frac{\gamma_n n_0}{\mu}\ ,\ b_4 = \frac{\gamma_t T_0}{\mu},\ m_1 = \frac{\lambda_4^2 + \xi^2}{2i\,\xi}$$

5.1 Uniformly distributed force

Implementing

$$\{\psi_1(x),\psi_2(x)\} = \begin{cases} 1\ if & |x| \le c\,, \\ 0\ if & |x| > c\,, \end{cases}$$

On (18), Laplace and Fourier transform with respect to the pair $(x\,,\xi)$ for above mention case (non-dimensional) becomes

$$\{\hat{\psi}_1(\xi),\hat{\psi}_2(\xi)\} = \left[2\sin\left(\frac{\xi c_1 c}{\omega_1^*}\right)\Big/\xi\right],\qquad \xi \ne 0. \tag{25}$$

5.2 Linearly distributed force

Implementing

$$\{\psi_1(x),\psi_2(x)\} = \begin{cases} 1-\dfrac{|x|}{c} & if \quad |x| \le c\,, \\ 0 & if \quad |x| > c\,, \end{cases}$$

On (18), utilizing (8) , (10)-(11) exert

$$\{\hat{\psi}_1(\xi),\hat{\psi}_2(\xi)\} = \frac{2[1-\cos(\xi c_1 a/\omega_1^*)]}{\xi^2 c_1 a/\omega_1^*}\,. \tag{26}$$

Using (26) in (19)-(24),the displacement, stress, temperature distribution and carrier density are established.

6 UTILIZATION

F_0 , inclined load *ith* angle of inclination δ is applied on *y*-axis.

$$F_n = F_0\cos\delta,\qquad F_t = F_0\sin\delta \tag{27}$$

Using Eq. (27) in (19)-(24) and along with (25)-(26), we find the components for concentrated force applied on the surface of photo-thermo-elastic medium(semiconductor medium).

7 NOTABLE CASES

Omitting the photothermal effect (i.e. $E_g = 0$, $D_e = 0$, $\tau = 0$), in (19)-(24), with (25)-(27) we find the components in generalized thermoelastic half-space.

8 INVERSION OF THE TRANSFORMATION

To acquire the results in the physical domain, invert the transforms in (19)-(24) by

$$\bar{f}(x,z,s)=\frac{1}{2\pi}\int_{-\infty}^{\infty}e^{-i\xi x}\hat{f}(\xi,z,s)d\xi=\frac{1}{\pi}\int_{0}^{\infty}(\cos(\xi x)f_e-i\sin(\xi x)f_0)d\xi, \tag{28}$$

where f_e and f_0 are, respectively, even and odd parts of the function $\hat{f}(\xi,z,s)$.

9 NUMERICAL RESULTS AND DISCUSSION

We choose silicon material for numerical purpose to show the theoretical results as by [33].

$$\begin{gathered}C_e=695Jkg^{-1}k^{-1},\quad \mu=5.46\times10^{10}Nm^{-2},\quad \lambda=3.64\times10^{10}Nm^{-2},\quad E_g=1.11eV,\\ s_0=2ms^{-1},\quad E=2.33eV,\ D_e=2.5\times10^{-3}m^2s^{-1},\ \alpha_t=3\times10^{-6}k^{-1},\ K=150Wm^{-1}k^{-1}\\ \rho=2330kgm^{-3},\ \tau=5\times10^{-5}s,\ n_0=10^{20}m^{-3},\ d_n=-9\times10^{-31}m^3,T_0=300k\end{gathered} \tag{29}$$

The values of normal displacement u_3, normal stress t_{33}, temperature distribution θ and carrier density N for Dual phase photo-thermo-elasticity (DP) and without photo-thermo-elasticity With Dual Phase(WDP) (for $\delta=0^0$ and $\delta=90^0$). Time as $t=0.5$ (non-dimensional). The solid line and the small dashed without center symbol predict the variations DP for different values of δ whereas the solid and the small dashed and with center symbol predict the variations of WDP for distinct $\delta's$.

9.1 Uniformly Distributed Force (UDF)

At initial angle i.e $\delta=0^0$ the variations of normal displacement u_3 for DP and WDP has opposite oscillatory behavior in the whole range. At at extreme angle i.e $\delta=90^0$ for DP it has little alteration near zero whereas for WDP u_3 shows oscillatory pattern near zero. (Fig.1)

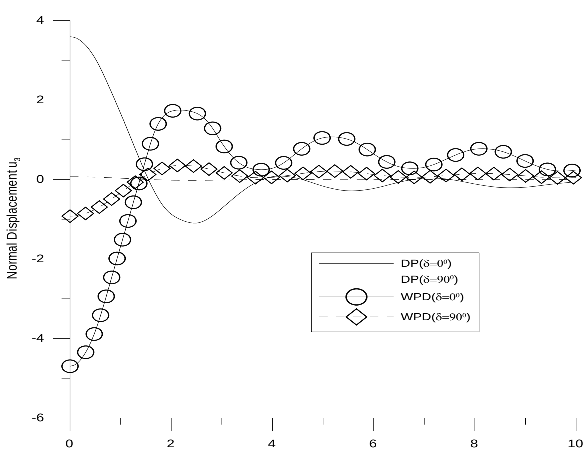

Fig.1
Variation of u_3 with *x*.

Fig.2 represents the variation of normal stress t_{33} along x .It is observed that t_{33} at $\delta=0^0$ for DP shows sharp increase in $0\le x\le 2$ sharp decrease in $2\le x\le 4$ and have oscillatory pattern in remaining whereas $\delta=90^0$ it follows small variations in the whole range $0 \le x \le 10$. Further t_{33} for WDP at both angels it starts decreasing in $0 \le x \le 2$ and then has little alteration near zero in the rest range.

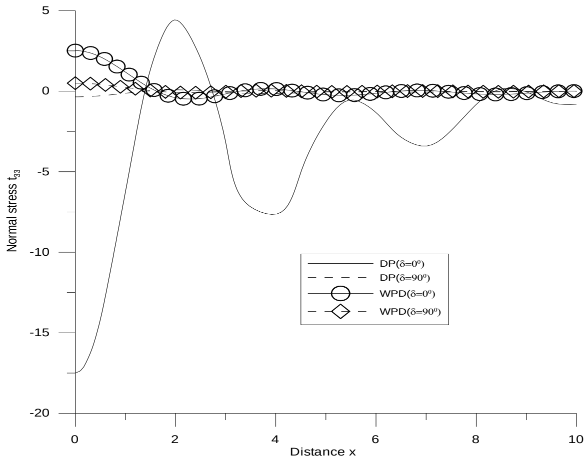

Fig.2
Variation of t_{33} with *x*.

Fig.3 shows θ with x . The patterns of curves for both DP and WDP at initial and extreme angel are same with different magnitude and lessen gradually with jump in x till achieving values zero.

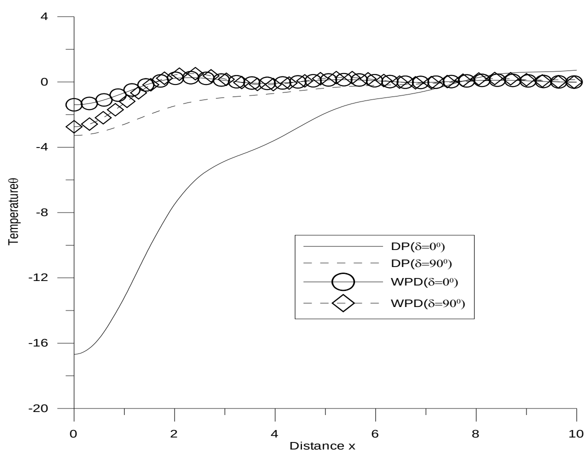

Fig.3
Variation of θ with *x*.

Fig.4 displays N along x . It noted, N at $\delta = 0^0$ and $\delta = 90^0$ follow same pattern upto $0 \le x \le 6$ then reduces to zero with further increase in x .

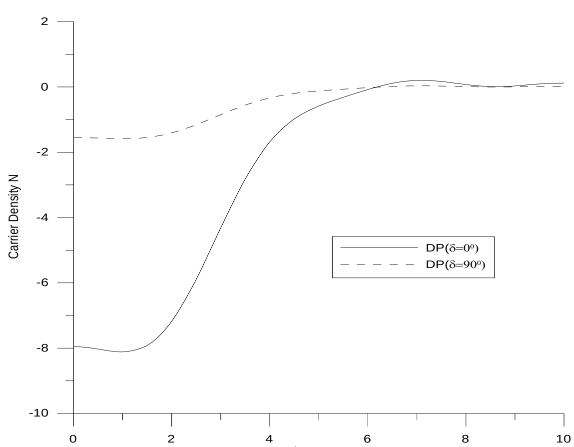

Fig.4
Variation of N with distance *x*.

9.2 Linearly distributed force (LDF)

At both initial and extreme angels u_3 for DP and WDP follows almost same pattern .The values of u_3 for all curves move toward zero with increase in *x* (Fig.5).

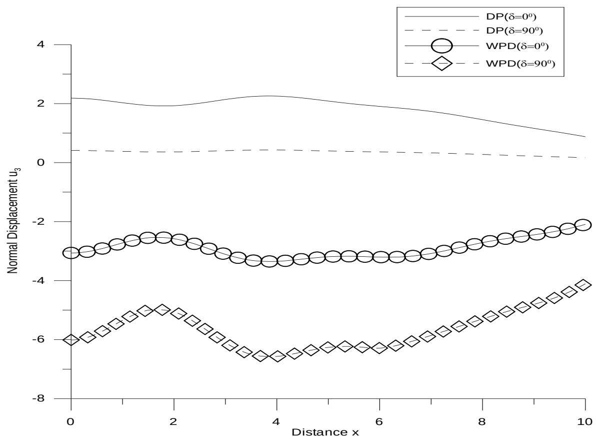

Fig.5
Variation of u_3 with *x*.

From Fig.6 evident that t_{33} incase of DP for both $\delta = 0^0$, $\delta = 90^0$ shows oscillatory behavior with different magnitudes whereas for WDP at both $\delta = 0^0$ and $\delta = 90^0$ follow same pattern further with rise in *x* all curves for t_{33} converges to zero.

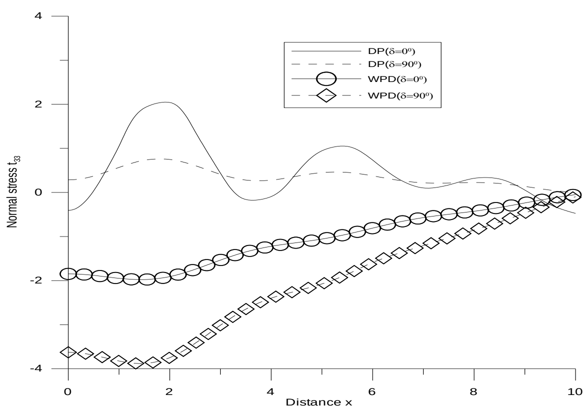

Fig.6
Variation of t_{33} with *x*.

Fig.7 depicts the variation of temperature distribution θ with distance *x*. The values of θ at both initial and extreme angels for DP and WDP lessen gradually with jump up *x* till achieving values zero.

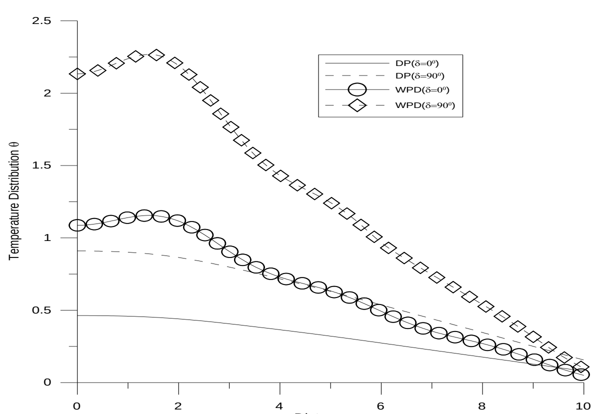

Fig.7
Variation of θ with *x*.

Fig. 8 displays the carrier density N with x. The values of N monotonically decrease and reaches to zero at $x = 10$ at both initial and extreme angel.

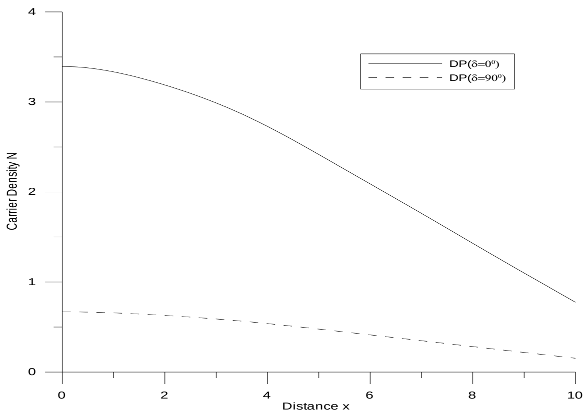

Fig.8
Variation of N with x.

10 CONCLUSIONS

Problem is examined to explain the impact of angle of inclination and phase lag on the physical quantities like displacements, stresses, temperature distribution and carrier density function.

This article is to analyze the deformation due to inclined load in photothermoelastic with dual phase lags medium. Laplace transform w.r.t time and Fourier transform w.r.t space variable are employed to study the problem. Impact of angle of inclination as well as phase lag parameters on the physical quantities like displacements , stresses, temperature distribution and carrier density function are examined analytically and numerically for UDF and LDF . On the basis of the study following conclusions are made:

(a) Uniformly Distributed Force(UDF)

(i) Normal displacement observe opposite behaviour for limited domain in case of with and without phase lags.

(ii) High oscillation on normal stress normal force in comparison to tangential force.

(iii) Magnitude of temperature field decrease due to phase lags and normal force.

(iv) Tangential force increases the magnitude values of carrier density function.

(b) Linear Distributed Force (LDF)

(i) Phase lags increased the magnitude of u_3 for both the forces. Also, away from the source application opposite behaviour is observed.

(ii) Near the boundary surface values of normal stress are opposite in comparison to UDF. Also phase lag increase the values of normal stress due to normal force.

(iii) Phase lags decrease the values of θ . Also, away from the source application all computed values converge to boundary surface. Also, opposite variation is noticed in comparison to UDF.

(iv) Magnitude of N is higher in case of normal load in contrast to tangential load.

Numerically computed results with different angle of inclination vs. distance are analyzed with help of visual representation for photo-thermoelastic model with and without dual phase lags. It is observed that body is stressed to a more extend when the inclination is in the normal direction in contrast to the tangential direction. From this we may conclude that the deformation of the body increases with angle of inclination of the source with normal direction.

The result obtained in this study are significant to analysts working in material science, continuum thermodynamics, earthquake engineering, geomechanics are designs of new materials where the major concerned is to examine displacements, stresses, temperature distribution and carrier density field due to application of certain sources.

REFERENCES

[1] Mandelis A., 1987, *Photoacoustic and Thermal Wave Phenomena in Semiconductors*, Elsevier Science, New York.

[2] Almond D. P., Patel P., 1996, *Photothermal Science and Techniques*, Springer Science and Business Media.

[3] Mandelis A. , Hess P., 2000, *Semiconductors and Electronic Materials*, Spie Press.

[4] Lord H.W., Shulman Y., 1967, A generalized dynamical theory of thermoelasticity, *Journal of the Mechanics and Physics of Solids* **15**: 299-309.

[5] Green A. E., Lindsay K. A.,1972, Thermoelasticity, *Journal of Elasticity* **2**: 1 -7.

[6] Dhaliwal R.S., Sherief H.,1980, Generalized thermoelasticity for anisotropic media, *Applied Mathematics* **33**: 1-8.

[7] Tzou D.Y.,1995(a), A unified field approach for heat conduction from macro-to-microscale, *Journal of Heat Transfer* **117** : 8-16.

[8] Tzou D.Y., 1995(b), Experimental support for the lagging behavior in heat propagation, *Journal of Thermophysics and Heat Transfer* **9**(4): 686.

[9] Abbas I.A., Zenkor A.M., 2014, Dual-phase-lag model on thermoelastic interactions in a semi-infinite medium subjected to a ramp-type heating, *Journal of Computational and Theoretical Nanoscience* **11**(3): 642-645.

[10] McDonald F.A., Wetsel G.C., 1978, Generalized theory of photoacoustic effect, *Journal of Applied Physics* **49**: 2313.

[11] Jackson W.M., Nabil A., 1980, Piezoelectric photoacoustic dection: theory and experiment, *Journal of Applied Physics* **51**: 3343.

[12] Stearns R. ., Kino G.S., 1985, Effect of electronic strain on photoacoustic generalization in silicon, *Applied Physics Letters* **7**: 1048.

[13] Zenkor A.M., Abouelregal A.E., Aifantis E.C., 2016, Two-temperature dual-phase-lags theory in a thermoelastic solid half-space due to inclined load, *Mechanical Science* **7**: 179-187.

[14] Hobiny A., Abbas I., 2018(a), Analytical solution of fractional order photo-thermoelasticity in non-homogeneous semiconductor medium, *Multidiscipline Modeling in Materials and Structures* **14**: 1017-1030.

[15] Hobiny A., Abbas I., 2018(b), A DPL model of photo-thermal interaction in an infinite semiconductor material containing a spherical hole, *The European Physical Journal Plus* **11**: 133.

[16] Lotfy Kh., 2019, Analytical solutions of photo-thermal elastic waves in a semiconductor material due to pulse heat flux with thermal memory, *Silicon* **12**: 263-273.

[17] Lotfy Kh., Tantawi, 2019, Photo-thermal-elastic interaction in a functionally graded material (FGM) and magnetic field, *Silicon* **12**: 295-303.

[18] Kuo J.T., 1969, Static response of multilayered medium under inclined surface loads, *Journal of Geophysical Research* **74**(12): 3195-3207.

[19] Kumar R., Rani L., 2005, Response of thermoelastic half-space with voids due to inclined load, *International Journal of Applied Mechanics and Engineering* **10**(2): 281-294.

[20] Sharma N., Kumar R., Lata P., 2015, Disturbance due to inclined load in transversely isotropic thermoelastic medium with two temperature and without energy dissipation, *Material Physics and Mechanics* **22**(2): 107-117.

[21] Othman M.A., Abo-Dahab S.M., Alosaimi H., 2018, The effect of gravity and inclined load in micropolar thermoelastic medium possessing cubic symmetry under G-N theor, *Journal of Ocean Engineering and Science* **3**(4): 288-294.

[22] Lata P., Kaur I., 2019, Effect of inclined load on transversely isotropic magneto thermoelastic rotating solid with harmonic source, *Advances in Material Research* **8**(2): 83-102.

[23] Abd-alla A.N., Abbas I. A., 2002, A problem of generalized magnetothermoelasticity for an infinitely long, perfectly conducting cylinder, *Journal of Thermal Stresses* **25**(11): 1009-1025.

[24] Abbas I. A., 2006, Natural frequencies of a poroelastic hollow cylinder, *Acta Mechanica* **186**: 229-237.

[25] Palani G., Abbas I. A., 2009, Free convection MHD flow with thermal radiation from an impulsively started vertical plate, *Nonlinear Analysis: Modelling and Control* **14**(1): 73-84.

[26] Abbas I.A., Abd-alla A.N., Othman M., 2011, Generalized magneto-thermoelasticity in a fiber-reinforced anisotropic halfspace, *International Journal of Thermophysics* **32**(5): 1071-1085.

[27] Abbas I.A., 2014, Eigenvalue approach in a three-dimensional generalized thermoelastic interactions with temperature-dependent material properties, *Computers & Mathematics with Applications* **68**(12): 2036-2056.

[28] Abbas I.A., Marin M., 2017, Analytical solution of thermoelastic interaction in a half-space by pulsed laser heating, *Physica E: Low-Dimensional Systems and Nanostructures* **87**: 254-260.

[29] Hobiny A., Abbas I.A., 2018, Analytical solutions of photo-thermo-elastic waves in a non-homogenous semiconducting material, *Results in Physics* **10**: 385-390.

[30] Todorvo D.M., 2003, Plasma, thermal and elastic waves in semiconductors, *Review of Scientific Instruments* **74**: 582.

[31] Todorvo D.M., 2005, Plasmaelastic and thermoelastic waves in semiconductors, *Journal de Physique IV* **125**: 551-555.

[32] Mandelis A., 1997, Thermoelectronic-wave-coupling in laser photothermal theory of semiconductors at elevated temperature, *Optical Engineering* **36**(2): 459-468.

[33] Song Y., 2014, Bending of semiconducting cantilevers under photothermal excitation, *International Journal of Thermophysic* **35**(2): 305-319.