Mustansiriyah Journal of Pure and Applied Sciences, Print ISSN: 2957-9910. Online ISSN: 2957-9929, Vol. 4, No. 2, 2026, Pages 22-32
DOI: 10.47831/mjpas.v4i2.378

MJPAS

MUSTANSIRIYAH JOURNAL OF PURE AND APPLIED SCIENCES

Journal homepage:
https://mjpas.uomustansiriyah.edu.iq/index.php/mjpas

RESEARCH ARTICLE - PHYSICS

Electrical contribution in heat transfer at Germanium between 75K and 375K by Comsol Multiphysics

Ali K. Mohammed Ali *

Ministry of Education, General Directorate of Education in Rusafa I, Baghdad, Iraq.

* Corresponding author E-mail: g66gg166@gmail.com

Article Info.	Abstract
Article history: Received 17 January 2025 Accepted 21 April 2025 Publishing 30 June 2026	This article models germanium's thermoelectric properties since semiconductors are increasingly used in current technologies. Modelling and simulation are necessary because testing new, inventive concepts in a lab which needs time and money. This work discuss. heating the germanium model to determine its electrical conductivity. During the simulation, one end of the semiconductor is supplied with 10 A of current while the other is connected to the ground. Using COMSOL Multiphysics, we found that a model of a semiconductor's electrical properties (electric field, current density, space charge density, external current density) varied with temperature. As the germanium model was heated from 75K to 375K, an increase in the electrical properties was observed. This, in turn, increase the semiconductor's (germanium) electrical conductivity.

The official journal published by the College of Education at Mustansiriyah University

Keywords: current density, heating, simulation, thermoelectricity, Comsol.

1. Introduction

Energy is critical to the functioning of our modern society. Oil, gas, and coal are the traditional fuel sources for power plants. Oil and gas reserves are dwindling, and their combustion has environmental risks; as a result, people are looking for inexpensive ways to generate sustainable energy. Photovoltaics, nuclear power, biogas, wind power, and thermoelectricity are only a few of the renewable energy sources [1]. The various approaches have their benefits and drawbacks. Solar cells, for instance, can generate power throughout the day, but their production necessitates sophisticated machinery. Generating nuclear power requires expensive and potentially dangerous nuclear power reactors [2]. As with solar power, wind energy can only be generated in particularly windy regions. However, thermoelectricity is a simple and low-cost option for producing clean electricity. Seebeck's now-famous 1821 statement describes the Seebeck effect, the foundation of thermoelectricity [3]. Electrical conductivity is an essential material property that specifies how easily electric current may travel through a substance. Conductors carry current. While Insulators impede current [4]. When considering current flow, certain materials are between conductors and insulators and are called semiconductors. The flow of current through a semiconductor is temperature dependent [5]. With a temperature rise, semiconductors exhibit greater electrical conductivity. As the temperature of a material goes up, more and more electrons may move freely from the valence band into the conduction band. This makes the material more conductive [6]. At low enough temperatures, quantum mechanical tunnelling ('hopping') between defect states near the Fermi level dominates charge carrier transport in disordered semiconductors. So, as the temperature goes down, the activation energy of the electrical conductivity often goes down slowly [7]. In the past, Monte Carlo simulation has been used to investigate this scenario for the case of an energy-independent density of localised states by simulating the carrier hopping mobility inside a very large computer-generated random array of sites (DOS [8]. The resultant data was analyzed using a novel approach, it has found remarkable agreement with the simulated DOS. In this work, the method was further developed so that it can be used to measure DC electrical conductivity data [9]. The simulation data were found to be easy to implement and consistent with DOS power and strength dependence. It has already been applied to all the previous different experimental trials. It removes the Mott "$T^{-1/4}$" model's significant inconsistencies [10]. It has been shown that the organization of the "transfer energy" within the local state distribution helps explain the jumping behavior at low temperatures [11]. Semiconductive germanium is one of the most interesting thermoelectric materials, and this article [12] talks about research on its electric and thermoelectric properties [13]. This study aims to assess the efficacy of germanium in the electronics and solar cell sectors.

2. Modeling in Comsol Multiphysics

In the Multiphysics package of Comsol, a two-dimensional model is employed to analyze a semiconductor at a specific temperature [15]. As can be observed in Figure (1) and table (1), the semiconductor that was used has a rectangle with dimensions of (width 1 cm, height 1 cm) and a square with dimensions of (side length 0.2 cm, x = 0.4 cm, y = 0.4cm). The simulation employed was selected [14]. The thermoelectric effect encompasses both the transfer of heat in solids and the flow of electric current at the same time [16]. As a result of this physics, the boundaries that are subjected to temperature (75 K, 150 K, 225 K, 300 K, and 375 K) are selected [17]. Additionally, the amount of electric current (10 A) for semiconductors is determined in order to determine the effect of (electric field, current density, charge density, and external current density) with the change in temperature in order to determine the electrical conductivity of the semiconductor. In the first table, the parameters that were utilized in the simulation are presented. [18].

Table 1. Germanium physical characteristics.

Parameters	value
electrical conductivity	2.12 s\m
relative permittivity	16
seebeck coefficient	330uv\K
Density	5.323 g/cm^3
Conductivi	0.58 W cm^{-1} °C^{-1}

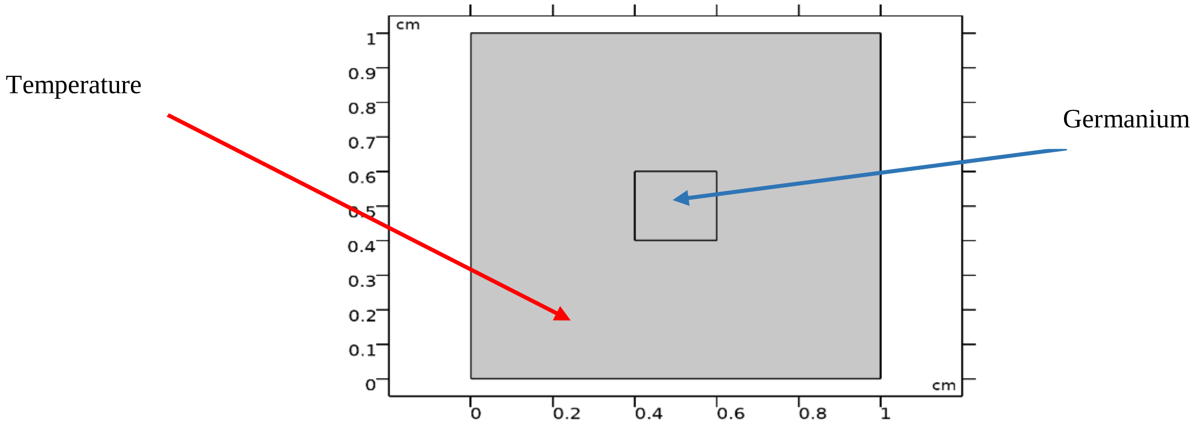


Fig. 1. Geometrical model of semiconductor.

3. Simulated physics equations

The heat equation is the basis for the mathematical modeling done in Comsol Heat Transfer in Solids module [19]. This equation may be written as follows see table (2):

3.1. Solid

$$d_z p C_p U \cdot \nabla T + \nabla \cdot q = d_z Q + q_0 + d_z Q_{ted} \quad (1)$$

$$q = -d_z k \nabla T \quad (2)$$

3.2. Thermal Insulation

$$-n \cdot q = 0 \quad (3)$$

3.3. Temperature

$T = T_0$ (4)

In the COMSOL electric current module, mathematical modelling is performed using the current equation. The formula for this expression is as follows [20]:

3.4. Electric Current

$\nabla \cdot J = Q_{j\cdot v}$ (5)

$J = \sigma E + J_e$ (6)

$E = -\nabla V$ (7)

3.5. Current Conservation

$\nabla \cdot J = Q_{j\cdot v}$ (8)

$J = \sigma E + J_e$ (9)

$E = -\nabla V$ (10)

3.6. Electric Insulation

$n. J = 0$ (11)

3.7. Ground

$v = 0$ (12)

3.8. Terminal

$\int_{\partial\Omega} J \,.\, ndS = I_0$ (13)

3.9. Thermoelectric Effect

$p = ST$ (14)

$q = p J$ (15)

$J_{e=-\sigma s}\nabla T$ (16)

3.10. Electromagnetic Heating

$PC_p u \cdot \nabla T = \nabla \cdot (k\nabla T) + Q_e$ (17)

$Q_e = J \,.\, E$ (18)

Table 2. Physics Symbols

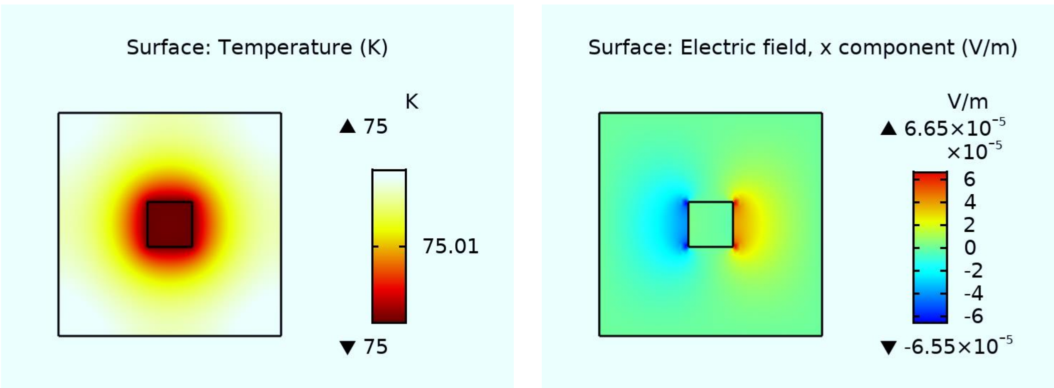
quantity	Symbol	quantity	symbol
Q	Heat	p	pressure
T	temperature change	s	seebeck coefficient
ρ	Resistivity	d	distance
C	heat capacity	v	potential
q	absorbed heat	∇v	potential change
u	Mobility	T	temperature
E	electric field	I_0	initial intensity
J	current density	T_0	initial temperature

σ	electrical conductivity	q_0	initial absorbed
k	thermal conductivity	u	permeability
Cp	specific heat	Q_e	electron heat
Q	Heat	J_e	electron current density
$\mathbf{d_z}$	atomic distance	Q_{ted}	final temperature
$\mathbf{Q_{j.v}}$	electric heat	∇	change

4. Results

4.1. Temperature-electric field relationship

Figure (2) depicts a simulation of the change in the electric field strength of a semiconductor (germanium) as a function of temperature. The simulation was carried out using thermal simulation software. The electric field strength distributions may be seen to imply an increase when the temperature rises across all five distinct values. This is something that can be observed. Throughout the entirety of the simulation that was carried out with the COMSOL Multiphysics software, this was the correct outcome. Because there is a heat source in the middle of the semiconductor, it is feasible to detect that the electric field strength of the semiconductor in the middle is greater than that of any other end. This is because the heat source is located in the middle of the semiconductor. The fact that there is a positive relationship between the electric field and thermal energy is demonstrated by the fact that the electric field increases in proportion to the amount of thermal energy that is introduced, and the electric field decreases in proportion to the amount of thermal energy that is introduced. When the temperature was 75 K, the electric field strength was 6 x 10^{-5} v/m. This was the value that was observed. A strength of 15 x 10^{-5} v/m was seen in the electric field when the temperature was measured to be 150 K. When the temperature reached 375 K, the electric field voltage increased to 50 x 10^{-5} v/m. This was the highest value that was observed. It is evident from this that the values of the electric field strength are not constant but rather change in a dynamic way in response to variations in the temperature that is influencing the situation.



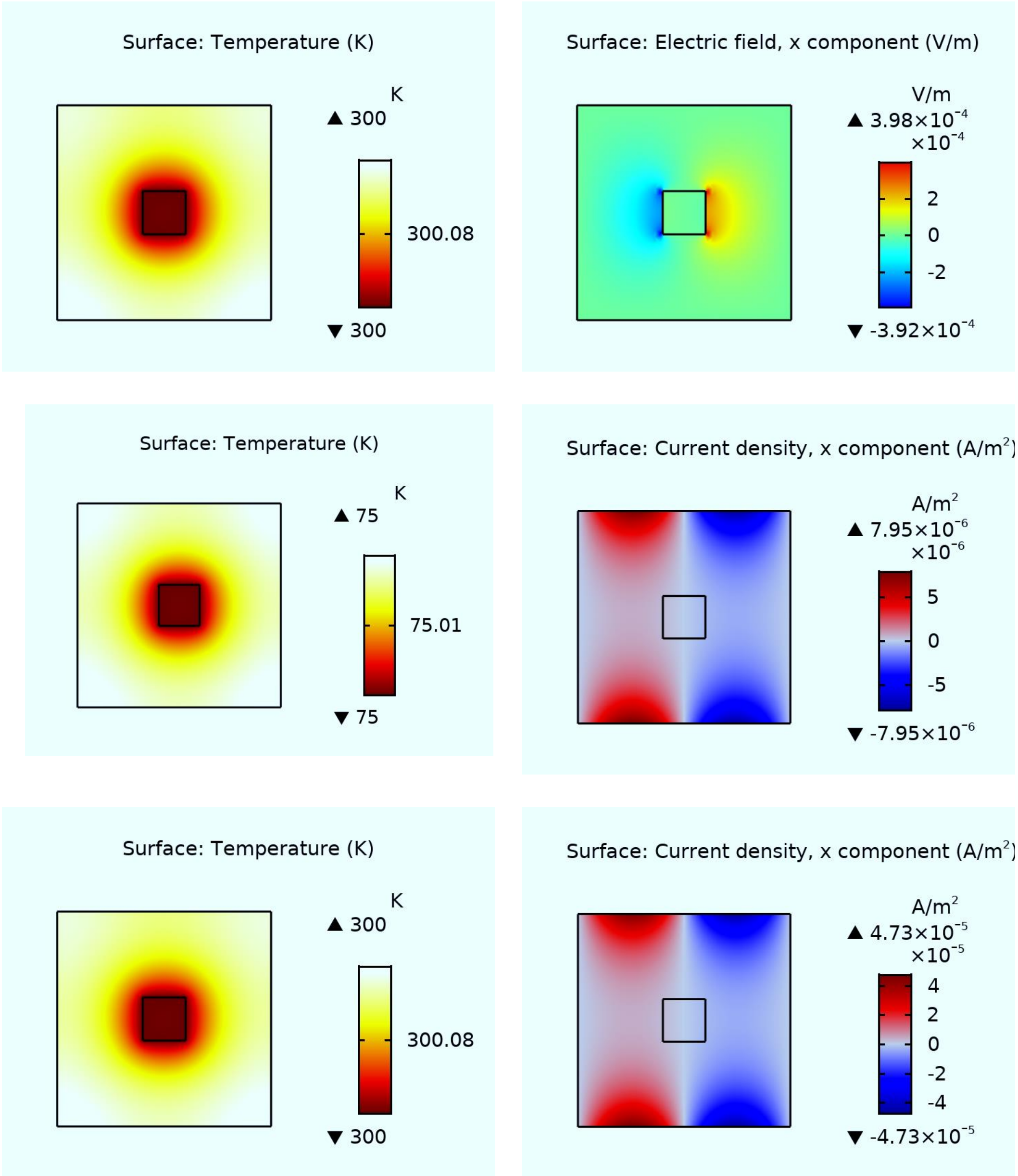


Fig. 2. Electric field and current density at 75 K and 300 K in temperature.

The results showed in the table (3) an increase in the space charge density values (3.7,10,15,22,29) x $10^{-9}\frac{c}{m^3}$, and an increase in the external current density values (1,4,6,8,11) x $10^{-2}\frac{A}{m^2}$ .This is because as the temperature goes up, a lot of electrons move from the valence bund to the conduction bund, and the value of the electrical conduction goes up a lot. As a result, the surface charge density values and the external current density values both went up.

Table 3. The simulation reveals the electrical characteristics of germanium.

Temperature (K)	Electric field ($\frac{V}{m}$)	current density ($\frac{A}{m^2}$)	space charge density ($\frac{c}{m^3}$)	external current density ($\frac{A}{m^2}$)
75	6 x 10^{-5}	8 x 10^{-6}	3.7 x 10^{-9}	1 x 10^{-2}
150	15 x 10^{-5}	20 x 10^{-6}	10 x 10^{-9}	4 x 10^{-2}
225	28 x 10^{-5}	33 x 10^{-6}	15 x 10^{-9}	6 x 10^{-2}
300	40 x 10^{-5}	47 x 10^{-6}	22 x 10^{-9}	8 x 10^{-2}
375	50 x 10^{-5}	60 x 10^{-6}	29 x 10^{-9}	11 x 10^{-2}

To evaluate the data in table (3) for different temperatures and the current that was used in this simulation was equal to (10 A), a graph was drawn between the values of temperature (red colour) and electric field (blue colour) in Figure (3) to describe the relationship between them. The linear relationship between them can be clearly seen.

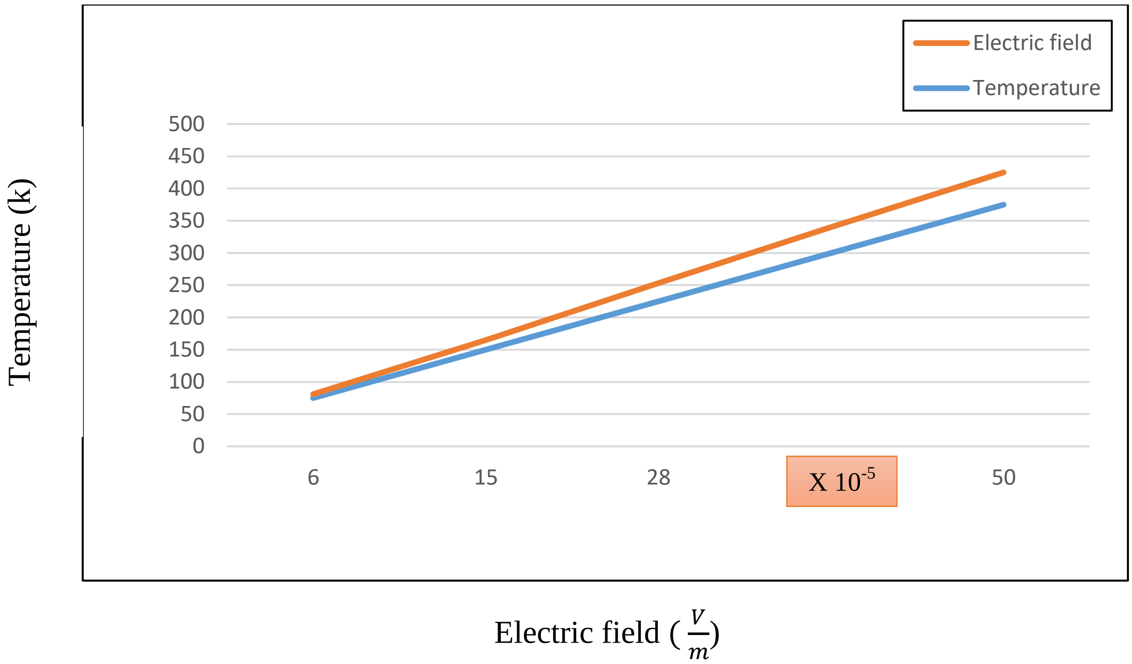


Fig. 3. Temperature-electric field features in Comsol Multiphysics Germanium model.

4.2. Temperature- current density relationship

In general experiments, measurement data is usually one-dimensional, but in simulations, electrical parameter distribution profiles can have two dimensions. Table (3) shows the results of the temperature and current density distribution, in the middle model at (75K, 150K, 225K, 300K, and 375K) The simulation is run with a 10 A current provided to one end of the semi-conductor, while the other end is grounded. shows the results of the current density values (8,20,33,47,60) x $10^{-6}\,\frac{A}{m^2}$,with the change of semiconductor temperature between 75K and 375K, where the simulation results can be considered to be close to the measurement. As it shows the rise in the current density values with the rise in the semiconductor temperature from 75K and 375K, it can be observed that when 75 K gives the lowest value for the current density, while 375 K gives the highest value for the current density. Figure (3) shows the current density and the temperature along the path for data evaluation (table. 2) through the simulation model, the transport current used in these calculations was again a (10A). An interesting result is that the current density starts to penetrate the semiconductor with higher values at a temperature of 375 K. More explicitly this behavior behavior is shown in Figure (4) the two variables have the same effect, where the temperature and the current density at a point on the boundary of the semiconductor are shown. In this simulation, at longer times this redistribution of the current density is proceeding further till the current density reaches its last value everywhere in the semiconductor. This equalization happens because of the finite electrical conductivity in the simulated semiconductor, which is necessary for numerical reasons.

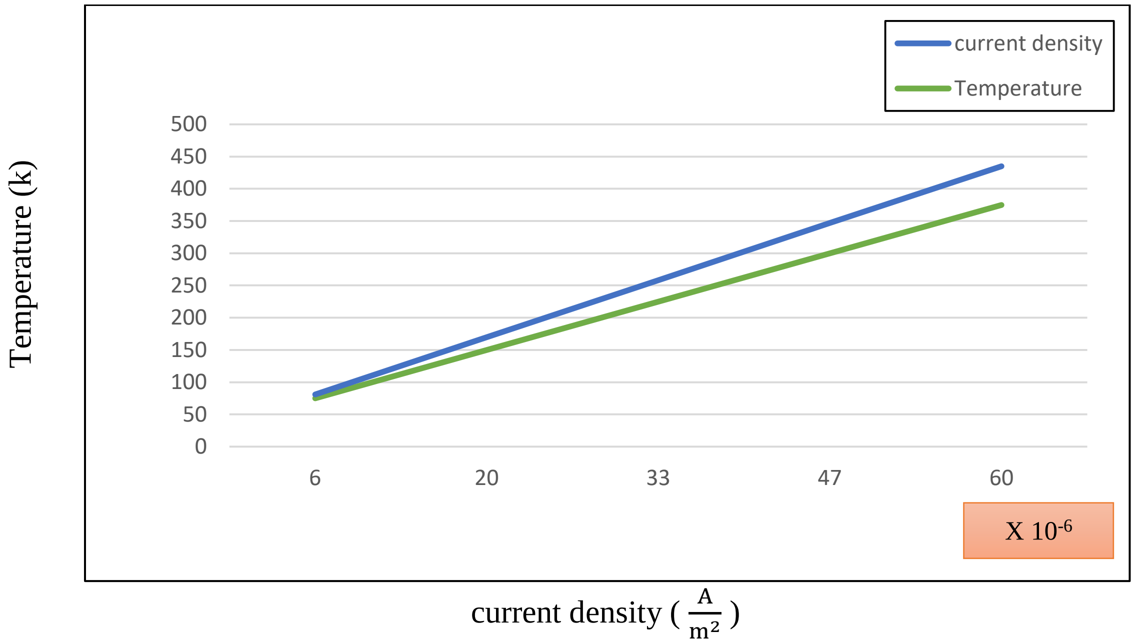


Fig. 4. Temperature-current density features in Comsol Multiphysics Germanium model.

4.3 Temperature- Space charge density relationship

Space charge density within the semiconductor material (germanium) is shown in Figure (5,7), with a higher percentage of space charge density in the center of germanium than in the other parts, which results in a stronger electric field strength in the same region due to the effect of heat on the medium. Figure (6,7) shows how temperature (75K,300K) affects the distribution of external current density. The effect spread to cover most of the semiconductor material but had less of an effect on the sides. As can be seen in Figure (7), when the temperature is increased to (300K), the external current density rises to $(8 \times 10^{-2})\,\frac{A}{m^2}$, from the value of $(1 \times 10^{-2})\,\frac{A}{m^2}$ at the initial temperature of (75K). These results point to a positive correlation between heat and, electrical conductivity.

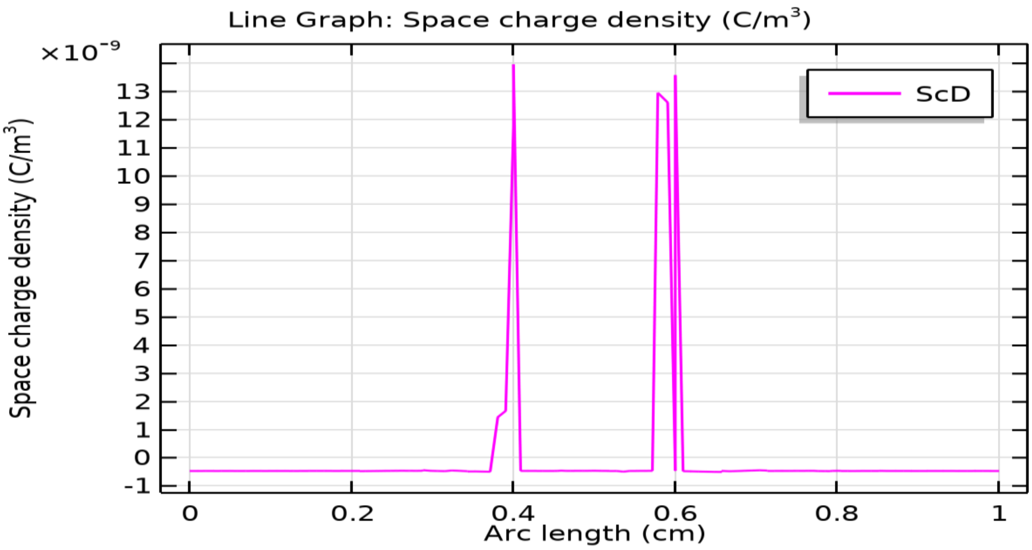


Fig. 5. Temperature and space charge density profile map along the Germanium model.

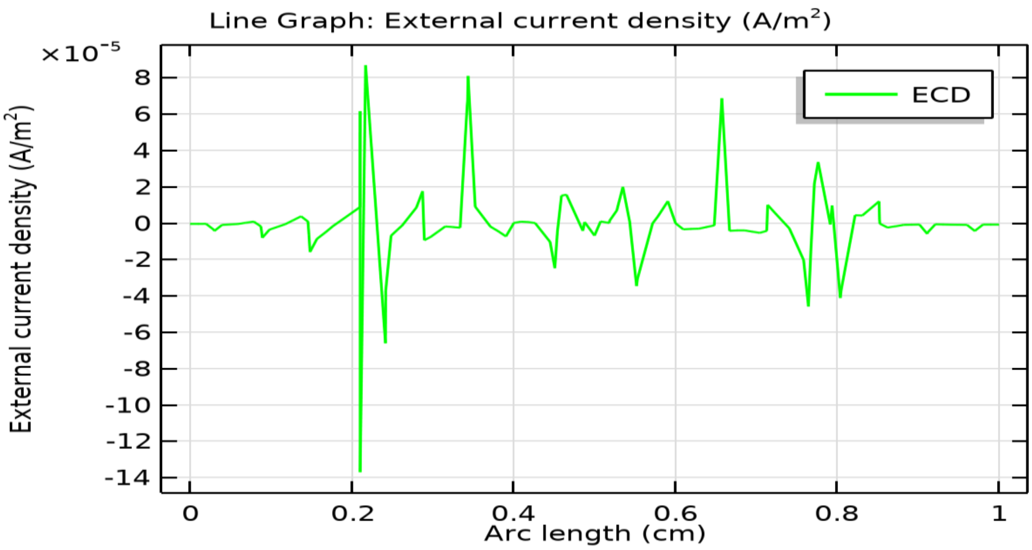
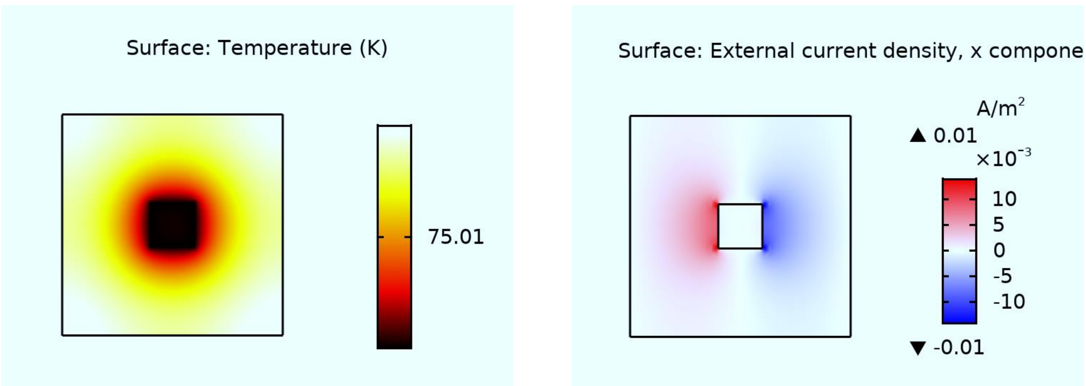


Fig. 6. Temperature and external current density profile map along the Germanium model.



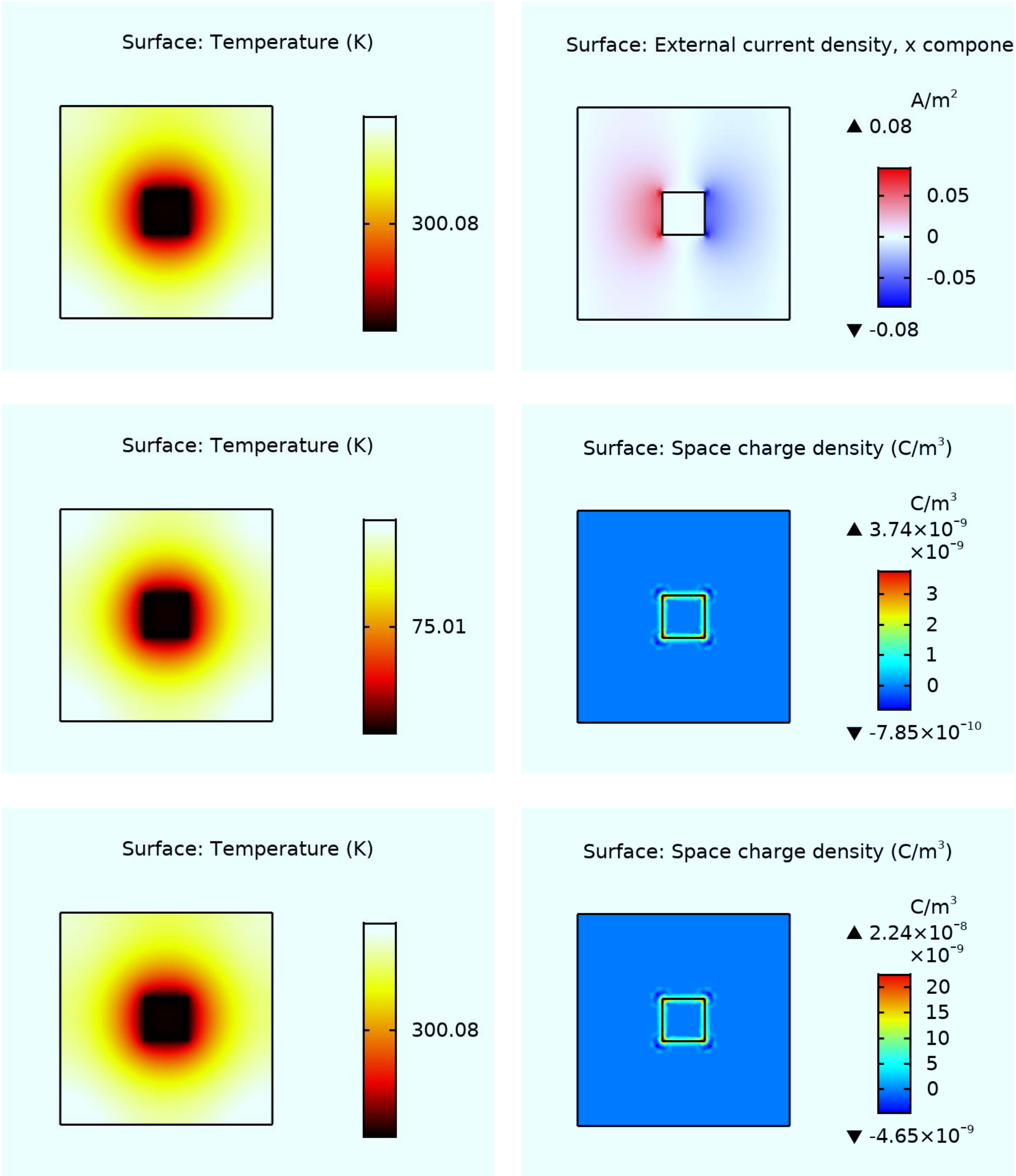


Fig. 7. 75K and 300K in temperature-space charge density and external current density.

Conclusion

The following conclusions were drawn from tests using temperature alterations on a simulated semiconductor (Germanium).

- Thermoelectric differences in the electric field of a semiconductor model were explored using the COMSOL Multiphysics software. because of the shift in temperature. In the middle of the semiconductor, researchers found that the electric field value rose with rise in temperature.
- The current density increased when the temperature was increased in the central region of the semiconductor.
- By heating the germanium model, it was found that the charge density increases.
- When a temperature was given to the germanium model, a rise in the external current density was recorded,
- With a small increase in electrical potential by an average of one degree for each value of the temperatures selected in the end, we concluded that as the temperature rise too, the electrical

properties measured during the simulations also went up. This, in turn, caused the electrical conductivity of the semiconductor (germanium) to go up.

- In the end, it can conclude that as the temperature went up, the electrical properties measured during the simulations also went up. This, in turn, caused the electrical conductivity of the semiconductor (germanium) to go up. As a result, germanium can be used in solar cells and some electronic chips.

Acknowledgement

The author is thankful to a physics professor at Al-Mustansiriya University's College of Science who assisted in the research.

References

[1] P. J. Manga, M. Maina, H. Samaila, E. W. Likta, R. O. Amusat, and S. Daniel, “Exploring the structural mechanics of titanium nickel solid alloy using COMSOL Multiphysics: A Poisson equation and continuity equation perspective,” *Sci. World J.*, vol. 19, no. 1, pp. 71–77, 2024, doi: 10.4314/swj.v19i1.10.

[2] M. A. Abdulrahman, B. B. Kadhim, and M. A. Dawooda, “Simulation of Structural , Electronic and Pharmacodynamics Properties of Developed Zeolite Docking with Hemoglobin,” *Mustansiriyah J. Pure Appl. Sci.*, vol. 2, no. 4, pp. 70–79, 2024.

[3] B. Albiss and M. Al-Widyan, “Numerical Simulation, Preparation, and Evaluation of Cu(In, Ga)Se2 (CIGS) Thin-Film Solar Cells,” *ChemEngineering*, vol. 7, no. 5, 2023, doi: 10.3390/chemengineering7050087.

[4] K. Hasan, M. A. Üstüner, and H. Mamur, “Enhancing Bi 2 Te 2 . 70 Se 0 . 30 Thermoelectric Module Performance through COMSOL Simulations,” *Thermo*, vol. 4, no. 2, pp. 185–201, 2024.

[5] H. M. Talib, A. A. Yousif, and A. H. O. Alkhayatt, “Investigate the influence of Al content on the structure and surface morphology of Al : CdS-PVA nanocomposites,” *Mustansiriyah J. Pure Appl. Sci.*, vol. 3, no. 1, pp. 176–185, 2025, doi: 10.47831/mjpas.v3i1.52.

[6] H. Sun *et al.*, “Electric Field in Metal Stress Cone of Cable Quick Repair/Test Joint,” *J. Phys. Conf. Ser.*, vol. 2666, no. 1, 2023, doi: 10.1088/1742-6596/2666/1/012022.

[7] M. H. Khudhur, M. H. Al-jiboori, and K. M. Abood, “Effect of the density and height of F 2 layer on ground-based observation of jupiter ’ s radio signal,” *Mustansiriyah J. Pure Appl. Sci.*, vol. 2, no. 4, pp. 140–156, 2024.

[8] N. Neophytou, P. Priyadarshi, Z. Li, and P. Graziosi, “Electronic transport computation in thermoelectric materials: from ab initio scattering rates to nanostructures,” *J. Comput. Electron.*, vol. 22, no. 5, pp. 1264–1280, 2023, doi: 10.1007/s10825-023-02075-z.

[9] A. S. Abdulhameed, H. A. Hadi, and R. A. Ismail, “Structural and optical properties of black silicon prepared by wet chemical etching,” *Mustansiriyah J. Pure Appl. Sci.*, vol. 3, no. 1, pp. 123–134, 2025, doi: 10.47831/mjpas.v3i1.199.

[10] Rajesh Rao J R, Nachiappan D, Dr. Nitinkumar D Banker, and Dr. Ashok S, “Simulation Workflow Evaluation and Validation of Power Converter’s Electro Thermal Performance and Framework For Physics Based Prediction Model,” *Int. Res. J. Adv. Eng. Manag.*, vol. 2, no. 08, pp. 2710–2719, 2024, doi: 10.47392/irjaem.2024.0392.

[11] K. Aishwarya and B. Lakshmi, “TCAD simulation study of heavy ion radiation effects on hetero junctionless tunnel field effect transistor,” *Sci. Rep.*, vol. 14, no. 1, pp. 1–13, 2024, doi: 10.1038/s41598-024-58371-6.

[12] C. Series, “Numerical Simulation of Deterioration Process in Reinforced Concrete Based on COMSOL Multiphysics,” *J. Phys. Conf. Ser.*, vol. 2736, no. 1, p. 012006, 2024, doi: 10.1088/1742-6596/2736/1/012006.

[13] G. Fotis, “Electromagnetic Fields Radiated by Electrostatic Discharges: A Review of the Available Approaches,” *Electron.*, vol. 12, no. 12, 2023, doi: 10.3390/electronics12122577.

[14] Y. Xu, Y. Tong, and J. Su, “RF Characterization of GaAs HBT under Load Mismatch with Reverse Wave Injection Technique,” *Micromachines*, vol. 14, no. 11, pp. 1–14, 2023, doi: 10.3390/mi14112058.

[15] T. A. Abbas and A. I. Altmimi, “Weibull Distribution Modified Using Fourier transformation Height-,” *Mustansiriyah J. Pure Appl. Sci.*, vol. 3, no. 1, pp. 34–48, 2025, doi: 10.47831/mjpas.v3i1.115.

[16] M. R. Akbarzadeh, H. Ghafourian, A. Anvari, R. Pourhanasa, and M. L. Nehdi, “Estimating Compressive Strength of Concrete Using Neural Electromagnetic Field Optimization,” *Materials (Basel).*, vol. 16, no. 11, pp. 1–14, 2023, doi: 10.3390/ma16114200.

[17] G. Liu and D. Qian, “Investigation of Bandgap Properties of a Piezoelectric Phononic Crystal Plate Based on the PDE Module in COMSOL,” *Materials (Basel).*, vol. 17, no. 10, p. 2329, 2024.

[18] C.-A. Wang, E. Ekmel, M. Gyure, G. Scappucci, M. Veldhorst, and M. Rimbach-Russ, “Modelling of planar germanium hole qubits in electric and magnetic fields,” *npj Quantum Inf.*, vol. 10, no. 1, pp. 1–9, 2022, doi: 10.1038/s41534-024-00897-8.

[19] V. K. Singh *et al.*, “Thermoelectric cooler (TEC) based thermal control system for space applications: Numerical study,” *Appl. Therm. Eng.*, vol. 224, no. June 2022, pp. 2022–2023, 2023, doi: 10.1016/j.applthermaleng.2023.120101.

[20] Y. Wang, G. Chang, K. Han, X. Qian, Z. Bao, and D. Sheng, “Parameter Design of a Self-Generated Power Current Transformer of an Intelligent Miniature Circuit Breaker Based on COMSOL,” *electronics*, vol. 13, no. 12, p. 2285, 2024.