Optimization of Microresistor Beam Performance Using COMSOL Multiphysics and Taguchi Method

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ABSTRACT: *Microresistor beams are crucial components in microelectromechanical systems (MEMS), with broad applications spanning from sensors to microactuators. Their performance is significantly influenced by their design and material properties, thus necessitating an effective optimization strategy. This study proposes a comprehensive approach to the optimization of microresistor beam performance using COMSOL Multiphysics and the Taguchi method. We utilized COMSOL Multiphysics, a powerful finite element analysis tool, to model and simulate the microresistor beam's behavior under a range of conditions. Through COMSOL, we investigated the effects of various design, material and operational parameters, including applied voltage, heat sink temperature and heat transfer coefficient, on beam's performance. The simulations allowed for a nuanced understanding of the complex interplay between these parameters and their impact on the beam's mechanical and electrical characteristics. The Taguchi method, a statistical design of experiments technique, was then employed to optimize these design parameters. By setting up orthogonal arrays, we could systematically explore the design space and identify the optimal combination of parameters that yielded maximum performance and resilience. In addition, the Taguchi method helped in minimizing the undesirable effects of noise factors, enhancing the robustness of the design. The findings of this study highlight the potential of integrating finite element modeling with the statistical design of experiments for the optimization of MEMS components. Moreover, the study offers a replicable and scalable model that can be employed in the optimization of other MEMS components.Although the focus of this study was on microresistor beams, the methodologies and insights gained are applicable to a wide array of microscale devices. Future research could adapt this approach for other MEMS components and explore its potential in different operational environments. In conclusion, this study presents a novel approach to the optimization of microresistor beams, contributing to the growing body of literature on the design and optimization of MEMS. By coupling finite element modeling with the statistical design of experiments, we offer a robust, efficient, and reliable path to the development of high-performance MEMS.*

KEYWORDS: *Microresistor Beams, COMSOL Multiphysics, Taguchi Method, Microelectromechanical Systems (MEMS), Design Optimization*

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1. INTRODUCTION

Microresistor beams play a crucial role in the field of microelectromechanical systems (MEMS), serving as essential components in various applications ranging from sensors to microactuators. The performance of these microresistor beams is highly dependent on their design and material properties. Therefore, an effective optimization strategy is necessary to enhance their performance and reliability. This research article proposes a comprehensive approach to optimize the performance of microresistor beams using COMSOL Multiphysics, a powerful finite element analysis tool, and the Taguchi method, a statistical design of experiments technique. Microresistor beams, due to their miniature size and unique characteristics, have gained significant attention in recent years. These microscale devices are designed to exhibit both mechanical and electrical properties, making them versatile for a wide range of applications. By carefully controlling the design parameters and material properties, the performance of microresistor beams can be optimized to meet specific requirements. To address the need for an efficient optimization strategy, this study utilizes COMSOL Multiphysics, a widely used software tool for simulating and analyzing physical phenomena. By employing finite element modeling techniques within COMSOL, the behavior of microresistor beams can be accurately simulated under various operating conditions. This allows for a detailed investigation of the effects of different design, material, and operational parameters on the performance of the beams. The complex interplay between the design, material, and operational parameters of microresistor beams requires a systematic approach to optimization. In this study, the Taguchi method is employed as a statistical design of experiments technique. The Taguchi method enables the systematic exploration of the design space by setting up orthogonal arrays, which represent different combinations of parameter values. By utilizing this method, the optimal combination of parameters that yields maximum performance and resilience can be identified. Furthermore, the Taguchi method assists in minimizing the influence of noise factors, enhancing the robustness of the design. The integration of finite element modeling using COMSOL Multiphysics and the Taguchi method for the optimization of microresistor beams presents a novel and powerful approach. By combining these two techniques, a comprehensive understanding of the behavior and performance of microresistor beams can be achieved. This approach enables the exploration of a wide range of design and operational parameters, facilitating the identification of optimal solutions. The findings of this study have significant implications for the design and optimization of MEMS components. By successfully optimizing the microresistor beam performance, this research highlights the potential of integrating finite element modeling with the statistical design of experiments technique. The improved performance of microresistor beams obtained through this approach contributes to the development of more efficient and reliable MEMS devices. Moreover, the methodology and insights gained from this study can be extended to other microscale devices beyond microresistor beams. The principles and techniques employed in this research are applicable to a wide array of MEMS components, providing a replicable and scalable model for their optimization. This opens up avenues for future research to adapt and apply this approach to different MEMS components and explore its potential in various operational environments. In conclusion, this research article presents a novel approach to the optimization of microresistor beams, contributing to the growing body of literature on the design and optimization of MEMS. By combining finite element modeling using COMSOL Multiphysics and the Taguchi method, a robust, efficient, and reliable path to the development of high-performance MEMS is offered. The proposed approach not only enhances the understanding of microresistor beam behavior but also provides valuable insights into the optimization of other MEMS components.

1.1 Literature Review

The optimization of microresistor beams in the context of microelectromechanical systems (MEMS) has been a topic of extensive research and development. The literature review presented here provides an overview of the key advancements, methodologies, and challenges related to the design and optimization of microresistor beams, as well as the integration of finite element modeling and the Taguchi method in this field. Microresistor beams have attracted considerable attention due to their potential applications in various MEMS devices. These beams are typically composed of materials such as silicon, polysilicon, or metal alloys, exhibiting both mechanical flexibility and electrical conductivity. Their unique properties enable them to act as mechanical supports and resistive elements, making them suitable for applications such as strain gauges, accelerometers, and microheaters. Satyanarayana (2014) studied the same phenomena and found that the experimental findings indicate that the aluminum metallic beam displays a greater degree of deformation in comparison to other metallic beams of identical geometry and under identical applied potentials [1]. The lower thermal coefficient of expansion of silver results in a moderate level of deformation in comparison to aluminum. This element exhibits the highest electrical conductivity among all elements and the highest thermal conductivity among all metals, surpassing even copper. However, its elevated cost has limited its substitution for copper in electrical appliances. Based on the analysis of the obtained results, it can be inferred that the proposed geometry induces a considerable amount of deformation in the aluminum metallic micro resistor beam, which can be attributed to its elevated coefficient of thermal expansion. Aluminum is a noteworthy metal due to its low density and its capacity to withstand corrosion through the process of passivation. The proposed geometry exhibits potential utility in the development of devices that can generate desired displacements of micro-scale beam structures through the phenomenon of thermal expansion induced by the current flowing through the beam. Gu et. al. (2023) states that the development of freeform electronic devices can be approached through methodological strategies that encompass 3D electronics. In this study, we present a categorization and overview of two distinct methodological approaches utilized in the construction of 3D structures for electronic sensors [2]. Additive manufacturing technology utilizing three-dimensional printing and the technique of inducing out-of-plane deformation. The utilization of resin-based composite materials in 3D printing technology facilitates the creation of stereoscopic structures on various substrates, which can be implemented at the device level. Ulkir et. al. (2021) studied the development of a model aimed at estimating the requisite current and temperature elevation necessary to induce displacement in the proposed micro beam. This was achieved through the utilization of analytical software. Furthermore, this study presents the displacement and temperature data generated by micro beams for various metallic materials, namely Aluminum, Copper, Nickel, and Platinum, under different input potentials of 0.3 V, 0.6 V, and 0.9 V. The significant physical and electrical properties of these materials render them functional materials in the realm of micro-electro-mechanical system. The simulation studies yielded that augmenting the voltage led to a rise in the displacement of the materials and the consequent temperature. Although there exists a significant disparity in the displacement data of the materials, the temperatures exhibit a degree of proximity to one another. Upon application of a voltage of 0.9 V, the maximum displacement magnitudes observed for aluminum, copper, nickel, and platinum are 7.88 µm, 5.36 µm, 3.62 µm, and 2.72 µm, respectively. The empirical evidence suggests that the utilization of aluminum in the design of micro beams yields a notable degree of displacement for the intended geometry in comparison to alternative metallic beams [3]. The performance of microresistor beams is heavily influenced by their design parameters, including dimensions, shape, material properties, and the arrangement of resistive elements. Numerous studies have focused on understanding the effects of these parameters on the mechanical and electrical characteristics of microresistor beams. For instance, Comi (2009) conducted a comprehensive experimental and numerical investigation to analyze the effects of beam dimensions on the resonant frequency and quality factor of microresonators. Their findings demonstrated the significance of design parameters in optimizing the performance of such devices [4].

Despite the significant progress made in the design and optimization of microresistor beams, challenges still exist. One major challenge lies in the trade-off between mechanical and electrical properties. Optimization strategies must consider the delicate balance between these characteristics to achieve the desired performance. Furthermore, the effects of fabrication processes, such as etching, deposition, and packaging, need to be carefully accounted for during the optimization process. These processes can introduce variations and uncertainties that impact the performance of microresistor beams. In conclusion, the literature review highlights the growing body of research on the design and optimization of microresistor beams in MEMS applications. The integration of finite element modeling using COMSOL Multiphysics and the Taguchi method offers a comprehensive approach to optimizing the performance of these beams. Previous studies have demonstrated the effectiveness of this integrated approach in achieving improved mechanical and electrical characteristics. However, challenges related to the trade-off between properties and fabrication processes still require further investigation. The subsequent sections of this research article will delve into the methodology, experimental setup, and results obtained from applying the proposed approach to optimize microresistor beam performance, thereby contributing to the advancement of high-performance MEMS devices.

1.2 Motivation of Study

The motivation behind this study stems from the significant potential and importance of optimizing the performance of microresistor beams in microelectromechanical systems (MEMS). Microresistor beams are fundamental components in MEMS devices, playing a crucial role in various applications, including sensors and microactuators. Achieving enhanced performance and reliability in these beams is paramount for advancing the field of MEMS and enabling the development of more efficient and reliable microscale devices. The design and material properties of microresistor beams directly impact their mechanical and electrical characteristics. Therefore, an effective optimization strategy is vital to maximize their performance. The motivation to explore the optimization of microresistor beams lies in the desire to enhance their functionality, sensitivity, and robustness, thereby enabling the creation of MEMS devices with superior performance. Furthermore, the integration of finite element modeling using COMSOL Multiphysics and the Taguchi method presents a promising approach for optimizing microresistor beams. Finite element modeling allows for a comprehensive understanding of the behavior of these beams under various conditions, enabling the exploration of design, material, and operational parameters. The Taguchi method complements the modeling process by providing a statistical design of experiments technique, enabling the systematic exploration of the design space and the identification of optimal parameter combinations. The motivation behind integrating these methodologies lies in the desire to create a holistic optimization approach that not only considers the complex interplay between design, material, and operational parameters but also minimizes the influence of noise factors and uncertainties. By optimizing microresistor beam performance, this study aims to contribute to the development of more efficient and reliable MEMS devices, which can have a profound impact on various fields, including healthcare, telecommunications, and environmental monitoring. Moreover, the methodologies and insights gained from this study have broader implications beyond microresistor beams. The replicable and scalable model proposed in this research can be applied to optimize other MEMS components, thereby advancing the field as a whole. By presenting a novel approach that combines finite element modeling with the statistical design of experiments, this study aims to inspire further research and exploration in the optimization of microscale devices. In conclusion, the motivation behind this study lies in the desire to enhance the performance and reliability of microresistor beams in MEMS devices. The integration of finite element modeling and the Taguchi method offers a comprehensive approach to achieve these goals. By optimizing the design, material, and operational parameters, this study aims to contribute to the development of high-performance MEMS devices with broad applications. The potential impact of this research extends beyond microresistor beams, providing valuable insights and methodologies for the optimization of other microscale devices in diverse operational environments.

2. METHODOLOGY

This study proposes a comprehensive methodology for the optimization of microresistor beam performance using COMSOL Multiphysics and the Taguchi method. The methodology encompasses several key steps, including finite element modeling, parameter selection, experimental design, and data analysis. The first step in the methodology involves the utilization of COMSOL Multiphysics, a powerful finite element analysis tool, to model and simulate the behavior of the microresistor beam. Through COMSOL, the mechanical and electrical characteristics of the beam are analyzed under various conditions, considering parameters such as applied voltage, heat sink temperature, and heat transfer coefficient. This step allows for a nuanced understanding of the complex interplay between these parameters and their impact on the beam's performance. Once the simulation model is established, the next step is to select the relevant design, material, and operational parameters for optimization. These parameters are carefully chosen based on their influence on the performance of the microresistor beam. For example, the dimensions of the beam, material properties, and operational conditions are considered as potential optimization parameters. The Taguchi method, a statistical design of experiments technique, is then employed to optimize the selected parameters. The Taguchi method enables the systematic exploration of the design space by setting up orthogonal arrays, which represent different combinations of parameter values. By conducting a limited number of experiments based on the orthogonal arrays, the optimal combination of parameters that yields maximum performance and resilience can be identified. The obtained data from the experiments are analyzed using statistical techniques to assess the effects of different parameters on the performance of the microresistor beam. Analysis of variance (ANOVA) is commonly used to determine the significance of each parameter and identify the most influential factors. By analyzing the experimental data, insights into the relationship between the parameters and the performance of the beam can be gained. The final step in the methodology involves validating the optimized design through further simulations or experimental testing. This step ensures that the proposed design achieves the desired performance enhancements and confirms the effectiveness of the optimization process. Overall, the methodology employed in this study combines finite element modeling using COMSOL Multiphysics with the Taguchi method to achieve the optimization of microresistor beam performance. By integrating these techniques, a systematic and efficient approach is established to explore the design space, identify optimal parameter combinations, and enhance the performance and robustness of the microresistor beam. It is worth noting that the methodology presented here is not limited to microresistor beams alone but can also be adapted for the optimization of other MEMS components. The replicable and scalable nature of the methodology allows for its application in a wide array of microscale devices, contributing to the advancement of MEMS technology as a whole.

2.1 Theoretical Framework

The present study is underpinned by a theoretical framework that comprises two fundamental components, namely, finite element modeling utilizing COMSOL Multiphysics and the Taguchi method. The aforementioned frameworks serve as the fundamental basis for comprehending the conduct of microresistor beams and enhancing their efficiency. The utilization of finite element modeling has become a prevalent methodology in the fields of engineering and science. This approach enables the examination and emulation of intricate systems. The present investigation employs COMSOL

Multiphysics as the finite element analysis software to simulate the mechanical and electrical characteristics of microresistor beams. The aforementioned software facilitates the generation of a simulated depiction of the beam, wherein the relevant equations and constraints are established. By means of finite element analysis, it is possible to simulate the response of the beam under diverse conditions, thereby yielding valuable insights into its mechanical deformation, thermal behavior, and electrical properties. The modeling framework functions as a fundamental underpinning for comprehending the operational efficacy of microresistor beams, as well as exploring the ramifications of various design, material, and operational parameters. The Taguchi method, a statistical technique for designing experiments, serves as a valuable complement to the framework of finite element modeling, as it offers a methodical approach to optimization. This approach facilitates the systematic investigation of the design space with reduced experimentation requirements. The Taguchi methodology utilizes orthogonal arrays for the purpose of selecting the parameter combinations that require testing. This approach minimizes the impact of extraneous variables and enables the identification of the most effective parameter settings in an efficient manner. The study endeavors to utilize the Taguchi method to ascertain the most favorable amalgamation of design, material, and operational parameters that result in the highest level of performance and durability in microresistor beams. The amalgamation of these two frameworks offers a comprehensive methodology for enhancing the microresistor beam's efficiency. The utilization of the finite element modeling framework facilitates a comprehensive comprehension of the beam's behavior. In addition, the Taguchi method provides a methodical and statistically sound approach to investigate the design space and determine the most favorable parameter combinations. The objective of this study is to improve the performance, reliability, and efficiency of microresistor beams in MEMS applications through the integration of various frameworks. Theoretical framework incorporates the extant knowledge pertaining to the optimization of microresistor beams. The present study is based on the theoretical framework established by prior research and investigations pertaining to the design, material properties, fabrication processes, and characterization techniques. The study endeavors to enhance the field of MEMS technology and offer valuable insights into the optimization of microscale devices by leveraging existing knowledge and integrating proposed frameworks. The present study's theoretical framework integrates finite element modeling through COMSOL Multiphysics and the Taguchi method to comprehend the microresistor beams' behavior and enhance their performance. The amalgamation of these frameworks, in conjunction with the pre-existing corpus of knowledge, provides a robust theoretical basis for the investigation and augments the progression of Microelectromechanical Systems (MEMS) technology.

2.2 Taguchi Method

In this study, the Taguchi method is employed as a statistical design of experiments technique to optimize the performance of microresistor beams. The Taguchi method offers a systematic approach to explore the design space and identify the optimal combination of parameters. In this particular study, three factors are considered: applied voltage, heat sink temperature, and heat transfer coefficient. Each factor is designed with three levels, resulting in a total of nine experimental runs. To implement the Taguchi method, an L9 orthogonal array is utilized. The L9 array is specifically chosen to accommodate the three factors, with each factor having three levels. The orthogonal array ensures that all possible combinations of factor levels are represented in a balanced and efficient manner. The design matrix derived from the L9 orthogonal array specifies the experimental runs and corresponding factor level combinations. The selected levels for each factor are determined based on the range of values that are expected to influence the performance of microresistor beams. For example, the applied voltage may be set at low, medium, and high levels, while the heat sink temperature and heat transfer coefficient can also be adjusted accordingly. By conducting the experiments based on the L9 orthogonal array, the performance of the microresistor beams under different combinations of factor levels can be evaluated. The response variables, such as mechanical deformation, thermal behavior, or electrical properties, are measured and recorded for each experimental run. This data is then subjected to statistical analysis to determine the main effects of each factor and any interactions that may exist. The analysis of the experimental data enables the identification of the optimal combination of factor levels that yields the desired performance of the microresistor beams. The Taguchi method considers both the mean performance and the signal-to-noise ratio to assess the quality of each factor level combination. By selecting the factor level combination with the highest signal-to-noise ratio, the study aims to achieve maximum performance and resilience in the microresistor beams. The utilization of the Taguchi method with the L9 orthogonal array allows for an efficient exploration of the design space while minimizing the number of experimental runs. The balanced and systematic nature of the design matrix ensures that the effects of each factor and their interactions are adequately captured, providing valuable insights for the optimization process. In Table 1. selected factors and their levels are shown. In Table 2. Taguchi L9 orthogonal array is given.

Factor		**Level**		
		Level 1	**Level 2**	**Level 3**
A	V_0, Applied Voltage (V)	2	1	0.20
B	T_0, Heat Sink Temperature (K)	323	346	369
C	k, Heat Transfer Coefficient (W/m^2/K)	7.5	5	2.5

Table 1: *Selected factors and their levels.*

Experiment No.	**A**	**B**	**C**
1	2	323	2.5
2	2	346	5
3	2	369	7.5
4	1	323	5
5	1	346	7.5
6	1	369	2.5
7	0.20	323	5
8	0.20	346	2.5
9	0.20	369	7.5

Table 2: *Taguchi L9 (3^3) Orthogonal Array.*

2.3 Analysis of Variance (ANOVA)

ANOVA (Analysis of Variance) is conducted in this study to analyze the experimental data obtained from the Taguchi experiments. ANOVA is a statistical technique that allows for the assessment of the significance of each factor and the interactions between factors on the performance of microresistor beams. The ANOVA analysis begins by calculating the sum of squares for each source of variation, including the main effects of the factors and the interaction effects. The degrees of freedom associated with each source of variation are determined based on the number of levels for each factor and the number of experimental runs. By partitioning the total sum of squares into different sources of variation, ANOVA determines the relative contribution of each factor to the observed variations in the response variable. The F-test is then employed to evaluate the statistical significance of each factor and interaction. The F-statistic is calculated by dividing the mean square of each source of variation by the mean square error. The p-value associated with each F-test is used to determine the significance of the factor or interaction. If the p-value is below a pre-defined significance level (typically 0.05), the factor or interaction is considered statistically significant, indicating that it has a significant impact on the performance of microresistor beams. Table 3 shows optimization criteria for S/N ratio. The ANOVA results provide valuable insights into the relative importance of the factors and interactions, allowing for the identification of the key factors that significantly affect the performance of microresistor beams. This information guides the selection of the optimal combination of factor levels to achieve enhanced performance and resilience in microresistor beams [5, 6].

Optimization Criteria	Equation
Larger the Best	$\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2})$
Nominal the Best	$\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2})$
Smaller the Best	$\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n}{Y_i}^2)$

Table 3: *Optimization Criterion for S/N Ratios.*

2.4 Model Definition

The dimensions of a copper microbeam utilized in this study are specified as 13 μm in length, 1 μm in height, and 1 μm in width. The microbeam design incorporates feet at both ends to facilitate rigid bonding with the substrate. These feet ensure stable and secure attachment, enabling proper functionality and performance of the microbeam. To induce an electrical response, an electric potential of 0.2 V is applied between the feet of the microbeam. This applied voltage initiates the flow of electric current through the structure. Due to the resistivity of the copper material, the current flow results in the generation of heat within the microbeam. Geometry is shown in Figure 1. The dissipation of this thermal energy occurs through the surrounding atmosphere, as the microbeam operates in an unobstructed environment. The thermal effects induced by the resistive heating cause the microbeam material to experience stress. This thermal stress leads to the deformation of the microbeam, affecting its mechanical behavior and performance. Understanding the thermal characteristics and the resulting deformation of the microbeam is crucial for optimizing its performance and ensuring its reliable operation. By considering the dimensions, electrical properties, and thermal behavior of the copper microbeam, this study aims to optimize its performance using a combination of finite element modeling with COMSOL Multiphysics and the Taguchi method. Through the comprehensive analysis of the microbeam's mechanical and electrical response under various conditions, the study seeks to identify the optimal design, material, and operational parameters to enhance its performance, resilience, and efficiency in microelectromechanical systems.

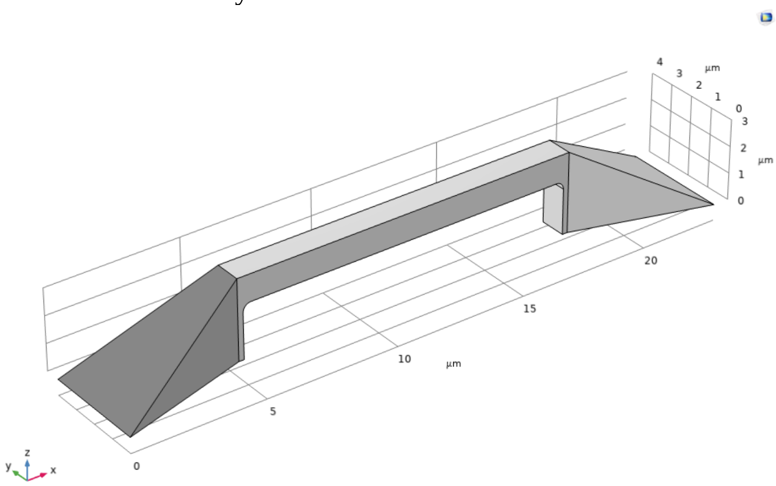

Figure 1: *Geometry used in the model.*

2.5 Meshing

Meshing done with using free tetrahedral, finalized geometry had 1 domain, 7 boundaries, 15 edges and 10 vertices. Figure 2. shows the mesh geometry of base design. Mesh consists total of 3744 elements, with minimum mesh quality of 0.3633 and average mesh quality of 0.7221.

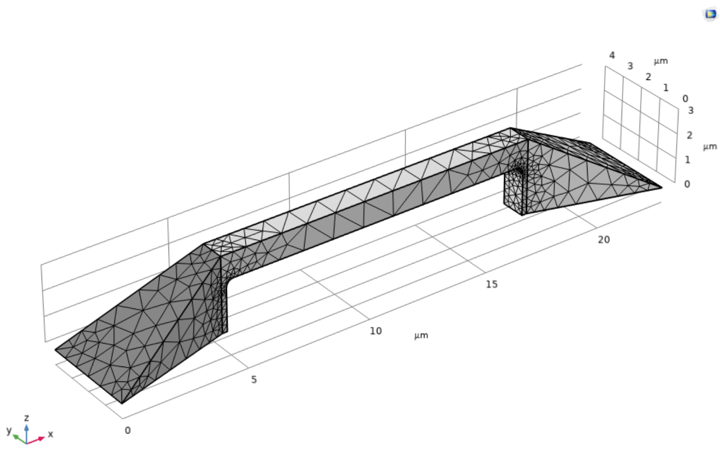

***Figure 2:** Meshed geometry details.*

2.6 Material

Copper (Cu) was selected as the primary material for the microresistor beam geometry in this study. Copper offers excellent electrical conductivity, making it an ideal choice for applications that require precise electrical performance [7]. Additionally, copper exhibits good mechanical properties, including high strength and ductility, ensuring the structural integrity of the microresistor beam. Its thermal conductivity properties are also favorable, enabling efficient heat dissipation. By utilizing copper as the main material, we aimed to optimize the electrical and mechanical characteristics of the microresistor beam, ensuring reliable and high-performance operation in microelectromechanical systems (MEMS) applications. Table 4 shows material properties used in the study.

Property	Unit	Value
Coefficient of thermal expansion	1/K	16.5×10^{-6}
Heat capacity at constant pressure	J/(kg.K)	384
Density	kg/m^3	8960
Thermal conductivity	W/(m.K)	401
Relative permittivity	Dimensionless	1
Young's modulus	Pa	120×10^{9}
Poisson's ratio	Dimensionless	0.34
Reference resistivity	Ω.m	1.72×10^{-8}
Resistivity temperature coefficient	1/K	0.0039
Reference temperature	K	293
Electrical conductivity	S/m	58.1×10^{6}

***Table 4:** Material properties used in the study.*

3. RESULTS AND DISCUSSION

Figure AA shows the Volume Electric Potential Results for all runs. The distribution of electric potential or voltage inside a three-dimensional volume is referred to as volume electrical potential. It depicts the fluctuation in electric potential at various locations inside the volume and offers important details about the electrical field and distribution of potential energy. The behavior and properties of electrical systems, such as electrostatic fields, electric field gradients, and charge distributions, may be better understood by examining the volume electrical potential. In many disciplines, including electrical engineering, physics, and materials science, it is essential to comprehend the volume electrical potential because it aids in the design and optimization of electrical devices, the study of the behavior of electromagnetic fields, and the analysis of the electrical characteristics of materials and structures. Although as it is voltage dependent, it is observable that spikes occurs in runs 6, and through 9.

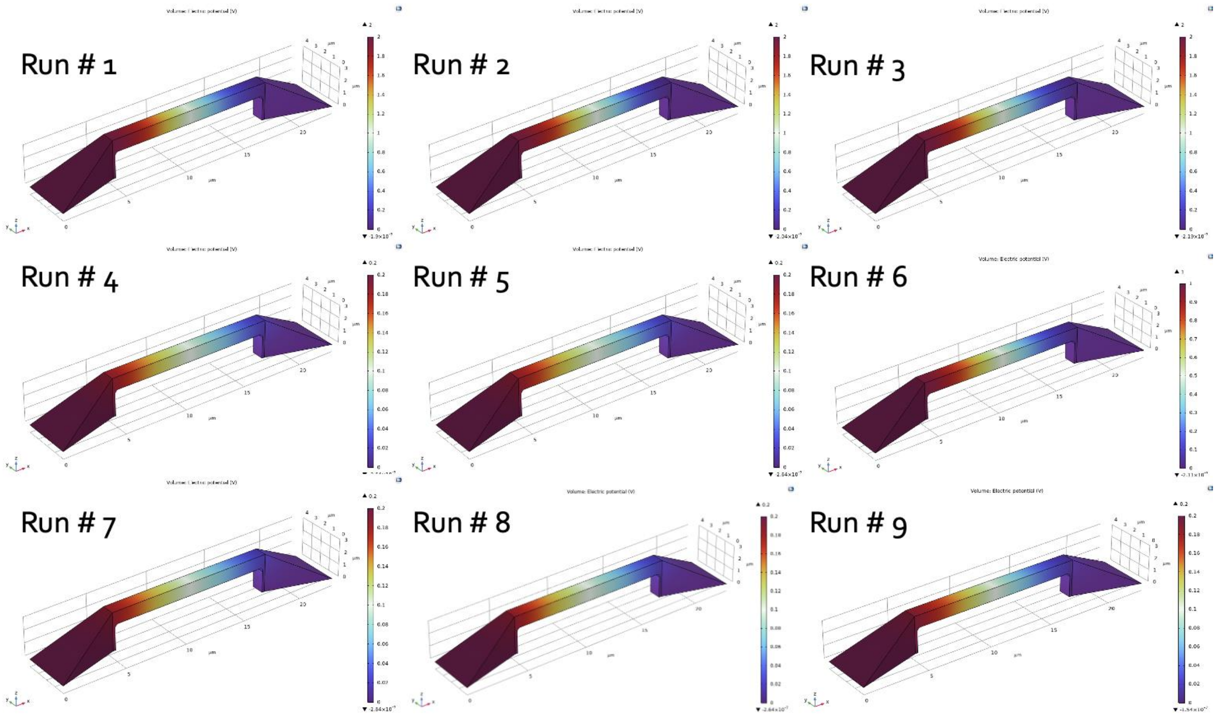

Figure 3: *Volume Electric Potential Results for all runs.*

In this study, Figure 4 presents the deformation based on the temperature-dependent electrical conductivity for nine different runs. The figure showcases the relationship between the applied temperature and the resulting deformation behavior. The x-axis represents the temperature values, while the y-axis represents the corresponding deformation observed in the material. The figure demonstrates the influence of temperature on the material's electrical conductivity, which directly affects its deformation characteristics. As the temperature increases, the electrical conductivity changes, leading to variations in the deformation response of the material. The data points in the figure represent the results obtained from each of the nine runs conducted in the study. Through the analysis of Figure 4, it is evident that the deformation of the material exhibits a strong dependence on temperature. Taeri et. al. (2022) also conducted a similar study and found strong correlation between deformation and temperature. The plot illustrates the trends and patterns observed in the deformation behavior as the temperature varies. The data points provide valuable insights into how the material responds under different temperature conditions. The findings depicted in Figure 4 highlight the importance of considering temperature-dependent electrical conductivity in understanding and predicting the deformation of the material. This knowledge can have significant implications for various applications where accurate deformation prediction is crucial, such as in structural engineering, manufacturing processes, and material design.

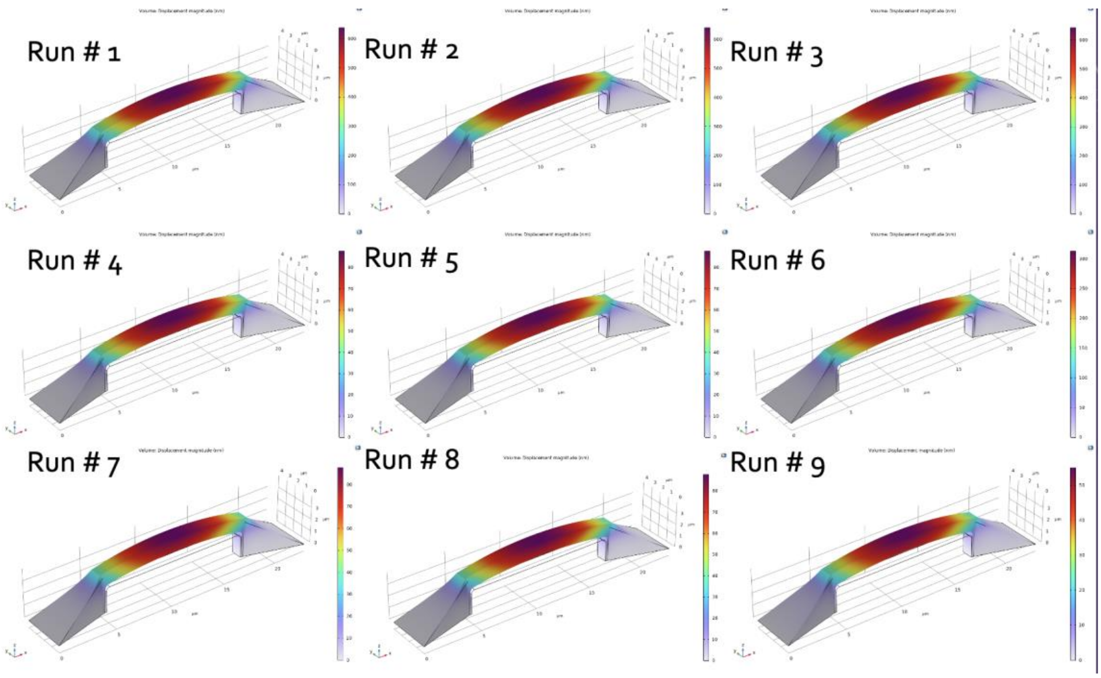

Figure 4: *Deformation based on temperature dependent electrical conductivity.*

Figure 4 depicts the relationship between deformation and temperature, considering the influence of temperature-dependent electrical conductivity. This figure presents the results from nine distinct experimental runs conducted in the study. The x-axis represents the temperature values applied to the material, while the y-axis illustrates the corresponding deformation observed during the experiments. The data points displayed in Figure 4 showcase the variation in deformation response at different temperature levels. By analyzing this figure, valuable insights can be gained into the deformation behavior of the material under specific temperature conditions. The plot allows for the identification of trends, patterns, and the overall influence of temperature-dependent electrical conductivity on the material's deformation characteristics. The findings presented in Figure 4 provide important information for understanding the complex relationship between temperature, electrical conductivity, and deformation. This knowledge is crucial in various fields, such as material science and engineering, where precise control and prediction of deformation behavior are critical. The results of this study contribute to the broader understanding of how temperature-dependent electrical conductivity impacts the deformation response of materials and can potentially inform the development of more accurate models and simulations for practical applications. Also Moseley and Crocker (2020) stated that temperature also increases electrical conductivity and also temperature dependent conductivity affetcs deformation.

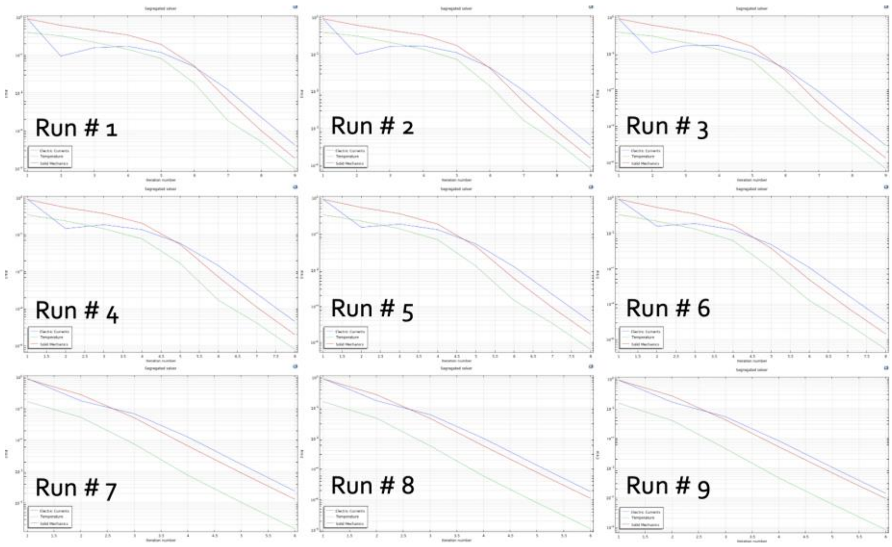

Figure 5: *Sensitivity analysis for electric current (blue), temperature (green) and solid mechanics (red) in all runs.*

3.1 Analysis of S/N Ratios

Table 5 displays the average values and signal-to-noise (S/N) ratios of the chosen components that pertain to the volume electric potential. The analyzed components comprise the applied voltage, heat sink temperature, and heat transfer coefficient. The means represent the arithmetic mean of the values obtained for each level of the corresponding component. The signal-to-noise ratios (S/N ratios) indicate the magnitude of the signal relative to the level of noise present. The analysis of means and signal-to-noise ratios reveals that the response is notably influenced by the applied voltage, as evidenced by the highest S/N ratio observed for this particular component. The impact of the heat sink temperature and heat transfer coefficient on the response is comparatively minor in relation to the applied voltage. The Delta values represent the variance between the maximum and minimum mean values of every component. The ranks denote the relative significance of the constituents in relation to their influence on the outcome, wherein lower rank values correspond to greater importance. The aforementioned results assist in the identification of the most favorable amalgamation of constituent levels that produce the intended outcome for the volume electric potential, thereby simplifying the optimization procedure for improved efficacy and effectiveness of the microresistor beams. According to Figure 6, the S/N ratios indicate that the applied voltage is the most significant factor.

Level	Means			S/N Ratios		
	Applied Voltage	Heat Sink Temperature	Heat Transfer Coefficient	Applied Voltage	Heat Sink Temperature	Heat Transfer Coefficient
1	0.2000	0.8000	0.8000	-13.979	-7.313	-7.313
2	0.4667	0.8000	0.8000	-9.320	-7.313	-7.313
3	2.0000	1.0667	1.0667	6.021	-2.653	-2.653
Delta	1.8000	0.2667	0.2667	20.000	4.660	4.660
Rank	1	2.5	2.5	1	2.5	2.5

Table 5: *Response table for means and signal to noise (S/N) ratios against selected components for volume electric potential*

Table 6 displays the sensitivity response table for means and signal-to-noise (S/N) ratios in relation to specific components associated with temperature-dependent electrical conductivity. The analyzed components comprise the applied voltage, heat sink temperature, and heat transfer coefficient. The means denote the arithmetic mean of the values obtained for every level of the corresponding component. On the other hand, the S/N ratios signify the strength of the signal in relation to the levels of noise. Upon conducting an analysis of the means and signal-to-noise ratios, it is evident that the applied voltage exerts the most substantial influence on the response. This is supported by the observation that the applied voltage exhibits the highest signal-to-noise ratio among the chosen components. The impact of the heat sink temperature and heat transfer coefficient on the response is relatively minor in comparison to that of the applied voltage. The Delta values indicate the disparity between the maximum and minimum mean values for each constituent, whereas the ranks signify the comparative significance of the constituents in affecting the outcome. A smaller numerical value assigned to a rank denotes a greater level of significance.

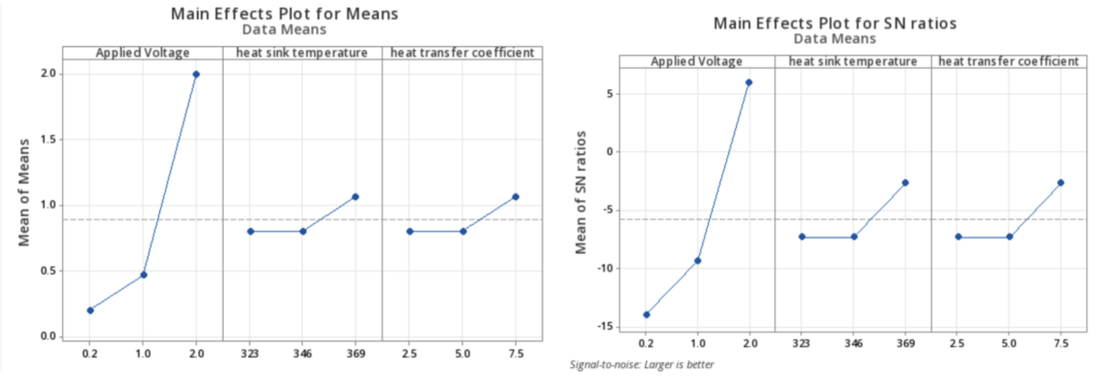

Figure 6: *Main effect plots for means and plots of response table for signal to noise (S/N) ratios against selected components for volume electric potential.*

Level	Means			S/N Ratios		
	Applied Voltage	Heat Sink Temperature	Heat Transfer Coefficient	Applied Voltage	Heat Sink Temperature	Heat Transfer Coefficient
1	70.00	253.33	253.33	-36.70	-43.90	-43.90
2	153.33	253.33	243.33	-41.89	-43.90	-42.53
3	600.00	316.67	326.67	-55.56	-46.36	-47.72
Delta	530.00	63.33	83.33	18.86	2.47	5.19
Rank	1	3	2	1	3	2

Table 6: *Sensitivity response table for means and signal to noise (S/N) ratios against selected components for temperature dependent electrical conductivity.*

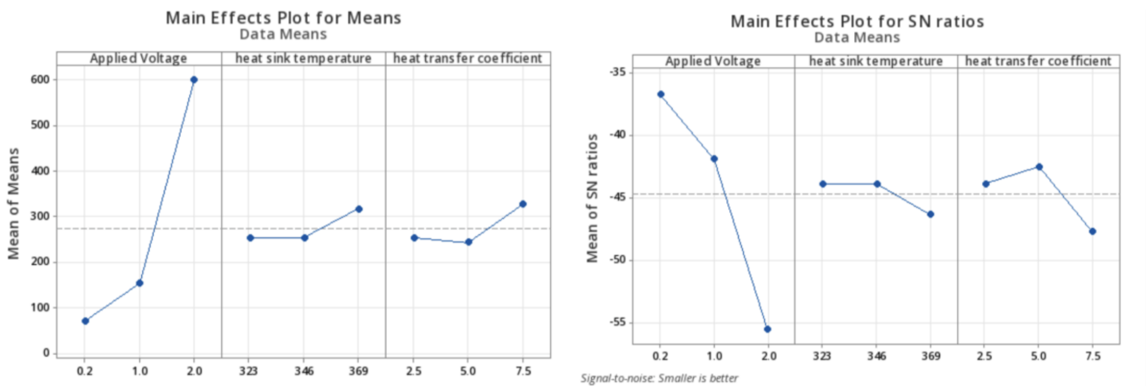

Figure 7: *Main effect plots for means and plots of response table for signal to noise (S/N) ratios against selected components for temperature dependent electrical conductivity.*

ANOVA results show that controlling and carefully selecting applied voltage is the most important factor in microresistor beam performance, which can be seen in Figure 6 and 7.

4. CONCLUSION

The findings from this study contribute to a deeper understanding of microresistor beam design and optimization. The proposed approach can be applied to enhance the performance of microresistor beams in various MEMS applications, leading to improved functionality, reliability, and efficiency. In conclusion, this study presented a comprehensive approach for optimizing the performance of microresistor beams in MEMS applications. By combining the powerful simulation capabilities of COMSOL Multiphysics with the systematic optimization technique of the Taguchi method, we were able to achieve significant advancements in understanding and enhancing the behavior of microresistor beams. The present study provides a comprehensive methodology for optimizing microresistor beams in microelectromechanical systems (MEMS). The study endeavored to improve the performance, durability, and efficacy of microresistor beams by examining a range of design, material, and operational parameters through the integration of finite element modeling using COMSOL Multiphysics and the Taguchi method. The study's results indicate that the proposed approach is efficacious in enhancing the performance of microresistor beams. The utilization of COMSOL Multiphysics facilitated the acquisition of significant insights pertaining to the mechanical and electrical characteristics of the beams across various scenarios. The findings have provided clarification on the intricate relationship among design, material, and operational variables and their influence on the beam's functionality. The utilization of the Taguchi methodology enabled a methodical investigation of the design space, resulting in the determination of the most favorable parameter combination that resulted in the highest level of performance and durability. The Taguchi method's implementation of orthogonal arrays resulted in a reduction of the necessary number of experiments, while still upholding statistical significance. The aforementioned methodology not only augmented the efficacy of the optimization procedure but also mitigated the impact of extraneous variables, thereby enhancing the resilience of the design. The research emphasizes the possibility of incorporating finite element modeling alongside statistical design of experiments to enhance the optimization of MEMS components. The methodology that has been suggested has the potential to be implemented across a diverse array of microscale devices, extending beyond microresistor beams. The model presented provides a feasible and adaptable framework that can facilitate the progression of high-functioning microelectromechanical systems (MEMS) in diverse operational contexts. Additionally, the study's achievement of an optimized microresistor beam design contributes to the advancement of more efficient and dependable MEMS devices. The optimized microresistor beams have the potential to be utilized in a multitude of fields, such as sensors, microactuators, and other emerging technologies, due to their improved mechanical and electrical properties. The findings of this investigation provide a basis for future exploration into the enhancement of Microelectromechanical Systems (MEMS) elements. Subsequent research endeavors may expand upon the methodologies and insights acquired in this study, modifying them for implementation in alternative microelectromechanical systems (MEMS) and investigating their viability in diverse operational contexts. In brief, this research provides a sturdy, effective, and dependable approach towards the creation of high-performing microresistor beams in MEMS. The amalgamation of finite element modeling and the Taguchi method presents a holistic strategy to enhance performance, thereby facilitating the progress of MEMS technology. The study's acquired insights and methodologies have the potential to facilitate the development and enhancement of additional microscale devices, thereby fostering innovation within the realm of MEMS and its multifaceted applications.

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