International Journal of Multidisciplinary Engineering in Current Research - IJMEC
Volume 8, Issue 12, December-2023, http://ijmec.com/, ISSN: 2456-4265

# DESIGN AND ANALYSIS OF MEMS BASED CAPACITIVE ACCELEROMETER

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**Abstract:** In the project 'Design and Analysis of Capacitive Accelerometer,' the focus was on evaluating slotted shapes like Circle, Square, and Rectangle on a Square Plate Capacitive Accelerometer. Uniform slotted areas of the shapes were simulated using COMSOL Multiphysics software to see how these shapes react when we push them (Applying stress) and see how thickness of the di-electric material changes accordingly. We wanted to know how much they move when pushed and how their ability to hold electricity changes (Capacitance) with the material's thickness. Surprisingly, we found out that the Circle Slotted shape moves the most when applied stress. Also, changing the material's thickness makes a big difference in how much electricity the sensor can hold. These discoveries are a step forward in making sensors that can sense movements better and work well in different situations.

## 1. INTRODUCTION

### 1.1 PROBLEM STATEMENT

Accelerometers are pivotal sensors used across industries, providing crucial data on acceleration forces in various applications, including automotive safety systems, consumer electronics, aerospace navigation, and industrial machinery monitoring. The continual demand for miniaturized high-performance sensors has fuelled the evolution of Micro-Electro-Mechanical Systems (MEMS) technology. Within this landscape, MEMS-based capacitive accelerometers have emerged as promising candidates due to their potential for compactness, precision, and versatility in measuring acceleration forces.
Moreover, while capacitive accelerometers offer advantages in terms of sensitivity, their performance might be susceptible to environmental factors such as temperature variations or material limitations, necessitating robust designs that remain accurate across diverse conditions.
Despite their promise, existing MEMS capacitive accelerometers encounter several challenges that hinder their widespread adoption and optimal performance. These challenges encompass design limitations, performance inconsistencies, and practical constraints that impede their seamless integration into diverse technological landscapes.
One of the fore-most issues pertains to the design complexity inherent in developing MEMS-based capacitive accelerometers. The miniaturization demands in modern applications often conflict with the necessity for maintaining high sensitivity, precision, and durability. Achieving a delicate balance between size reduction and maintaining robust performance remains a significant challenge.

### 1.2 OBJECTIVE

- The main objective of doing this project is to design a MEMS based Capacitive Accelerometer using the constant area of the plates and taking different slotted shapes with-in the plates.
- The MEMS based Capacitive Accelerometer sensor is designed in COMSOL Multi-Physics 6.0v and the MEMS Capacitive Accelerometer is analysed by placing different slotted shapes.
- From the different slotted shapes designed using COMSOL software, the enhanced performance is observed from the circle slotted square plate accelerometer designed using COMSOL Software.

### 1.3 MOTIVATION

The development of MEMS capacitive accelerometers stands at the forefront of cutting-edge sensor technology, offering a pivotal solution in diverse industries due to their compactness, high sensitivity, and reliability. The motivation behind this pursuit is rooted in the inherent advantages and burgeoning demand for precise and miniaturized sensors that cater to various applications. Leveraging the powerful capabilities of COMSOL Multiphysics software, our motivation stems from addressing the persistent need for highly accurate accelerometers capable of capturing nuanced acceleration data across multiple axes.
The motivation behind the development and exploration of MEMS Capacitive Accelerometers stems from a confluence of technological advancements, practical applications, and the pursuit of enhanced precision in measuring acceleration.


**DOI: https://doi-ds.org/doilink/12.2023-84473891**

At the heart of this endeavour lies the utilization of COMSOL Multiphysics software, an invaluable tool that empowers engineers and researchers to simulate, model, and analyse the intricate behaviour of micro-electromechanical systems (MEMS).

The contemporary landscape of technology demands solutions that are not only compact but also highly efficient. MEMS technology, particularly in the realm of accelerometers, offers a promising avenue towards achieving this balance. The integration of MEMS with capacitive sensing brings forth a remarkable combination of miniaturization and high-precision measurement capabilities. This synergy has sparked a surge in interest, driving researchers to delve deeper into the intricacies of designing and optimizing MEMS Capacitive Accelerometers.

COMSOL Multiphysics software plays a pivotal role in this pursuit, providing a comprehensive platform to simulate the behaviour of these complex systems. The software's multifaceted nature allows for the modelling of various physical phenomena governing MEMS operation, including mechanical deformation, electrical behaviour, and even fluid dynamics in certain configurations. By leveraging the capabilities of COMSOL Multiphysics, engineers and researchers can virtually prototype and refine the design of MEMS Capacitive Accelerometers before physical fabrication, reducing time and resource expenditures while enhancing the prospects of producing optimized sensors.

The motivation to explore MEMS Capacitive Accelerometers extends beyond theoretical curiosity. These sensors hold immense promise across diverse fields. In the automotive industry, they can revolutionize safety systems by offering compact yet highly responsive solutions for airbag deployment and vehicle stability control. Similarly, in consumer electronics, the quest for smaller, more efficient devices aligns perfectly with the miniature yet powerful nature of MEMS Capacitive Accelerometers. Applications in healthcare, aerospace, and industrial machinery promise transformative impacts, from precise motion tracking in healthcare devices to enabling navigation and stability control in aircraft.

## 2. LITERATURE SURVEY

### 2.1 ACCELERATION

Acceleration refers to the rate of change of velocity over time, encompassing alterations in an object's speed, direction, or both. It is a fundamental concept in physics, denoted as the derivative of velocity with respect to time, and is measured in units of meters per second squared ($m/s^2$). In simple terms, it signifies how rapidly an object's velocity is changing. This change can either be an increase (positive acceleration) or decrease (negative acceleration), including alterations in the object's direction of motion without a change in speed. Beyond classical mechanics, the understanding and quantification of acceleration have evolved significantly with the emergence of advanced technologies and the interdisciplinary nature of scientific research. Through a comprehensive literature survey spanning various fields—ranging from physics and engineering to medicine and beyond—it's evident that acceleration plays a crucial role in diverse applications.

In automotive engineering, understanding vehicle acceleration aids in designing safety systems like airbags and traction control. In aerospace, it's pivotal for navigation, manoeuvring, and controlling spacecraft or aircraft. Accelerometers, often based on micro-electromechanical systems (MEMS), have revolutionized industries by providing accurate measurements of acceleration. They find applications in smartphones for screen orientation, fitness trackers for monitoring physical activities, and even in healthcare devices for patient monitoring.

Recent literature highlights advancements in MEMS-based accelerometers, emphasizing miniaturization, increased sensitivity, and integration capabilities. Research papers discuss innovative designs, materials, and fabrication techniques aiming for higher precision and lower power consumption. Moreover, studies explore novel applications in emerging fields such as robotics, Internet of Things (IoT), and autonomous vehicles, showcasing the expanding relevance and potential impact of acceleration measurement technologies. This broad survey of literature demonstrates the pervasive significance of acceleration across scientific disciplines and its continuous evolution through technological advancements, driving innovation and practical applications in various domains.

### 2.2 ACCELEROMETER

An accelerometer is a sensor that measures proper acceleration, which refers to the rate of change of velocity in an object with respect to time. It detects and quantifies the acceleration forces acting upon it, irrespective of gravitational effects. These sensors utilize various principles such as piezoelectric, capacitive, or micro-electromechanical systems (MEMS) to detect and convert mechanical forces into electrical signals. The accelerometer's fundamental function lies in its ability to sense changes in motion, including linear and angular acceleration, vibration, tilt, and shock. This information is crucial in understanding an object's movement, orientation, and dynamic changes in speed, providing valuable insights across diverse fields.

A thorough literature survey reveals the extensive applications and advancements in accelerometer technology. Piezoelectric accelerometers, employing piezoelectric materials to generate electrical charge under mechanical stress, have been prominent. Capacitive accelerometers, utilizing variations in capacitance to measure acceleration, have gained attention due to their high sensitivity and miniaturization potential through MEMS technology. MEMS-based accelerometers, characterized by microscale structures integrated with electronics, have revolutionized sensor design, offering compactness, precision, and cost-effectiveness. These sensors find wide applications in consumer electronics (like smartphones for screen orientation and gaming), automotive safety systems (for airbag deployment and stability control), aerospace navigation, healthcare devices, industrial machinery, and structural health monitoring.

## 3. DESIGN OF MEMS BASED CAPACITIVE ACCELEROMETER USING COMSOL MULTIPHYSICS

### COMSOL MULTIPHYSICS

COMSOL Multiphysics is a software package which is widely used for modelling. This software not only helps to define the geometry, meshing, defining physics but also helps to visualize the end results. The mathematical structure in COMSOL Multiphysics is a system of partial differential equations.

Using these applications modes, you can perform various types of analysis including.

- Stationery and time-dependent analysis
- Linear and non-linear analysis
- Eigen frequency and modal analysis

When designing, COMSOL Multiphysics uses the proven Finite Element Method (FEM). MEMS module is a part of the COMSOL Multiphysics software. This module helps in designing any type of MEMS device and do further analysis.

## 4. RESULT ANALYSIS

In the pursuit of optimizing the performance of capacitive accelerometers, our project ventured into meticulous simulations using COMSOL Multiphysics software. Specifically, our focus was on examining the impact of different slotted shapes—Circle, Square, and Rectangle—on the square plate capacitive accelerometer. The objective was to discern their efficacy in two critical parameters: Displacement under applied stress and Capacitance concerning applied potential voltage.

The Shapes, tabulated, graphs results obtained from COMSOL simulations revealed intriguing insights into the performance of these shapes concerning two critical parameters

– displacement under applied stress and capacitance with varying applied potential voltage.

### DESIGNS OF SLOTTED MEMS BASED SQUARE

### ACCELEROMETER

The designs are obtained from COMSOL Multiphysics. They are Square Slotted, Rectangle Slotted and Circle Slotted. Each design variation—square slotted, rectangle, and circle— carries distinct geometric features that affect the capacitive accelerometer's mechanical response to applied force and its capacitance characteristics in response to applied potential voltage.

Through COMSOL simulations, we meticulously crafted a square plate capacitive accelerometer, exploring shapes—Circle, Square, and Rectangle—on its surface. Each shape was designed to have the same slotted area, ensuring a fair comparison. These simulations enabled us to model the intricate interactions between applied forces and the resulting plate displacements. The design iterations and analyses within COMSOL Multiphysics allowed us to evaluate how each shape responded to applied stress, providing crucial insights into their mechanical behaviors. This methodical design exploration facilitated a comprehensive understanding of shape-induced variations in the accelerometer's displacement response under different stress conditions. These designs contribute to the unique performance attributes observed in the simulation and analysis phase of the project.

### SQUARE SLOTTED ACCELEROMETER

This design comprises a square plate with slotted or patterns. The slots or perforations are strategically placed on the square plate, allowing for variations in stress distribution and capacitance changes. The slotted pattern influences the plate's flexibility and capacitance response, affecting its displacement under force and electrical charge storage capabilities. Below Shown figure is the Square Slotted MEMS Based Square Plated Accelerometer.

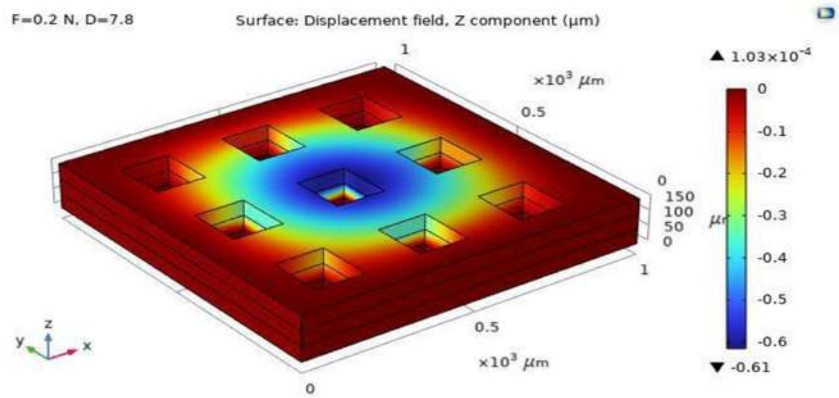


**Fig.4.1.1.1 Square Slotted**

**RECTANGLE SLOTTED ACCELEROMETER**

The rectangle design involves a square plate with a rectangular-shaped pattern or slots. Like the square slotted design, the placement and dimensions of the rectangle influence stress distribution and capacitance variations. Its structural geometry impacts how the plate responds to applied force and changes in electrical potential, affecting displacement and capacitance.

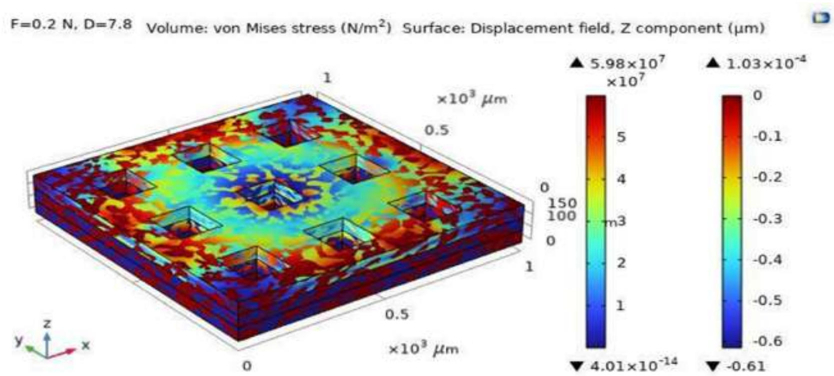


**Fig.4.1.2.1 Rectangle Slotted**

**CIRCLE SLOTTED ACCELEROMETER**

In contrast, the circle design features a square plate with circular patterns or perforations. The circular shape's geometry plays a role in stress distribution, potentially influencing the plate's flexibility and deformation under force. Additionally, the circular perforations impact the capacitance response of the plate concerning changes in applied electrical potential. Below shows the Circle Slotted Square Plate Accelerometer.

ISSN: 2456-4265


**DOI: https://doi-ds.org/doilink/12.2023-84473891**

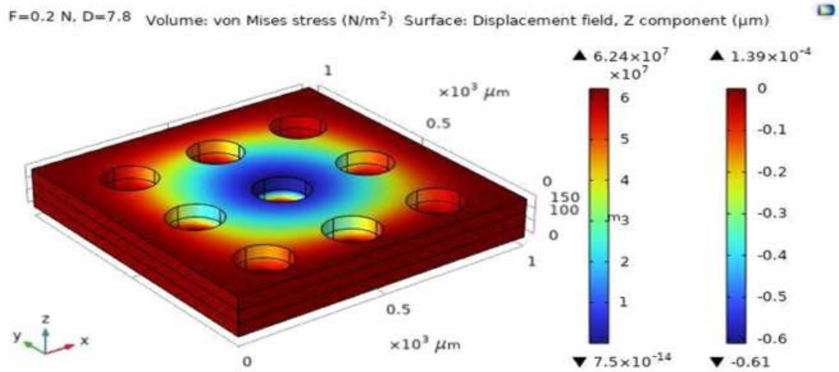


**Fig.4.1.3.1 Circle Slotted**

## COMPARISION FOR DIFFERENT SHAPES IN CAPACITIVE ACCELEROMETER

The calibration of capacitive accelerometers involves determining sensitivity, linearity, and other essential performance parameters for accurate and reliable measurements. In our project, we meticulously analyzed and tabulated calibration values for the Circle, Square, and Rectangle shapes embedded within the square plate design. From the observation we seen circle slotted has more sensitivity values ranging from $4.65x10^{-5}$ to $13.9x10^{-5}$ than other slotted shapes of the accelerometer.

| S.No | Square Slotted | Rectangle Slotted | Circle Slotted |
|---|---|---|---|
| 1 | $1.57x10^{-5}$ | $3.42x10^{-5}$ | $4.65x10^{-5}$ |
| 2 | $2.35x10^{-5}$ | $5.13x10^{-5}$ | $6.97x10^{-5}$ |
| 3 | $3.14x10^{-5}$ | $6.84x10^{-5}$ | $9.3x10^{-5}$ |
| 4 | $3.92x10^{-5}$ | $8.55x10^{-5}$ | $11.6x10^{-5}$ |
| 5 | $4.7x10^{-5}$ | $10.3x10^{-5}$ | $13.9x10^{-5}$ |

**Fig.4.2.1 Calibration of Different Shapes of Accelerometer**

## DISPLACEMENT WITH APPLIED STRESS

The results obtained from COMSOL simulations revealed intriguing insights into the performance of these shapes concerning two critical parameters – displacement under applied stress and capacitance with varying applied potential voltage.

Firstly, our simulation results for Displacement versus Applied Stress showcased intriguing revelations. The data derived from COMSOL simulations, the Circle Slotted square plate emerged as the frontrunner, exhibiting the highest displacement when subjected to applied force. This finding alludes to the advantageous mechanical response of the circular perforation design, indicating its potential for accommodating higher stress-induced displacement compared to the other shapes under investigation.

From the observation we seen circle slotted has more sensitivity values ranging from $4.65x10^{-5}$ to $13.9x10^{-5}$ than other slotted shapes of the accelerometer.

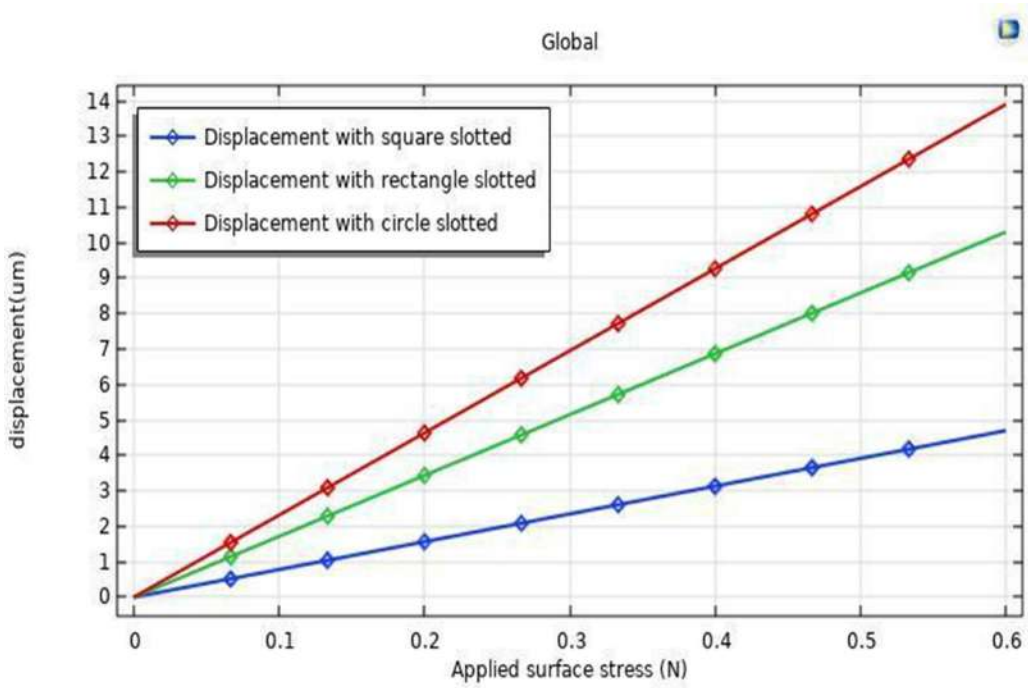


**Fig.4.3.1 Plot: Displacement (um) vs Applied Surface Stress (N)**

**CAPACITANCE WITH APPLIED POTENTIAL VOLTAGE**

The analysis of capacitance in relation to applied potential voltage highlighted the Circle Slotted square plate's superior performance in attaining higher capacitance levels compared to other shapes. The detailed tabulation illustrating capacitance variation across different applied potential voltage values (Table 2) underscores the dominance of the Circle shape in eliciting higher capacitance readings within the designed capacitive accelerometer. From the table, we have observed the large variations of capacitance with applied potential in circle slotted accelerometer i.e., $3.63 \times 10^{-26}$ Farads of capacitance.

| Name | Capacitance [F] |
|---|---|
| Square Slotted | $2.82X10^{-26}$ |
| Rectangle Slotted | $3.2X10^{-26}$ |
| Circle Slotted | $3.63X10^{-26}$ |

**Fig.4.4.1 Capacitance vs. Applied Potential**

The analysis delving into Capacitance versus Applied Potential Voltage further unraveled valuable insights. As gleaned from the comprehensive tabulated results derived from COMSOL simulations, the Circle square plate exhibited notably superior capacitance concerning applied potential voltage. These findings not only emphasize the significance of shape configurations in influencing displacement and capacitance within square plate capacitive accelerometers. This observation signifies the remarkable capacitive performance offered by the circular perforation design, hinting at its efficacy in achieving higher capacitance levels in response to varying potential voltages compared to the other shapes explored in the study.




DOI: https://doi-ds.org/doilink/12.2023-84473891

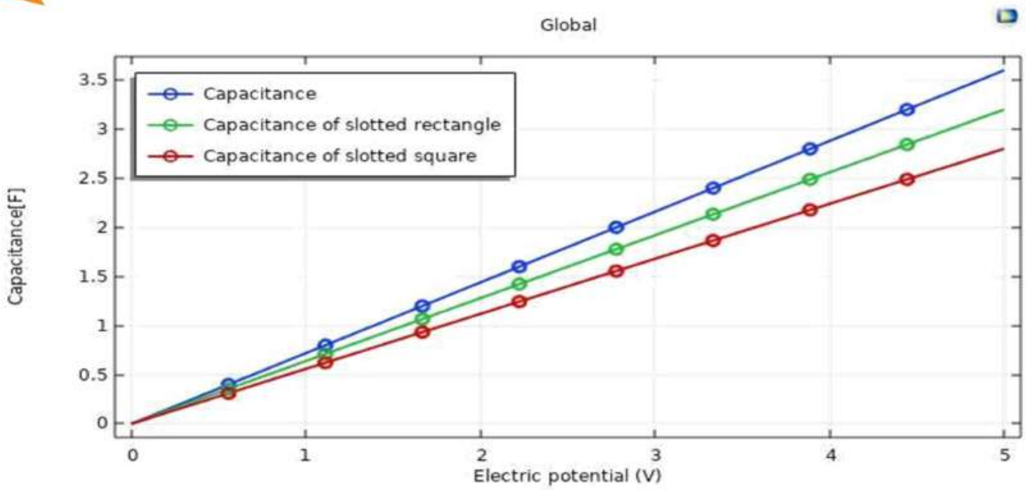


**Fig.4.4.2 Plot: Capacitance (F) vs Electric Potential (V)**

## 5. RESULT

In presenting these findings, tabular comparisons, graphical comparisons between the shapes in terms of Displacement versus Applied Stress and Capacitance versus Applied Potential Voltage will serve as crucial visual aids. The graphs will aptly illustrate the observed trends, showcasing the relative performances of the different slotted shapes on the square plate capacitive accelerometer. Furthermore, these graphical representations will offer a clear depiction of the superiority of the Circle Slotted square plate in displacement response and the Circle square plate in capacitive performance.

## 6. CONCLUSION

In our project exploring the design and analysis of capacitive accelerometers, we've uncovered some interesting discoveries. We focused on different shapes—like circles, squares, and rectangles—added onto a square plate for the accelerometer. Our aim was to see how these shapes affected two important things: how much the shape moves when pushed (displacement) and how well it can store electric charge (capacitance) when given electricity.

After running lots of tests using the COMSOL software, we found that the circle-shaped slots on the square plate were good at moving the most when we pushed on them. From the observation we seen circle slotted has more sensitivity values ranging from $4.65x10^{-5}$ to $13.9x10^{-5}$ than other slotted shapes of the accelerometer. From the table, we have observed the large variations of capacitance with applied potential in circle slotted accelerometer i.e., $3.63x10^{-26}$ Farads of capacitance.

This means they were more flexible and could handle force better than the other shapes we looked at. When it came to storing electric charge, though, the square plate with circle-shaped holes was the best. It could hold more charge when we applied electricity compared to the other shapes we studied.

In conclusion, our project highlighted that different shapes on the square plate of a capacitive accelerometer have varying effects. Circle-shaped slots showed great flexibility, making them move the most under pressure. Meanwhile, circle-shaped holes stored more electric charge compared to the other shapes.

## 7. FUTURE SCOPE

As we conclude our exploration into designing and analysing capacitive accelerometers with various shapes on square plates, it's essential to peer into the future possibilities. This project has unravelled promising avenues for further advancements in sensor technology.

Looking ahead, one significant future scope lies in enhancing the designs we've studied. By refining the shapes and configurations, we could potentially optimize these sensors for even better performance. For instance, exploring novel shapes beyond circles, squares, and rectangles might unlock new possibilities.


DOI: https://doi-ds.org/doilink/12.2023-84473891

Additionally, delving deeper into the dimensions, orientations, and arrangements of these perforations could lead to further improvements in displacement response and capacitance levels.
Moreover, the integration of these capacitive accelerometers into emerging technologies presents an exciting realm of exploration. As the world gravitates towards the Internet of Things (IoT) and smart devices, these sensors could play a pivotal role. They might find applications in advanced wearable gadgets, healthcare devices for real-time patient monitoring, or futuristic navigation systems for autonomous vehicles.
Furthermore, collaborating across disciplines holds immense promise. Partnering with experts in material science, nanotechnology, or signal processing could foster innovative breakthroughs. Exploring new materials that enhance sensitivity or experimenting with advanced signal processing techniques might elevate the performance of these accelerometers to unprecedented levels.
Overall, the horizon brims with possibilities. By refining designs, integrating with emerging technologies, collaborating across domains, and focusing on environmental adaptability, the future of capacitive accelerometers seems promising. Embracing these prospects could pave the way for groundbreaking innovations, making these sensors ubiquitous in our technologically evolving world.

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ISSN: 2456-4265



**DOI: https://doi-ds.org/doilink/12.2023-84473891**