Analyzing the Capacitance and the Voltage Characteristics of Nickel and Graphene (Electrode) with Boron Based Spring Mass Model (Dielectric) by Varying the Electrode Length in MEMS

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Analyzing the capacitance and the voltage characteristics of nickel and graphene (electrode) with boron based spring mass model (dielectric) by varying the electrode length in MEMS.

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Abstract

This aim is to improve the voltage characteristics and capacitance of graphene and nickel (electrode) using a boron-based spring mass model (dielectric) by manipulating the electrode length in MEMS. Materials and Methods:Two sets of 23 samples each, representing Nickel(Ni) and Graphene, are used in this work. Using Clincalc.com, sample size calculations were performed with an alpha value of 0.05 and a power of 80% with G power. The simulation specifically looked at the Mean capacitance by gradually changing the Nickel and Graphene electrode lengths in order to get the Mean capacitance. result: When comparing nickel and Graphene, the maximum mean capacitance was 9.56*10^-12 F for Nickel and 8.71*10^-12 F for Graphene, respectively, for the identical electrode length of 600 nm. With a p-value of 0.11 ($p < 0.05$), an independent T-test statistical analysis revealed a significant variance in Nickel properties. Conclusion: The overall accuracy in These research findings demonstrate that Nickel performs significantly better than Graphene.

KEYWORDS: Capacitance, Voltage Characteristics, Boron-based Spring-mass model, Dielectric thickness variation, Energy storage.

I. Introduction

A MEMS (Micro-Electro-Mechanical-System) lab typically focuses on research, development, and experimentation related to miniature devices that integrate electronic and mechanical components on a microscale(Lyshevski 2018). MEMS devices are highly advantageous, especially due to their small size, closely related to characteristics such as ease of integration, lightweight, low power consumption, and high resonance frequency(Uttamchandani 2016).MEMS technology has applications in various fields, including sensors, actuators, biomedical devices, and communication systems(Nihtianov and Luque 2018). By adjusting the electrode length in nanometers, the research aims to analyze the capacitance and voltage characteristics of graphene and Nickel(Ni) (electrode) with a boron-based spring mass model (dielectric). A comprehensive understanding of the effects of electrode length variations on capacitance and voltage characteristics is essential for MEMS device performance optimization. By using this on microelectromechanical systems that are more responsive and efficient can be designed and built. Capacitance and voltage characteristics are an important role in the energy efficiency of MEMS devices, particularly in applications where power consumption is a critical consideration(Islam 2012). This research reveals optimizing energy usage and extending the operational life of MEMS devices. Nickel can be used as an electrode material in capacitive MEMS devices due to its good electrical conductivity and mechanical properties.Nickel is commonly used in the production of electrical contacts, lead frames, and connectors due to its excellent conductivity and resistance to corrosion. This research is used to examine the mean capacitance of Nickel and Graphene by varying their electrode length (Inamuddin 2020).Graphene and nickel were selected for their superior EDS properties, including high mechanical stress, heat conductivity, wear lubrication, surface directionality, and electron mobility, enhancing electrical conduction efficiency.Various graphene synthesis methods have been explored, including Sun's photochemical reduction process, which controlled oxidation-reduction with light dosage, producing high-quality, conductive graphene suitable for fuel cell electrodes and devices (Huang, Lu, and Liu 2023).This paper explores a dimple-type RF MEMS capacitive shunt switch incorporating novel meandering techniques to enhance performance with low actuation voltage and high isolation. Using FEM analysis through COMSOL and HFSS, the design achieves a pull-in voltage as low as 10.3 V and isolation of −54.13 dB at 40 GHz, operating efficiently across 26.5–40 GHz.MEMS-based RF switches are increasingly utilized in high-frequency communication applications due to their superior performance in isolation and insertion loss compared to solid-state switches. Despite competition, MEMS technology demonstrates significant potential, particularly in high-frequency ranges, making it a promising choice for advanced communication systems and related applications (Girija Sravani et al. 2019).This work investigates the alignment of microparticles in a drying water droplet using standing flexural plate waves (FPWs) generated by a piezoelectric MEMS transducer. A silicon diaphragm with aluminum nitride layers and interdigital transducers drives the FPWs, enabling precise, noninvasive particle patterning for enhanced lab-on-chip application control (Nastro et al. 2024). These facilities are for microscale bonding, etching, photolithography, and deposition(Sawane and Prasad 2023). Sensors, robotics, biomedical devices, and telecommunications are just a few important domains in which MEMS laboratories, which are mainly used for research facilities, universities, and tech firms, are focused on developing(Kumar and Varghese 2022) . Using a boron-based spring mass model (dielectric) graphene and Nickel(Ni) (electrode) capacitance and voltage characteristics, this research shows that they investigate them by varying the dielectric thickness in nanometers. MEMS-based sensors are important for environmental monitoring applications, including weather sensing, pollution detection, and air quality monitoring. Enhancing the sensitivity, selectivity, and stability of MEMS sensors while changing the dielectric thickness it might improve their capacitance and voltage properties(Spearing 2000).The energy efficiency of MEMS devices is influenced by their capacitance and voltage characteristics, especially in this situations power consumption is a major factor(Wei et al. 2010). This research can provide an optimizing energy usage of MEMS devices. Graphene outstanding conductivity and strength make it ideal for enhancing device performance as an electrode material(Morenghi et al. 2022).The last five years have seen a significant increase in research on nickel and graphene, Utilizing boron-doped microporous carbon from biowaste enables high-capacitance supercapacitors with excellent cyclic performance, showcasing a cost-effective and straightforward method for biowaste recycling(Poornima and Vijayakumar 2022). The electric double layer (EDL) in electrochemistry has been better understood theoretically recently. This highlighted the difficulties in comprehending complex interfaces and charging mechanisms, which are essential for maximizing energy storage and electrocatalysis applications(Wu 2022).Recent focus on supercapacitors for energy storage drives exploration of quantum capacitance in advanced materials. This review highlights quantum capacitance enhancements, emphasizing their role in sustainable energy solutions and guiding future device design (Kolavada, Gajjar, and Gupta 2024).According to the author's research, this article they uses an analog-mixed-signal capacitive-coupling computing for binary neural networks, achieving high energy efficiency and accuracy (98.3% for MNIST, 85.5% for CIFAR-10 (these are data sets commonly used for training and testing machine learning models, particularly in image classification tasks.)) in a 65-nm CMOS (Jiang et al. 2020).

Notably, extensive academic databases on these topics are available from publishers such as Elsevier, Springer, IEEE Xplore, and others; each database has about 390 articles. Structural analysis confirms oxide layer formation then emphasizes Ni foam's most important contribution to enhancing the supercapacitor energy density(Salleh, Kheawhom, and Mohamad 2020). Supercapacitors are most important for energy storage when we investigate renewable energy in the face of defects. Because of its low conductivity and limited rate capability. By methodically classifying and improving nickel-based materials,These attempts in recent years have addressed these issues(Zhang et al. 2019).Graphene-based materials can exhibit potential in supercapacitors and energy storage. Due to their adjustable surface area, superconductivity, chemical stability and mechanical strength (Ke and Wang 2016). Co-doped graphene can exhibit enhanced quantum capacitance, making it promising for asymmetric supercapacitors. It shows the stability and high quantum capacitance for symmetry supercapacitor electrodes(Xu et al. 2019). Porous boron-doped diamond (PBDD) electrodes will surely show high potential, stability, controllable conductivity, and tunable surface. Achieving an oxygen-terminated (OT) PBDD surface through cyclic voltammetry increased specific capacitance and enabled high-performance symmetric devices with substantial energy and power density.(Wang et al. 2021)

Improving electrode length and having an effect on the MEMS size reduction's mean capacitance are important. A solution to this problem has been introduced using a MEMS device that integrates Nickel into the Microelectromechanical system.

II. Materials and methods

This study used the NanoHub tool, which is accessible at NanoHub (https://nanohub.org/), and was carried out at a nanotechnology lab at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences in Chennai, India. A sample size of 23 was included in the development process for each material category. Using a 0.11 alpha value, 80% G Power and the sample size was determined using information from previous studies on Clincalc.com.

Using the NANOHUB tool (Madhavan et al. 2013) this research explores the influence of different Dielectric thickness on two distinct novel MEMS materials. To access the tool, follow the steps below

1. Start by opening your web browser and going to the nanoHub website.

2. Once there, click to the "explore" area to find a variety of tools.

3. Look for the "Tools" item in the Explore menu.

4. To discover the MEMS LAB tool, use your browser's search feature and type "MEMS LAB" into the search box.

5. After finding it, choose the MEMS LAB tool from the search results.

6. Finally, select the MEMS lab from the available resources to begin the research

The NanoHub tool at the MEMS lab was crucial to the material modeling for the research, which involved selecting, utilizing, and initiating new MEMS. To produce the output for Nickel modeling, carry out the following actions.

Step 1: Select the numerical simulation type and alter the electrode configuration to a Spring mass model form.

Step 2: Select the voltage and enable DC analysis.

Step 3: Alternate the electrode length for a total of 23 rounds, going from 415 µm to 600 µm at intervals of 10 µm.

Step 4: Enter the dielectric constant value of boron (3.5) after selecting nickel for the electrodes and "custom" for the dielectric material.

Step 5: Execute the simulation and save the data file and image that shows the outcome.

In the MEMS lab, the NanoHub tool was essential for material modeling, starting new MEMS projects, choosing tools, and carrying them out. The process for producing the product is followed by graphene modeling.

Step 1: Set the simulation type to numerical and substitute a Spring mass model form for the electrode arrangement.

Step 2: Select the voltage settings and activate the DC analysis.

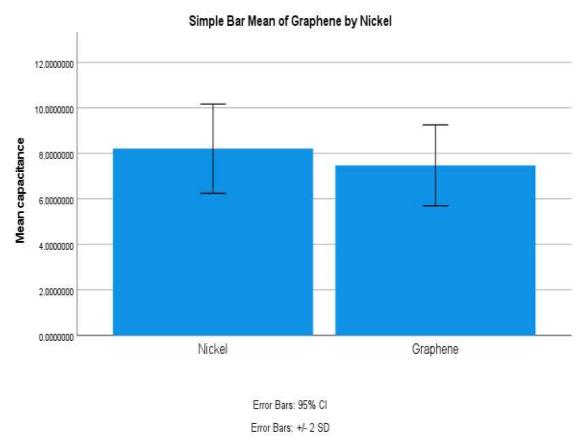
Step 3: For 23 rounds, adjust the electrode length by 10 µm increments, starting at 415 µm and going up to 600 µm.

Step 4: select "custom" for the dielectric material and graphene for the electrodes, then input boron (3.5) as the dielectric constant.

Step 5: Complete the simulation and store the data and image files with the outcomes.

SCFA statistical analysis:

Mean values and significance were determined for nickel and graphene for each group. Capacitance was the dependent variable, and comparisons were made between two pairs of components for the electrode length (415 nm), electrode width(300), and dielectric thickness (250 nm).



III. Results and discussions

The Mean Capacitance of Nickel and Graphene while varying the electrode length is shown in above graph. The X-axis represents the Mean Capacitance of Nickel, and the Y-axis shows the Mean Capacitance of graphene . Both materials exhibit an increase in Mean capacitance by using MEMS while varying the electrode length it increases when compared to Nickel and Graphene.The materials made of Nickel and Graphene achieved the highest Mean capacitance values at 410 nm electrode length, attaining $8.21 * 10^{-12}$ F and $7.47 * 10^{-12}$ F respectively.

The research outcomes suggest that variations in Electrode Length for Nickel ($8.21 * 10^{-12}$ F) mean capacitance that better than Graphene ($7.47 * 10^{-12}$ F). A statistical analysis, employing an Independent T-test, emphasized a significant divergence in the characteristics of both Nickel and

Graphene, revealing a p-value of 0.011 ($p > 0.05$). This statistical significance is the difference between the capacitance values compared with Nickel and Graphene under some experimental conditions.

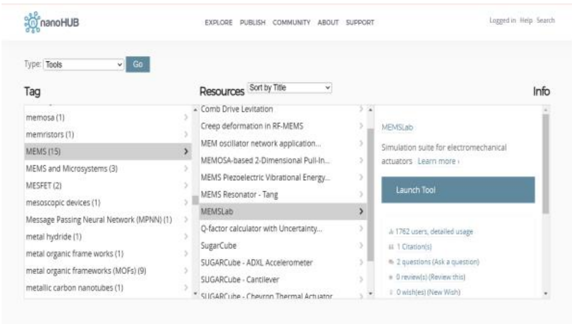


Fig 1: Select MEMS and to Launch the tool open the MEMSLAB.

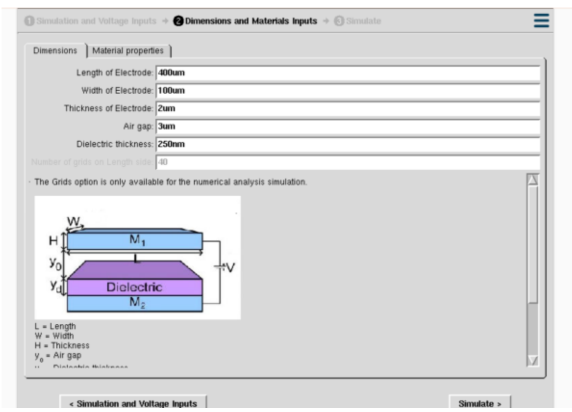


Fig 2: In This step Change the Electrode length .

According to the author's research, This represents a variable capacitor that achieves a broad tuning range and high tuning ratio through sequential switching and reversible latching techniques. This Research Adjusting the capacitance experimentally results in a tuning ratio of 9.42 and a range of 3.74 pF to 35.24 pF. Capacitance, measured at 100 kHz, ranged from 0 to 12 V. With coordinated switching and gap-closing, a maximum capacitance of 35.24 pF and tuning ratio of 9.42 also obtained (Baek et al. 2014). The varactor's ALD process yields a, measuring of 1.54 pF at 1 GHz. The equivalent capacitance of the varactor after trench etching is 0.68 pF at 1 GHz, This research is determined by subtracting the contribution of the RF pads from the varactor's reactance(Bakri-Kassem and Mansour 2008) .This Research shows that non-Faradaic 2Cdl (double-layer capacitance) values are not enough to account for differences in Faradaic OER/HER (Oxygen Evolution Reaction/Hydrogen Evolution Reaction) activity for catalysts. The activity patterns are challenged when the surface of SS 304 (stainless steel with approximately 18% chromium and 8% nickel) foil is modified, altering capacitance (Anantharaj 2021). Nickel nanoparticles embedded in graphitic carbon after 2500 cycles maintained 86.8% of their specific capacitance of 320.0 F/g at 2 A/g. In reducing p-nitrophenol and methyl orange, From these (1) and (2) nanocatalysts Nickel performed better than the others (Hammud et al. 2024).The research looks at the capacitance voltage properties of circular MEMS actuators made of dielectric materials such as SiO_2 and TiO_2. Pull-in state for a SiO_2-based actuator is $3.66040E^{-12}$ F, and The Pull-in state for a TiO_2-based actuator is $1.30261E^{-10}$ F. TiO_2 has a capacitance that is significantly higher than SiO_2 (Reddy and Azariah 2023)

A limiting factor in the Nickel based MEMS is the Electrode length range found by researchers, specifically between 410 and 560 nm. Addressing this limitation in future research may involve investigating electrode materials with higher dielectric material This outcome includes a potential reduction in the MEMS Mean capacitance providing opportunities for enhanced operational efficiency and increased in various applications. This Research advancement is to hold the overall device performance for improving and overcoming electrode length . Spring Mass Models have an important role in microelectromechanical systems (MEMS) as individual components and in integrating electrical and mechanical functionalities for compact and efficient systems (Takahata 2013). MEMS Spring Mass Models offer more advantages in micro-scale manipulation, actuation, and sensing due to their ability to function at high frequencies with minimal power consumption (Yurish 2014). Nickel is preferred in MEMS due to its superior mechanical properties, including high strength, ductility, and corrosion resistance (Gibson, Ashby, and Harley 2010). The research looks into a comprehensive analysis of the detailed variances in capacitance exhibited between two distinct electrode materials, gold and graphene, when interfaced with a shared dielectric medium, sulfur, through modification of electrode width. Gold, a common electrode material in MEMS, has high electrical conductivity, providing robust connections and corrosion resistance(Kang et al. 2023).Graphene in MEMS makes use of its exceptional mechanical, electrical, and thermal characteristics to improve device performance and functionality, hence enhancing many areas of microelectromechanical systems (Liu et al. 2023).In contrast, MEMS piezoresistive microphones modify their electrical resistance in response to sound pressure. MEMS capacitive microphones use parallel plates to act as a mass-spring system, with sound pressure causing membrane oscillation, which changes capacitance and generates an electrical signal (Loboda and Salamatova 2021).Charging of electrical double layers in cylindrical pores, which is critical for supercapacitors and batteries, is analyzed. Direct numerical simulations provide overlapping double layers, which help to refine the effective circuit model (Gupta, Zuk, and Stone 2020).By changing the distance between the mirror and the surface, the researchers are able to accurately control the polarization of the reflected light. Many changes are possible as a result, including the conversion of linear to circular polarization (Meng et al. 2022).The review assesses high-temperature dielectric polymers for capacitive energy storage. Assesses the structural impacts on capacitance, energy density, and cyclability. Reviews present methodologies, identify problems, and propose future research prospects (Li 2021).Nickel is commonly used in the production of electrical contacts, lead frames, and connectors due to its excellent conductivity and resistance to corrosion.Iron-nickel bimetallic nanoparticles were synthesized and tested for azo dye removal from water. Lower Ni:Fe ratios (80–99% efficiency) performed better than higher Ni ratios (70–90% efficiency). Kinetic modeling showed a decrease in the rate constant with increasing Ni, and post-reaction analysis revealed Fe_2O_3 and FeOOH formation(Foster et al. 2021).A novel graphene-based photonic device with two monolayers and vertically stacked microring resonators offers efficient tuning of electronic and optical properties with low voltage. This compact design, suitable for phase-shifting or delay lines, achieves a maximum group delay of 360 ps, tuning range of 230 ps, and switching energy of 26 pJ(Ciminelli et al. 2015).

IV. Conclusions

This research provides the results of Nickel and Graphene through MEMS technology. Nickel demonstrates significantly enhanced mean capacitance at $8.21* 10^{-12}$ F with a p-value of 0.011 ($p > 0.05$), while Graphene shows a lower mean capacitance at $7.47* 10^{-12}$ F in comparison.

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