

Design, Fabrication, and Characterization of System-on-Chips Accelerometer Using SOI Technologies: A Deep Dive into Secured Interfaces

Eze Nicholas Ude, Odewale Opeyemi Tolulope, Anyalebechi Felicia Nneamaka, Ibeh Ogbonna Mercy Chinenye

Department of Computer and Robotics Education, University of Nigeria Nsukka
Department of Industrial Technical Education, University of Nigeria, Nsukka
Corresponding Author: opeyemi.odewale@unn.edu.ng

ABSTRACT

The main objectives of this work are to examine, recommend, and design a silicon-on-insulator (SOI) SoC device that is incorporated inside a metallic container and connected to an optical fiber. In the connected System-on-Chip (SoC) sensor, four specially engineered springs are integrated into the device layer, together with a mass structure and handle layers. For displacement interrogation, an optical reading system with a Fabry-Pérot interferometer (FPI) and a demodulation method is utilized. Because of its great sensitivity and immunity to electromagnetic interference (EMI), the (FPI) is also used. Findings depicts that our proposed SoC sensor show a resonant frequency of 1274Hz with damping ratio of 0.0173 under running conditions up to 7g. This finding fits in nicely with the existing analytical framework. Our experimental findings, however, suggest that our designed SoC sensor has the ability for engineering uses to detect vibrations under extreme electromagnetic ambient situations when compared to other similar designs.

Keywords: Accelerometer; Fabry-Pérot interferometry (FPI); micro-electro-mechanical system (MEMS); silicon-on-insulator (SOI); System-on-chips (SoC); vibration Analysis

1. INTRODUCTION

A key element of contemporary SoC sensor designs is security architecture, or a technique to guarantee the protection of critical assets from malevolent, unauthorized access. Vibratory analysis is a vital technique in the design of sensor monitoring technologies for System-on-Chip, including applications for machining operations and severe electromagnetic environments, which may be used to minimize monitoring times with regard to the technical aspect of failures of high-power chips [1]. Strong signal-conditioning electronic interfaces were a few challenge for the majority of recent vibration analysis studies for applications using strong electromagnetic forces [2].

However, vibrational analysis can be performed with microelectronic devices like the System-on-Chip (SoC) displacement sensors. These sensors use sensing concepts like capacitance to keep an eye out for cyberattacks on mobile SoC components [3], electromagnetics [4], photodiode-based principles [5], and lasers or optics [6]. However, depending on the micro-scale sensing mechanism being employed, each sensing principle has pros and cons of its own. For example, capacitive sensors measure the physical space between the two plates to translate changes in capacitance into displacement information. But their output is usually correlated with the

plate area [7]. When a magnetic field induces an electric current, electromagnetic sensors measure the change in intensity of the current [8]. To prevent interference with the measurement, a strong electric shield must be placed around the active current-sensing device.

The proof mass displacement in System-on-Chip (SoC) sensors modifies the output light's properties. They employ a variety of strategies, including intensity-based detection, [5] fiber Bragg grating (FBG) [9], and Fabry-Pérot interferometry (FPI) [10]. An optical displacement sensor that is intensity-based detects changes in light intensity and translates these into displacement data. However, this method is dependent on the laser diode's stability as well as the optical components' surface conditions.

On the other hand, the FBG approach makes use of a waveguide incorporated in a SoC device or a periodic modulation index inside an optical fiber. Vibration from this type of vibration sensor causes stress or strain in an optical fiber or waveguide. This alters the FBG's timeframe. This alteration can be used to understand variations in the wavelength of light [9]. To track the wavelength shift, the FBG needs an optical spectrum analyzer and a more involved manufacturing procedure for the waveguide inside the SoC chip.

An FPI and micro technology were used in this experiment. Due to its high sensitivity, low cost, straightforward design, and immunity to electromagnetic interference (EMI), this interferometer has been employed extensively [11] [12]. We employed photonics and SoC because their combination helps to address issues that are mostly encountered in electromagnetic interference (EMI) circumstances, when standard sensors and/or electrical instruments are either prohibitively expensive, inoperable, or impossible to use.

The proposed SoC micro-device sensor detects motion of a proof mass supported by four custom-built springs by optical interrogation with an FPI. SoC has been utilized to measure pressure [5] [13], strain [14], and in-plane motion [10] in other relevant studies. Nevertheless, some still need open optical access channels to the moving target section, even in the absence of a mechanical connection and a steady optical reference [11]. As far as we are aware, no method has been created that utilizes the structural structure of the SoC device and mechanically attaches the optical interface to a moving target. The design and

development of the SoC sensor are described in this publication. We constructed a metal package to interface an optical fiber with the proof mass's mirror section so that we could do an optical interrogation of the proof mass displacement. To ensure precise characterization of the entire sensor system, a verified vibration system was also used.

II. SENSOR PROOF MASS: MATERIALS AND METHODS

1. Sensor Structure

A SoC chip, an optical interface, and a metal vessel make up the suggested sensor system. Figure 1a illustrates the SoC construction, which consists of a cylindrical proof mass set on an anchor frame and centered around four identical springs. The metal packing is secured to the optical fiber and anchor frame structure. As a result, an optical cable can be used to optically interrogate the proof mass for displacement, as seen in Figure 1b,c. The SoC chip is shielded and connected to an optical fiber by the

metallic container. To put it another way, it consists of an optical fiber ferrule, with the surface of the proof mass serving as the optical attachment point on one end. For mass-motion sensing, the opposite end tip of the optical fiber is linked to an FPI reading apparatus. The SoC device is depicted in Figure 2 from both the front and rear, with an enlarged anchor frame added for improved metallic package support. As a mirror in the interferometric reading system, the front side displays the proof mass's reflective surface (see Figure 2a). Figure 2b displays the rear of the SoC structure as well as the enlarged frame's anchor parts. The SoC sensor is affixed to the metallic package's lower half in Figure 2c, where it is firmly held in place with powerful adhesive. The metallic package's precise dimensions are displayed in Figure 2d. The upper portion of the package contains the optical fiber end tip, which is hidden in Figure 2. Each of the four springs in the SoC device is coupled to a set of serpentine springs, as can be seen in Figure 3.

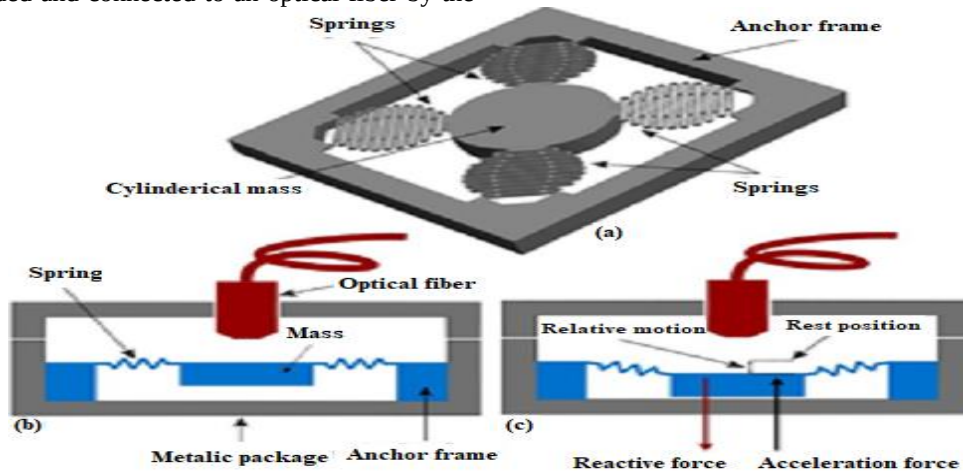


Fig. 1. an illustration of the SoC device in (a), the metallic package connecting the SoC structure to an optical fiber in (b), and the sensor's response to applied acceleration in (c).

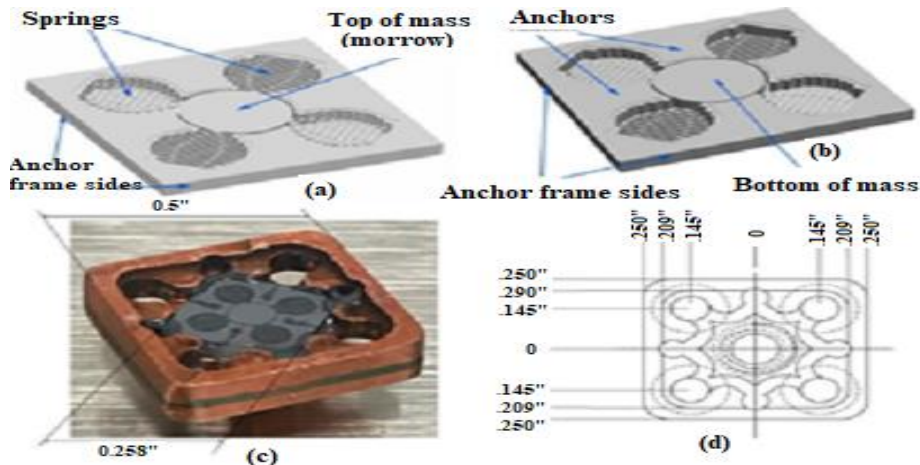


Fig. 2. The expanded anchor frame of the SoC device design displays the following: (a) front/mirror side, (b) back/mounting side, (c) manufactured SoC structure attached to the metallic package, and (d) metallic package dimensions.

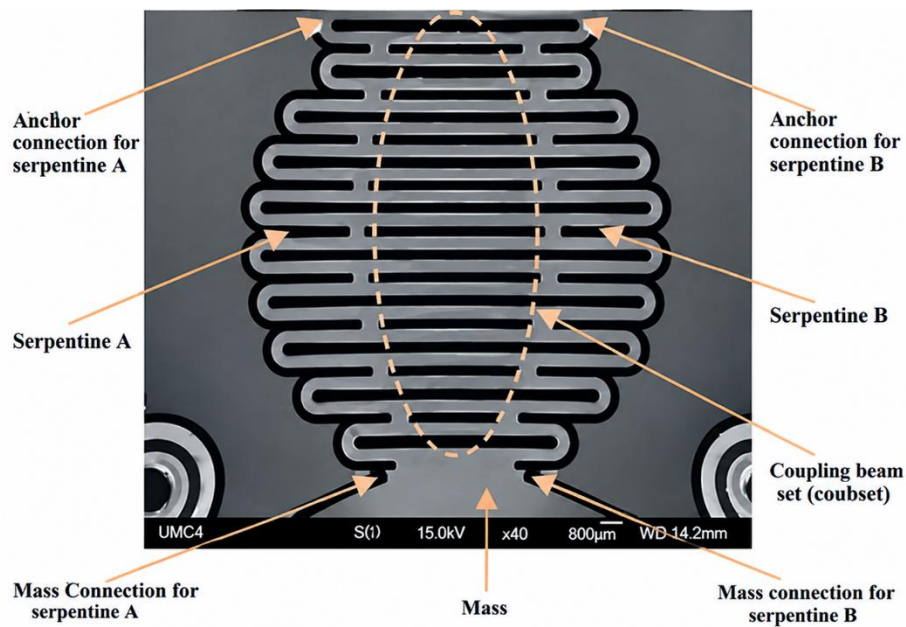


Fig. 3. SEM picture shows a single proof mass supporting spring.

The recommended SoC gadget is distinct because of its spring design and integration system. It was suggested in [15] to use serpentine-type springs (ST) with linearly scaled (LS) units, which were initially recommended and examined. In one configuration, four identical ST LS springs supported a center proof mass. The springs were directed at $+x$, $-x$, $+y$, and $-y$ based on the location of the proof mass. However, the frequencies for the unwanted vibration modes were low and close to the intended mode (z-axis motion) since each spring had a simple anchor connection in the x- or y-direction.

Consequently, two parallel ST springs were added to the design for every four springs as a result. Using a scanning electron microscope (SEM), Figure 3 depicts the underpinning spring of the proof mass and the two adjacent serpentine springs, A and B. The proof mass is connected to one side of each serpentine spring, and the anchor frame section is connected to the other. The anchoring portions of springs A and B are clearly physically farther away than the corresponding mass connection sections. Furthermore, a beam set called the coupled beam set, or simply coubset, joins the serpentes in Figure 3 by joining each semicircle link of serpentine A with its matching semicircle link of serpentine B, thus stabilizing the proof mass along the z-axis.

2. Fabrication of Sensor

As seen in Figure 4a, the SoC device was manufactured on a 4" silicon-on-insulator (SOI) wafer. The silicon 100 handle layer measured 450 μm , the buried oxide (BOX) layer 2 μm , and the silicon 100 device layer 65 μm . The actions listed below were put into effect. Initially, the thickness of the proposed cylindrical proof mass and the anchor structures were established. This was accomplished by deep reactive-ion etching (DRIE) of the handle layer's silicon, which took 10 μm . We were also

able to find the right spring stiffness by using DRIE to mill 5 μm of silicon on the device layer. However, two-side alignment lithography was necessary for the device and handle layers prior to the etching process. Figures 4b,c show the required lithography and etching steps. Before the device and handle layers, which needed 100 and 20 nm of chrome, respectively, could be sputter-deposited, the photoresist remains on both wafer surfaces had to be scraped off. While the chrome on the handle layer acted as a hard mask for the subsequent all-through handle DRIE machining, the chrome on the device layer functioned as an optical reflection layer for the mirror section of the proof mass. Utilizing lithography and chromium etching techniques was the last phase.

The four spring-like springs and core mass that comprised the device layer structure of the sensor were defined in this step. Meanwhile, as shown in Figure 4d, the holes at the base of the device's layer-formed springs and the core mass of the handle layer were defined. The fourth technique required implementing DRIE on the device layer in order to access the BOX layer, as shown in Figure 4e. The thin BOX layer and springs may break under the helium cooling push on the wafer's back during the handle layer's etching procedure. Therefore, in order to protect the fragile spring structure before etching the handle layer, a thick photoresist was used in the fifth phase. In Figure 4f, you can observe the 20 μm KMPR® photoresist that covers the device anatomy. As seen in Figure 4g, sixth stage DRIE etching of the handle layer was carried out till it reached the BOX layer. Two steps made up the second step. Utilizing a buffered oxide etch (BOE), the BOX layer was initially etched following the design of the handle DRIE apertures in the sixth phase. In the second stage, the thick photoresist was etched using dry etching with oxygen plasma at a flow rate of 40 standard cubic centimeters per minute (sccm) at 25 mT, 380 W of

inductively coupled plasma (ICP) power, and the temperature at 20 °C in a tray.

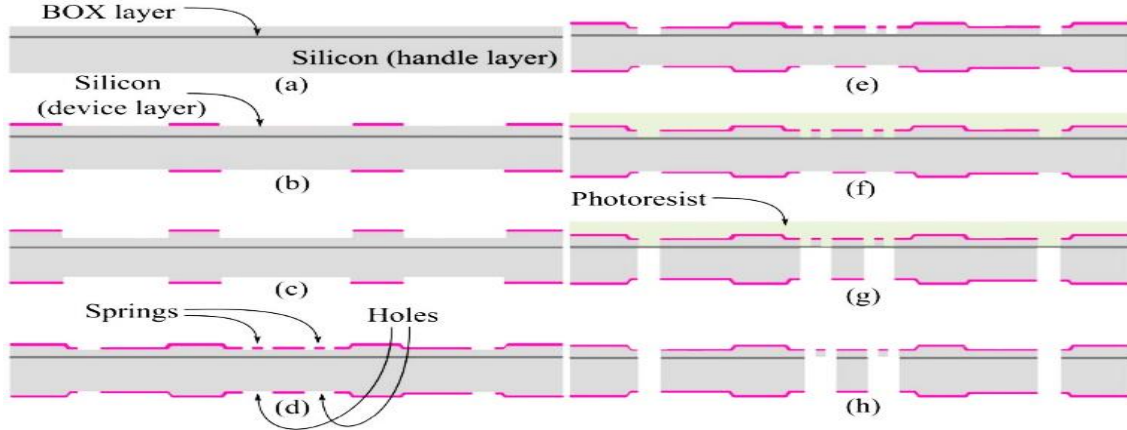


Fig. 4. The following steps are used to fabricate the SoC structures: (a) SOI wafer; (b) double-side alignment lithography; (c) device and handle DRIE process for the desired mass weight and stiffness; (d) lithography for the device's spring design and handle proof mass design; (e) device etch for the spring machining; (f) thick resist protection for the device's side structure; (g) handle etch in preparation for the bulk machining proof mass; and (h) BOX etch from the handle side in advance of resist cleaning.

The following were the prerequisites of the DRIE process for the creation of SoC devices. For C (sub4)F(sub8) and SF(sub6), an Oxford Instruments Plasmalab 100 system was utilized. The passivation and etching stages lasted 5 and 6 s, with 60 and 87 sccm flow rates, respectively. A platen was used for both procedures, which were run at 20 °C, 700 W of ICP power, and 28 mT of RF.

The results of the fabrication process employing a 4" SOI wafer are displayed in Figure 5. To machine the frame of each SoC structure, the fourth phase of the process was used on the device side and the sixth step on the handle side. The SoC structures are held in position on the wafer by readily braking cantilevers at each frame's corners. Therefore, dicing is not necessary in order to remove the SoC die off the wafer.

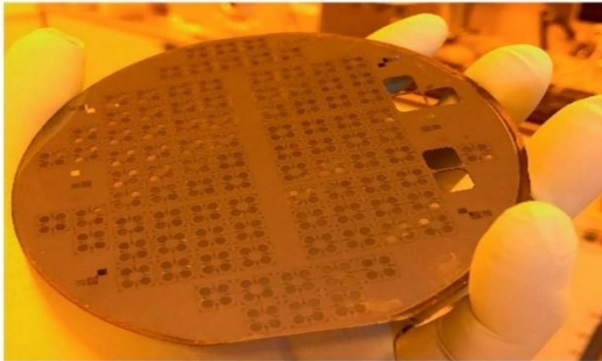


Fig. 5: Components manufactured on a 4" SOI wafer.

III. MODEL OF DYNAMIC SENSORS

By treating the device sensor like a spring-mass-damper system, a dynamic model was created. Figure 6 shows the schematic representation of the three counterforces that are produced when the metallic shell accelerates and acts onto the SoC chip. Assuming the mirror layer face to be planar to the x – y-axes, this means that when the housing is driven by acceleration in the z-direction, the housing

motion, y_{hs} , is not always equal to the proof mass motion, y_m , and the difference between the motions results in a relative motion, y_r .

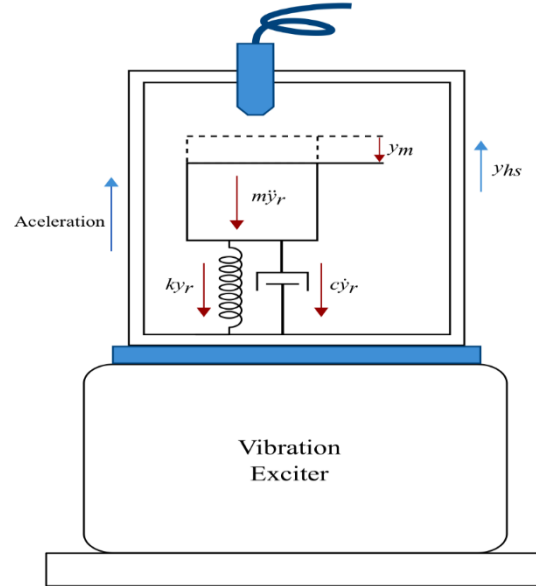


Fig. 6. Acceleration of the metal container and the opposing forces of the SoC structures.

Given that the housing motion $y_{hs} = A \sin \omega t$, Newton's second law [16] governs y_r .

$$m \frac{d^2 y_r}{dt^2} + c \frac{dy_r}{dt} + k_z y_r = -m \omega^2 A \sin \omega t \quad (1)$$

Where k_z is the spring stiffness supporting the moving mass along the z-axis, m is the device's moving mass, c is its damping coefficient (for these systems, the impact of air or embedded gas between the housing and the proof mass is commonly the damping coefficient), and $y_r = y_m - y_{hs}$. The symbols A and ω denote the amplitude and angular frequency of y_{hs} , in that order.

Our intention was to restrict the sensor's operation to frequencies below 800Hz. Thus, we select 1200Hz in the z-direction as the fundamental frequency ($f_n = \omega_n / 2\pi$) or the initial vibrational mode. Additionally, regarding the related vibration modes on the x- and y-axes in addition to the torsional modes on the x-, y-, and z-axes, we decided to minimize the parasitic or noisy motions of the proof mass. Consequently, we recommended employing a spring design that seeks to minimize these parasitic motions (see Figure 2). They were employed in the mass, spring, and damper calculations.

The spring mass was not taken into account while calculating the mass of the device sensor. It considered solely the body of evidence. The silicon density, $\rho_0 = 2329 \text{ kg/m}^3$, the radius of 1.11 mm for the cylindrical mass, and the thicknesses of 60 μm , 2 μm , and 438 μm for the device layers were used. A total mass of 4.5215 milligrams was computed.

The relevance of the spring design is explained by contrasting how well it performed with FEA simulations carried out in CoventorWare® and the normative conduct of the SoC device. The sensing device's spring arrangement are made up of four distinct springs, and the symbol k_z denotes the overall stiffness of these springs along the z-axis. But each spring has a different design, as shown in Section 2, which is comprised of two serpentine-type springs connected opposite one another by a coubset. One of the strings is with the coubset, while the other is without the coubset. We simulated and compared the two spring designs. A stress-induced FEA simulation of the SoC with a coubset is depicted in Figure 7. Giving a push in the z-direction to the bottom of the proof mass produced this outcome. This time, the stress in the serpentine part is represented with a paler color, extending along each spring.

Note that there was not a single strained beam emanating from the coubset. Ignoring the coubset in Figure 3, the mass-spring system's vibration exhibits three major (lower frequency) vibrational modes. Since the other modes appear at higher frequencies, these modes are important to us. Nevertheless, the primary modes increased with the addition of the coubset. The first vibration mode without a coubset was at 1315.89Hz. As can be seen in Figure 8, this was quite close to the first vibration mode at 1327.48Hz when the coubset was used. Since the stiffness in this motion mode (as seen in Figure 8) was not significantly changed by the coubset, the frequencies were similar.

The vibration modes at 2433.08, 2433.33, and 3359.94Hz migrated to higher frequencies when the coubset was taken into consideration. In addition, the frequencies of the vibration modes at 3422.60 and 3422.85Hz in the absence of the coubset were similar to those of systems that had the coubset at 3518.08 and 3518.83Hz. In light of this, the FEA simulation demonstrates that the coubset contributes an increased stiffness regarding certain mode

behaviors, showing an improved performance of the sensing technique employed for this study.

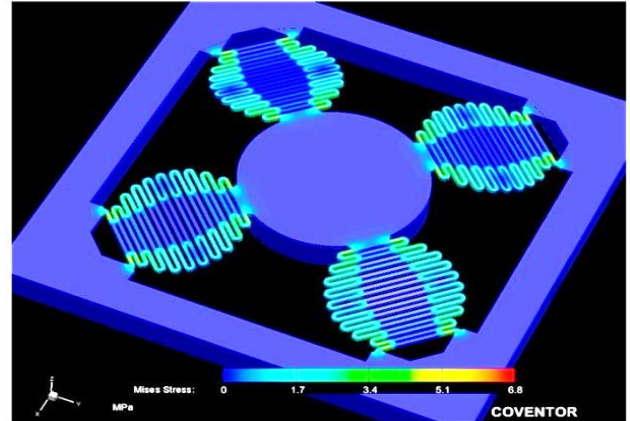


Fig. 7. FEA simulation with stress after the bottom of the proof mass is force-applied.

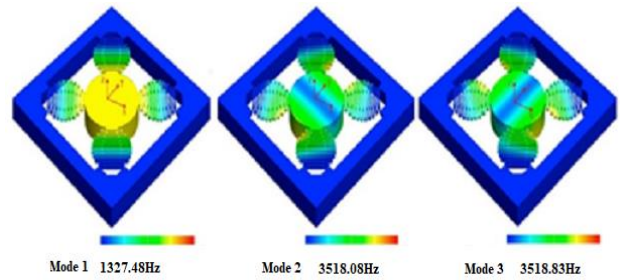


Fig. 8. Modes of vibration that arise from the system when the coefficient is applied to the springs (exaggerated by a factor of 150).

Using finite element analysis (FEA), the resultant spring stiffness (k_z) was determined. This was done through the application of an average static force of 640 μN to any of the uppermost or bottom of the proof mass. In the FEA simulations, the force was split by the total mass displacement. If the highest stress given to the structures is far less than the silicon yield strength, then any force can be applied to them. In this instance, the yield strength employed was less than 50 MPa of that used by [17] or less than 1% of that needed by [18].

Equation (1), with a housing frequency of 60Hz and an amplitude $A = 1 \mu\text{m}$, produces a response for the sinusoidal input with a corresponding dynamic force of 640 μN . The measured thicknesses of the device and handle layers were 438 μm and 59.75 μm , respectively, after the spring and proof mass were created. With these settings, the FEA simulation produced a mass displacement of 2.9338 μm utilizing a silicon Young modulus of 130.18 GPa (E_x, E_y, E_z), a 0.278 Poisson ratio, as well as a 79.64 GPa shear modulus. Using these values, the stiffness along the z-axis was determined to be $k_z = 289.7266 \text{ N/m}$.

The calculation of the damping coefficient c was done using data from both experiments and theory. The steady-state solution of equation (1) for the relative motion y according to the calculus of c takes this expression [19]:

$$(y_r)_{steady} = \frac{\left(\frac{w}{w_n}\right)^2 A \cos(wt - \varphi)}{1 - \left[\left(\frac{w}{w_n}\right)^2\right]^2 + \left[2\zeta\left(\frac{w}{w_n}\right)\right]^2} \quad (2)$$

Where $w_n = \frac{\sqrt{kz}}{m}$, $\zeta = \frac{c}{\sqrt{2kzm}}$, $\omega = 2\pi f$, and φ shows the change in phase of the system reaction. An authorized accelerometer characterization apparatus was utilized in the experimental configuration designed for this study. This implies that the system's sensor housing uses a known acceleration measured in m/s². Next, by adjusting the input angular frequency ω and applying an input acceleration of 20 m/s², or almost 2 g, we were able to determine the resonant frequency (f_r). The maximum of the steady-state amplitude, or $(y_r)_{steady}$, was likewise found by changing ω . A second order system's phase shift is known to be 90° when $\omega = \omega_n$ and $c = 0$. And $f_n = f_r$ was validated by our theoretical and experimental results. Our experiment's phase shift at $\omega = \omega_r$ was less than 90°, and $c \neq 0$ because it wasn't conducted in a vacuum. However, we expected the damping coefficient to be sufficiently small because the experiment was conducted in air. Hence, we could consider $f_r \approx f_n$. Equation (2), where $\omega \approx \omega_n$, can be used to approximate $(y_r)_{steady}$ as follows:

$$(y_r)_{steady} \approx \frac{A}{2\zeta} = A \frac{\sqrt{kzm}}{c} \quad (3)$$

With $(y_r)_{steady} = 8.97 \mu\text{m}$, f_r was measured empirically at 1274Hz, which is only 5Hz away from the predicted value of f_n . Consequently, the controller amplitude for this frequency was obtained using $\omega_r = 8004.8 \text{ rad/s}$ and an acceleration of $A\omega^2 = 20 \text{ m/s}^2$. Equation (3) yielded $c = 0.00125523$, and Equation (1) yielded $\omega = \omega_r$ and $A = 0.31213 \mu\text{m}$. The MATLAB ode23 function was used to calculate the resultant value of $y_r(t)$ for all of the sinusoidal input at a particular velocity and rate after each of the variables from equation (1) had been obtained. Figure 9a displays the relative mass displacement, y_r , for an input signal, y_{hs} , that has an acceleration of 0.5 g and a frequency of 1100Hz. A close caption of the steady-state signal $(y_r)_{steady}$ and its phase shift are displayed in Figure 9b. Equation (4) can be used to plot the phase shift for this model directly, or, as Figure 9b illustrates, it can be approximated by comparing $y_r(t)$ and $y_{hs}(t)$ for a constant acceleration input. By comparing the phase shifts with $y_r(t)$, the amplitude and phase shift that were generated using this model were then verified empirically.

$$\varphi = \tan^{-1} \left| -\frac{2\zeta\left(\frac{w}{w_n}\right)}{1 - \left[\left(\frac{w}{w_n}\right)^2\right]} \right| \quad (4)$$

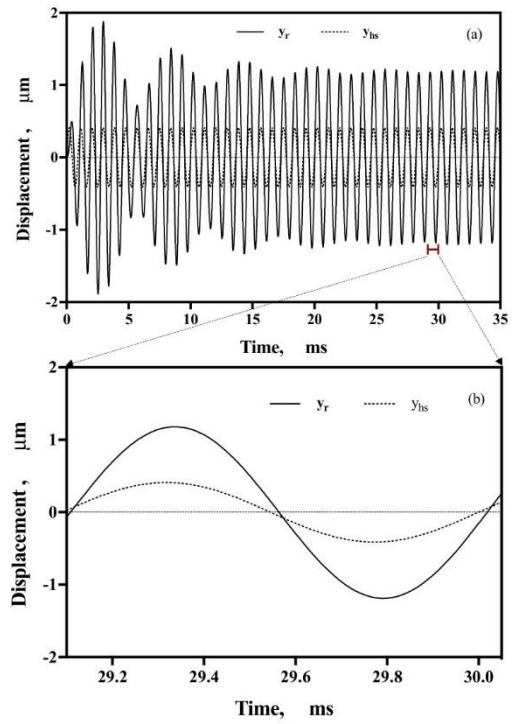


Fig. 9. displacement $y_r A$ (continuous line) at 1100Hz and 0.5 g of acceleration for a reference input signal y_{hs} (dotted line); (b) phase shift of 7.92 degrees observed in the last cycle from (a).

3.1. Configuration Description

An FPI-based interferometry technology that monitors displacement y_r is the basis for the interrogation approach utilized for reading the mass displacement [9]. A representation of the optical apparatus utilized in the Fabry-Pérot approach is presented in Figure 10. Given that the reflection values at each optical contact are alike, the photodetector observed the following optical signal:

$$1(t) = I_0 \left| 1 + 2 \cos \left(\frac{4\pi}{\lambda} D_x(t) \right) \right| \quad (5)$$

where $D_x(t)$ is the actual separation between the end fiber tip and the SoC center mirror, that differs based on the housing signal acceleration, and I_0 is the diode laser power, where λ is the diode laser wavelength. D_x is specifically determined by a sinusoidal signal stimulates the SoC. If it does, the D_x is equal to:

$$D_x(t) = D_0 + Y_r A \sin wt \quad (6)$$

Where, $y_r A$ and ω are the amplitude and angular frequencies and D_0 indicates the starting D_x at rest. Then Equation (5)'s time-varying component can be written as follows:

$$1(t) \cong \cos \left| \frac{4\pi}{\lambda} Y_r A \sin wt + \Phi_1 \right| \quad (7)$$

Thus, when the proof mass is at equilibrium (resting position), Φ_i is the phase difference between the interfering beams. Through the application of Fourier series to expand Equation (7), taking into account that

$(4\pi/\lambda)y_{rA} \ll 1$, and configuring the interferometer to $\phi_i = (\pi/2 + \pi k)$, the electrical signal may be directly connected to the amplitude and frequency of y_r , as follows:

$$1(t) \cong \frac{2\pi}{\lambda} Y_r A \sin wt \quad (8)$$

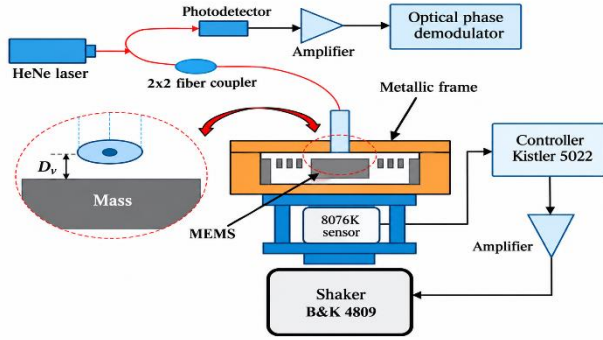


Fig. 10. The optical characterization of the SoC chip was conducted using an experimental setup.

Equation (7) provides the output sensor signal, though, If the input excitation's vibration amplitude rises over $\cong 123$ nm. To recover the sensor response, a demodulation approach needs to be applied. In this work, we developed a procedure based on LabVIEWTM programming to match a synthetic interferogram to the experimental one. The proper amplitude and phase parameters were adjusted while taking the input frequency into account in order to fit this data. With this demodulation technique, we were able to demodulate input excitations of both large and small amplitude.

To verify the input motion of the SoC sensor, we used a well-tried characterization setup composed of a Kistler 5022 controller, an 8076 K reference accelerometer, and a B&K 4809 shaker. It is assured that the system operates in the frequency range of 50Hz to 10kHz. From 60Hz to 1.6kHz, the sensitivity increases linearly, ranging from 1.022 mV/(m/s²) at 50Hz to 1.029 mV/(m/s²) at 1600Hz. Figure 11 shows the experimental setup that was used to characterize the SoC sensor.

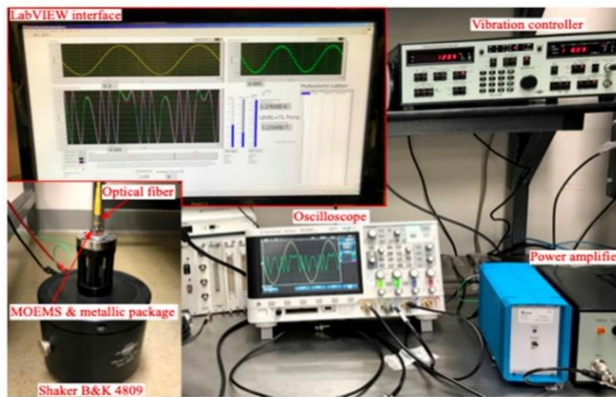


Fig. 11. The oscilloscope, vibration controller, power amplifier, metallic package mounted on the shaker, LabVIEW interface for processing and gathering data, and yellow optical fiber connector are all part of the electronic setup.

The frequency response of the sensor was determined by a methodical series of experiments and individual measurements. Put another way, we collected phase and magnitude data. First, the electrodynamic shaker was run with the Bruel & Kjaer vibration control setup. Subsequently, the frequency was varied for every one of the many acceleration inputs supplied to the sensor. Next, using a data collecting equipment, each interferometric signal was recorded in LabVIEWTM. Ultimately, each received interferogram signal was as nearly matched as feasible by using the experimental frequency to chart the matching synthetic interferogram and modifying the amplitude and phase variables using Equation (3) in LabVIEWTM. Figure 12 illustrates this.

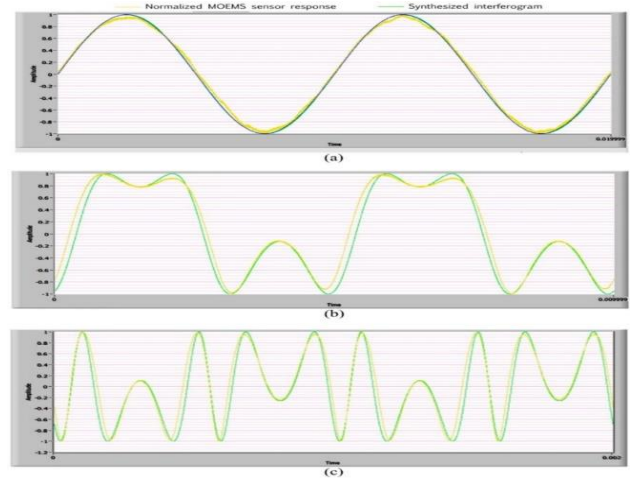


Fig. 12. Normalized sensor response (yellow plot) and synthesized interferogram (green plot). When the acceleration input's amplitude is sufficiently small, (a) a sinusoidal output results. (b) A distorted sinusoidal output with an acceleration input of 20 m/s² at $f = 200$ Hz and (c) $f = 1000$ Hz.

IV. RESULTS AND DISCUSSION

The final die dimensions were 6.391×6.391 mm, after the SoC device was manufactured on an SOI wafer with handle layers and device size 59.75×438 μ m. The round mirror, which constituted the top component of the mass, had a diameter of 2.22 mm. The smallest size characteristic of the spring structure has a width of 45.7 μ m.

Through rigorous testing, we succeeded in enhancing the initial vibration mode's performance in comparison to the other designs that use traditional serpentine springs by canceling the vibration modes in the close frequency area. We demonstrated this obstruction of the vibration modes through contrasting the outcomes of the two designs' FEA simulations that are shown in Section 2.

With the coubset in the spring, Figure 8 illustrates the various vibration modes of this apparatus: At a frequency of 1327.48Hz, the first vibration mode exhibits motion along the z-axis; at 3518.08Hz, the second mode displays a small rotating wave; and at 3518.83Hz, the third mode exhibits a slight rotational wave. Since the primary goal of this work was to sense the mass motion in the z-

direction, using coupled springs produced a wider range of vibration modes, which is helpful (see mode 1 in Figure 8).

The sensor's experimental response and the anticipated interferograms are displayed in Figure 12. Equation (4) is shown to be appropriate for an input signal that has a modest enough amplitude to produce a sinusoidal output in Figure 12a. This calls for $y_r A \ll 123 \text{ nm}$. The findings for the 200 and 1000Hz stimulation frequencies as well as the distorted sinusoidal signal are displayed in Figure 12b,c since the condition $y_r A \ll \frac{4\pi}{\lambda}$ was not satisfied. We used a Thorlabs photodetector model DET30B, which photoconductive mode responsivity at 1550 nm wavelength was 0.8 to transform the interferogram into an electrical signal. The photodetector signal appeared to be quite comparable to the synthesized interferogram, as shown in Figure 12. The spurious vibration of the optical fiber connection introduced an extra optical phase when the sensor was powered by the shaker, which resulted in a difference between the synthetic and experimental interferograms. It should be mentioned that our objective was to match each shifted interferogram waveform's peak with the experimental interferogram waveforms. We initially calculated the amplitude ($y_r A$) and angular frequency (ω) of the sensor in order to estimate the housing's max acceleration. Then, we solved the problem for A, the amplitude of the housing, by estimating the acceleration using the terms that were known in Equation (3).

Figures 13 and 14 give an analysis of the differences in the experimental data and the model for the amplitude and phase, respectively. It is evident that the model and the experimental data agreed well. According to Figures 14 and 15, the resonant frequencies are $f_r = 1274 \text{ Hz}$ and $(y_r)_{steady} = 8.97 \text{ }\mu\text{m}$. Further analysis revealed that the system characteristics were mass (m) = 4.5215 mg, damping ratio $\zeta = 0.0173$, damping coefficient (c) = 0.00125523, and spring stiffness (kz) = 289.7266 N/m.

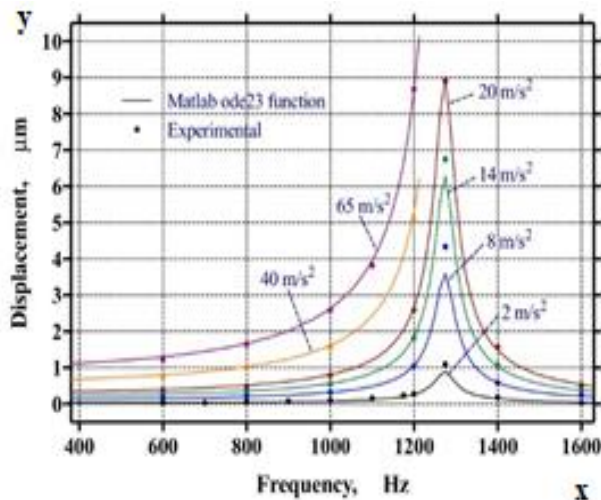


Fig. 13. Resulting amplitude sensor response.

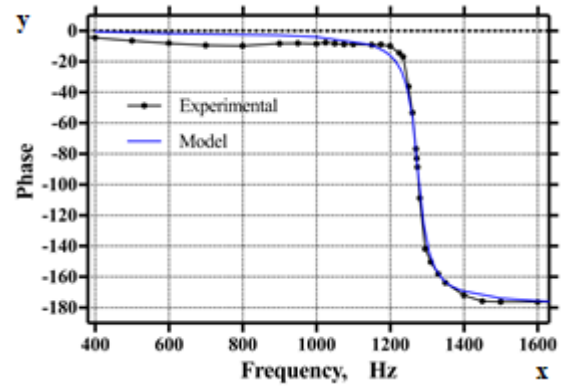


Fig. 14. Resulting phase shift of the system with a 90-degree shift located a 1274.5Hz.

V. Conclusions

A system-on-a-chip (SoC) with a mass-spring design and a Fabry-Pérot interferometer reading system integrated into a metallic packaging was conceived, designed, and tested. The handle layers and device produced SoC dimensions of 59.75 μm and 438 μm , respectively. The measurements of the anchor frame construction were 6.391 mm by 6.391 mm, and the diameter of the round mirror were 2.22 mm. Four specifically crafted springs for the SoC chip supported the proof mass. Each spring design utilized two separate serpentine springs performed better in terms of vibration modes in this study. We experimentally determined the relative displacement of the proof mass with a Fabry-Pérot interferometer. The weight range of the experimental testing was 0.2–7g. We developed a SoC model by combining FEA simulations, empirical research, and the conventional spring-mass-damper second-order system model. It was discovered what the primary parameters of the system were: mass, damping ratio, damping coefficient, spring stiffness, and frequency response. Comparing the experimental and theoretical results, we discovered very few differences. For instance, the variation at the resonant frequency was just 5Hz ($\approx 0.4\%$). Still, the main focus of future study will be on creating an electronic demodulator that can estimate the measurement magnitude instantly.

ACKNOWLEDGEMENTS:

The authors thank everyone who contributed to making this research a reality.

DISCLOSURE STATEMENT:

The authors hereby declare that they are not associated with, or involved with any organization or institution that might have a financial interest, or a non-financial interest, in the topics or materials covered in this paper. Thus, there are no possible conflicts of interest for the author or authors.

Funding:

A portion of the publication costs of this work were covered by funding from the Tertiary Education Trust Fund (TETFund) 2024 Institution Based Research (IBR) of the National Universities Commission of the Federal Government of Nigeria. This work is under the research project number TETF/DR&D/CE/UNI/NSUKKA/BR/2024/VOL.1. with project title: "Unlocking The Potentials of Young School Leavers Through the Promotion of Makerspace Library for Entrepreneurial Skills in Nigeria."

Author contributions statement:

Conceptualization, E.N.U.; methodology, E.N.U; data analysis of the modelling simulation and writing—original draft preparation, E.N.U., O.O.T., U.C.P., C.N.E., O.N.S., A.T.A., S.A.A., O.S.N., E.C.J., and O.W.U.; formal analysis and writing—review and editing, E.N.U., O.O.T.; supervision and writing—review and editing, E.N.U. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: Data supporting this study are available on request

REFERENCES

- [1] W. Luo, W. Su, Z. Nie, Q. Huang, S. Li, and X. Dong, "Vibration Characteristic Measurement Method of MEMS Gyroscopes in Vacuum, High and Low Temperature Environment and Verification of Excitation Method," *IEEE*, 2021. Vol. 9, pp. 129582–129593.
- [2] J.S. N'cho, and I. Fofana, "Review of Fiber Optic Diagnostic Techniques for Power Transformers," *Energies*, 2020. Vol. 13, 1789.
- [3] X. Zheng, S. Liu, Y. Lin, H. Wu, L. Teng, and Z. Jin, "An Improved Phase-Robust Configuration for Vibration Amplitude-Phase Extraction for Capacitive MEMS Gyroscopes," *Micromachines*, vol. 9, no 362, 2018.
- [4] Y. Zhao, S. Gao, X. Zhang, W. Huo, H. Xu, C. Chen, J. Li, K. Xu, and X. Huang, "Fully Flexible Electromagnetic Vibration Sensors with Annular Field Confinement Origami Magnetic Membranes" *Adv. Funct. Mater.*, vol. 30, 2020, 2001553.
- [5] Y. Qi, M. Zhao, B. Li, Z. Ren, B. Li, and X. Wei, "A Compact Optical MEMS Pressure Sensor Based on Fabry-Pérot Interference," *Sensors*, vol. 22, 1973, 2022.
- [6] Q.B. Lu, Y.N. Wang, X.X. Wang, Y. Yao, X.W. Wang, and W. Huang, "Review of micromachined optical accelerometers: From mg to sub- μ g," *Opto-Electron. Adv.*, vol. 4, 200045-1–200045-24, 2021.
- [7] J. Wang, Z. Yang, G. Yan, "Silicon-on-insulator out-of-plane electrostatic actuator with in situ capacitive position sensing," *J. Micro/Nanolithogr. MEMS MOEMS*, vol. 11, 033006, 2012.
- [8] Y.M. Choi, J.J. Gorman, N.G. Dagalakakis, S.H. Yang, Y. Kim, and J.M. Yoo, "A high-bandwidth electromagnetic mems motion stage for scanning applications," *J. Micromech. Microeng.*, vol. 22, 105012, 2012.
- [9] B. Malayappan, U.P. Lakshmi, B.V.V.S.N. Pabhakar Rao, K. Ramaswamy, and P.K. Pattnaik, "Sensing Techniques and Interrogation Methods in Optical MEMS Accelerometers: A Review," *IEEE Sens. J.*, 2022, vol. 22, pp. 6232–6246.
- [10] Y.S. Kim, N.G. Dagalakakis, and Y.M. Choi, "Optical fiber Fabry-Pérot micro-displacement sensor for MEMS in-plane motion stage," *Microelectron. Eng.*, 2018, pp. 187–188, 6–13.
- [11] D. Guo, H. Jiang, L. Shi, and M. Wang, "Laser Self-Mixing Grating Interferometer for MEMS Accelerometer Testing," *IEEE Photonics J.* 2018, vol. 10, pp. 1–9.
- [12] M. Zhao, K. Jiang, H. Bai, H. Wang, and X. Wei, "A MEMS based Fabry-Pérot accelerometer with high resolution" *Microsyst. Technol.* 2020, vol. 26, pp. 1961–1969.
- [13] A.S. Havreland, S.D. Petersen, C. Østergaard, K. Reck-Nielsen, E.V. Thomsen, "Micro-fabricated all optical pressure sensors," *Microelectron. Eng.*, 2017, vol. 174, pp. 11–15.
- [14] Y. Bai, J. Zeng, J. Huang, S. Zhong, Z. Cheng, and D. Liang, "Measurement of Structural Loads Using a Novel MEMS Extrinsic Fabry-Pérot Strain Sensor" *Appl. Sci.*, 2019, vol 10, no 18.
- [15] N. Lobontiu, and E. Garcia, "Mechanics of Microelectromechanical Systems," 1st ed.; Springer: New York, NY, USA, 2005, pp. 131–182.
- [16] R. Figliola, and D. Beasley, "Theory and Design for Mechanical Measurements," 5th ed.; John Wiley and Sons Inc.: Hoboken, NJ, USA, 2011, pp. 49–63.
- [17] Q. Lu, J. Bai, K. Wang, and S. He, "Design, optimization, and realization of a high-performance meems accelerometer from a double-device-layer soi wafer," *J. Microelectromech. Syst.*, 2017, vol. 26, pp. 859–869.
- [18] G. Kovacs, "Micromachined Transducers Sourcebook", 1st ed.; McGraw-Hill: New York, USA, 1998, pp. 19–27.
- [19] R. Figliola, and D. Beasley, "Theory and Design for Mechanical Measurements," 5th ed.; John Wiley and Sons Inc.: Hoboken, NJ, USA, 2011; pp. 49–63.

Cite this article as:

Nicholas, Ogbonna and at. al. "Design, Fabrication, and Characterization of System-on-Chips Accelerometer Using SOI Technologies: A Deep Dive into Secured Interfaces", *Special Proceedings of Applied Energy System and Computer Science*. Displayed as online in October 2026.

Link: <http://actsoft.org/science/act2026-pro/88-micro2024.pdf>

@Copyright to 'Applied Computer Technology', Kolkata, WB, India. Website: <https://actsoft.org>, Email: info@actsoft.org,