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Analytical Review on Enhancing Sustainability in microsystems by Integrating MEMS for Compact Design

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Abstract. By combining silicon-based microelectronics with micromachining technology, microelectromechanical systems (MEMS) have been identified as one of the most promising technologies for the 21st Century. With its microsystem-based devices and technologies, it will have a dramatic impact on the way we live and the way we live our lives. With an emphasis on both commercial applications and device fabrication methods, the paper provides an introduction to the field of MEMS. As well as discussing the range of MEMS sensors and actuators, the phenomena that MEMS devices can sense and act upon, and the major challenges facing the industry, the presentation discusses the challenges faced by the MEMS industry. An introduction to the field of MEMS is presented in this paper, which is divided into four sections. A section on MEMS introduces the reader to its definitions, history, current applications, and miniaturization-related issues. Photolithography, bulk micromachining, surface micromachining, and high-aspect-ratio micromachining are among the fundamental fabrication methods discussed in the second section, as well as assembly, system integration, and packaging of MEMS devices. A brief description of the basic principles of sensing and actuation mechanisms is provided in the third section, which discusses the range of MEMS sensors and actuators, as well as the phenomena that can be sensed or acted upon with MEMS devices. Toward the commercialization and success of MEMS, the final section illustrates the challenges facing the industry.

Keyword-: Electron Beam Melting; Selective Laser Melting; Microstructure, Sustainability, Environmental Impact.

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1 Introduction

One of the new areas of interest is the micro-electromechanical systems, or MEMS. Getting electrical and mechanical components married creates compact integrated devices or systems through a process called MEMS. They can be fabricated in dimensions from a few micrometres to millimetres and are constructed on the available integrated circuit, or IC, batch production processes. These devices, which are mostly referred to by the term systems, can sense, control and actuate at the micro scale yet the effects are felt on the macro scale. Since MEMS is a multidimensional field, it integrates most of the other technical fields such as semiconductor manufacturing, electrical engineering chemistry and chemical engineering fluid engineering, optics, instrumentation, conventional and packaging. The fact that MEMS devices are used in so many different sectors and applications serves as more evidence of their complexity [5-7]. MEMS is used in systems in the defense, medical, electronics, communications, and automotive industries.

Accelerometers used in airbag sensors, inkjet print heads, and many more are examples of contemporary MEMS devices that are produced and disseminated. Significant sales quantities. One of the most fascinating inventions of the twenty-first century, MEMS combines micromachining and silicon-based microelectronics. It has enormous potential to change goods for customers and companies alike. Its innovations and microsystem-based devices have the capacity to profoundly alter the way that each of us lives. Semiconductor micro manufacturing was the first micro manufacturing revolution, and MEMS is the second [8-12].

Compact integrated devices or systems with mechanical and electrical components are created using a manufacturing process known as microelectromechanical systems, or MEMS. They have a size range of a few micrometres to millimetres and are made by processing integrated circuits (ICs) in a sequential manner [13-15]. These instruments (or systems) possess the capacity to function, identify, and regulate on a small scale while exerting influence on a big one. In the US, microsystems technology is called MEMS, while in Europe it is called Microsystems Technology.

For the micromechanical components of the device, micromachined silicon and other substrates are used, while "computer chip" integrated circuits (ICs) are used for the electronics [16]. Mechanical and electromechanical components may be constructed with selective silicon removal or structural layers added using HARM techniques. Micromachining with a high aspect ratio (HARM) and bulk/surface machining are two of these techniques [17].

MEMS utilize both the electrical and mechanical qualities of silicon, whereas integrated circuits are made to benefit from silicon's electrical characteristics. Since MEMS was originally applied to commonplace items in the early 1950s, it has been utilized outside of the laboratory. In the mid-1990s, MEMS components were widely available for use in a variety of commercial systems and industries. Inkjet printer heads, medical pressure sensors, and accelerometers that control how airbags are installed in automobiles are a few examples of these [18-20].

These days, micro positioners in storage for data and visual displays also use MEMS devices. Nonetheless, novel applications in the domains of control, biology, and hard and wireless communication hold the most promise for MEMS devices [21]. MEMS has some unique advantages as a manufacturing method. ‘First, the functional nature and broad range of application fields of MEMS and mechanical engineering technologies have enabled a multitude of applications and combinations in unrelated disciplines (e.g., biology and microelectronics). Second, by using MEMS and mass production methods to create devices and components with better performance and reliability, the benefits of reduced physical size, volume, weight, and cost may be attained. Thirdly, MEMS provides the basis for producing items that cannot be produced with any other method. These factors suggest that MEMS technology may have broader applications than integrated microelectronics [22].

2 Micromachining Technologies

Microelectromechanical Systems (MEMS) have gained substantial importance due to their wide-ranging applications in various industries. One of the key aspects of MEMS fabrication is micromachining, which involves the precise removal or deposition of materials at the micro scale. This paper provides an overview of different micromachining techniques used in MEMS fabrication and highlights their significance in achieving the desired device functionalities and performance. The description of the microsystems association with microelectronics has been focussed in review.

Microelectronics is widely acknowledged as one of the most significant technological advancements of the 20th century. Without the maturation of microelectronic technology, the MEMS sector would not have seen its current surge. Given the numerous manufacturing processes shared by the two technologies, it is true that a large number of engineers and scientists working in the MEMS sector today are former microelectronics industry veterans. But placing too much focus on how similar the two technologies are is not only incorrect, but it may also substantially impede the development of microsystems going forward [23]. The design, packaging, and assembly of microsystems differs significantly from that of integrated circuits and microelectronics. Engineers must understand these distinctions and create the appropriate processes and technologies in response.

The parallels and differences between the two technologies are enumerated in Table 1. Shows that there are in fact enough distinctions between the two technologies. The following are some of the most notable distinctions between these two technologies:

- There are more distinct materials used in microsystems than in microelectronics. Microsystem substrates can be made of materials other than silicon, which is the most prevalent. GaAs and quartz are two examples of such materials. Polymers and metallic materials are common elements in LIGA-created microsystems.
- Glasses, polymers, and metal are among the packaging materials used in microsystems but not in microelectronics.
- Compared to ICs, microsystems are made to carry out a wider range of tasks. The latter are restricted to particular electrical purposes.

Table 1: Comparison of Microsystems and Microelectronics [24].

Microsystems and MEMS	**Integrated Circuits**
Complex three-dimensional structures	Primarily 2-dimensional structures
Packaged goods may require accessibility to light beams, moving parts, and sealing chemicals and fluids.	Stationary structure once they are packaged
To carry out a range of specialized chemical, biological, optical, and electromechanical tasks.	Transmit electricity for specific electrical functions
There is no industry standard to adhere to when it comes to design, material choices, fabrication techniques, packaging, and assembly.	Industrial standards available

Moving components including gears, pumps, and micro valves are found in many microsystems. Numerous systems, including analytic and biosensor systems, need fluid flow to function. In micro-optical devices, light beams require input/output (I/O) ports. Microelectronics and integrated circuits, on the other hand, do not have any moving parts or ways to provide fluid or light. The majority of microsystems have intricate three-dimensional architecture, although integrated circuits are primarily two-dimensional devices that are confined to the silicon die surface. Therefore, mechanical engineering design is essential to the development of microsystem products [24]. After being packed, the fundamental components of integrated circuits are protected from their surroundings by passivation materials. However, many essential components of microsystems, including sensing elements, must come into touch with working medium. This leads to a number of technical issues with design and packaging.

2 Types

Initially, the governmental as well as defines industries drove the need towards Micro-electronic devices. More subsequently, the maturation of all the semiconductors production processes connected also with microelectronics chips used in computers, along with the massive demand inside the automobile and consumer device industries, has driven MEMS sensors further into the mainland. Inertial sensors, gyroscopes, and pressure transducers are the most common MEMS sensors nowadays.

2.1 Accelerometer (Mechanical Sensors)

The MEMS accelerometer sensors detect tilting by detecting the influence of the gravity on the accelerometer's axes. This type of 3-axis sensor has three distinct outputs that detect acceleration all along three axes namely X, Y, and Z motion axes. A micro-electro-mechanical accelerometer device is used to monitor force and acceleration. The market is filled with several types of accelerometers, which are categorized according to the force that has to be measured. Among these is the piezoelectric accelerometer, which is widely used. Nevertheless, their size limits their usage in several applications, which is why a very practical and tiny sensor like the MEMS accelerometer was developed.

Such Micro-electro-mechanical sensors do have variety of applications, including pressure sensors, magnetometer, Tracking devices, and mobile phones for numerous options such as switching between portrait and landscape modes and switching between filters and perhaps even miniature configuration processes, in use for anti-blur identification, playing games through remote controller , used as photograph consistency in video recorders, and indeed the three dimensional sensor is utilized in mobile phone company namely Nokia for touch motions, for instance – one could perhaps start changing MPEG Audio Layer by touching just on mobile phone when they are turned on [25-27].

These sensors have superseded traditional inertial sensors in automotive accident air-bag release systems. The prior solution employed numerous massive accelerometers built of independent components positioned at the rear of the vehicle with independent circuitry around the airbags as well as costing over than $50 each unit. The automobile has an airbag, which implies it includes a sensor module known as "MEMS accelerometer," which comprises a tiny IC.

2.2 Gyroscopes Pressure Sensors and Magnetic Field Sensors

The proof mass may have specific geometries, such as a tuning fork or a vibrating ring, depending on the gyroscope design. Drive electrodes provide the excitation or actuation signal to induce motion in the proof mass, while pickoff electrodes detect the resulting motion [28].

Pressure sensors have been piezo - resistive pressure measurements that have been produced using technology of MEMS. There are several pressure sensor applications accessible; a person must choose the appropriate sensor from a broad range of uses based on the intended usage.Pressure sensors are categorized depending on the nature of pressure, eg rising or falling pressure, and also the types of analysis. Such sensors are used in many fields of defense, healthcare, commercial, Foodservice Machineries, Washers and dryers, aerospace industries, Industrial Industrial equipment, and automobile industries to observe and quantify the external forces. The device is embedded into tyres of a motor, either external or internal, to track and measure tyre pressure. It also serves as a braking system inducer inside the braking system.

Magnetic force detectors are micro - electro - mechanical devices which detect and measure magnetic flux.Sensors can detect force changes, allowing current frequencies to be monitored electrically. It may be located near the monitoring site, resulting in increased spatial and temporal resolution.It blends embedded mass Hall cell - based technology with measurement circuitry to reduce thermally batch variations within silicone Hall cell properties. These sensor technologies are deployed in business, commercial, and automobile industries to detect regression inclination, motion, rpm, linear orientation, and placement.

2.3 Optical Sensors

A high-sensitivity diaphragm-based interferometryfibre optical microelectromechanical system sensor for the on - line monitoring of sonic vibrations generated during partial discharge within high-voltage electrical generators is developed and validated. In concept, the device is built using Fabric Perot interruption and is positioned as a hydraulically component on such micro machined flat silicone membranes.

Resonance electronic microsystems (REMS) are silicon chips with many embedded microchips. This is the most popular version of MEMS. Following its processing, the microelectronics causes a change in the environment by sending signals to the micro actuators to respond.

MEMS technology uses tiny parts. Even steam engines are composed of MEMS, which are tiny pieces that include levers, gears, pistons, and engines. The term "MEMS" is a little deceptive, as many mechanical devices aren't really mechanical at all. Nevertheless, the area of MEMS contains more than only producing silicon objects or decreasing mechanical components.

MEMS technology is a way to use batches manufacturing methods to create and build intricate mechanical systems and gadgets, including integrated electronics.

3 Primary Design of MEMS

This section focused on the primary MEMS design approaches in order to understand how this information are interpreted and used by the design during the process. That ought to enable us to pinpoint the time throughout the design process when each participant contributes. There appear to be two different approaches: The first is design for manufacturability, which is a technique that takes into account manufacturability in order to create MEMS that can be manufactured. [29] suggests using an existing approach from classical mechanics or electronics to the construction of manufacturable MEMS.

The typical design process, which is a highly iterative process with a need-based approach to problem solving, is insufficient for MEMS design. Size, form, operation principle, fabrication techniques, miniaturization, material, and the integration of mechanical and electrical systems are among the primary issues in MEMS design. The current research examines the numerous MEMS design approaches that are available. A key factor in the success of MEMS is the design of the mask and the packaging. The Manufacturing Phase starts concurrently with the start of the design group's work, having the following goals in mind:

- Determining vital process elements like surface roughness or verticality
- Identify and assess current processes to determine which should be used: a standard process, a standard process that has been minimally changed, or a freshly established process.

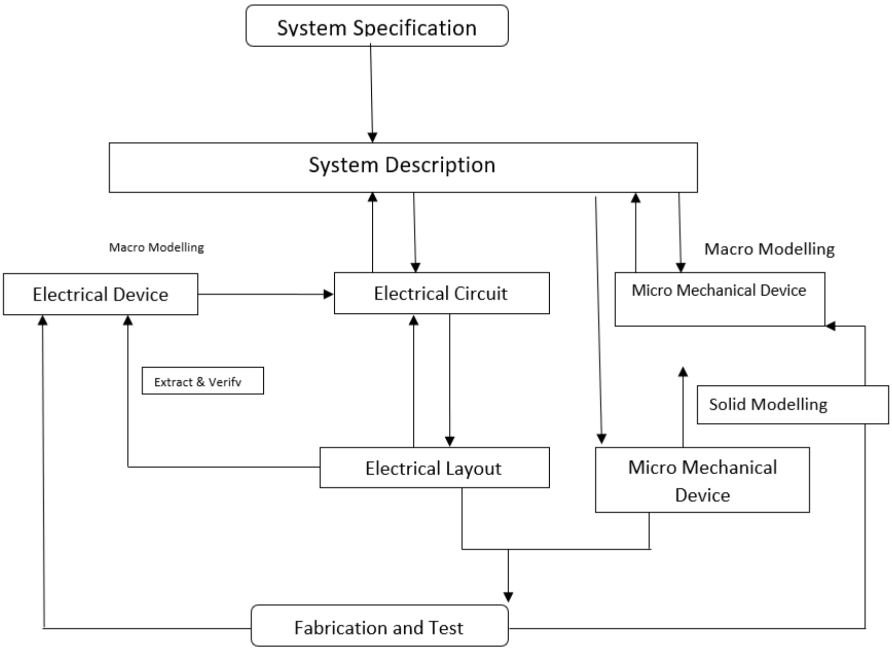

Fig. 1: MEMS general design flow.

Fig. 1 illustrates how electronics and micromechanical components interact; this work is essentially an expansion of the author's earlier research [30]. The datasheet typically serves as the system specification. Design ideas are expressed in an abstract description of the system. The system has a "top-down" design path that is highly developed and clearly specified, as well as a "bottom-up" verification path. There is a decoupling between the electronics and MEMS design [31]. But before MEMS can fully realize its potential, a number of challenges and technological roadblocks related to shrinking need to be overcome. MEMS goods are centered on technology-product paradigms rather than product-market paradigms because they are an emerging technology. As such, a MEMS device can have wide-ranging applications in several sectors. For instance, a nozzle initially employed in nuclear separation gave rise to the MEMS inkjet printer head nozzle that is commonly utilized today.

The design process known as Design for Manufacturability (DFM) aims to minimize manufacturing time and expense [32]. This study, attempts to quantify the help that such an approach offers in the important subject of process selection. FM is a substitute for the conventional MEMS product development cycle, which raises design costs and processes especially with its "build and test" methodology. One of the most well-known integrated, specialized MEMS design tools, CoventorWareTM, which consists of four primary products—an architect, an analyzer, and an integrator—also endorses this approach. Applications of the techniques employed in such items, such as those described in [33], will pique our attention. The second approach relies on the dissemination of manufacturing expertise using distributed web tools, which do not fall within the integrated design tool category, to assist designers in choosing production procedures and material combinations.

The requirement for integrated MEMS Design Concept Process Technology Mask Layout Fabrication increased with the first attempt to simplify MEMS design processes. Simulated final product packaging and testing Quantitative Evaluation Design Iteration Process Iteration large-scale models. The commercialization of MEMS will significantly progress with the development of feasible approaches for designing and manufacturing MEMS application-specific integrated circuits (ASICS) at a cost similar to digital ASICS [34]. Commercial MEMS design calls for a sizable multidisciplinary team of highly qualified engineers. It was time to give MEMS and its electrical integration some serious thought. The datasheet serves as the standard system specification.

4 Sustainability in Microsystems Integrating MEMS

The development of micro fabrication and miniaturization technologies has led to the rising dominance of MEMS and microsystems goods in all facets of the market. Currently, there are two primary commercial markets for these products: the automobile industry and the information technology sector, which produce read/write devices for data storage and inkjet printer heads, respectively. Because of the greater range of items, we shall concentrate our attention on the latter. Due to the magnitude of its market, the automobile sector has been the primary consumer of MEMS technology for the past 20 years [35]. The main reasons for using MEMS and microsystems in cars are to achieve high fuel efficiency standards and to make cars safer and more pleasant for drivers. All things considered, the car can become "smarter" for the demands of its users if these goods are widely used. The phrase "smart cars" was initially used in a trade magazine cover story for a special edition. Today's cars have many of the seemingly fantastical predictions of their intelligent features implemented in them. Actuators and sensors are heavily utilized in the construction of smart cars. Actuators are employed to carry out the necessary activities to address the circumstances of the road or environment, while various types of sensors are utilized to detect these situations. Thanks to micro sensors and actuators, automakers may employ more and smaller devices to handle the situation significantly more effectively. An early study has detailed summaries on the application of sensors and actuators [36-37].

1. Insertion Loss and Isolation

When the RF MEMS switch is in its up state, or the ON state, the insertion loss displays the signal loss, and the isolation displays the signal isolation level when it is in its down state, or the OFF state. The value between the input and output may be measured to determine the isolation and insertion loss. The signal loss is lower and the signal isolation level is higher when there is a larger insertion loss and isolation.

2. Power Consumption

A device's power consumption may be divided into two categories: static power, also known as leakage power, and dynamic power, also known as switching power. Leakage power has emerged as the primary power consumer in geometries less than 90 nm, whereas switching is the major contribution in larger geometries. Both forms of power can be reduced by employing power reduction techniques. The total power is the product of the leakage and dynamic powers.

$$\text{Total Power} = P_{\text{switching}} + P_{\text{short-circuit}} + P_{\text{leakage}}$$

The total of switching power and short-circuit power is known as dynamic power. When internal and net capacitances are charged or discharged, switching power is lost. The power lost as a result of an immediate short-circuit connection between the supply voltage and ground during the gate switching state is known as short-circuit power.

$$P_{\text{switching}} = a.f.C_{\text{eff}}.V_{dd}^{2}$$

Where a = switching activity, f = switching frequency, C_{eff} = the effective capacitance and V_{dd} = the supply voltage.

$$P_{\text{short-circuit}} = I_{sc}.V_{dd}.f$$

Where I_{sc} = the short-circuit current during switching, V_{dd} = the supply voltage and f = switching frequency.

Table 2: Study on Variation of RF MEMS switching over different frequency.

				Switching	
Switches	**Frequency**	**Isolation (dB)**	**voltage (V)**	**time (μs)**	**(switching cycles)**
[3]	10 GHz	20	90	10	10^9
[5]	20 GHz	18	45	2.1	…
[6]	20 GHz	15	10	40	…
[8]	8 to 12 GHz	22	5.4	…	…
Proposed paper	18 GHz	21.28	8.9	31	10^9

The RF MEMS switches over semiconductor RF switches are low power consumption, minimal insertion loss, and good isolation; these features are critical to wireless transceiver systems. The performance comparison between the RF MEMS switch and semiconductor RF switch is shown in Table 2.

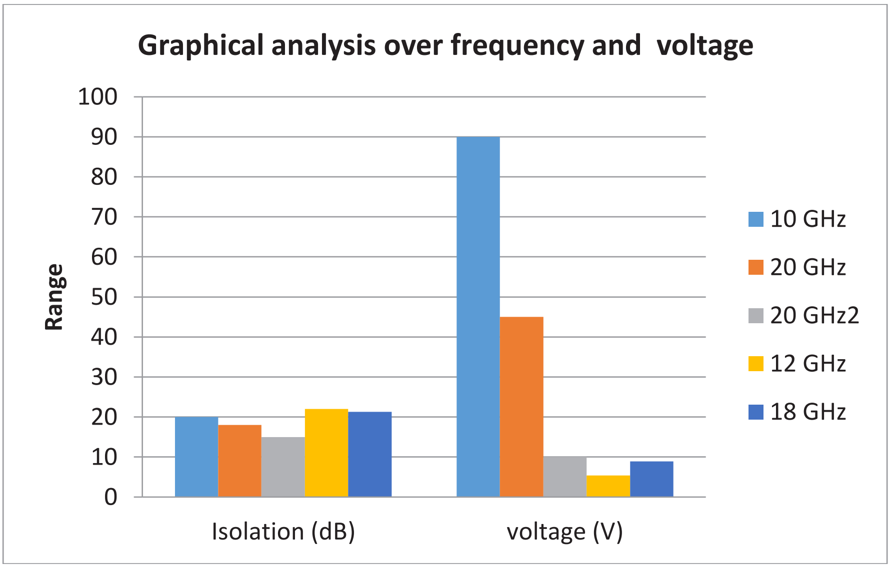

Fig. 2: Graphical analysis over frequency and voltage.

Voltage and frequency are two distinct concepts. The number of cycles that a voltage waveform repeats itself per second is known as its frequency. DC voltage, sometimes referred to as a voltage with zero frequency, is essentially constant at a certain value. In the above fig. 2 the voltage values at 20GHz frequency is 90V, at 18GHz frequency is 45V and so on. This study describes the fabrication and testing of a series-contact RF MEMS switch operating in the DC to 18 GHz frequency range. The switch has a simple construction, excellent isolation, low actuation voltage, relatively quick switching time, and long lifespan. These characteristics could make this kind of RF MEMS switch beneficial for contemporary microwave test tools and wireless communication devices.

5 Conclusion

MEMS has the potential to spark a second miniaturization-driven technological revolution, which might result in an industry—or industries—that surpass the semiconductor industry in terms of scale and societal effect. MEMS and micromachining technologies are effective instruments for facilitating the downsizing of systems, actuators, and sensors. Specifically, batch manufacturing methods hold the potential to lower MEMS costs, especially for high-volume production.

- The versatility and acceptability of MEMS will increase as the topic is embraced by several fields and its many attractive scaling qualities are investigated. Micro sensors, micro actuators, and microsystems will provide cost savings and enhanced effectiveness of an unmatched degree of monitoring and control over our physical environment. The number of cycles that a voltage waveform repeats itself per second is known as its frequency. DC voltage, sometimes referred to as a voltage with zero frequency, is essentially constant at a certain value. In the result analysis section the voltage values at 20GHz frequency is 90V, at 18GHz frequency is 45V is shown.
- Even while the development of commercially viable micro sensors frequently progresses significantly faster than that of micro actuators and microsystems, the demand for sophisticated and dependable micro actuators and microsystems is growing. The fast development of innovative MEMS technologies is supported by ongoing efforts to improve MEMS standards and hierarchical MEMS CAD solutions that can be integrated with IC CAD tools for full-real-time system-level simulations.
- MEMS commercialization has a number of challenges, despite the fact that these activities are growing in both number and breadth. In reality, MEMS could soon have a significant influence on space exploration.

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