

Review on Micro-Electromechanical Systems (MEMS)

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Abstract—MEMS is an acronym for micro- electro mechanical systems. This technology was first introduced in the 1980s and since then it's used to produce very small sensors and actuators whose size is in microns. These micro size transducers are capable to be blended with the signal conditioning or processing in electronics circuitry to form a system which can perform real time processing like the distributed control etc. MEMS are mainly based on silicon as their basic element and these have a long list and variety of applications where they can be used such as, mobile equipment, automobile sensors and actuators, printers, networking and sensor arrays and medical applications etc. Being extremely small in size, they have a small footprint hence consume very little space on chip compared to conventional sensors and the size can be related to the power consumption as well, most of the MEMS need power in Milli-Watts range hence the efficiency of the devices also gets improved and we can get more operation time using the same power supply like a battery or cell. This paper is a review related to the importance of MEMS in our day-to-day life, the current trends in small scale and largescale industries and the future scope of this technology in various applications is also been discussed.

Index Terms— Actuators, FET, GPS, Lab-on-chip, MEMS, Sensors, Silicon.

I. INTRODUCTION

MEMS can be known to have their origins back from April 1954 as Smith from Bell telephone labs presented a physical review about the technology [1]. He was the one who was for the first time able to show that silicon and germanium were few of the stress sensitive elements which showed piezoresistive effects. So, by 1950 the researchers began to study whether similar technologies that had yielded the transistor, which had transformed the electronics industry and whether they can be used to develop the sensors required for various applications. They thought of replacing the bulky sensors with micro sensors as earlier did with transistors and vacuum tubes. From Smith's study Pearson and Paul in the early 1960's published a set of papers from Bell labs and Honeywell Research center putting forward an idea of silicon diaphragm-based pressure sensor and strain gauges. Interest of the researchers in the sensor technology based upon silicon increased very rapidly and a wide number of companies of America commercialized the 1st Silicon pressure sensor. These sensors were very primitive compared to current standards as shown in Fig. 1.1 but few years later i.e., by the early 70's the significant development in the micromachining technology helped in the manufacturing of non-planar diaphragm geometry-based pressure sensor whose performance was highly improved compared to the previous one. These sensors can be truly called as the first actual MEMS. The exact meaning or explanation of MEMS can be answered as that MEMS is actually a misnomer as not all MEMS are not "electromechanical" or "systems". The term MEMS is usually now applicable or all kinds of miniaturized devices mostly to those who have 3D

microstructure of a sort. These are generally fabricated from a silicon wafer and the numerous manufacturing techniques related to micro-electronics industry such as isotropic and anisotropic micro-etching, thin film deposition techniques, anodic bonding, and other doping and masking methods that are deployed in the manufacturing of IC's. MEMS in today's world mean as the silicon based microsensors so called "lab-on-a-chip" and micro total analytical systems abbreviated as micro-TAS. The progress made in MEMS since Smith's innovation is indescribable as the technology has been highly successful in the physical sensing world and has led to a wide range of inexpensive, small and ruggedized devices like microphones [2], strain gauges, pressure sensors, temperature sensors, accelerometers, gyroscopes, air mass flow sensors etc. The sensors which we are talking about are been developed for a wide range of applications like the automotive industry in the Engine Control Unit (ECU) or the Engine Management System (EMS) which can be used to control the inflation of the air bags or the GPS systems, etc. Most of the concentration is been given on the pressure sensing sensors as it has the greatest impact on the applications like aerospace, medical, automation and process control, etc. The pressure sensors are being complex day by day as they are been made extremely small and also are able to filter the capacitive and the piezoresistive effects as the sensors are been doped by the ion-implantation method rather than diffusion method. Since 80's the manufacturers had invested the efforts to make the sensors more intelligent by embedding the on-chip signal processing power so as to make them capable of producing the digital output, Fig 1.2 shows the device with mentioned characteristics. The case is similar with the accelerometers as they have also undergone same advancement in fabrication methodology and technology wise like the advanced surface micromachining that makes the sensor capable to be 'multi-modal' i.e., they can simultaneously sense the changes in all the 3 axes. Many of the sensors also contain the electronics which can test the self-diagnostics and other important functions. The yaw-rate sensor Fig 1.3 has very complex geometry and can be said the most complex MEMS to be mass produced which was used mainly in the automotive sector for the acceleration measurement along the vertical axis [3]. But this sensor is still less complex compared to the TI-Texas Instrument's Digital Micromirror Devices abbreviated as DMD's. DMD's can't be associated as the sensors but they are highly miniaturized and the most complex MEMS which any of the world's company produces that are used in Projectors. The DMD system was invented by TI's R&D member Larry Hornbeck in 1978. DMD chips as shown in Fig 1.4 comprises of rectangular array of individually addressable hinge mounted 2 million micro mirrors each of which is connected to the integral electronics. Fig 1.5 shows an illustration of the mirror support structure and Fig 1.6 shows a microscopic image of the micromirrors and their extremely small size.

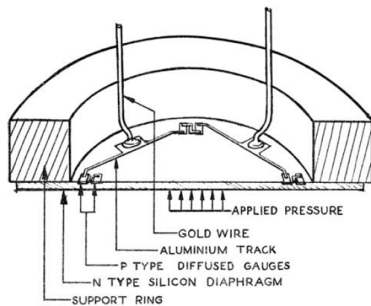


Figure 1.1. Early pressure sensor sectional schematic [1]

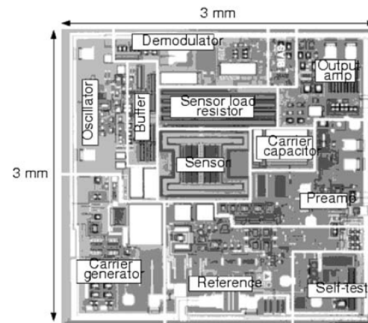


Figure.1.2. Micromachined MEMS accelerometer sensor block diagram with System on Chip design concept [1].

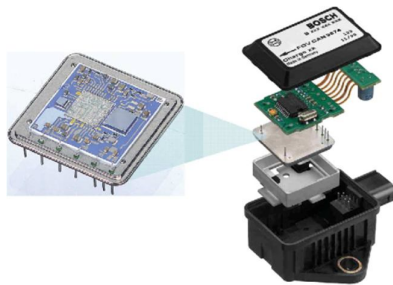


Figure.1.3. Bosch angular rate sensor [3]



Figure.1.4. Texas Instruments DMD array chip [8]

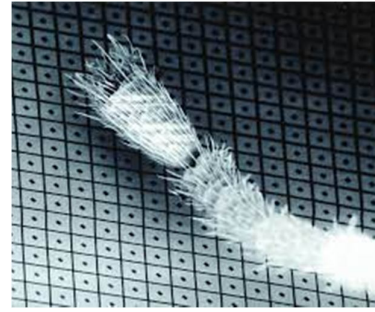
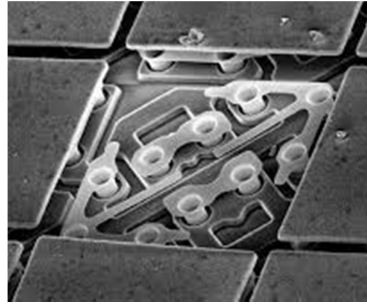


Figure.1.5. DMD array mirror support structure [9] Figure.1.6. DMD array mirrors size comparison with ant leg [10]

II. LITERATURE REVIEW

Steadily moving on from the successful development of the early physical sensing of 1970's researchers also tried to focus on making gas detection sensors using silicon and MEMS. But the impact of research seems very minute compared to the systems discussed earlier as there is less variety of the products available but still the production is very high. So called GasFETs (gas-responsive field effect transistors) were the first of a kind to be developed (Lundstrom et al., 1975), where aluminum gate of FET was replaced by gas sensing elements such as Palladium or Platinum. The sensors were still not that capable to meet the actual accuracy demand and hence were used in very niche applications. Most of the modern gas sensors contain micro-engineered silicon substrates which are mainly called micro-hotplates [2]. The above-mentioned technique is relatively simple compared to other methods like the NDIR i.e., Non-Dispersive IR absorption or the photo-acoustics or the thermal conductivity along with the micro-spectrometers. And these modern techniques mentioned are facing limited development in commercial environment. These devices being miniaturized are relatively inexpensive, rugged and small which results in downgraded performance during the use. To imply the NDIR sensor if made small faces accuracy and sensitivity related issues as the optical path length is shortened which constraints its application to only high gas concentration applications only.

Lundstrom and other 2 research members of Stanford university were researching upon micromachining of the complex silicon microstructure of a gas chromatograph that had separation capillary column of length 1.5m which was etched including thermal conductivity detector and injection valve as shown in Fig 2.1. Micro-gyroscopes abbreviated as MCG were used in Viking mission i.e., on the probe sent to mars. Being this reliable the sensor has gained popularity but still they are not commercialised to that level. These types of chips are often called as micro TAS or Lab on a chip device [4]. Before these type of chips silicon-based Ion Selective FETS (ISFETs) were used in the sensing of liquid chemicals. Fig 2.2. shows the construction was similar that of gas responsive sensors. A bit of modification was done to the conventional FET by not using the gate electrode and the gate's oxide was replaced by a layer of ion-selective material like Silicon nitride or polymer substance. By 1980's the research activities gained momentum and around thirty years pH responsive ISFET were commercialised practically after Bergveld's publication. They gained popularity due to their ruggedised built and cheap costing hence they are now replacing the conventional glass counterparts in fixed and portable instruments too. The current scenario of MEMS is that this technology has got an immense impact on the physical sensing.

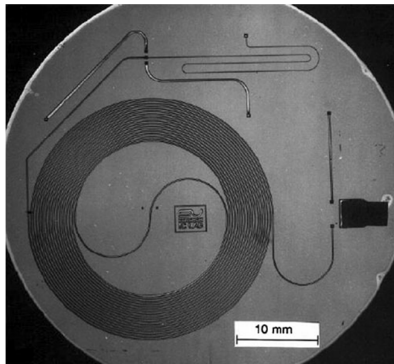


Figure.2.1. Silicon gas chromatograph [4].

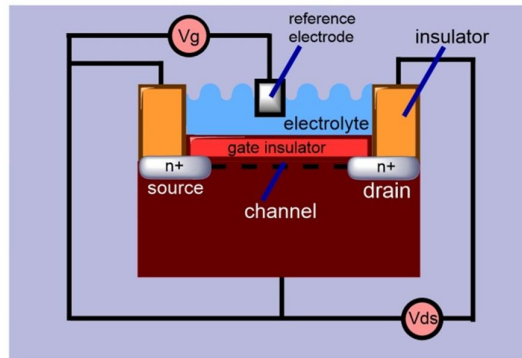


Figure.2.2. ISFET pH sensor schematic [11].

Although there is a very low impact on chemical sensing the development is still going on. The question is that whether we can say the situation will change or not. As per physical sensing point of view we can say that on a short-term basis the demand and consumption of MEMS will increase as the applications are widening as the use of such sensors can be made in multiple applications. As an example, MEMS type mics have taken a grip in production since 2004 as their applications in small devices such as mobile phones, computers, headsets are justifiable. MEMS gyro modules have also gained a pace and are rapidly expanding on commercial market basis. The technology is growing in automotive [5][6], defence and various other applications where it can accumulate a high volume in the market like the consumer products, home appliances, mobile phones, cameras and Cam recorders, play stations (videogames). In the automotive industry, the demand for various sensors like the gyro sensors, yaw sensors, pressure sensors, accelerometers, oxygen sensors, temperature sensors are continuously rising day by day.

The MEMS gas sensor future seems a bit slowly growing. This is due to the fact that other options such as optical or electrochemical sensors are available as a good choice and with a strong competition. But in spite of that MEMS gas sensors is the wide ranged area of researches and a potential development item in the automotive sector where a significant impact can be noticed. To meet the laws and regulations sensors are likely to monitor the concentrations of exhaust gases like the NO_x, CO, CO₂ and other unburnt hydrocarbons from the vehicle exhaust hence MEMS can be one of the best competitors for these applications. Sensors that are made up as a prototype and that are in the development stage make the use of Silicon and its related compounds such as Silicon carbide called micro hot plates that are coated with metal oxides and Gas FET MISiCFETs precisely which stands for Metal Insulator Silicon Carbide FET which can remain operational at temperatures of up to 800 deg Celsius. Although many auto manufacturers from Europe, America, Japan etc are focusing on MEMS technology for the future, still the competition is faced to the tech from thick film and solid electrolyte devices. Another application where MEMS can excel is the field of indoor air quality monitoring majorly the monitoring of the organic compounds that are volatile in nature which can further be used in the places where we believe monitoring of harmful and toxic substances is necessary. As of now there are no cheap sensors available that can detect the organic compounds such as benzene, butadiene, toluene and various other research groups selectively. Another interesting field of MEMS technology research is in the bio field and is known as BioMEMS i.e., biological electro-mechanical systems as discussed in [7]. In this kind of devices, the capabilities of the MEMS and their sensing function is used in health science and biomedical applications. An important application can be PCR which is an abbreviations of polymerase chain reaction. An example for this can be the “In-Checke” developed by “ST Microelectronics”. In-Checke is a useful tool in sampling and identification of the oligonucleotide sequence [2]. As shown in Fig.2.3, It has micro channels through which fluid is channelized for the testing. It has built in miniature PCR reactor and a custom micro array. The chip is made in plastic-based material and has all the required connections such as the electrical, thermal, and the fluidic connections. In short, we can say that the MEMS technology has been proven as a boon to mankind in transforming the bulky operational devices to as microscopic as possible. The research for such devices still goes on in improving the other characteristics and side-by-side reducing the size of the systems.

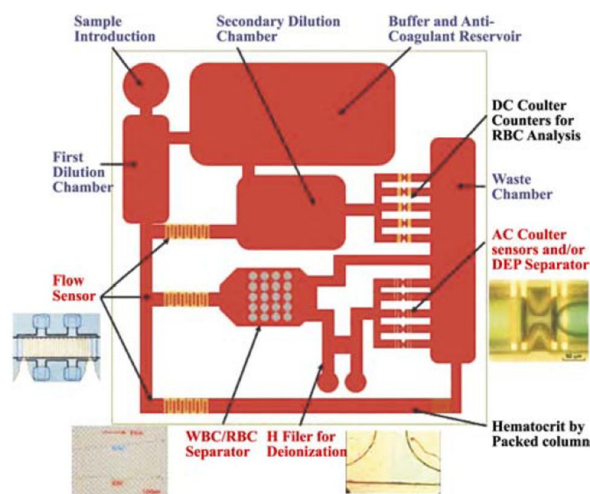


Figure.2.3. Blood analysis Lab-on-Chip type MEMS [1]

III. CONCLUSION

To conclude, after a detailed comprehensive review of the papers and the literature review it is very clear that MEMS technology is highly effective in the area of physical sensing and sensors used for sensing those quantities. Various applications ranging from mechanical sensing, automotive applications to the gas and chemical sensing, biological areas of research and development utilize MEMS concepts and the demand for such systems will be increased in the upcoming future as the world is moves towards optimizing the efficiencies, improving the computational capabilities while reducing the size of the systems and making them cheap and affordable as well. Mass production of such systems may bring the costs down. Moreover, the efforts to improve the accuracy and precision are going on so as to make them more viable for the respective applications. A variety of MEMS sensors can be used depending upon the quantity they measure which is summarized in the table given below.

TABLE I. TYPES OF SENSORS USED TO MEASURE DIFFERENT TYPES OF PHYSICAL QUANTITIES

Sr. No.	Variable	Type of sensor used to measure the variable
1	Pressure	Piezoresistive and capacitive pressure sensors
2	Vibration, shock, motion	Accelerometers
3	Position, rotation	Gyroscopes, Yaw-rate
4	Inclination, angle	Inclinometer
5	Strain	Semiconductor strain gauges
6	Infrared	Microbolometers
7	Sound	Microphones
8	Flow	Thermal mass flow sensors

FUTURE SCOPE

MEMS have proven that they have a significant impact on the devices we use in the daily life and a continuous effort is being made by the researchers and scientists to make them more economically viable, improve their accuracy and precision and to improve the computational power of these devices. The future applications may range from highly complex applications such space research devices to the simplest applications such as a micro switch. In the biological field micro robots are been developed which can alter cancer cells and help eradicate cancer, or in surgeries of tumors etc. In the field of consumer electronics, the MEMS can be made to detect sound in a mobile phone, the orientation of the phone so as to set the screen rotation or the GPS based navigation etc. The number of applications of such systems are less to explain in the paper as research is been carried out throughout the world on daily basis and as the time goes, the range of applications where these devices can be used will grow.

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