International Research Journal of Engineering and Technology (IRJET) **e-ISSN: 2395-0056**
Volume: 04 Issue: 12 | Dec-2017 **www.irjet.net** **p-ISSN: 2395-0072**

Evolution of MEMS Technology

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Abstract – *The discussion of miniaturization begins with the advent of Integrated Circuit (IC) technology. The Intel 4004 chip in the year 1971 consisted of only 2250 transistors, then thereafter in 1982 and 1999 the Intel 286 and Pentium processors consisted of 1,20,000 and 24 million transistors respectively. The density of the transistors has been increasing twice every 12-18 months as said by Gordon Moore [1].*

The microfabrication technology is the most important thing behind the miniaturization of electronics. That's the foundation for the current smaller gadgets with high performance. It was between 1960s and 1980s when lot of evolution took place in the field of IC technology with the tremendous research having taken place post the invention of the first semiconductor transistor [2]. The microfabrication and miniaturization are the pillars for whatever revolution we are seeing today in the field of electronics and the growing technology. In this paper the growth of MEMS technology has been discussed

Key Words: MEMS, microfabrication, micromachining,

INTRODUCTION

The field of MEMS evolved from the Integrated Circuit industry. The origins of MEMS technology can be traced back to1 April 1954, when a paper by Smith (1954), then at the Bell Telephone Laboratories, was published in Physical Review. This described for the first time certain stress-sensitive effects in silicon and germanium termed piezoresistance. During 1960s to 1980s many researchers in academics and the industries started developing micro mechanical devices with the help of Integrated Circuit processing technology. The initiation of first micro sensors had begun then [3-5]. The bulk micromachining and surface micromachining technology were involved [6-8] although the techniques were yet to be matured.

There are a number of notable early works. In 1967, Harvey Nathanson at Westinghouse introduced a new type of transistor called the resonant gate transistor (RGT) [9]. The gate electrode of the RGT was not fixed to the gate oxide but was movable with respect to the substrate. The distance between the gate and the substrate was controlled by electrostatic attractive forces. The RGT was the earliest demonstration of micro electrostatic actuators.

In the 1970s, Kurt Petersen at the IBM research laboratory, developed diaphragm-type silicon micromachined pressure sensors using silicon bulk micromachining. The diaphragm deforms under differential pressures, inducing mechanical stress that was picked up by the piezoresistors. The thin diaphragm allowed greater deformation under a given pressure differential, hence greater sensitivity compared with conventional membrane-type pressure sensors. The sensors could be micromachined in batch, therefore increasing the uniformity of performance while reducing the costs of production. Pressure sensors for applications including blood pressure monitoring and industrial control provided the earliest commercial success of MEMS technology.

Silicon micromachining technology played an enabling role for the ink jet printing technology [10-12]. Hewlett-Packard pioneered the technology of silicon micromachined ink jet printer nozzles in 1978. Arrays of ink jet nozzles eject tiny ink droplets ("drop on demand"), upon expansion of liquid volume by thermal bubbles. The collapse of the bubble draws more ink into the ink cavity for the next firing. In 1995, the number of nozzles per cartridge has increased to 300 while the average weight of ink droplet is only 40 ng. In 2004, ink jet heads are based on a variety of principles, including thermal, piezoelectric, and electrostatic forces. The volume of each drop is on the order of 10 *pl*, with resolution as high as 1000 *dpi* reached [13].

In the late 1980s, researchers in the field of micromachining mainly focused on the use of silicon– either single crystalline silicon or polycrystalline silicon. IC industry was already using silicon extensively and hence it was readily available. Three dimensional mechanical structures, such as suspended cantilevers or membranes, can be made out of bulk silicon (single crystalline silicon) or thin film silicon (polycrystalline silicon). In 1984, Petersen published a seminal paper titled "Silicon as a mechanical material" [6]. This paper was (and still is) widely quoted in the 1990s as the field expanded rapidly.

The surface micromachining mechanism was used to develop springs, gear trains, and cranks, to name a few. In 1989, a first silicon surface micromachined micromotor driven by electrostatic forces was demonstrated by researchers at the University of California at Berkeley [14]. A polysilicon rotor, less than 120 μm in diameter and 1 μm thick, was capable of rotating at a maximum speed of 500 rpm under a three-phase, 350 V driving voltage. This motor, though with limited application at that time, brought the excitement of MEMS to the broader scientific community and the general public. Micro rotary motors based on different actuation principles, covering a wider range of scales (even down to nanometers), and with much greater achievable torque and power have been demonstrated since then [15,16].

A few years later, the phrase Micro Electro Mechanical Systems – MEMS was introduced. It gradually became an internationally accepted name of the field. Many research results and products of MEMS technology are indeed components within a bigger system. The phrase embodies both a unique machining and manufacturing approach (micromachining), and a new format of devices and products.

During 1990s MEMS gained lot of attention and started growing extensively. Government and private funding agencies in many countries throughout the world funded and supported focused research activities. Early research efforts at several companies started to bear fruits. Most notable examples include the integrated inertial sensors by Analog Devices for automotive air-bag deployment and the Digital Light Processing chip by Texas Instruments for projection display. These two applications are discussed in the following.

The ADXL series accelerometer which monitors excessive deceleration and initiate air-bag deployment in the event of a life threatening collision, was made by Analog Devices Corporation and it consists of a suspended mechanical element and signal-processing electronics integrated on the same substrate. The initial development targeted the automotive market [17]. Today, one can find a variety of micromachined acceleration sensors on the market based on a number of sensing principles and fabrication technologies. Accelerometers based on capacitive sensing [18, 19] piezoresistivity [20], piezoelectricity [21], optical interferometry [22] and thermal transfer [23, 24] have been demonstrated. Advanced features include integrated three axis sensing [25], ultrahigh sensitivity (nano-g) for monitoring seismic activities [26, 27] increased reliability by eliminating moving mass [24], and integrated hermetic sealing for long term stability [28].

The MEMS technology offers significant advantages over then existing, macroscopic electromechanical sensors, mainly in terms of high sensitivity and low noise. The MEMS approach is very economical too, due to batch fabrication techniques involved.

The Digital Light Processor (DLP) of Texas Instruments has replaced the traditional projection displays which are basically analog in nature. The DLP is a revolutionary digital optical projector [29, 30] consists of a light-modulating chip with more than 100,000 individually addressable micromirrors, called digital micro mirrors (DMD). Each mirror has an area of approximately 10x10 μm2 and is capable of tilting by +/- 7.5 degrees. The mirror array is illuminated by a light source. Each mirror, when placed at a correct angle, reflects light towards the screen and illuminates one pixel. An array of such mirrors can form an image on a projection screen. This has made the communication and presentations much easier to carry out.

The MEMS technology has evolved a lot in the past years and a lot of revolutionary devices have been developed at a very low cost. Currently MEMS has been combined with the field of nanotechnology and new devices are being researched in the field of bio-medicine and for military applications as well. Apart from this the research in the field of MEMS also involves the design and production of the devices using polymer materials rather than the silicon. Many sensors and actuators are needed to operate in harsh conditions, such as direct exposure to environmental elements, high temperature, wide temperature swing, or high shock. Delicate microstructures made of silicon or inorganic thin film materials are not suited for such applications. Several inorganic materials are being introduced for MEMS applications in harsh environments. Silicon carbide, in both bulk and thin film forms, are explored for applications including high temperature solid-state electronics and transducers [31-33]. Diamond thin films provide the advantage of high electrical conductivity and high wear resistance for potential applications including pressure sensors and scanning electron microscopy probes [34, 35, 36]. Other compound semiconductor materials including GaAs ([37-40]) are also being investigated. Microfabrication processes have also been expanded to reach nano scale resolution to realize nano electro mechanical systems (NEMS) [41, 42]. NEMS is going to be a boon to field of biomedicine.

CONCLUSION

The MEMS as a technology has been evolving still and booming and is going to contribute for benefitting the world with a lot of new devices that are going to make the living much better. The smarter devices are going to be a big support to the military system and in the field of Biomedicine, Biochemistry and Automation, MEMS is a promising technology to develop revolutionary devices in the years to come.

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