MOEMS: Towards Nano Approach for Technology & Devices

Dr. Umesh Kumar[1],

Principal, Govt.Women's Polytechnic,
Ranchi

Dr Ramesh Kumar[2]
Professor (CSE) B I T, Bhilai, Durg
Ranchi

Abstract:

Micro **O**pto **E**lectro **M**echanical **S**ystems (MOEMS) contain movable components that have an effect on an optical signal that is pointed at the surface of this optical component. Silicon or or some selected compound semiconductor can be micro machined and this micromachining have the advantage of small scale and easy integration with electronic circuits and sensors, resulting in the production of miniaturized and smart micro-systems with moving parts. The size of MOEMS devices is immediately compatible with the size of integrated optics (IO), and is appropriate to control or manipulate optical radiations. This Technology is therefore suitable to fabricate precision-defined optical components and offers relative easy alignment procedures of optical parts. MOEMS technology has benefited from the integration of microstructures with free-space micro-optics and guided wave optics. Much novel architecture including micro mirrors, micro lenses, modulators and switches, micro choppers, micro platforms for integrated optics, fiber optics, scanners, optically driven actuators, integrated optical sensors, and other devices with optical functions have been developed. In this paper we focus our attention on MOEMS, combining micro machined structures and optical waveguides on silicon substrate. MOEMS are fabricated by batch process, these devices are potentially low cost, and their monolithic structure improves their reliability. This approach of integrating optics with micromechanics has applications for integrated sensors, micro actuators, Optical adaptors and in optical communication.

Keywords: MEMS, optics, miniaturization, communication, fabrication, digital processing, industrial application.

Introduction:

Mechanical systems of Micro-Electro-Mechanical-System (MEMS) are well known systems by now but addition of Optical technology making it Micro-Optic-Electro-Mechanical System (MOEMS) are micron to nano size devices that can sense or manipulate the physical world. MOEMS are created using so-called micro machining processes, essentially operations like those used to produce integrated circuit (IC) devices. This allows a two or three-dimensional mechanical system to be created in the same small area typical of an IC device. Because the manufacturing process is similar to that of producing ICs, MOEMS are most typically created on silicon wafers but can employ other substrate types as well. Due to their size as shown in fig 1, tens of thousands of these devices can be fabricated on a single wafer.

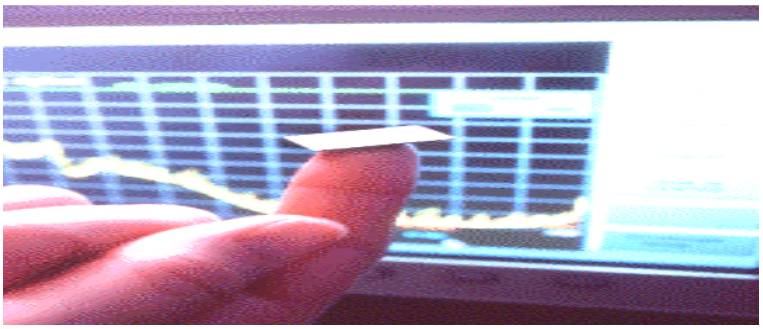


Figure 1

MOEMS technology has actually been demonstrated in research and development facilities since last 25 years. In some forms it has been in production for almost 20 years, specifically in the area of pressure sensors. For example, the auto pressure sensor and disposable blood pressure sensor became a commercial reality in the 1980's. Today, the widespread use of MOEMS as accelerometers and gyroscopes in the automotive sector is commonplace. Presently, new techniques have enabled the formation of many more types of surface structures, and true micro-machines have been enabled by recently developed thin film and etching techniques. MOEMS now span a wide range of applications including sensors, telecommunications, micro-switches, and medical devices. Everyday industry is realizing new applications for MOEMS in different technology areas.

A MOEMS is a miniaturized system (fig-2) combining optics and micro-mechanics, fabricated with collective techniques derivate from the microelectronic industry. These devices generally offer reduced cost and improved reliability.

Figure 2

Construction of MOEMS:

MOEMS is based on IC fabrication technology, or micro fabrication, the primary enabling technology for the development of MOEMS. The major steps in IC fabrication technology are film growth, doping, lithography, etching, dicing, and packaging.

Film growth: Usually, a polished Si wafer is used as the substrate, on which a thin film is grown. The film, which may be epitaxia, SiO2, silicon nitride (Si3N4), polycrystalline, or metal, is used to build both active or passive components and interconnections between circuits.
Doping: To modulate the properties of the device layer, a low and controllable level of an atomic impurity may be introduced into the layer by thermal diffusion implantation.
Lithography: A pattern on a mask is then transferred to the film by means of a photosensitive (i.e., light sensitive) chemical known as a photoresist. The process of pattern generation and transfer is

called photolithography. A typical mask consists of a glass plate coated with a patterned chromium film.

Etching: Next is the selective removal of unwanted regions of a film or substrate for pattern delineation. Wet chemical etching or dry etching may be used. Etch-mask materials are used at various stages in the removal process to selectively prevent those portions of the material from being etched. These materials include SiO2, Si3N4, and hard-baked photoresist.

Dicing: The finished wafer is sawed or machined into small squares, or dice, from which electronic components can be made.

Packaging: The individual sections are then packaged, a process that involves physically locating, connecting, and protecting a device or component. MOEMS design is strongly coupled to the packaging requirements, which in turn are dictated by the application environment.

Packaging

MOEMS devices typically require an extra fabrication process where the device wafer is bonded to a second wafer, which effectively encapsulates the MOEMS structure (fig-3).

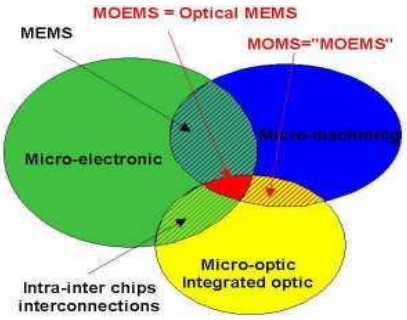


Fig. 3

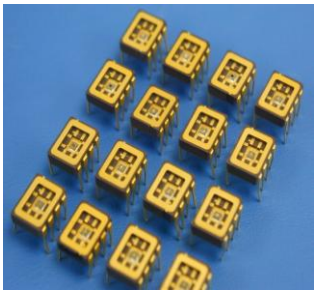


Fig. 4

This method leaves the device free to move within a vacuum or an inert gas atmosphere. These bonds are typically hermetic and therefore prevent moisture contamination and subsequent failure of the microstructure. Once protected in this way, devices are considered robust. They can then be assembled into a wide variety of package options including SOIC,PLCC, System-in-Package (SiP) or *Micro*LeadFrame® (MLF®) which can all be adapted to meet the height requirement of the capped device.

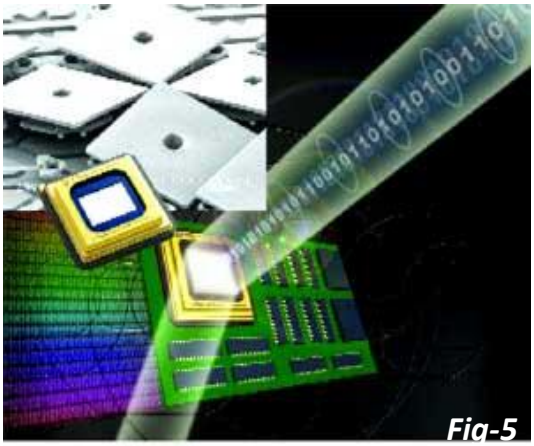
Even though either embedded or capped, MOEMS devices can exhibit sensitivities that must be accounted for in the packaging solution. Device performance can be affected by stresses imparted to the body of the die by the packaging materials. Options developed to address this type of issue include cavity packages (premolded) (fig-4) and specially designed die coat and transfer molding processes. Existing packages in this arena include CERDIP, Ceramic LCC, SOIC, and MLF® derivatives. These applications also typically include the packaging of more than one die per package, and all of the aforementioned package solutions offer multi-die capability.

Protection is a key element in packaging MEMS and MOEMS because corrosion, moisture, and debris can prevent the devices from working. Each device must be hermetically sealed in order to prevent the devices from becoming contaminated. Presently builds of MOEMS in a variety of hermetic packages for air bag and rollover detection sensors for automotive applications. It is also developed in System in Package (SiP) solutions that combine multiple chips and passives into one package. These SiP solutions are aimed at reducing the cost of MOEMS packaging, and increasing functionality through greater levels of integration.

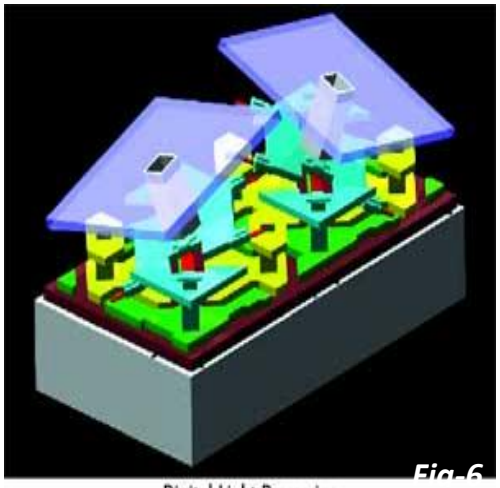
Principles of operation There are various manufacturing methods for MOEMS devices, all of which involve the deposition of various layers of material and etching away the sacrificial layers to

produce the desired structures. One process we use is the LIGA process, which is a German acronym for lithography, electroplating, and molding. Each layer of a different material is deposited lithographically and these layers are different thickness and may overlap one another. In this way one layer may be used as a sacrificial layer to fill in and support a void area. The next layer can be used to make a mold for a subsequent layer. The succeeding layer will overlap the first and be molded into shape by the second. Then the first two layers can be removed and it is left with a freestanding structure - whatever it is. This procedure can be repeated over and over again to build up complicated parts. This is essentially 3-D integrated circuit processing. With MEMS technology already demonstrating sensors (fig-5), actuators (fig-6), and motors, only the optics are missing to create miniature versions of most electro-optic devices. Even small laser diode chips can be mounted as light sources.

The basis for these technologies is micromachining which involves the manufacture of mechanical structures in the micron to millimeter range. Precision machining is typically work done above the mm range and molecular machining is work done in the nanometer or molecular regime. When it is combined micro-machined devices with micro-electronics and micro-optics, MOEMS technology is the result. MOEMS technology requires a different set of rules for operation as opposed to common sense in our normal macro world. Many physical properties are proportional to area or volume (such as heat transfer, surface area, and mass), which scale respectively as the square or cube of linear dimension. For example, a cube may be shrunk by a factor of ten, but its surface area will shrink by a factor of 100 and its mass by a factor of 1000. On a microscale, intermolecular forces are so strong that the pages of a micro book cannot be separated. But, just as laser speckle was a problem until we learned how to use it to for advantage, such potential problems on a microscale can be turned to advantage once we learn how to use them. For example, the deformation of a beam anchored at one end is proportional to its mass. This means that comparing the deformation of a one millimeter long beam to a one micron long beam, the microbeam appears much stiffer by having a deformation one billionth of the mini-beam and only being a thousand times smaller. This makes a very good proof mass for accelerometers as it is very strong against shocks.



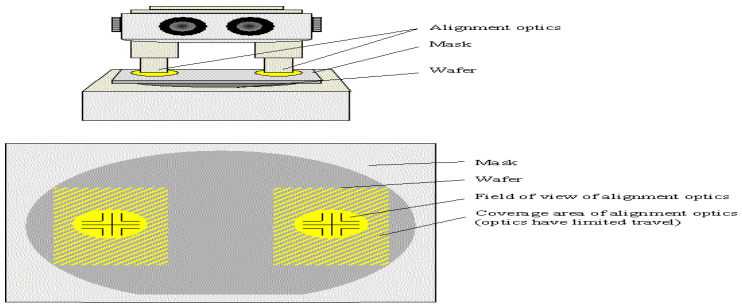
Digital Light Processing



Digital Light Processing

Benefits of MOEMS

Customers today are demanding smaller, lighter products with more features. Manufacturers are therefore being forced to develop technology (fig-7) that satisfies this demand. Precisely because MOEMS are a combination of mechanical and electrical features on a very small scale, they can be used where traditional mechanical structures would be too bulky.



MOEMS are extremely small and can therefore be capable of faster, more precise and more reliable operation than their larger mechanical counterparts.

For example, RF MOEMS components are mostly tunable, and offer low loss switching and high quality factors not possible with conventional components. Similarly, in optical switching applications where bandwidth and data volume trafficking must be maximized, the use of advanced optical modulation technologies is finding application in the form of Micro Optical Electronic Machines (MOEMs). The areas where performance / size / cost benefits can be realized using MEMS are almost unlimited.
Today's optical networking equipment must switch from the optical to the electronic domain.. Because it controls the flow of light rather than the flow of electrons, it is ultimately faster, smaller and cheaper. An entire R-OADM can be compressed into 2 cm x 1.5 cm in size, and can direct enormous amounts of data in ways that currently require large racks of assembled equipment.

"Waveguides" are very small conductors of light, about 5 to 6 microns or 1/10 the thickness of a human hair. MOEMS waveguide shuttle acts like a miniature train track switch for the fine waveguides.

The MOEMS switches and waveguides are made together on a single crystal silicon wafer using widely available semiconductor processing equipment. Such on-chip integration avoids the complex alignment issues associated with manually connecting different and larger components with optical fibers, and avoids the cost and space associated with manufacturing, assembling and packaging the separate components of Add/Drop Multiplexers.

In addition, the new technology eliminates the need for technicians to make routing changes in the field, ultimately bringing bandwidth to consumers faster.

Benefits of using MOEMS

MOEMS offer all the commonly cited potentialities of Optics:

- Accuracy in distance measurements
- EMI insensitivity in harsh environments
- Security in exploding fields
  Selectivity in chemical detection

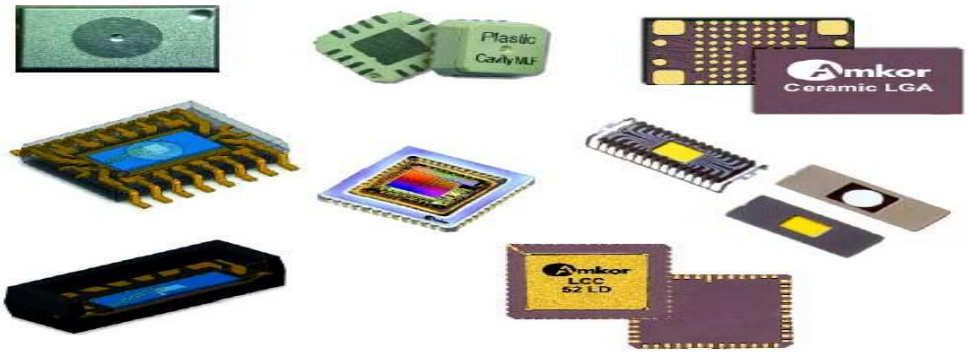
Together with the features of micro-system technology:

- Miniaturization
- Reliability
- Mass and size reduction
- Mass production capability
- Low manufacturing costs

Examples of MOEMS devices :

Today, examples of MOEMS devices as shown in figure-8 include:

- Arrays of micro-mirrors for digital image processing (projection, printing)
- Optical switches and routers, variable attenuators, shutters (optical communications)
- Tunable sources and filters, reflection modulators, spectral equalizers (optical communications, optical sensing, spectral analysis)
- Micro-scanners (image processing, bar code reading, obstacle detection)
- Deformable membranes for adaptive optics (astronomy, ophthalmology, FSO, defense)
- Free-space micro-optics: diffractive and refractive µlenses
- Guided optics devices
- Optical sources and photo-detectors
- Optical elements assembling: fiber-chip connection, optoelectronic hybrid integration



Typical Device Applications

- **Inertial Measurements -** Accelerometers, gyroscopes, rate sensors, vibration sensors.
- **Pressure Measurements -** TPMS (Tire Pressure Monitoring System) , disposable blood pressure sensors and various industrial applications.
- **Display Technology -** Optical MEMS in projectors, plasma displays.
- **RF Technology -** Tunable filters, RF switches, antennas, phase shifters, passive components (capacitors, inductors).
- **Chemical Measurements -** Microfluidics: Lab-On-Chip devices, DNA test structures, micro-dispensing pumps, hazardous chemical and biological agent detectors It has resulted in the fabrication of MOEMS that require minimal interconnects, which increases reliability and also decreases manufacturing cost - both important factors to the continued adoption of MOEMS in biomedical, telecommunications, automotive and aerospace industries.
- Another potential application for MOEMS devices is in **Signature Analysis** for Xerox printers and copiers. Signature Analysis is a technology that monitors a machine's components for "signature" vibrations that may indicate a part failure is imminent. MOEMS devices with tiny tuning forks can facilitate this by capturing vibration and transmitting it to

the machine's diagnostic equipment for analysis. The versatility, functionality, reliability and cost savings of MOEMS technology will be a key advantage in many industries.

Devices possible as MOEMS

- Digital or analog circuits
- Custom integrated circuit design
- Prototype or quantity fabrication
- Silicon CMOS or GaAs technology
- From 0.8 to 2.o micron gate length
- Toggle rate to 120 MHz
- Standard or custom packaging
- Low cost miniaturization of your electronics
- Deformable micro mirrors
- Optically addressed, MHz range, spatial light modulator
- Capacitive and inductive edge sensors
- Dynamic focusing mirror
- Application Specific Integrated Circuits - ASICs
- On-chip machines
- Optical chopper
- Optical switch
- Proximity sensors
- Optical scanner
- Micro optical bench with edge emitting laser or VCSEL
- Optical components; corner cubes, gratings, mirrors, deformable mirrors, diffractive optics, etc.
- Optical interconnect with micro-gratings
- Gyroscopes
- Force transducers
- Motors
- Sensors: acceleration, magnetic/electric field, temperature, strain, pressure, optical, mass flow, thermopiles, etc.
- Micro Actuators: electrostatic, thermal-bimorph, magnetic
- Mechanisms: rotary, prismatic joints, hinged 3-D structures
- Pumps and valves
- Accelerometers
- IR emitter

MOEMS applications:

Outstanding industrial applications of MOEMS are Peripherals and Telecom. However, other application areas with significant growth in the near future are:

- Biomedical
- Automotive
- Industrial maintenance and control
- Demotic
- Space and astronomy
- Environmental monitoring

Limitation: MOEMS and Nanotechnology is currently used in low- or medium-volume applications. Some of the obstacles preventing its wider adoption are:

Limited Options

Most companies who wish to explore the potential of MOEMS and Nanotechnology have very limited options for prototyping or manufacturing devices, and have no capability or expertise in microfabrication technology. Few companies will build their own fabrication facilities because of the high cost. A mechanism giving smaller organizations responsive and affordable access to MOEMS and Nano fabrication is essential.

Packaging

The packaging of MOEMS devices and systems needs to improve considerably from its current primitive state. MOEMS packaging is more challenging than IC packaging (fig-9) due to the diversity of MOEMS devices and the requirement that many of these devices be in contact with their environment. Currently almost all MOEMS and Nano development efforts must develop a new and specialized package for each new device.

Most companies find that packaging is the single most expensive and time consuming task in their overall product development program. As for the components themselves, numerical modeling and simulation tools for MOEMS packaging are virtually non-existent. Approaches which allow designers to select from a catalog of existing standardized packages for a new MOEMS device without compromising performance would be beneficial.

Fabrication Knowledge Required

Currently the designer of a MOEMS device requires a high level of fabrication knowledge in order to create a successful design. Often the development of even the most mundane MOEMS device requires a dedicated research effort to find a suitable process sequence for fabricating it. MOEMS device design needs to be separated from the complexities of the process sequence.

Conclusion:

MOEMS technology has the potential to change our daily lives as much as the computer has. However, the material needs of the MOEMS field are at a preliminary stage. A thorough understanding of the properties of existing MEMS materials is just as important as the development of new MOEMS materials.

Future MOEMS applications will be driven by processes enabling greater functionality through higher levels of electronic-mechanical integration and greater numbers of mechanical components working alone or together to enable a complex action. Future MOEMS products will demand higher levels of electrical-mechanical integration and more intimate interaction with the physical world. The high up-front investment costs for large-volume commercialization of MOEMS will likely limit the initial involvement to larger companies in the IC industry. Advancing from their success as sensors, MOEMS products will be embedded in larger non-MEMS systems, such as printers, automobiles, and biomedical diagnostic equipment, and will enable new and improved systems

Progress in the development of molecular machinery is being sought by researchers through cooperation between biotechnology and MEMS, thus resulting in Nano-Electro-Mechanical Systems (NEMS). In order to effectively build a molecular device, it is easiest to borrow a component or two from some biological machinery - proteins usually do nicely. For instance, researchers have recently taken advantage of a protein complex known as ATP Synthesis (or ATPase). Various versions of this protein are present in virtually every organism as it is responsible for most of the energy conversion in the biosphere. ATPase is a kind of molecular motor that converts an electrochemical potential across a membrane (a kind of nano-battery) into molecular energy in the form of ATP (the molecule that almost all living cells use for immediate energy). The protein can be run in reverse, thus re-charging the molecular battery at the expense of the ATP fuel. The researchers managed to attach the protein molecules onto a nanofabricated nickel surface in order to measure mechanical properties such as torque and efficiency.
At present these nanomachines have a very high potential for application though that potential has yet to be converted into real applications, called Nanomedicine.
Molecular machinery MOEMS, NEMS biotechnology, biomolecular nanotechnology , nanomachines ATPase ATP synthesis engine motor energy conversion fuel protein torque efficiency gears transmissions microengines dynamometer are also be the part of future.

References & Bibliography:

[1] P.Rai-Choudhary "MOEMS technology and application", Bellingham, Wash: SPIE, "MEMS and optical Engineering press, 2000

[2] Hiroyaki Fujita and Hiroshi Toshiyoshi," Optical MEMS", IEICE TRANS. ELECTRON, Vol. E83-C, No. 9, (2000) 1427

[3] Yu Fan and Mojtaba Kahrizi "An Optical MEMS Sensor System",Monttreal May/Mai IEEE 2003

[4] Deier, E; Wilde J; "Thermo Mechanical Behavior of the die attachment adhesive of a MEMS pressure sensor", 14th European Microelectronics and Packaging conference & Exhibition Friedrichshafen, Germany, 23-25 June 2003

[5] Ian Hunter ,"Theory and Design of microwave filters", Londan' Institution of electrical Engineers, 2001

[6] S.O.Kasap "Optoelectronics and Photonics principles and practices", Prentice Hall, 2004

[7] Wilde J, E Deier, Elena Zukowski " Influence of materials data on the performance Modeling in the design of MEMS Packages", IEEE 2004

[8] J Leuthold, F. Girardin, & et al " Polarization independent optical phase conjugation with pump signal filtering in a monolithically integrated Mach – Zehender Interferometer semiconductor optical amplifier configuration", IEEE 1998

[9] Arthur Morris, Stephen Bart, Derek Kane, Gunar Lorenz and Vladimir Rabinovich.: A design flow for MOEMS, SPIE Photonics East 2000

[10] Teegarden, D.; Lorenz, G. and Neul, R.: How to model and simulate microgyroscope systems. IEEE Spectrum, July 1998, pp. 66-75.

[11] Reinhard Neul, Gunar Lorenz and Stefan Dickmann: Modelling and Simulation of Micro Electromechanical Sensor Systems, Proceedings of the VDE World Microtechnologies Congress MICRO.tec 2000 September 25th - 27th, 2000, Hannover, Germany, Volume 2, pp. 67 - 72.

[12] Lorenz, G.: *Netzwerksimulation mikromechanischer Systeme*. Dissertation, Universität Bremen, Shaker Verlag, 1999.

[13] Przemieniecki, J. S.: Theory of Matrix Structural Analysis. Dover, 1985.

[14] Lorenz, G.; Neul, R.: Network-Type Modeling of Micromachined Sensor Systems. *Proc. Int. Conf. on Modeling and Simulation of Microsystems, Semiconductors, Sensors and Actuators*, MSM98, Santa Clara, April 1998, pp. 233-238.

[15] Coventor, http://www.coventor.com

[16] Kurzweg, et al., *Proceedings of Modeling and Simulation of Microsystems*, 768-773, June 2000.

[17] Walker and Nagel, "Optics & MEMS," Naval Research Lab, NRL/MR/6336 99- 7975.

[18] http://www.memsoptical.com

[19] http://www.amkor.com/enablingtechnologies

[20] http://www.infotonics.org/

[21] www.revoltech.com

[22] http://www.nsti.org