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TRENDS OF ANALYSIS AND MODELING OF MOEMS

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ABSTRACT

The interaction of Optics , Electronics and Mechanics paves the way for MOEMs (Micro Opto Electro Mechanical Systems). It is further integration of Optics in the MEMS (Micro Electro Mechanical Systems). The paper deals with the development of MEMS and subsequently MOEMS. The advantages of this over the former one , its application and its uses. The approaches of analysis and modeling has been classified into groups. The mathematical approach deals with the a) Computational Optoelectromechanics approach , High Fidelity Modeling of Electromagnetic Field , Beam Propagation Technique , and Hardware Description Language.

The other approaches are as :- Adaptive optics , Switching Devices with Spatial & Spectral Resolution , Wavelength Selective and Tunable Light Emitters Model MOEMS , The Behavioral and characteristics changes on types of substrate, Optical Sensing and Optical Fiber Sensors , and Modeling of MOEMS sensors are the hot topics and areas these days.

KEYWORDS: MEMS , MOMEMS, Photonics, Parameters, Miniaturization, ICs.

INTRODUCTION

MEMS Concept

Micro-Electro-Mechanical-System (MEMS) is micron to millimeter scale devices that can be fabricated as discrete devices or in large arrays.[1]

MEMS INTRODUCTION

With the advancement and day to day use and development of information system the individuals are getting closer to the physical world with the use of technology. We notice and become witness of the treating new opportunities for perceiving and controlling our machines, structures and environments. To explore these possibilities, opportunities information systems will need to sense and act as well as compute. Investing engineered system with superior capabilities to sense and act is driving force for the development of the relatively new product of 1990's, newer microelectromechanical systems (MEMS) Keeping in view of the technological competence and need for automations for which we are always in lookout, the basic devices which needs integration of the mentioned electrical/electronic devices together with mechanical ones. [2]The devices so fabricated needs the mentioned three things or approaches which is as follows:

1. **Miniaturization**
2. **multiplicity i.e. multiple component and**
3. **microelectronics [3]**

Using the fabrication techniques and materials of microelectronics as a basis, MEMS processes construct both mechanical and electrical components. Mechanical components in the MEMS like transistors in microelectronics have dimensions that are measured in microns and numbers measured in from few to millions. MEMS are not about any one single application or device nor is it defined by a single fabrication process or limited to a few materials. More than anything else, MEMS is a fabrication approach that conveys the advantages of miniaturization, multiple components and microelectronics to the design and construction of integrated electromechanical systems. The dimensions of mechanical devices /actuators are three to six times larger in sizes.

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MEMS devices have applications in areas ranging from measurement of quantities through sensors etc, automobiles and telecom switching to printers and internal guidance systems. While MEMS devices will be a relatively small fraction of the cost, size and weight of these systems. MEMS will be critical to their operation, reliability and affordability. MEMS devices, and the smart products they enable, will increasingly be the performance differentiator for a wide Varity of commercial applications/products.

The basic thrust for MEMS is the reliability and lower power consumption needs besides the multiplicity of components for perfect matching of parameters. It further serves as minimization of costs as the products are fabricated in batch processing and very large sizes which reduces the manufacturing costs.

APPLICATIONS OF MEMS

MEMS will and has created new capabilities, make high-end functionality affordable to low end systems, and extend the operational performances and lifetime of existing products and systems. For example, MEMS will enable complete inertial navigation units on a chip, composed of multiple integrated MEMS accelerometers and gyroscopes. The inertial navigation system of today, however, are large, heavy, expensive, power consumptive, precision instruments affordable only in high-end systems. Inertial navigation on a chip would not only make it possible to augment global positioning satellite receivers for tracking of individuals and equipment, but would also provide inertial measurement capability for high volume products that are currently measured. MEMS inertial navigation units on a chip will achieve performance comparable to or better than existing inertial navigation systems and be no larger, or more power consumption than microelectronic chips.

In addition to single chip inertial navigation units, there are many opportunities for MEMS insertion across a number of technologies and products. The main applications of the MEMS can be listed under the major commercial and military heads. The in the different heads such as

1. **Measurements of parameters**
2. **Telecommunication networks**
3. **Bio - Medical applications**
4. **Meteorological applications**
5. **Military applications etc.**

To be specific the applications can be which includes the ones mentioned as herein[3]

1. distributed unattended sensors for asset tracking, border control., environmental monitoring, security surveillance and process control
2. integrated fluidic systems for miniature analytical instruments, chip based DNA processing & sequencing , propellant and combustion control, chemical factories on chip
3. low power , high resolution, small area displays and workstation and portable, personal information systems
4. embedded sensors and actuators for condition based maintenance of machines & structures and on demand amplified structural strength in lower weight systems and disaster resistant buildings
5. mass data storage devices using magnetic and atomic scale patterning for storage densities of terabytes per square centimetre
6. integrated microoptomechanical components for low power optical communication, displays and fiber optic switches / modulators and
7. radio frequency and wireless for relay and switching matrices, reconfigurable antennas, switched fiber banks, electromechanical front and RF filtering and demodulation.

MOEMS CONCEPT

The answer in the most common words can be said as: -
"Normally in the MEMS technology, optical components can be combined with mechanisms to allow motion, and with electrical structures to provide actuation. Such devices are generally known as Micro-Opto_Electro_Mechanical_System (MOEMS)".[4]

MOEMS INTRODUCTION (DEVELOPMENT OF MOEMS)

MOEMS derives the functionality from the miniaturization of [5]

Optics
Electronics and
Mechanics

The figure illustrates the different outcomes of the integration of the three systems as shown here

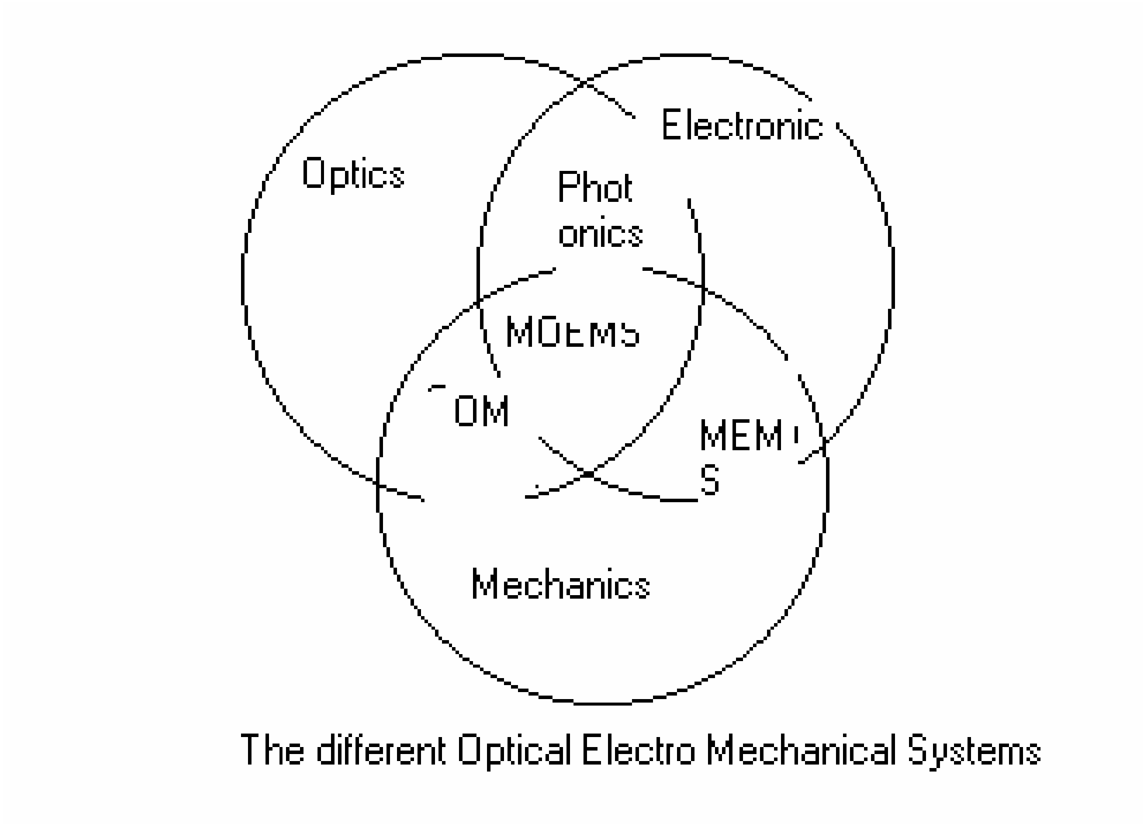

Figure 1

The MOEMS is the development from MEMS by integrating the optical systems to merge sensing, actuation and computing in order to realize new systems that bring enhanced level of perception, control, and performance to military and commercial systems. The MOEMS component of the program focuses on tasks whose primary goal is to endow systems with ability to alter or modulate the path of a light beam and in some cases, to temporally or spectrally modify the light beam. The most common micro optical elements are those that reflect diffract or refract light.

The field of modern optics has been largely concerned with the generation, manipulation, guidance and detection of light for information processing. The operation that is relevant to MOEMS is the manipulation of light in one-, two-, or three- dimensional space. For our purposes, we define light to be electromagnetic radiation in the spectral bands from about 0.20 – 15 micrometer. This is important because the wavelength of light that is manipulated or made to interact with micro optical elements imposes a lower bounden the size of the component. The lower bound is a consequence of the laws of diffraction. In order to avoid unintended diffraction effects, the feature sizes of micro optical elements must be at least 10 times larger than the wavelength of light that is intended to interact with the micro optical element. If diffraction is desired effect, then this restriction does not apply and the feature size is chosen accordingly.

There are three primary characteristics that make MOEMS an important technology development[6-10]

1. **batch process by which the systems are fabricated,**
2. **the size of the elements in the system and**
3. **Perhaps the most distinctive, is the possibility to endow the optical elements in the system with the ability for precise and controlled motion.**

Movement of a micro optical element permits the dynamic manipulation of a light beam. This dynamic manipulation can involve (amplitude or wavelength) modulation, temporal delay, diffraction, reflection, refraction or simple spatial re-alignment. Any two or three of these operations can be combined to form a complex operation on the light beam. The ability to carry out these operations, using miniaturized optical elements, is of the key attributes that distinguishes MOEMS from classical physical optics.

Advantages of MOEMS over MEMS

Following advantages of MOEMS over MEMS can be listed out

1. Variety of uses in optical communications as internal connectivity is available
2. Faster switching and sensing operations available compared to MEMS
3. More variety of uses such as bar code reader etc
4. Further reduction of power consumption
5. Use of motion optical components in MEMS makes or provides actuation which can be used for variety of applications
6. Multiplexed data transmission of varied pattern available in MOEMS
7. Advantages of electrical isolation with optical connectivity reduces the electrical interferences and consequently reduces the circuit requirements
8. More variety of ways of signal transmission is available as per light transmission i.e. reflection, refraction of diffraction etc.
9. Wider bandwidth very high channel limits available for communication
10. The transmission of signals in either modes available which is not possible in electrical signals which forms base of MEMS
11. The variable wavelength of lights to be used widens the band gap tailoring i.e. choice of semiconductor materials on which the MOEMS can be fabricated. This gives rise to even several III-V and II-VI compound semi conductors or even other combinations for systems fabrication
12. Reliability of MOEMS is higher than MEMS as reported in many researches
13. MOEMS are also used in analysis intends such as optical spectroscopes by considerably reducing its size. This has been reported in various researches.

APPLICATIONS OF MOEMS (MOEMS USES)

MEMS in general, and MOEMS in particular, have many potential insertion points in the both commercial and military sectors. In the military sector, the defense applications include": The applications are basically in the Optical Communication whether as sensor, switch, filter etc.

The major ones as per purpose are as listed herein: -

1. Internal navigation units on a chip for munitions guidance and personal navigation
2. Distributed unattended sensors for asset tracking, border patrol, environmental monitoring surveillance, and process control,
3. Integrated fluidic systems for miniature analytic instruments, hydraulic and pneumatic systems propellant and combustion control,
4. Weapons sating, arming and fazing to replace current warhead, systems and improve safety and reliability, embedded sensors and actuators for condition based maintenance of machines and vehicles, on demand amplified structural strength in lower weight weapons systems disaster resistant buildings,
5. Mass data storage devices and systems for storage densities of terabytes per sq. cm,
6. Integrated micro opto mechanical components for identity friend or foe systems displays and optic switches/modulators, and
7. Active, conformable surfaces for distributed aerodynamic control of aircraft, adaptive optic and precision parts and material handling.

8. Optical accelerometer based on antiresonant reflecting optical wave-guide to overcome drawbacks of electrical accelerometers. Their immunity against electromagnetic interference, together with the ability to have emitter and photo detector far from accelerometers i.e. connected through optical fibers, make them extremely useful in harsh environment.[11]
9. As a scanned detection optical position encoder. It uses the scanning & detection of optical no contact position sensing of bar pattern or any type of pattern with help of light from vibrating fiber tip and thereby forming images which when read and processed can result in the desired quantity.[12]
10. As filters whether as tunable or otherwise.
11. As an attenuator the MOEMS can be used. The insertion of a shutter into an optical beam source of the MOEMS with electrostatic, electromagnetic and electro thermal actuation can be modeled. The shutters are placed between two single mode fibers. The mechanism and the fiber mounts are fabricated in suitable materials by deep reactive ion etching or other mechanism. The device can be continuously adjusted into a discrete set. The attenuators can provide a considerable amount of attenuation[13]

Different types of Analysis & Modeling of MOEMS

The modeling and analysis of the MOEMS basically based on analytical and experimental and hybrid ways are primarily based on the propagation of optical waves, fabrication techniques, reliability, power consumption, semiconductor types i.e. elemental or compound types, substrates, applications, distributed types and likewise factors. The major types of analysis and modeling which has attracted are as follows

[1] The properties of attaining superior performance i.e. accurate beam pointing, maximal efficiency, enhanced robustness, minimal losses, minimal power consumption etc. MOEMS mathematical models can be developed. Due to complex optoelectromagnetic phenomenon the steady state, linear concept and finite element analysis alone cannot model MOEMS accurately. The MOEMS integrates many components e.g. MEMS, VCSEL, Bragg cell or active optoelectromagnetic microlenses, ICs. All these components and systems and subsystems has to be considered concurrently.

The mathematical modeling based on
Computational Optoelectromechanics i.e. High Fidelity Modeling of MEMS Based VCSELs :- For VCSELs equivalent circuit, Laguerre-Gaussian, single, two and multimode modeling well as other concepts can be applied. The shortcomings of one typical type of modeling can be improved by hybrid approach. To develop the model the differential equation approach for modeling, si8mulation and analysis solution in time domain for heterogeneous simulations and numerical simulations have been approached with certain assumptions. These assumptions can be further made realistic and modifications can be arrived at.[14]

High Fidelity Modeling of Electromagnetic Field: The electromagnetic field is modeled on the Maxwell's equations. Different paradigms can be successfully applied to perform modeling relaxing and computational difficulties to make the problem computationally tractable. Using the boundary conditions, the solution can be obtained from using fast Fourier transform method. The advanced MATLAB software and its toolbars i.e. toolboxes (partial differential equation toolboxes). It can be demonstrated that the complex electromagnetic phenomenon and effects can be thoroughly examined by help of numerical solutions based on high fidelity mathematical modeling tools. [14]

Beam Propagation Technique: This is well known technique that can be used for modeling of both free space and guided wave propagation. Different algorithms for BMP in the integrated optical domain are already in the research activities. The finite difference BMP seems to be more suitable for hardware description languages, however the other suggested algorithms such as Fast Fourier Techniques etc., can be used and well tested analytically and compared for the results. [15]

Hardware Description Language (HDL) for analogue, digital and mixed types of signals can be thought of. The HDL analogue type model simulation can be done on the SPICE simulator where the use of electronic discrete components or micro models available in the net list of SPICE can be used. The HLDs supports various physical natures such as electrical, mechanical, thermal, fluid etc. Thus these can be both used at the system or MEMS/MOEMS levels where physical parameter extraction from filed specific simulators are used to create compact models describing the behavior of the systems devices.[15]

MOEMS FOR ADAPTIVE OPTICS

Adoptive optics systems typically consists of a wave-front phase sensor, focusing optics, a spatial light modulator (SLM) for correcting phase errors, image sensors, and the control ad processing electronics. These systems improve image quality by reducing the phase aberrations introduced when the wave front travels through turbulent atmosphere or aberrations introduced by optical system itself. The adoptive optical systems in innovative idea as it gives birth to lightweight, low power and compact advanced systems suitable for space, missile and man-portable applications. The technologies making it possible include highly integrated low power electronics, and new processing architectures for error sensing & control, flexible high density packaging. This all is available because of MOEMS.[16]

SWITCHING DEVICES WITH SPATIAL & SPECTRAL RESOLUTIONS

Switches with Spatial & Spectral Resolutions combining photonic crystal; (PC) and microoptoelectromechanical systems (MOEMS) structures are now a days gaining research activities. These are based on the multilayer suspended high refractive index dielectric (e.g. semiconductor) membranes, some of which are laterally preferred to from photonic crystal (one dimension grating formed by an array of slots, or two dimensions for complex, triangular lattice of holes). The analysis can be done on the single patterned membrane and combine the impact of the limited lateral size on the design of the membrane and simple phenomenological model that describes the spectral characteristics of the transmission properties of an arbitrary stack of patterned membrane under normal incidence. The model combines the coupled mode method. This approach is used for new type of PC-MOEMS switching devices for varied angle of incidences.[17]

Wavelength Selective and tunable Light Emitters or Photodetectors Model MOEMS: - The constraint of strain induced by additional material layer which may be contact layer or insulating layer etc. in resonant cavity enhanced design of MOEMS the present technique is introduced to overcome such constraints. Here the active layer is put out of the resonant cavity and placed on the top of the device before the filtering part. This active on top design can be made quite flexible in accommodating the strain, for instance by implementing thicker layers to the top active unit to strengthen its mechanical property. The design can supply improved spectrum resolution as compared to resonant cavity enhanced design offer individual optimization for the active and the resonant cavity part and is compatible with the planar technology and high speed applications.

The behavior and characteristics of the devices can differ on the types of substrates. The Polymer and Piezoelectric substrates can be used in this light. These will give rise to newer types of MOEM systems whose characteristics can be monitored and tailored. Direct laser writing of micro lenses on polymer piezoelectric substrate offers board to board or chip to chip optical interconnections in digital systems. Integration of MOEMS and photonic band gap structures is achieved it can work as a potential coupler and switch. The different photonic band gap structures can be developed theoretically in different ways. The photonic band gap structures or photonic crystals are the structures where the refractive index is a periodic function of space. They are characterized by a band gap that blocks the propagation of light of a certain frequency range. The various types of development in the photonic crystals indicate towards the possibility of inhibiting or enhancing spontaneous emission in active electro optic devices such as LEDs and LASERs. Photonic crystals allow realization of integrated optic devices, playing an important role in the minimization of opto-electronic equipment. Tuning of photonic crystals can be achieved either by dielectric constant of one of the constituents. The band structure of tunable photonic crystals is highly anis tropic.[20]

In field of optical communication the use of MOEMS in optical sensing involving optical fiber sensors is also gaining interest. The fiber optics in the application range of Fiber Bragg Grating the sensing mechanism of using modulation of reflected wavelength through changes of the effective grating period and refractive index induced by temperature, pressure, and strain is done. In order to measure variation various techniques other than reported could be used. The basic phenomenon can remain same. These technique can include passive detection schemes, active detection schemes which can be hybrid MOEMS tunable filter for Fiber Bragg Grating, wavelength tunable sources and laser frequency modulation, etc.

In the hybrid MOEMS tunable filter scheme of active detection scheme the angular rotation of an interference filter can be used for tuning its pass-band. The MOEMS tunable filter of micro-system nature where the combination of a passive optical component –an-off-the-shelf dense wavelength division – multiplexing (DWDM) filter-with a novel microelectromechanical system actuated platform which rotates about its axis, can be seen as an active tunable filter The scheme can be implemented for interrogation and demodulator[21]

The recent days are seeing optical sensor use of MEMS. The modeling of MOEMS as sensors can be seen as potential area as its application. The sensor tip is important step and this can be designed as a Fabry Perot Cavity etched on silicon or other suitable material. The Fabry-Perot cavity can be built with two-semi mirror in parallel. If the light is incident from the optical fiber and simultaneously the reflected optical signal from the cavity can be monitored. When certain ambient change forces the tip, the membrane of the cavity will vibrate deviating from resonance and consequently the reflected light will change by means of central wavelength shift and power degradation. The CMOS model tools can be used for modeling the MOEMS tip.

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