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"MEMS CHALLENGE: CAN THIS TECHNOLOGY CATCH THE INTERNET LIGHTWAVE?"

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ABSTRACT

The pundits of the money world tell us to be a "dotcom" or enable them for excitement and rewards. Traffic on the Internet Highway is certainly stepping up the pace as "slow" electrons make way for ultimate-speed photons creating major hardware opportunities. The "Copper Road" has become the "Glass Super Highway" as long-haul terrestrial and underwater communications links move up to Advanced Photonics.

Nothing can be faster than light, but more important, no other medium can offer wider bandwidth when wave-multiplexing strategies are used. Photonics, employing dense wave division multiplexing (DWDM) can carry the equivalent of 12,000 encyclopedias or 5-million phone calls on a single fiber. Recent advances in photonics hardware, including higher-powered lasers, more efficient amplifiers and cleaner optical fiber are enabling incredible bandwidth for the Internet and general communications services. But how do we route a light beam?

The long-haul segments of the Internet, now mostly fiberoptics, have been converting modulated light to electronic signals, routing with conventional electronic hardware and then re-converting back to light. Yes, O-E-O (Opto-electro-opto) works, but with cost and time-delay penalties. The communications industry has decreed that the double conversion process must go, but what technology will be the replacement?

Enter optical MEMS, or MOEMS (micro-opto-electro-mechanical systems). The MOEMS switch/router approach was endorsed by the Internet carrier and hardware industry that paid billions of dollars in 2000 to acquire MEMS companies, some that had not even shipped a product. But what are the issues and are there competing technologies that could win? Micro-mirror technology is at the top of the popularity chart right now. Can MOEMS mirror routers solve cost problems and can they even switch at the rates demanded. What is the ideal mirror switch strategy: binary "off/on" or point-to-light pipe arrays? What about other MEMS approaches such as micro-bubble fluid beam refraction that appears to offer a much simpler construction? Maybe the mechanical devices are only an interim destined to obsolescence by a future solid state optics switch. The optical switch, powered totally by photons, is already in the lab and could be the final answer.

This paper will survey MOEMS inside the Internet to seek answers to the billion dollar questions. The focus will be on micro-mirrors and their packaging issues both inside and out. We will deal with selecting the ideal optical MEMS package and choosing the right atmosphere control. Certain in-package contaminants are death to mirrors, but they can be controlled even if generated after the package is sealed. So tune in to find out if MEMS can catch the WAVE!

INTRODUCTION - MEMS/MOEMS

MEMS is about high-level integration of dissimilar functions. This *unification of functions* includes motion, light, sound, electromagnetic radiation and analysis of data. Computation, analysis and central control of these input/output functions results in a fully integrated system of incredible versatility. MEMS is the convergence site for many dissimilar technologies. Mechanics adds gears, pivots, hinges, sliders and elevators. Optics brings mirrors, filters, prisms and modulators. The electrical field delivers motors, heat and other energy. Chemistry adds molecular detection and manipulation. Finally, general electronics delivers radio, computation and control to this new microworld. And we can expect more biotechnology to enter the MEMS arena soon as indicated by IBM's recent announcement of a DNA detector. MEMS synergistically merges subsystems into a fully integrated, self-contained microcosm that once existed only in the macroworld and this is the essence. How remarkable that these once isolated technologies can converge into the microscopic world of solid state using wafer-level mass processes.

But there are perhaps decades of challenges ahead! Specialists in this field insist that microelectromechanical systems fabrication, packaging and assembly will require the greatest effort our industry has ever deployed[1]. Not only are the advanced MEMS devices small and highly complex, many, especially MOEMS, communicate with the outside world by direct-path non-electronic signals. A high burden is placed on packaging and assembly to provide electromechanical connections that do not interfere with or alter sensing, receiving, transmission and control functions. Fiberoptic connections are starting to be added. These tasks are new since MEMS has previously dealt mostly with electrical signals of motion devices. The additional input/output photonic "signals" with extreme control and precision adds considerable perplexity.

Some MEMS devices send and receive light beams, others detect specific molecules, including biological analysis such as DNA. The merging of motion, sensing and computation most certainly represents a new level in technology that is still embryonic. Surprisingly, this "new" technology has been around for nearly three decades but at a simple level such as motion sensing. More recently, optical MEMS, called MOEMS, has become the hot area. The Internet is the new and powerful market force. The solid and durable opportunities are in hardware, not in the present domain of "dotcoms" and it is better to enable them than become one. The modern Internet is really *a fiber glass intercontinental highway* system, a system of photonic light pipes. In the US and Europe, over 90% of long haul is on fiber and the fiber moves ever closer to the home. Light control will be the master key that opens up efficient photonics. MOEMS appears poised to be the winner in the realm of light routing. Just during the year 2000, the Internet giants spent billions of dollars to acquire MEMS companies while others, like Lucent, announced impressive "home grown" breakthroughs. So as the light wave highway moves from the present long haul or backbone and approaches fiber-to-home (FTH), we can expect the volume for MOEMS assemblies to increase geometrically.

Most of the nearly three decades of MEMS has involved simple "bending motion" devices like transducers and accelerometers. Table 1 list MEMS/MOEMS devices with relevant information. We will concentrate on the optical MEMS, or MOEMS area and specifically analyze how this exciting technology fits the runaway Internet.

TABLE 1

MEMS Device	Packaging	Input	Output
Accelerometer	EMC (Epoxy Mold. Compound)	Motion	Electrical
2D and 3D Motion Detection	EMC	Motion	Electrical
Ink jet	Selective	Electrical	Motion
Digital Mirror Array	**Hermetic/window**	**Electrical & light**	**Controlled light**
Micro-Spectrophotometer	Hermetic/window	"Light"	Electrical
DNA Analyzer	Liquid access	Biological samples	Electrical
Disk Drive Heads	None	Magnetic	Electrical
Optical Switches	**Hermetic/window**	**Electrical and light**	**Electrical & light**
Capacitors, Tunable	EMC	Electrical/RF	RF
RF Tuners	EMC	Electrical/RF	RF
Gyroscopes	EMC	Electrical/motion	Electrical
Diagnostics (in vitro)	Open	Electrical, samples	Electrical
Infrared Imagers	Hermetic/window	IR, Electrical	Electrical
Micro-Relay	EMC	Electrical	Electrical
Pressure Sensors	Sealed thin wall is OK	Force directly/indirectly	Electrical

PHOTONICS

Distance communications began in ancient prehistoric times. Early civilizations used only light and sound waves. About 3,000 years ago the Greek victory in the Trojan War was communicated by lighting hilltop bonfires one after the other. But when did technology-based communications begin? Many would suggest the telegraph or telephone started the communications revolution. Some would consider the Marconi wireless radio as the beginning of sophisticated technology. While both copper wire and radio frequency communications are important and remain the basic modes today, this is changing. Photonics, the use of photons as a communications messenger, is rapidly becoming the most important terrestrial and submarine system. In fact, most long-distance telecom and Internet communications use photonics. New system installations are typically photonic and some new homes are fiber –ready. The long-haul Internet is about nearly all glass fiber, not copper. Several submarine fiberoptic lines have been laid recently and more are planned. Long-distance telephone service began moving to fiber about three decades ago and the newer Internet simply followed along. Photonics has quietly moved in and now dominates long-haul communications. And we are just starting to see new free-space photonics deployed for “last mile” links. But photonics, or more specifically, optoelectronics has also been used for many decades in the short-range market, such as TV controllers. So when did photonics really begin?

We need to step back all the way to the 1800’s and examine the fundamental breakthroughs of the communications revolution. Alexander Graham Bell received his famous telephone patent in March of 1876. This patent would make him richer in today’s dollars than the Internet barons. Yet Bell was dissatisfied. The telephone and Morse’s telegraph were *land locked* and of little value to ships that were often in desperate need of communications. Bell realized that transmitting voice on a beam of light could be the answer. He reasoned correctly that the photoelectric effect demonstrated with selenium could be used to modulate an electrical signal for the receiver. The transmitter was a greater challenge. Bell hit upon the idea of using sound vibrations to modulate a sunbeam directed by a pivoting mirror although glass gratings were also tested. The voice-modulated beam of sunlight was detected by the selenium photocell – and photonics was born. Bell had heard a sunbeam laugh. The year was 1880 and Bell’s first wireless had been demonstrated well before Marconi’s radio wave version. Bell considered the Photophone to be his most important invention and perhaps he was right. However, the photophone and optical communications were not a business success in that early era. Many other inventions would be needed to make photonics of practical value, but they would not come until the next century.

In 1958, Charles Townes and Arthur Schawlow of Bell Laboratories proposed the laser as a source of intense and coherent light for photonics. In 1960, a laser system was operated by Theodore Maiman of Hughes Research Laboratory. By 1962, lasing phenomenon was observed in a semiconductor chip heralding solid state laser technology. In 1970, Robert Maurer and colleagues at Corning announced Photonics is well advanced in terms of discrete devices, but systems are not really integrated like an ultra-pure silica fiber with losses reduced to 4db/km. So this is how photonics was launched and while we might be tempted to say, “And the rest is history”, a more accurate statement is, “And the rest is the future”.

INTERNET HARDWARE

The key to Internet “speed” is bandwidth – total amount of data per unit of time. Light has a much higher frequency than radio or any type of electronic signals. Since data capacity is directly related to frequency, photonic signals can carry over a million times more information than electronics. What’s more, light can be easily split into numerous wavelengths (colors) with each wavelength carrying separate data on the same strand of glass fiber. We could, for example, use yellow light to send high-speed data along a fiber and than double our capacity by adding a green wavelength signal. Fiber cables, of course, carry many individual strands of glass fiber to provide nearly endless bandwidth.

The industry is already adopting multiple wavelengths and may use 100 different “channel colors” by 2001. This will increase single-fiber, single-color capacity to an astounding level but keep in mind that each signal color handles much more data than copper wire. Multiple colors is what high density multiplexing is all about, hence the market excitement. The fiberoptics Internet is just now reaching an amazing 10 gigabits/second (Gb/s), but soon moves to 40 Gb/s and then doubles again in 2002. The fastest single fiber rate in a lab exceeds 3 trillion bits/sec (terebits/sec). The recent mega-mergers by Internet giants demonstrates that the carriers and hardware makers are betting their companies on light and are determined to catch the *photonic wave*! There is a furious pace of consolidation within the industry that is accelerated by the ongoing photonics revolution.

The substantially optical Internet backbone uses relatively few switches/routers since nodes (switch points) can be 500 miles or more apart. These nodes connect to cities, or metros. The metro network requires many more switches per length of cable. Many think that the Metros will be well on their way to optical conversion by 2001. The next level for optical is enterprises and then the end user. These markets could generate 100 or even 10,000 times more hardware business. But there’s a “Catch 22” since cost must drop substantially for each of the more hardware-intensive steps.

electronics. The optical transistor could already be here, but the optical IC will be the big breakthrough.

The photonics pace will be much faster than electronics because of powerful drivers, confidence in this approach and the availability of high technology that can be tapped from other fields. The winners will move at "Internet speed", take bigger risks and bet on strategies while waiting for implementation.

Here are some of the present components for photonics in general communications and the Internet.

Fiber: Fiber became the long-haul backbone of telecom by the mid-1980's. It was the obvious choice for Internet and glass rapidly displacing copper. Corning is the dominant player and could garner half of the world's optical fiber market. Corning's aggressive hardware acquisition strategy has moved the company into lasers, routers, switches and all kinds of related hardware.

Lasers: These are the "light" transmitters and modulators that send signals along the optical fibers. There are dozens of types, but for now, the laser diode is the workhorse. But major efforts are underway to commercialize tunable lasers, those that will transmit different wavelengths (colors) on demand. The key to very high bandwidth will be the use of multiple wavelengths, with more than one hundred colors. The tunable laser, while not essential to this strategy, would produce major cost reductions and go a long way in simplifying the system.

Multiplexers/demultiplexers: A multiplexer encodes information into modulated light beams of various colors that are sent along optical fibers. A demultiplexer at the other end, or at a node point, separates signals and extracts the information. This is a key technology for very high bandwidth. The latest approach is called Dense Wave Division Multiplexing (DWDM) and it simply means using many colors of light with each carrying separate information to maximize the amount of information sent on a fiber.

Amplifiers: Very long optical fiber runs, like trans-oceanic (submarine), require signal boosts. Erobium-doped fiber amplifier (EDFA) types are the present favorite. They are assembled in a very labor-intensive and expensive manual process. Market leader E-TEK (JDS-Uniphase acquisition) just announced a product that can be directly soldered to a printed circuit board. But we have a long way to go for systems integration.

Routers/Switches

Internet and telephone information must obviously be sent to the proper locations and this is the task of the routers and switches (while not identical, we will use the two terms as synonyms). There is a tremendous effort to develop all-optical switches/routers that can direct photonic signals to the proper location at hubs along the Internet without converting back to electrons. Breakthroughs seem to occur nearly every week. Here are 4 basic approaches:

1. **MOEMS micro-mirrors** using electrical signals to move individual mirrors can be used to switch wavelengths off and on; "on" mirrors send the light to an output fiber while "off" deflects the beam. A more complex mirror could direct the light beam to any number of output fibers for very efficient signal routing. Many of the big companies have either developed prototypes or acquired companies; Lucent and Nortel (through recent acquisitions) are leaders. Xros (Nortel) appears to be a winner having demonstrated the highest capacity mirror modules and multi-directional pointing. Lucent and others only have "on" and "off" mirror function. JDS-Uniphase just bought one of the last independent US MEMS companies a few months ago.

2. Agilent (HP) has announced a very clever and simpler optical switch based on liquid bubble jet principles after five years of development. A micro-drop of liquid that is "pumped" into the path of a light beam to refract and thus divert it from point A to B. The approach leverages HP's MEMS ink jet technology that has been so successful for ink jet cartridges.

3. Oak Ridge National Laboratories appears to have made a major breakthrough with a light wave switch requiring NO ELECTRICITY. Their **optical transistor** is switched on and off by photons at a speed of 1 microsecond. This device appears to be the true equivalent of the electronic solid state switch used in electronic routers/switches. However, the device is very rudimentary at this stage.

4. Add/drop filters can filter out (drop) specific wavelengths and also add to them composite signals as required by traffic demand. The add/drop capability could be used for switching and many are pursuing this.

Shedding light on MOEMS

MOEMS products add a high level of complexity. The chip should be hermetically sealed but a light path is another obvious requirement. The solution is somewhat apparent, but implementation can be a Herculean task. A light-transmissive lid or "port hole" is designed into the package. Several materials can be used. The micro-mirror module from Texas Instruments is one of the best examples of the packaging of complex photonic products. Figure 1 shows the Digital Micro-mirror Device™ (DMD)[2].

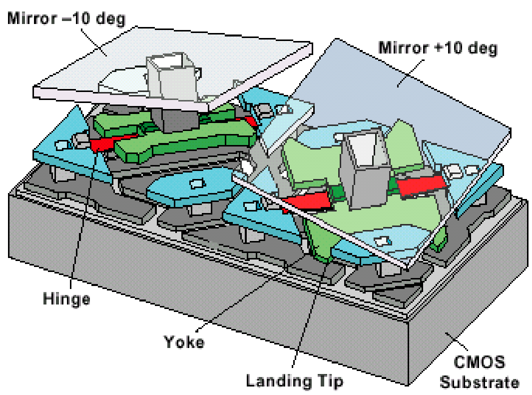

Figure 1 – TI Micro-Mirror Module - ref. 2

The Digital Micro-mirror Device is very likely the most sophisticated MOEMS product that has yet been commercialized and a preview of what lies ahead. The chip incorporates light beam-directing mirrors that move independently and almost instantaneously during operation. A pixel is turned "on" by pointing a mirror at a projection lens while turning "off" involves pointed away. Let's look more closely at the optical package. Figure 2 shows a section of the micro-mirrors with some pointed "on". Large arrays are being used for digital projectors right now, but there are other applications such as digital video and optical switches.

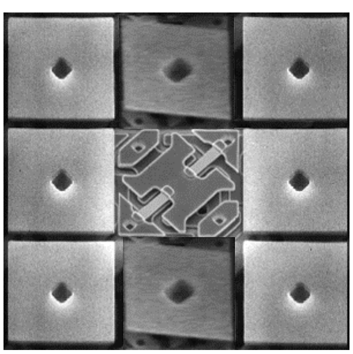

Figure 2 – TI Micro-Mirror Array Close Up, ref. 2

The movable mirror principle would appear to be a good fit for Internet routing of lightwave signals. An incoming beam could be directed toward the intended outbound fiber. A number of companies have announced products or plans for micro-mirror switches. Some pivot, like TI's while others, like Lucent's, use a bending lever action. Still others rotate and some even have multiple axis movement. Almost certainly some moving reflector based optical routers will be introduced if not already the case. Regardless of the specific director mechanism, the mirrors will probably need a similar type of high level package that is light-transmissive. The TI package is therefore a good model to explore the packaging issues for MOEMS.

Most optical systems use a high-vacuum hermetically sealed package. Although many researchers recommend a high vacuum, others suggest a specific range for gases. Movable optical systems require that the package atmosphere not only start off clean, but that nothing within will later degrade lens clarity. One added problem is that materials can outgas to generate atmospheres that cause damage later, even though the initial package had a very high vacuum. Microscopic particles can also dislodge or even form during operation. How can we deal with gases and contaminants that are produced long after the package is sealed and the product is in the field? The best solution appears to be "getters" that will be discussed in more detail later. Figure 3 shows the TI package with getters attached to metal section of the lid assembly.

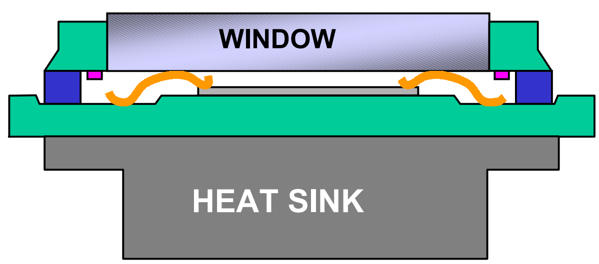

Figure 3 – TI's DMD & Package Diagram

ATMOSPHERE CONTROL

The MEMS package can consume (absorb) and emit materials (outgas), but the atmosphere needs to be controlled within certain ranges[3]. The atmosphere maintenance approach must be simple but effective and a class of materials called, getters, may be the best answer. Getters are agents true to their name and "get" things – primarily contaminants. Today's getters for electronic packages are very selective. While the present list of commercial getters is small, other types are feasible. The common moisture getters use compounds that absorb and tightly bind water molecules. A special polymer matrix can be used as the "breathable" binder to hold the agent. Particle getters are made with permanently sticky polymers. The getter must be easy to use, maintain performance over extended time and not produce contamination. Getters could simply be "printed" on inside of the package. MOEMS devices often use moisture and particle getters as is the case with the TI mirror package.

MODERN GETTERS

Many may not have heard of getters, but they are important materials for many sealed packages. Getters have been around since the earliest phase of the electronics revolution. The early electronic vacuum tubes experienced unacceptably short lifetimes because of the oxidation of filaments and electrodes. Back in the early 1900's, it was not practicable to produce a high and stable vacuum. But the life-limiting culprit was oxygen. The simple solution was to add an oxygen getter to the package. The getter was simply a metal or compound with a strong affinity for oxygen. The tube, even with a small leak, remained at a low oxygen level provided that some of the getter remained active. Now back to the 21st century.

TABLE 2

Getter	Form	Status
Moisture: H_2O	Film, paste	Com.
Particle	Film, paste	Com.
Hydrogen: H_2	Film, paste, thin film	Com.
Oxygen: O_2	Film, paste, thin-film	feasible
Humidity range	Film, paste, fluid?	feasible

Moisture getters use compounds, like zeolites and metal oxides that absorb and tightly bind water molecules. A thermoplastic polymer binder is used that can be formed into film or pastes, such as Staystik 415 / 482 and StayDry SD1000 / SD800 from Alpha-Fry Technologies. Particle getters are made with permanently sticky polymers that maintain this characteristic over extended time and not produce contamination. Hydrogen getters, used to prevent poisoning of GaAs devices, are more complex. Although hydrogen-adsorbing palladium (Pd) metal can be applied to lids, a better solution is to use a polymer-bound system. This is because the plated Palladium compound has a tendency to embrittle and flake over time, leaving the possibility of unwanted particulates forming in the package. The Hydrogen Getter H2-3000, for example, utilizes palladium oxide (PdO) in combination with zeolite dispersed within a stable polymer matrix. The PdO converts H_2 gas to water that is then consumed by the zeolite making the reaction irreversible. Incidentally, the H_2 sources include the electroplating on the metal package, die attach adhesives and RF absorbers. Released hydrogen degrades the semiconductor structure of the GaAs devices reducing device performance over time.

Some suggest that a specific range of moisture is best since it can act as a lubricant[4]. Can getters control humidity within a specific range? This is certainly

Today's getters for electronic packages are designed to absorb and sometimes neutralize specific contaminants. Products are available that absorb gases, liquids and solids. While the present list in Table 2 is not that extensive, additional getters can be designed as the need arises.

feasible although the term getter may not be entirely accurate here. Specific compounds or mixtures are known that can maintain moisture within specific limits inside a sealed container. Equilibrium levels are soon reached with atmospheric water to regulate humidity. The appropriate selection of such desiccants and polymer carriers could produce "atmospheric control agents" for specific humidity ranges. Work is in progress at Alpha-Fry Technologies on such materials and intended for use with MEMS devices.

Surface Control - Friction, and Stiction

As you can see, MEMS has its own vocabulary. So what's stiction and why should we care? Stiction is a form of friction where a much higher force is required to get things moving. Once the gear, wheel, slider or arm is unstuck, we are back to ordinary friction. Stiction goes unnoticed in the macroworld where it is a minor factor. The attractive forces in the microworld are relatively higher and stiction is a big deal. It can require a high initial force to start a mechanism moving if stiction can't be overcome and will mean excessively large motors.

But stiction can be a greater problem for even simple bending mode devices. What happens if the motion beams make contact? They stick! They stay stuck! We can't just pry the beams apart since the package is already sealed. But what made the beams come together? Jarring the parts or just moving them too quickly can cause the "floating" beam to move and make contact. So the assembler or user can unknowingly "lock up" the MEMS/MOEMS part just by handling. Worse yet, the only evidence for stiction immobilization is testing. The stiction problem applies to all moving devices where interfacial contact can occur. Mirror pivots, hinges, beams and sliders can all suffer the stiction-debilitating phenomenon.

A micro-mechanism with a potential to lock up or never get moving cannot be considered for high reliability Internet switching. The problem must be solved by design, materials or processing. There is still some debate as to what kind of atmosphere is best for reducing stiction since it can involve mechanical interlocking, atomic forces and even chemical reactions such as hydrogen bonding. Many advocate the highest vacuum possible while others suggest that a small amount of moisture can reduce wear and stiction as mentioned earlier[4] But there are some surface chemistry complexities involved with silicon and its oxides that appear to make surface coating a logical option. Organic coatings with low surface energy and perhaps hydrophobic properties can help[5]. The coating would need to be very thin and this is the realm for vacuum coating technology.

Anti-Stiction Coatings

Many have heard of Parylene (poly-para-xylylene) as a special polymer film applied to substrates with a vacuum coater. The Parylenes are noted for high chemical inertness, strong barrier properties and perfect conformity. The surface energy is very low. A new fluorinated, teflon-like version (Nova HT) has been recently developed by Specialty Coatings Systems for semiconductors that can handle over 500°C. Nova HT could be ideal for anti-stiction. Hopefully, work in the near future will determine if this material is a good solution to stiction and mechanical in MEMS[6]. The high optical clarity would also seem to make it a good candidate for MOEMS devices.

MEMS-Specific Package Designs

Many of the MEMS packages started off as the standard Cerdip (ceramic Dual In-Line) package since a ceramic or metal hermetic package offers a high level of protection, but at a cost penalty. Many Internet hardware packages are the hermetic metal type costing hundreds of dollars. New packaging may be needed as photonics branches outward from the core.

Now we will examine some newer packaging concepts that could eventually become standard. Although the MEMS package can be very application-specific, some general design concepts are emerging. The MEMS devices have a universal requirement that the "motion zone" cannot be obstructed. A protective cap over the action area can permit the component to be overmolded while still allowing unrestricted movement within the device. Once the cap is in place, standard transfer molding can be used. In some cases, liquid encapsulants may produce less stress. Liquids may be applied by automated needle dispensing equipment commonly used for some BGAs. But overmolded packages would require modification for MOEMS.

Another possibility is to use Flip Chip. Since the active surface of the device with moving parts is placed downward toward the substrate, a natural protective zone can be formed. The standoff distance, or chip gap, can be accurately controlled by the chip bump height. High melting alloys or even non-fusible bumps can be used to insure a specific minimum gap between the chip and board. The next step is to selectively dispense underfill. Normally, underfill is applied to completely fill the chip gap, but this would interfere with MEMS movement or sensing. A more viscous encapsulant, resembling damming compound, could be applied to all four edges of the chip. This sealing encapsulant, a fillet without the underfill, would then thermally harden. Now the package can be fully encapsulated by conventional transfer molding or by needle dispensing a liquid encapsulant. A chip access port could be added to the packaging substrate if the device must communicate with the outside atmosphere such as with a gas analyzer. A glass port or fiber could possibly be used to limit entry to only the intended light. Figure 4 shows the Flip Chip designs with a light port. Another possibility is to use clear (no is used filler) "No Flow Underfill", NUF[7, 8.]

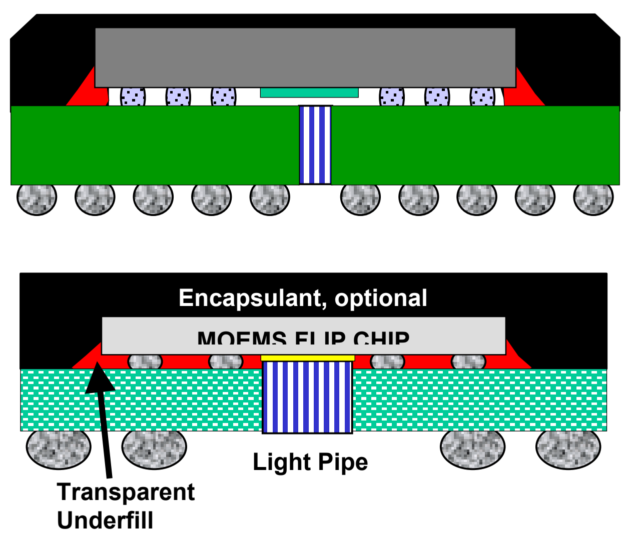

FIGURE 4 – FLIP CHIP MEMS PACKAGES

A more elegant concept is to apply a microcap at the device level or more preferably at wafer level and then proceed to standard packaging. Several groups, including AMKOR, IMEC (Belgium) and Georgia Institute of Technology are working on or have already developed "Cap-on-Chip" sometimes-called 0-Level packaging. The cap essentially produces a silicon micro-hermetic package well suited for accelerometers, gyroscopes or any other motion detectors. The present caps are made of silicon to achieve a perfect match of materials. However, the thin, flexible silicon cap may require a pre-molding step to prevent cave in due to high molding pressures. Perhaps low expansion metal caps can eliminate this problem. The alternative may be liquid encapsulation. Figure 5 shows the Cap-on-Chip concept. The final package, if successfully implemented, will be outwardly similar to the common SMT plastic packages although it is too early to know exactly what the form factors will be. But can this concept work for MOEMS? The cap would have to be transparent, as would the molding compound. Quartz or some other "glass" could possibly be used for the cap. Molding compound specialist also think that a clear EMC (Epoxy Molding Compound) is possible since many epoxy resins and hardeners are transparent. The filler, required to reduce CTE, could be the problem, however.

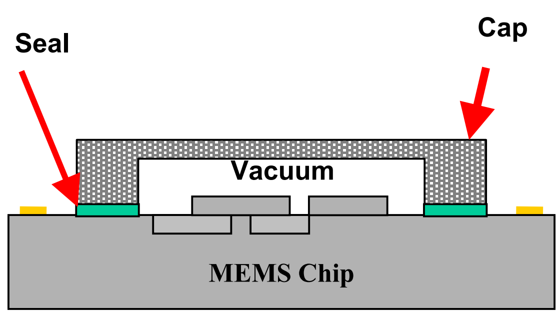

FIGURE 5 – 0-LEVEL HERMETIC PACKAGE

SUMMARY & CONCLUSIONS

There is no doubt that photonics is the preferred mode for terrestrial and submarine long-distance digital communications. Telephone systems began moving to fiberoptics several decades ago and the Internet simply followed this lead. Fiber appears well-suited for the high bandwidth required and the best technology going forward. Innovations in wave-based multiplexing appear able to satisfy the ever-increasing communications appetite. However, success in new fibers and DWDM systems has pushed the "bottleneck" to the routing and switching. Present O-E-O schemes must be replaced by an all-optical method that has moved MOEMS into the spotlight and wave path. While micro-mirrors would seem like the obvious photonics switch, other methods cannot be ruled out. Perhaps several winners will emerge within the next year or two. In the mean time, significant, yet very exciting challenges are placed before us. MOEMS design, fabrication, packaging testing and assembly will be a high action area. Jump in and catch the wave – the lightwave!

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