Overview of New Packages, Materials and Processes

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ABSTRACT

You've survived the chaotic 1990's Packaging Revolution but don't rest yet. The revolution's first decade made strides in conquering *Space*, shifting to efficient area array. Minimal packaging *reintroduced* CSPs and Flip Chips in our quest to compress the world onto a chip. Innovators invoked the 3rd dimension to stack chips in high-rise fashion. The densification seems amazing but submicroscopic DNA holds a million "pages" of code and could store the world's data on a pinhead. So, you haven't seen anything yet!

Flex-based packages gained stature by shedding weight and height with 25-micron films having lines and spaces approaching microns using vacuum-deposited metal. Flex-BGAs and micro-BGAs gain share while setting high-density records. Yet, flex-based packaging is nearly 40-years old.

We tried to pause and reflect but a new assault came from a different camp. MEMS (micro-electro-mechanical systems) moved to center stage when nano-machines perform remarkable feats. The world's most complex machine, the Boeing 777, moved to second place when a MEMS device took the title with over 1-million parts. MEMS that can *"move, breathe, see, hear and think"*, needs new packaging. And then came optics bringing MOEMS (micro-opto-electro-mechanical systems) into the *spotlight*. The Internet giants embraced lightwaves seeking MOEMS to catch the wave. Magical micro mirrors are the rage as they snatch light beams routing them into cyberspace. But MOEMS demands a different package with real *windows and no gates*. So stay connected, catch the wave and find out if its solder, sound, radio or light!

INTRODUCTION

The first decade of the new millennium promises and threatens to accelerate technical change. The most important driver for technical innovation is now telecommunications. The main demarcation of the new telecom is terrestrial and wireless. The terrestrial communications system is the photonics-based Internet and to a lesser extent, land-based telephone links. The telephone network will likely be incorporated into the Internet in the future however. Wireless is predominantly low power, short-range "last-link" services that connect to the terrestrial networks.

The Internet has become the center of the communications universe – The WorldWide Hub that will ultimately connect all systems and all people. But consumers insist on being untethered, hence the growth of wireless. Several forms of wireless have been deployed while others, like Bluetooth, are just now emerging. Wireless takes advantage of the electromagnetic spectrum and utilizes both radio frequencies and "light" (mostly infrared). The telecom revolution, that now leverages both electronics and photonics, has new requirements for process, materials and designs. One area that has been highly challenged is packaging. While advances in computer and telecom electronics push the envelope, photonics brings about a new set of requirements that have only been partially met.

ELECTRONIC PACKAGING

The theme continues to be "smaller-faster-cheaper" although perhaps we should replace "cheaper" with "optimal". Smaller is critical for portable telecom and computing devices that seem to be moving closer toward convergence on each product cycle. The size trend during the last several years has been toward chip-size packaging. Both flip chip (FC) and chip scale packages (CSP) have been the focus. But designers still want a smaller footprint. While some would suggest that nothing could be smaller than chip size, this is not really the case depending how one views density. How can we put pack more density in a chip-size package? Taking a lesson from building architects…stack!

The highest density packages are 3-D or stacked chip structures. The trend started several years ago in memory and is moving toward other devices as designers solve heat management problems. Several companies have developed stacked chip packages and this will be summarized in the presentation.

THE PHOTONICS CHALLENGE

The term photonics indicates that the minute photon, the quantum of electromagnetic energy appearing as light, is the basis for this extremely important field of technology. Photonics deals with the practical generation, manipulation, analysis, transmission and reception of photons in the visible and non-visible infrared (IR) and ultraviolet (UV) portions of the "light" spectrum. Our interest will in the narrower but very active area of telecom. Photonics is now the most important technology for efficient terrestrial and transoceanic voice, video and data communications. It has been adapted to high-speed Internet data transmission to make broadband high rate transmission possible. Web downloads would be impossibly slow without photons.

The photon, or light quantum, is weightless compared to the electron and has no electrical charge. This makes the photon the ideal messenger that travels at the speed of light – 186,000 miles per second (300,000,000 meters/sec.). Nothing is faster than photons and absence of weight and charge lets them to pass through many substances without interference or significant mutual interaction.

Today, nearly 100% of the long haul network, or Internet backbone, employs fiberoptics and advanced photonics. Electronic terrestrial communications is just too slow by orders of magnitude. The fundamental physics gives the photon and extraordinary cost and performance advantage over the electron. The increasing reliability and speed of Internet communications is due to recent advances in photonics. Additional capacity and bandwidth is now achieved by adding more "colors of light" through the same optical fibers. This new technology, called WDM (Wave Division Multiplexing), continues to add more "colors" (most are invisible infrared), or wavelengths, to deliver almost limitless bandwidth allowing your e-mail and data to ride the *photonics rainbow*. But packaging and assembly remain significant challenges.

PHOTONIC PACKAGES

Most photonics devices are integrated with electronics and fall into the optoelectronics (OE) category. Electrons are used for power, data and control. The photonics telecom industry uses optical fiber, transmitters (modulated lasers), signal conditioners (filters, equalizers, stabilizers, etc.), multiplexers, demultiplexers, amplifiers, receivers and the all-important router/switch. Photonics packaging is a challenge for two important reasons. The first and most obvious is that light must have access to the device. There must be a window, port or optical fiber interface. The other and more serious problem is that most devices require a highly controlled atmosphere. Oxygen and water cause problems with many photonic devices. Unfortunately, common plastic packages are not perfect barriers to gases and they allow the entry of small molecules like O_2 and H_2O. The plastic permeation problem has led the industry to using hermetic packaging that can add substantial cost and impede automatic packaging and assembly.

And if having to accommodate both electrons and photons were not enough, innovators have added mechanical motion to optical devices. MOEMS (Micro-Opto-Electro-Mechanical Systems bring photonics, electronics, optics, physics and mechanical engineering together on one semiconductor device. This appears to be the ultimate convergence of technology domains and can also include biology and chemistry that are beyond the scope of this presentation. Let's take a closer look at MOEMS to find out what added challenges are encountered and why telecom is even interested.

WHY MOEMS?

As stated earlier, the Internet backbone is primarily a photonic system linked by optical fiber that even connects continent and islands by undersea cables. The system is fast, economical and has extraordinary scalability for further increasing bandwidth. Adding more wavelengths through the same fiber with dense wave division multiplexing (DWDM) expands bandwidth. Eventually, we will move from hundreds of "lambdas" to thousands for an incredible band-boost of 1000's of times. So what's the problem?

Photonic signals need to be switched and routed to the correct fibers that make up the network. E-mail headed out of Atlanta will come to a node where the packet information tells the router where to send the data. So how is the routing process carried out? The photonic or optical data is first converted to electronic signal, routed and then re-converted back to photons. The method is called O-E-O for opto-electro-opto. The double-conversion is poor at best since hardware is complex and costly, switching is relatively slow and considerable power is used. Now add hundreds or thousands of different narrowly spaced wavelengths and the routing problem becomes critical although traditionalists will argue that it can be dealt with by using even more electronics.

So how should a beam of light be routed? Easy! Use mirrors and that's the big idea behind tiny MOEMS[1]. The Internet hardware giants, several government agencies, dozens of universities and many startups are betting on MOEMS. Micro-mirrors could catch the incoming data beam and reflect it to the desired out-going fiber. While this may sound like an R&D fantasy, MOEMS is commercial. In fact, several MOEMS switches were set up in 2000 and have performed so well that we can expect commercial systems to be implemented this year. Your e-mail may have traveled through a hair-thin strand of glass and then bounced into cyberspace by a mirror so small that a million fit on a square inch slice of silicon. It almost sounds like science fiction.

MOEMS DEVICES

Let's look at Texas Instruments DMD™ (Digital Micro-Mirror Device) system since it has been in commercial use in lightweight digital projectors for some time. The mirror module contains over 1.5-million microscopic mirrors and each can be individually addressed giving a near-instantaneous motion response. Figure 1 shows a close-up of the DMD array while Figure 2 shows the mechanical design features[2, 3]. This device uses 2D mirrors that point out (on) or away (off). The product must be housed in a dry, particle-free atmosphere with a window to allow the entry and exit of light. TI uses a hermetic package with a transparent window. While the package functions as required, the cost is high and a simpler idea is being sought. Figure 3 shows the MOEMS hermetic package design.

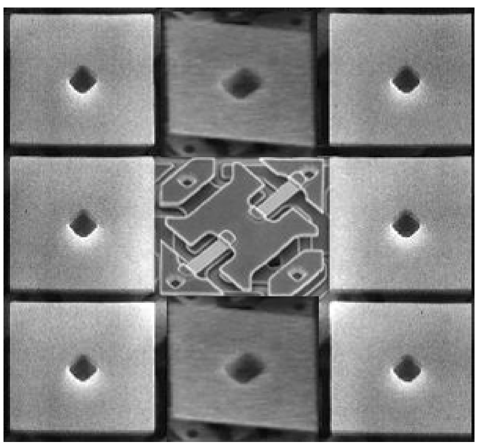

Figure 1 – DMD Close Up (ref. 2, 3)
(Center reflector removed for visualization)

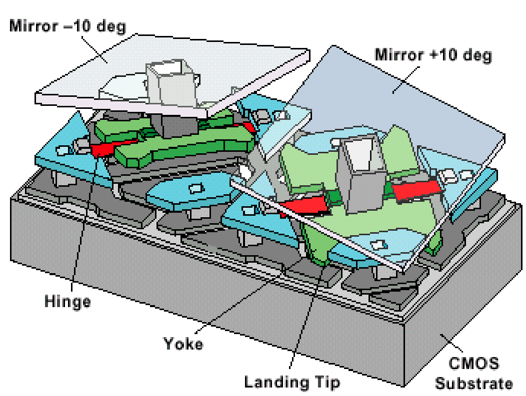

Figure 2 – DMD Mechanism (ref. 2, 3)

Do we really need a full hermetic package? Some have speculated that a simpler near- or quasi-hermetic package could probably be used with MOEMS. One possibility is to use an adhesive glass seal. Thermoplastic or thermoset polymer adhesives are available for lid sealing and this would especially simplify sealing a window lid. But polymers allow moisture to slowly invade the package. The micro-mirror systems are sensitive to moisture but not oxygen. Water can fog optics and cause corrosion problems. But water adds one more problem for most micro-mechanical devices. It increases "stiction".

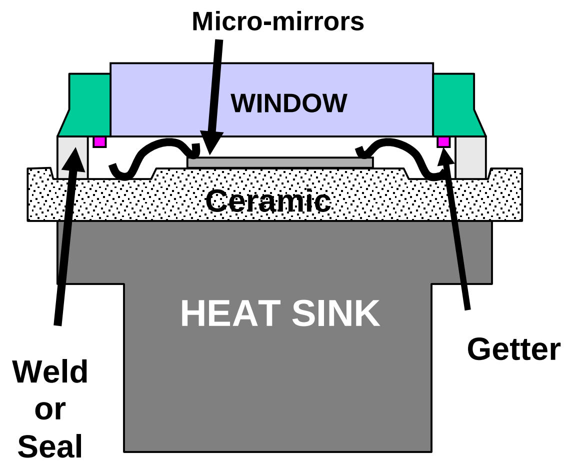

Figure 3 - MOEMS Full Hermetic Package

Stiction is a friction-related attraction between two surfaces that tends to cause immobilization. Stiction is unnoticed in the macro-world because areas of mechanical contact are very small compared to mass. But as we move into micron dimensions, area-to-mass becomes a very large number. Stiction is directly related to surface contact area and can create havoc with something as small as micro-mirrors even though designers minimize contact points. Moisture acts to catalyze the stiction effect and lower relative humidity is recommended for MOEMS packages. So the problem is that polymer adhesive seals will allow moisture to slowly bleed into the package. This would seem to preclude their use, but there may be an answer – getters.

Getters are molecular scavengers that selectively trap and remove deleterious agents within a system. The first ones used in electronics were oxygen getters placed into the first hermetic package, the glass vacuum tube. Early innovators used oxygen-grabbing active metals to lower oxygen levels in vacuum tubes. Oxygen reduced tube life by oxidizing the hot filament and getters extended operating life. The same oxygen getters may again find use for some photonics devices, like lasers, that are oxygen-sensitive. But moisture and particles can also be scavenged from the package atmosphere with getters.

GETTERS & QUASI-HERMETIC PACKAGES

Moisture and particle getters are commercially available and are used in many hermetic packages. There appear to be especially useful for MEMS and MOEMS products. Particles, of course, can quickly jamb the mechanical works of a micro-mechanical device. Since particles can be produced by wear during a product's use, the particle getter is a logical precaution. Particle getters are made with polymers that remain very sticky in a vacuum and do not outgas. Moisture getters incorporate efficient desiccants into a polymer matrix. The most suitable getters incorporate both particle and moisture gettering characteristics into a single material for maximum efficiency. The TI product uses this dual type of getter as was indicated in Figure 3.

The use of a sufficient quantity of an efficient moisture getter should allow quasi-hermetic packages to be used for MOEMS. Texas Instruments has been studying this approach and early results suggest that this can work, but more reliability data will be required. Jacobs and Malone[4] discovered that getters can extend the life of a polymer-sealed quasi-hermetic package by several years, but the full hermetic type is still better. What is needed here is a quantitative study of polymer seals vs. getter vs. product lifetime. Such a study may commence in academia with NSF sponsorship in the future[5].

Another approach may be to treat the micro surfaces to make them more water- and stiction-resistant. Low energy surfaces finishes typically produced by organo-silicones and fluoropolymers seem like a reasonable route. Silicone fluids have help reduce friction in MEMS devices, especially accelerometers used in airbags. Not much research has been done with fluoropolymers because of the difficulty of depositing a very thin film. However, fluorinated polymer-generating materials have become available that can be vacuum-deposited at micron levels. One such material is a fluorinated parylene called Nova NT. The new dimer produces a clear film with a melting point of 500°C and this is at least 250°C higher than traditional parylene family members. Nova HT could be used for MOEMS devices that require exposure to lasers and high intensity lamps because of its high UV resistance. And its telflon-like character should help reduce moisture adsorption and stiction. Once again, this is an area for further exploration.

OPTICAL PACKAGES?

At least two commercial micropackages may be suitable for MOEMS. One is from ShellCase and called ShellOp and the other is the OptoBGA from a European company. The ShellCase idea is to use wafer-level chip scale packaging techniques with optically transmissive materials. If successful, a wafer-level photonics package would represent a tremendous cost breakthrough. There are still many issues to consider for MOEMS packages, but wafer-level methods may be able to produce hermetic seals. Such a process may be referred to as "zero-level" hermetic packaging. While the ShellOp and other transparent CSP packages are too new for decisive data to have been accumulated, it's a step in the right direction. Figure 5 shows the design and figure 6 shows and actual package.

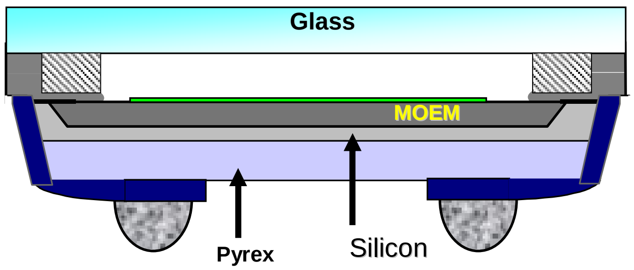

Figure 5 - ShellOp Cross-section (ShellCase)

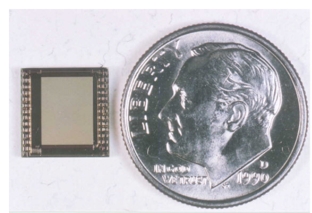

Figure 6 – ShelOp Optical Package (ShellCase)

Many other packaging concepts for MOEMS are possible and will be discussed in the presentation. For example, it may be possible to use flip chips with glass substrate so that the circuit, or chip carrier becomes the window. Several companies have used glass as circuit substrate because of its desirable electrical properties and they include HyComp and Intarsia. This is another area that should be explored as we try to simplify packaging for photonics. Figure 7 shows one of several flip chip concepts that will be discussed, but keep in mind that there are limitations for this and other concepts.

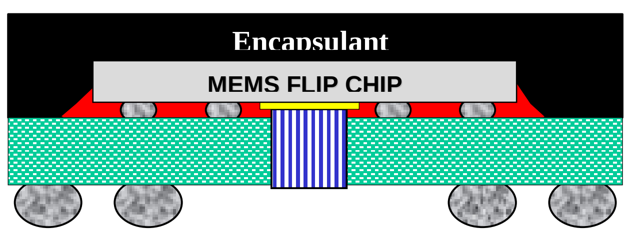

Figure 7 – FCIP for MOEMS?

CONCLUSIONS

We entered the new millennium but also launched into a new phase of technology where telecommunications moved ahead of the computer industry as the most important driver. While much of telecom technology revolves around emerging and existing wireless services, the Internet is the hub that will ultimately link all of these.

The Internet is unusual because it embraces the technology of photonics. While photonics is at least as old as electronics, much newer subsets of technology have recently emerged. One of the most important is MOEMS that now delivers high-speed digital projection and may eventually be used for all kinds of new displays. But MOEMS has become the darling of Internet hardware makers with the promise for efficient pure-optical switching and routing. Figure 8 shows a new 3D mirror switch from Lucent that is in limited use on the Internet. But MEMS, MOEMS and very high-density electronics require new packaging materials, processes and designs. One of the major challenges ahead for advanced electronics and photonics will be cost-effective packaging.

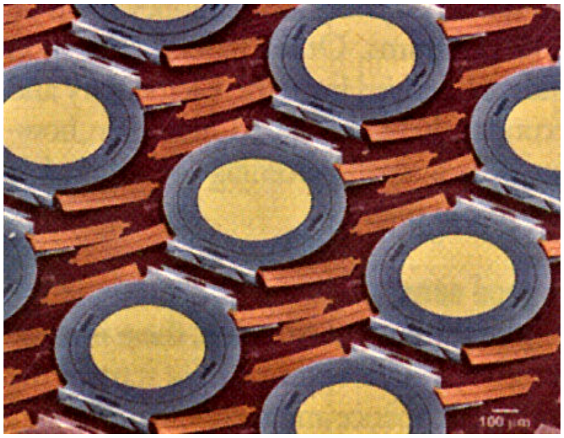

Figure 8 – LamdaRouter MOEMS (Lucent)

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