MEMS-Based Photonic Switching in Communications Networks

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Abstract: All Optical or Photonic switching is key to the next-generation intelligent optical networks. It enables rapid dynamic provisioning, protection and restoration of network connections cost-effectively, which support revenue-generating services including bandwidth on demand and DWDM over IP. In the past 12 months, MEMS-based Photonic cross connect switches have gone from the lab to commercial availability and are now in carrier field trials. Photonic switching is inherently capable of transparently switching any bit rate and data format. Optical MEMS enables switching any transmission wavelength, or wavelength band in a scalable, reliable, low power, compact size providing flexible solutions to the bandwidth demands of long haul, metro, and access networks. This paper will discuss OMM's MEMS based photonic switching subsystems and their commercial deployment

A Disruptive Technology: Photonic switching ushers in the next phase of communication network evolution after the wide-scale deployment of DWDM. When DWDM and EDFAs were first commercialized in the mid-1990s, they were also disruptive technologies that solved the bandwidth depletion problem but exposed the problem of managing increased traffic density, mixed data rates, and new signal formats just as the surge in demand for bandwidth resulted in an explosion in the number of fibers and wavelength channels. Photonic switching solves the problem of managing bandwidth created the deployment of DWDM & EDFA technology. By being able to handle any optical bit rate and any data formats, telecommunications carriers can realize new, revenue-generating services with significant savings resulting in future proof transparent networks. Optical Switching enables carriers to converge new networks with legacy networks, HFC networks, and metro loops. Carriers become free from reliance on many ATM and SONET functions when switching and protection are performed at the optical layer. Furthermore, the data-centric IP layer can converge with the optical layer because of photonic switching. OMM is the first to commercialize MEMS-based Photonic Switching - the disruptive technology that realizes the full potential of DWDM.

Photonic Switching Evolution: The option to switch fibers and wavelengths without electrical conversion is becoming a reality as even the most die-hard OEO proponents acquiesce to Hybrid-OEO switches with all-optical pass through capabilities. Photonic switching solutions introduce the concept of true network optimization. True network optimization allows the end user to customize network architectures to meet rapidly changing dynamics in data rates, signal formats and architectures, and the proliferation of WDM into the Metro and Access markets. Carrier class photonic switching solutions are just becoming available that allow for the transition to all-optical links where appropriate, and the addition of all-optical capability where requirements for electrical conversion still exist. Thus current requirements are very well suited to smaller photonic switch fabrics ranging from 8 to 32 ports, currently in carrier trials. As the wavelength density grows and the evolution to transparent networks progresses, a higher percentage of traffic will be switched without electrical conversion, harmonizing with the availability of larger port count switch fabrics beginning with 64x64 to 256x256 and eventually reaching thousands of ports.

OMM's MEMS Technology: OMM's switching components are based on MEMS micro-machined mirrors fabricated on silicon wafers, exploiting well established, low-cost silicon VLSI CMOS foundry processes that have been used for years by the computer industry to provide low cost reliable processors. MEMS (Micro Electro Mechanical Systems) are relatively new to optical networking but have been deployed for over a decade in applications such as airbag sensors, accelerometers, pressure sensors, displays, scanners, printers and micro-fluidics. MEMS technology has emerged as the clear choice for building a scaleable optical switch fabric. OMM has developed both two-dimensional (2D) digital MEMS and three-dimensional (3D) multi-position MEMS in order to offer a range of functionality from 4x4 to thousands of optical cross-connect ports. The 2D product line, in full volume production, is a Telcordiatested, photonic switching subsystem, which confirms MEMS as the superior technology for photonic switching. Integrating MEMS, optics and electronics into the same hermetically sealed ceramic package, reliability is radically improved. Building the MEMS-based switch core exploits well-established and automated silicon foundry processes in use for more than a decade. OMM has automated all key unit processes including fiber align and fix, module package and fiber sealing and device testing. This is the key to controlling high-volume manufacturing processes and ensuring high quality parts.

Electrostatic MEMS There are two primary methods of actuating a MEMS optical switch in commercial optical products – electrostatic and magnetic. The electrostatic method relies on the attraction of oppositely charged mechanical elements, and is one of the main actuation methods used for all types of MEMS devices. Its many advantages include repeatability; no shielding problems and well understood behavior. Magnetic actuation relies on attraction between magnets and typically one or more electromagnets. While magnetic actuation can generate larger forces, the MEMS community has generally not accepted its use because of the complications of integrating the magnets and difficulty of shielding neighboring devices from cross-talk resulting in less than optimum density on the MEMS wafer which can severely limit scalability. OMM's MEMS based switches exploit the advantages of electrostatic actuation yielding reliable, small size, scalable switching components and subsystems.

2D and 3D Architectures: MEMS-based photonic switches are based on one simple fundamental principle and two well-understood approaches. Photons are switched from one fiber-optic cable to another by routing the light through a collimating lens, reflecting it off a movable mirror, and redirecting the light back into one of *N* possible output ports. The two basic design approaches for translating this principle into optical switches are a two-dimensional (2D) or digital approach (N^2 architecture), and a three-dimensional (3D) or analog approach (2N Architecture).

The 2D/Digital Approach The 2D/digital approach is so named because the micro-mirrors and fibers are arranged in a planar fashion, and the mirrors can be either on or off at any given time. In this approach, an array of MEMS micro-mirrors is used to connect *N* input fibers to *N* output fibers. This is

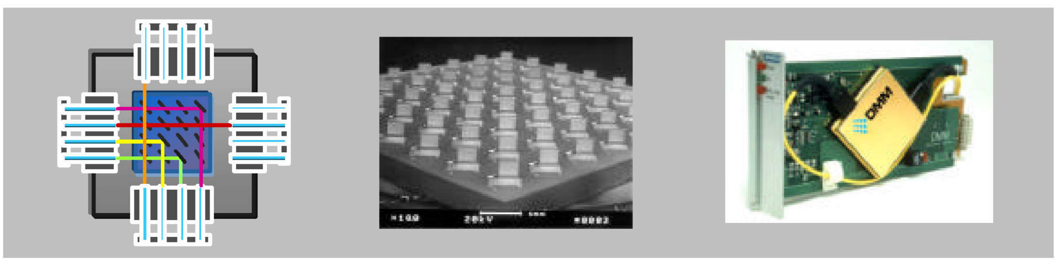

Fig.1 2D planar switch functional diagram, 8x8 OXC MEMS chip, 2D cross connect module,

named an N^2 architecture because it uses N^2 individual mirrors. For example, an 8x8 2D switch uses 64 mirrors. Figure 1 is a functional diagram of 2D planar switch, the digital planar 2D MEMS structure, and a board integrated 2D Optical cross connect module. OMM integrates the associated electronic high voltage up-converters in the package to provide the required voltage levels at each MEMS micro-mirror. The big advantage of OMM's 2D approach is that it requires only a simple TTL driver interface thereby reducing hundreds to thousands of pins to a simple 20 pin digital interface. Although the 2D design is inherently flexible, the greatest challenge in this approach lies in scaling to the types of applications that require very high port counts. As port count doubles, the distance light must travel through free space doubles. As the pitch of the micro-mirrors increases, the light propagation distance increases and the diameter of the light beam grows, placing tight constraints on collimator performance and mirror alignment tolerance. Such a tradeoff can lead to impractically large silicon devices with high costs and low yields. For these reasons, 2D technology is best optimized in cross connect products from 4x4 to 32x32 ports. 4x4, 8x8, and 16x16 have already been commercialized by OMM and have been shipping for over a year in applications ranging from Optical Add-Drop switching to fiber distribution frames, restoration as well as switching for DWDM over IP applications at both the core of the network as well as at the edge of the network. Several customers having OMM switch fabrics have reached carrier field trials and some have carried live traffic.

The 3D/Analog Approach – High Port Count Scalability: The 3D/Analog (or beam steering) approach is actually very similar to the 2D approach as it uses the same principle of moving a mirror to redirect light between an input and output fiber. The 3D approach is also called 2N architecture because two arrays of *N* mirrors each are used to connect *N* input to *N* output fibers. However, in this approach, as opposed to the 2D digital switch, each mirror is required to be able to reach multiple possible positions – at least *N* positions. This approach is much less constrained by the scaling distance of light propagation as the port count grows. Such architectures can scale to thousands by thousands of ports with low loss and high uniformity. OMM's focus in 3D technology is to bring to market a scalable robust 3D optical switch fabric, which is reliable, manufacturable in volume, and cost effective for the customer. To achieve this, it is important to emphasize ease of installation and ease of use for customers. Of primary importance is providing a fully connectorized switch fabric with simple TCP/IP software interface. (Shown in Figure 2. are a 3D dual gimbled MEMS scanner structure; a 64x64 cross connect module, the building block for a scalable 3D switching subsystem, and a fully integrated 3D cross connect subsystem with integrated electronics, control, and fiber management).

Fig.2 3D MEMS scanner, 64x64 cross connect module, 256x256 integrated solution

The central premise of OMM's 3D approach is based on design for reliability and availability in such that all key parts of the switch fabric are built and assembled with redundancy and hot swap capability.
One of the biggest challenges in moving from a digital 2D approach to a 3D analog approach is the increase in complexity at the controls level. There are two significant choices to make when designing a control system for a large 3D MEMS switch, open loop or closed loop control. While open loop control has been discussed and demonstrated, OMM's experience indicates that to meet Telecordia requirements for shock, vibration, and long term environmental drift effects, a closed loop control scheme with continuous real-time optical monitoring is fundamental. Apart from the robustness of closed loop control, features such as a high-availability controller, dual redundant Ethernet interface to the network element, fabric database back-up to network element, built-in subsystem maintenance (modularity, spare channels, fault detection and isolation, alarm reporting), as well as NEBS Level 3, ETSI, UL, CSA and CE compliance are key to a successful product. OMM will begin shipments to strategic customers of 3D based switch subsystems in Second Quarter 2001.

Conclusion: Photonic switching allows carriers to add a new dimension of flexibility and scalability to their DWDM networks. Different networks (Ultra Long Haul, Long Haul, Metro and Enterprise) require optical switching subsystems suited to their particular demands. Carriers are demanding photonic switching flexibility for very basic reasons, it provides: innovative new capabilities and services that generate new revenue in a very competitive market, and provides the potential for significant savings in operating and total lifetime costs by future proofing the network from rapidly evolving data rates, signal formats and protocols. To fill this tall order, photonic switching products must be based on a robust, scalable, optically transparent technology and designed for automation and volume production. Advances in MEMS manufacturing, optoelectronic integration and optical packaging are delivering the reliability required to realize the potential of the optical communications network and have established MEMS as the technology of choice for optical switching. OMM has shifted the paradigm in optical switching from hero demonstrations of elaborate concepts to commercial volume production capability of scalable switching solutions meeting Telcordia criteria for the entire network.