Optical Microsystems, Mechno-Optical-Electro-Mechanical Systems – *MOEMS*

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ABSTRACT

The Telecommunications infrastructure across the world is expanding at a staggering rate in response to an ever increasing demand for mobility, interconnectivity and bandwidth. This is evidenced through the increasing use of mobile telephones and the proliferation of optical fibre and microwave (RF) systems for data transfer and internet systems.

The rapid, world-wide installation of optical fibre-based telecommunication systems has given rise to a phenomenal growth in the number and size of manufacturers of optical components and devices. Initially, such manufacturers relied on costly precision-based engineering to produce optical fibre connectors, splices and alignment structures. Such manufacturing techniques have, however, evolved to encompass micromachining as the basis of manufacturing for low cost, mass-produced components.

Currently, micromachining methods, combined with IC-based processing techniques, enable the fabrication of complex opto-electronic integrated circuits and micro-electromechanical alignment devices in production quantities.

This lecture will introduce MOEMS in the context of optical communication and systems, providing a historical perspective and an overview of the current state of the art of this technology.

TELECOMMUNICATIONS APPLICATIONS

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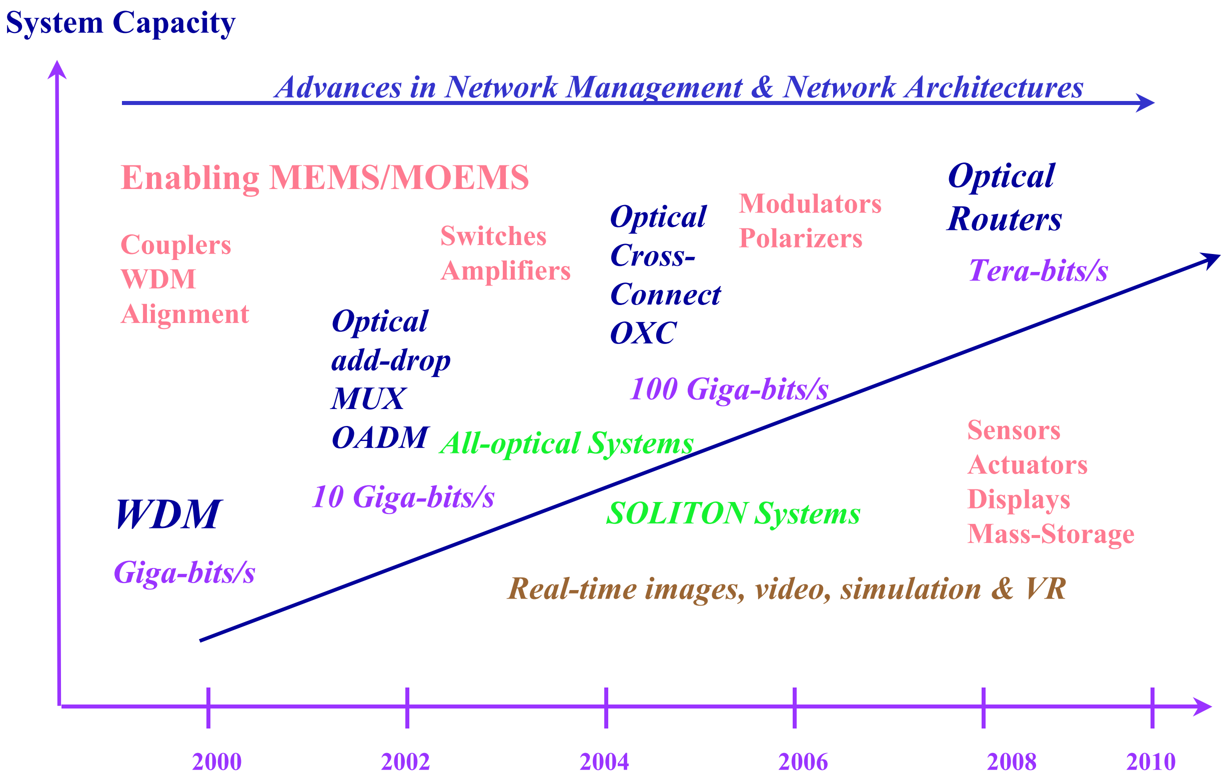
Paper presented at the RTO AVT Lecture Series on "MEMS Aerospace Applications", held in Montreal, Canada, 3-4 October 2002; Ankara, Turkey, 24-25 February 2003; Brussels, Belgium, 27-28 February 2003; Monterey, CA, USA, 3-4 March 2003, and published in RTO-EN-AVT-105.

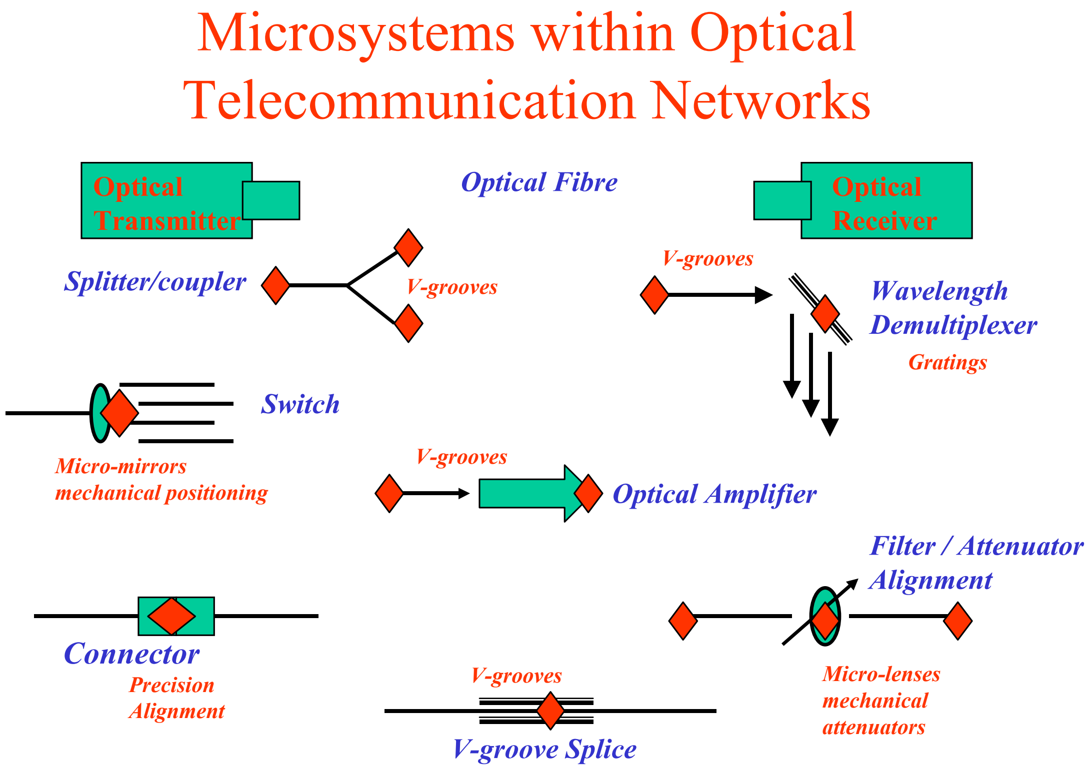
MST IN OPTICAL TELECOMMUNICATION SYSTEMS

The European Network of Excellence in Microsystems, NEXUS, through its User-Supplier-Club for Telecommunications has produced forecasts for the growth of optical systems, over the next 10 years, in terms of bandwidth capacity and network configurations:



Evolution of Optical Systems & Related MST/MEMS Technologies.

Indeed, the introduction of high capacity Wavelength Division Multiplexed (WDM) systems, over the past decade, and the proliferation of optical fibre systems/networks in the business and home environments is increasing the demand for low cost micromachined optical components. Microsystems, for such applications, will provide a range of functionalities, some of which are illustrated, diagrammatically, in the following chart:



Microsystems / MOEMS within Optical Telecommunication Networks.

This diagram identifies the range of typical components which are either fully based on a microsystem design/fabrication technology or incorporate some aspects of microtechnology such as v-grooves. A more comprehensive listing and description will include the following:

Optical Couplers

Components for coupling optical power from a single fibre (or optical source) onto a number (N) of output fibres. Most conventional designs are based on integrated optics waveguides (e.g. silica). The microsystems content is primarily associated with the v-groove alignment mechanism which is micromachined onto the substrate (e.g. silica). Simple 1X2 and 2X2 couplers, developed using the fused biconical all-fibre configuration, will, also, require some form of precision micromachined alignment mechanism such as a v-groove or a ferrule.

Optical Connectors

Demountable connectors for optical fibres based on precision engineered alignment mechanisms such as ferrules or v-grooves. The microsystems content is associated with the method of alignment adopted for such connectors.

WDM Devices

Wavelength selective components used for filtering-out and/or separating specific wavelengths from within a frequency / wavelength band. Such components rely on the use of dichroic filters or gratings. The latter are, usually, micromachined onto the surface of optical substrates (e.g. silica). WDM devices formed from wavelength selective fused biconical couplers will also require micromachined alignment mechanisms such as v-grooves.

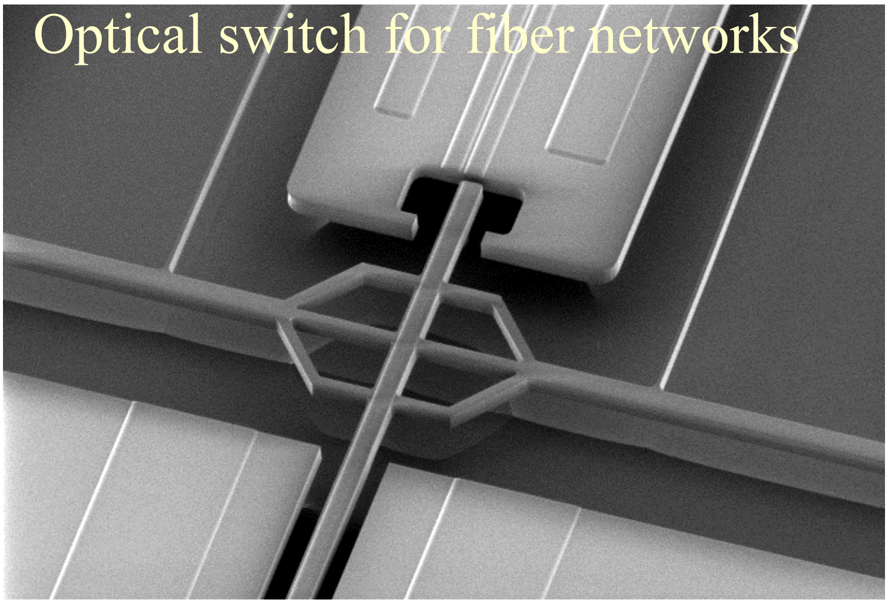
Wavelength Filters

Optical filters, such as WDM devices, may need to be tuneable. Such structures may be based on mechanically adjustable dichroic filters which could be constructed using microsystem-based mechanical shutters.

Optical Switches / Routers & Shutters

Optical switches enable optical signals to be routed from N inputs to M outputs. The routing / switching mechanisms are, on the whole, based on micromechanical mirrors / shutters and /or positioning structures. In this context, microtechnologies form an essential part of such systems for both functionality and interconnection.

A typical example of an optical switch design is shown below:



Optical Switch (Courtesy of Leti).

Optical Alignment Systems and Fibre Positioning Devices

Techniques for aligning optical fibre to either other fibre or to components are, increasingly, reliant on the use of micromachining and microtechnologies to satisfy the necessary sub-micron tolerances. Typically, such devices allow components (and fibre) to be micro-manipulated and positioned with high accuracy. Linear, rotational and 3-dimentinal movements are realised using microsystem-based mechanical transducers.

Polarisation Controllers

In some applications, including, coherent optical transmission systems, the need for controlling the state of polarisation of an optical signal is essential. Such a function could be achieved using mechanical structures for rotating and/or "squeezing" the fibres as appropriate. Additional complexities associated with the use of polarisation-maintaining fibre will also necessitate the use of high-precision alignment mechanisms that guarantee fibre orientation. Micromachining techniques and microsystems, clearly play an important role in realisation of such subsystems.

Optical Amplifiers

Optical amplification and signal regeneration using rare-earth (e.g. Erbium) doped fibre or waveguides are increasingly utilised for both long-haul as well as high density distribution networks. The content of microtechnologies within such components will, generally, be limited to alignment and positioning structures such as v-grooves.

Optical Attenuators

A number of applications demand the use of either fixed or variable optical attenuators in order to adjust optical signal levels at, for example, the receiving end. The construction of variable optical attenuators using microsystems rely on the use of mechanical adjusters for partially attenuating optical filters or shutters. These micro-mechanical structures are similar to those used for optical switches but with much simpler interconnections.

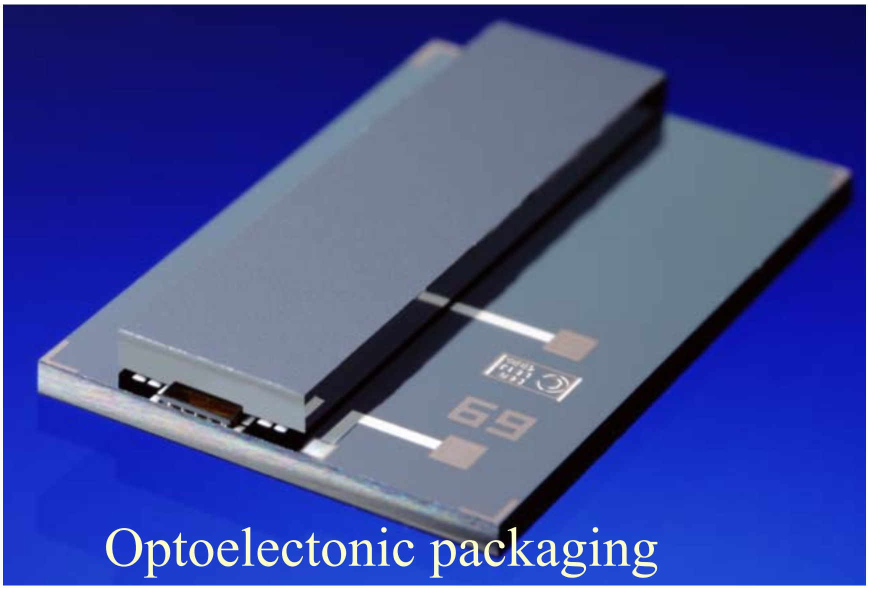
Micro-Lenses

Microtechnologies enable the fabrication of high precision lenses and lens arrays used for focussing and / or redirecting optical beams. Such micro-lenses may be used to maximise optical coupling between (laser) sources and fibre or between the input and output fibres of an optical switch. The lens structures are most likely to be integration with precision alignment microsystems.

Packaging

Complex optical devices and subsystems will, in future, demand rugged yet specifically-designed packages which could, in some application, allow for the external manipulation of the alignment mechanisms. In addition, packaging may become integral to the device construction. Microtechnologies provide the opportunity to integrate the process of device fabrication and its packaging. In future, "self-assembly" design techniques will be based on micro-mechanical constructions that link the devices with their associated housing.

An example of an advanced packaging system is shown below:

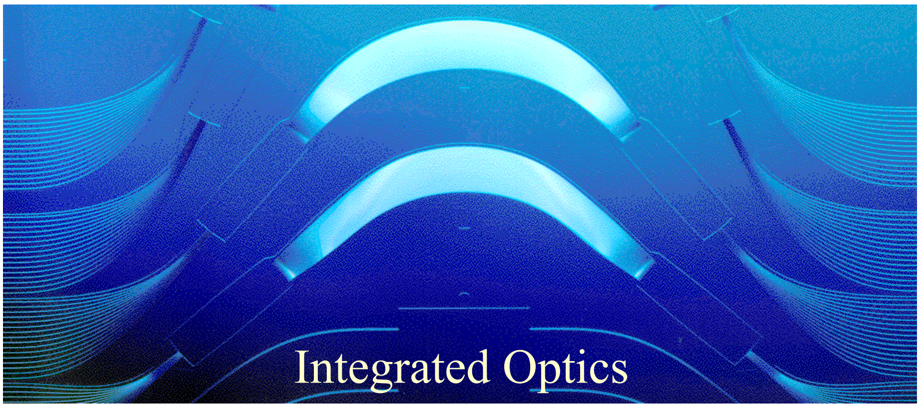


Optical Packaging (Courtesy of Leti).

Integrated Optic Circuits

The optical equivalent of electrical integrated circuits where optical signals are routed via waveguides (e.g. silica or polymeric). The waveguides form the basis of the optical circuits which may include embedded splitters, combiners, alignment devices (v-grooves) or switches. The microsystems content is high within such structures but, clearly, dependant on the functional complexity of the subsystem.

The following photograph illustrates a typical example of optical waveguides used for developing integrated optic circuits.



Integrated Optics (Courtesy of Leti).

In addition to the above examples, such systems will continue to require precision optical fibre connectors and splices which may, in certain applications, encompass some of these functional characteristics.

COMPANIES DEVELOPING OPTICAL MST/MEMS (MOEMS) COMPONENTS FOR TELECOMMUNICATIONS APPLICATIONS: (Information courtesy of VDI/VDE-IT)

ADC Telecom, Alcatel, Astarte, Axsum, C Speed, Calient, Corning / Intellisence, Cypress, Semiconductor / Silicon Light Machines, Fitel Technologies (Furukawa), Ilotron, Integrated Micro Machines, Ioλon, JDS Uniphase / Cronos, LightConnect, Lucent, Luxcore (Synchordia), MemLink, MEMSCAP S.A., Nanovation, Nortel / Xros / CoreTek, Onix Microsystem, Optical Micro Machines, PHS MEMS, Siemens, Standard MEMS, Zygo TeraOptix.

MICRODISPLAYS

In addition to the application of MOEMS within the telecommunication arena, microsystems and micromachining will play an important role in shaping the future of display technologies, in general, and micro-displays in particular.

In general, these applications can be classified as follows:

- Embedded **Direct View Systems**, where the image on the display is directly viewed by the observer
- **Front Projection And Rear Projection Systems**, where a real image is projected onto a screen and viewed from front or rear side
- **Near Eye Applications**, where a virtual image is projected internally within the eye

Direct View Systems are to be found within:

- Cell/ Mobile phones
- PDAs and other Internet Applications
- Computer games

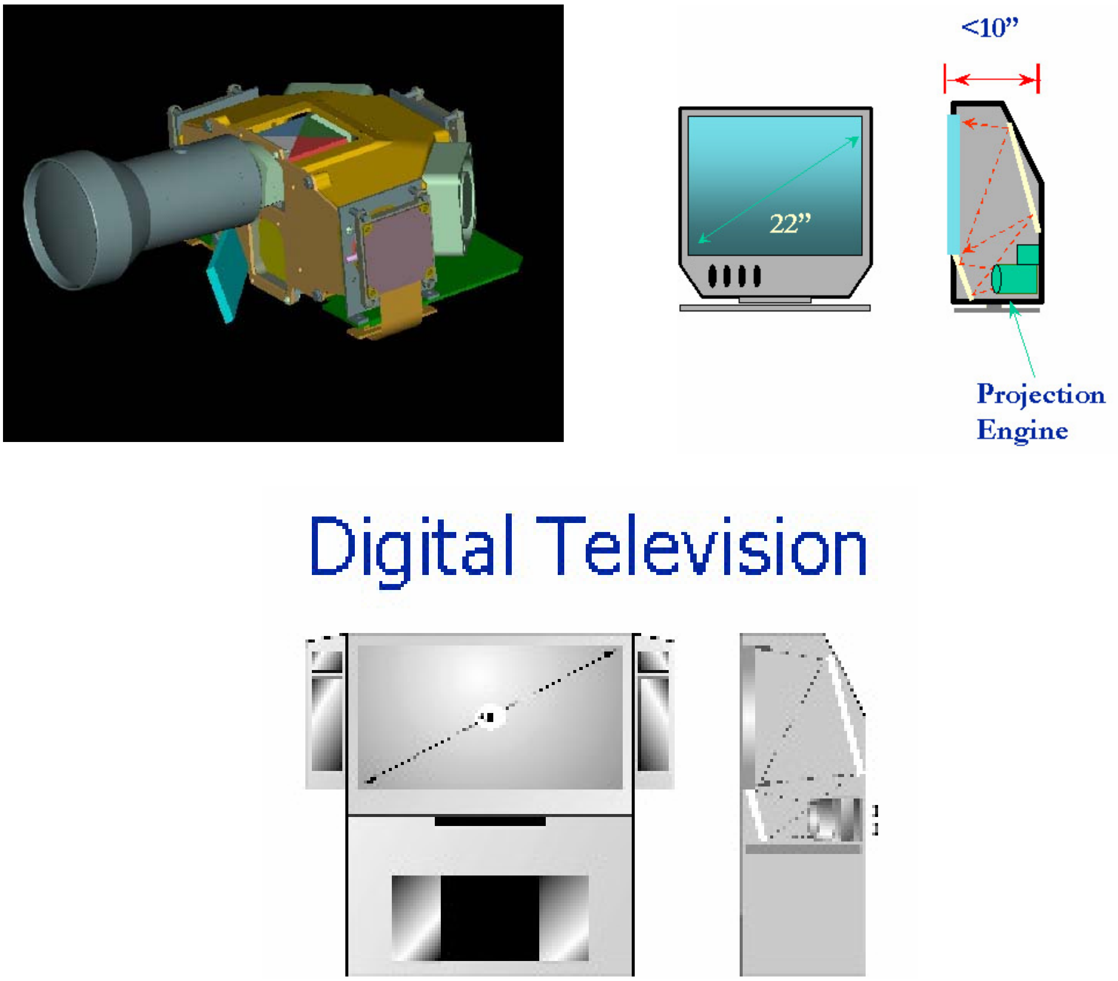
Direct View Application.

These applications are well-know and constitute the largest markets for conventional LCD-based technologies. At present, LCOS and MST/MEMS do not, as yet play a significant role. It is forecasted that Liquid Crystal on Silicon (LCOS) types of displays will in future penetrate these markets especially for high resolution applications. The direct view Field Emission Displays, which must also be considered as MST, will gain significant market share as from the year 2004.

Front Projection Systems include:

- Presentation systems (conference/ board room)
- Home TV/home theatre and entertainment (future)
- Movie houses / cinemas (future)
- *perhaps*: Automotive (future)

The following picture presents an “artists” impression of a digital projection TV incorporating a projection system.



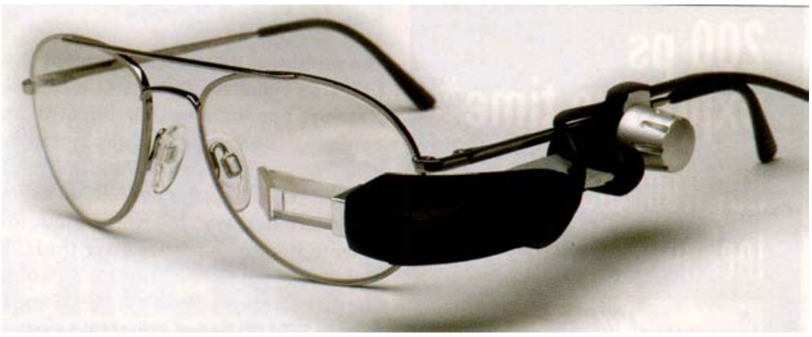
Front and Rear Projection Systems.

Rear Projection Systems include:

- PCs and computer desktops
- Home TV/home theatre and entertainment (future)
- Automotive (future)
- Avionics/cockpit applications (future)

Near Eye applications could include:

- Camcorders
- Digital cameras
- Head sets and personal viewers
- Head/helmet mounted displays



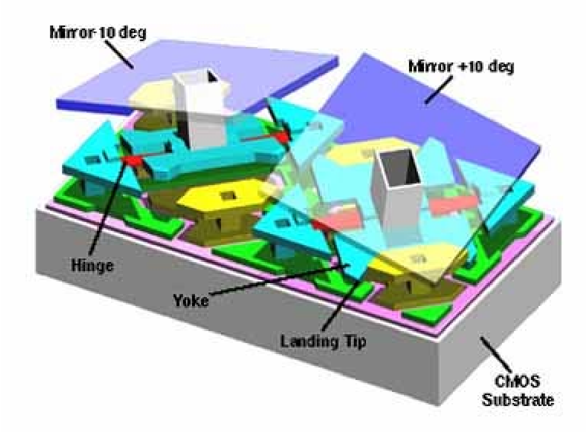
Technologies for Microdisplays

The following MEMS technologies are currently being developed for possible micro-display applications:

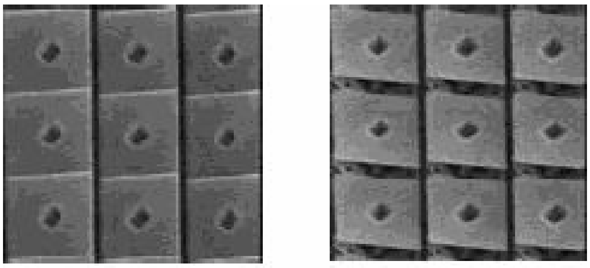
- Micro-mirror arrays (“MMAs”)
- Grated Light Valves
- Liquid Crystal on Silicon (LCOS)
- Field Emission Displays (“ThinCRT”).

Micromirror Arrays

Micromirror arrays are monolithically integrated MEMS structures fabricated over a CMOS control circuit. The MEMS structure consists of a silicon array of aluminized mirrors which can be rotated between two angles(TI approach: ± 10°). When the mirror is in its on-state, light from a projection source is directed towards a projection lens to appear as a pixel on a projection screen. In the off-position, the light is directed away from the lens and the pixel appears dark.



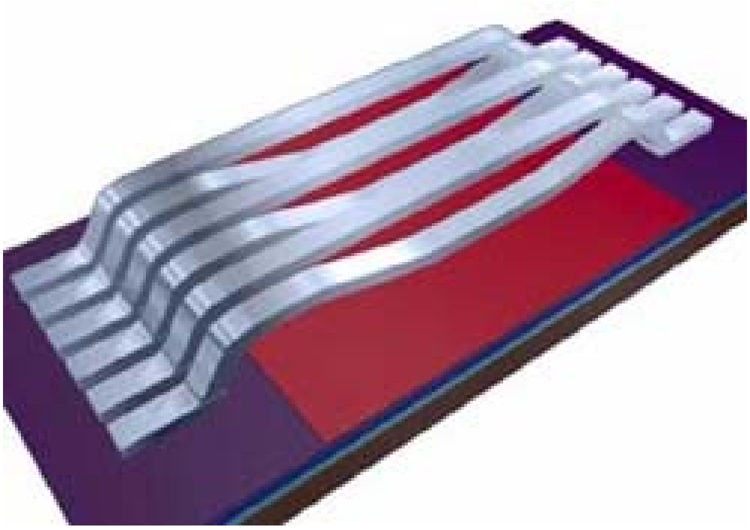
TI Micro Mirror Array.



SEM Video Images of Operating DMD.

Grating Light Valve

This technology was invented at Stanford University and is proprietary to Silicon Light Machines, CA. A Grating Light Valve pixel consists of an array of small ribbons, which can be moved up or down over a small distance by electrostatic forces. The ribbons are fabricated by surface machining MEMS techniques. These “ribbons” are arranged such that each element can either reflect or diffract light, hence, a beam of light can be switched between two directions at a very high speed. At present, only linear arrays are available. A microdisplay consisting of a grating light valve will require an additional linear scanner. The principle relies on the availability of cheap RGB laser sources.

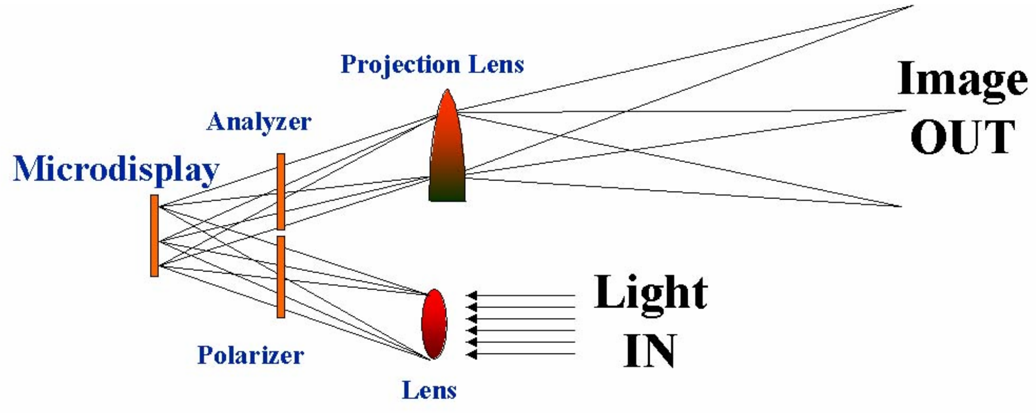


Grating Light Valve Pixel (from Sil_01).

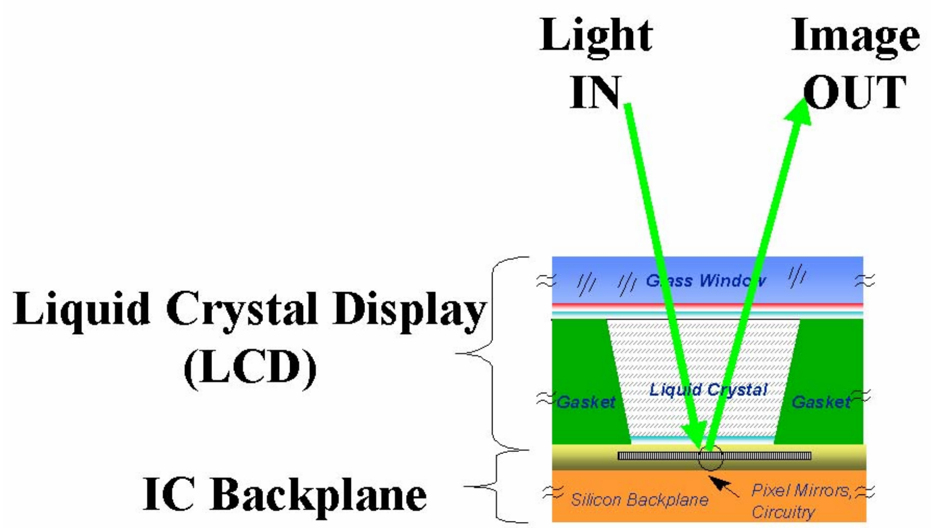
Liquid Crystal On Silicon (LCOS)

Microdisplays based on LCOS combine two mature technologies: IC and LC. Displays are constructed from a CMOS backplane (driving electronics) and a Liquid Crystal array. The devices are assembled in wafer-scale, allowing for a “fabless” business model, where design and integration companies, CMOS foundries and LC foundries operate together.

Microdisplays are realised by two approaches: transmissive LCOS, where the light passes through the chip, and reflective LCOS (rLCOS) as shown below. Reflective - rLCOS - offer several advantages including higher brightness, virtually no pixelation, and the possibility of higher electronics integration. As LCOS combines electronics, optical and micromachined functions (e.g. spacers), these structures are to be considered as microsystems.



Schematic of a Microdisplay using rLCOS Chips (from HAN_00).

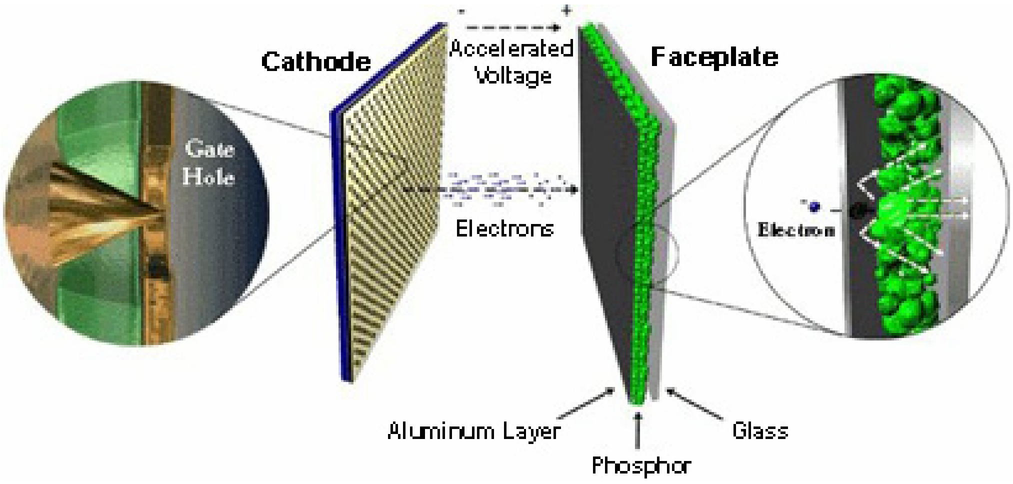


Schematic of a rLCOS Cell (from HAN_00).

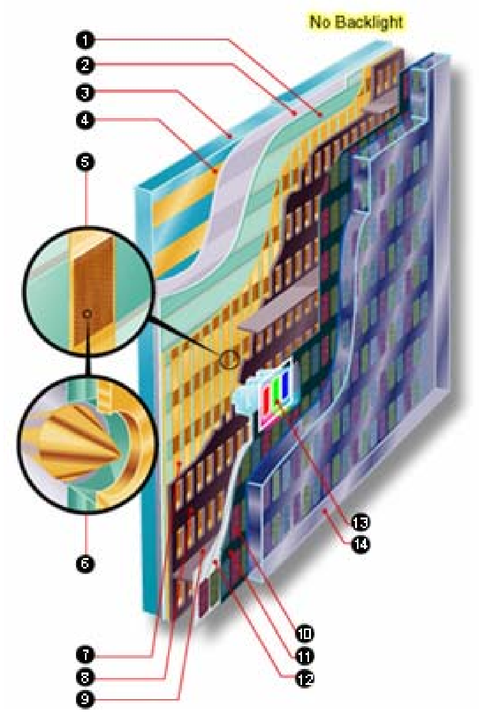
Field Emission Displays (“ThinCRT”)

This emerging technology is a combination of the familiar screen technology of a cathode ray tube (CRT) with a low-power, miniaturised cold cathode array to form a display that is only a few millimeters thick. Each pixel consists of thousands of emitter tips of approximately 0.15 µ in diameter. These tips emit electrons that are accelerated towards a phosphor screen on the faceplate to appear as a bright spot to the viewer. In contrast to the previous three technologies, which are spatial light modulators and require an illumination source as well as an optical projection system, Field Emission Displays are direct view systems.

The only company known to manufacture prototypes is Candescent (Can_01).



Principle of Field Emission Display ("ThinCRT", from Can_01).



1 dielectric
2 patterned resister layer
3 cathode glass
4 row material
5 emitter array
6 single emitter cone & gate hole
7 column material
8 focusing grid
9 wall
10 phosphor
11 black matrix
12 aluminum layer
13 pixel on
14 faceplate glass

Cross-Section of a ThinCRT (from Can_01).

MICROSYSTEMS AND THEIR FUTURE POTENTIAL IN TELECOMMUNICATION SYSTEMS

Advancements in microsystems are, primarily, driven by the requirements for intelligent diagnostic and sensing systems. The sophistication and complexity of such components is directly related to the increasing number of data sources, the processing power of the electronics and the simplicity of the transducted output. In essence, the microsystem of the future, will absorb multi-sourced data, process the data and produce a “decision”.

Researchers and developers predict that such, generically functional, devices will service all conceivable applications. In the telecommunications field, future microsystems will, it is stipulated, be networked and linked to the outside world. Within the home, microsystems will monitor the environment, safety and security and transmit this information to the user on command. Health monitoring diagnostic microsystems are, also, considered for incorporation within future communication devices. In essence, microsystems will form the basis of the “micro”-LAN of the future.

THE CHALLENGES

Whilst the important role of MEMS is confirmed for future military platforms, further developments in the design and performance of these devices is, however, necessary in order to satisfy the stringent requirements set for military applications. More specifically (and typically):

- **Military specifications (including aircraft, missiles and munitions) are particularly demanding (for example):**

  Vibration: 20 to 3,000 Hz (for 5g to 20g)
  Structural Resonance: > 3,000 Hz
  Temperature: -65oC to > +125oC
  Mechanical shock: up to 100g for fighter aircraft
  up to 300g for missiles
  more than 15,000g for gun launched munitions
  Angular Acceleration: >500,000 rad/S2 (spinning gun launched munitions)

Other, more generic, challenges will also need to be addressed, namely:

- **Military MEMS will depend, heavily, on the commercial / civil MEMS developments as low volumes, for the military markets, will attract high costs.**
- **Military product life-cycles exceed those for commercial / consumer products where, both process availability and product obsolescence become a major concern.**
- **Access to military-specific MEMS developments by the civil markets may have security implications.**
- **Repair of MEMS is not, normally, feasible and diagnostics is difficult.**

In spite of these hurdles, there is little doubt that microsystems will proliferate within military platforms providing intelligent functionality and enhanced performance.

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Ayman received his BSc from Loughborough University of Technology, UK in 1978 and his PhD from the University of Kent, Canterbury, UK in 1986. He joined the General Electric Company's Hirst Research Centre in 1978.

From 1984 to 1989, he worked in the Optical Fibres Division, where he contributed to the development of various novel optical fiber components and to photonics research. From 1990 to 1994 his responsibilities steadily increased including managing R&D in high temperature super conductivity, vacuum microelectronics, micromachining and biosensors, and later Fuzzy Logic Control, vision systems, high performance computing, advanced signal processing techniques and olfaction.

During May 1995, following Hirst's amalgamation within GEC Marconi Materials Technology (GMMT), Ayman was given charge of a newly formed Applied Technology Laboratory encompassing several additional technologies on Modelling and Simulation, Control and Decision Algorithms. In May 1996, he was appointed manager of the Signal Processing, Control and Communications Laboratory, amalgamating all the theoretical and signal processing activities within one laboratory.

Following the re-organisation of the research centres within Marconi, in 1998, Ayman was appointed Business Group Manager for the Data Analysis & Techniques Group as well as Deputy Manager for the Communications & Information Systems Division based at the Marconi Research Centre. The Group has 40 qualified staff whilst the Laboratory has 80 staff in total. This research establishment has recently become part of BAE SYSTEMS Advanced Technology Centres.

Ayman is, currently, manager of the Systems Department of the Advanced Technology Centre. The Department has four main Groups of researchers: (1) Space Systems, dealing with SAR signal processing and algorithms, sensor data fusion and ground-station IFMS systems. (2) Intelligence Systems, encompassing work on mathematical techniques, control systems and data processing systems. (3) Communications Systems, directed towards defence applications and the battlespace. (4) Signal Processing Systems for rapid prototyping, noise and vibration control and high performance computing.

Finally, Ayman is also an active member of NEXUS, the European network of excellence in multi-functional microsystems, was prime co-ordinator of BRAMMS, a European collaborative project on Military MEMS/MST and is also involved in many other national and international initiatives in this field of technology.