Mezmeriz

WHITE PAPER

MEZMERIZ, INC.

# Carbon Fiber MEMS micro-mirrors: enabling the next generation of picoprojectors

September 12, 2008

The explosion in computing power and data-communications has enabled mobile communications and multimedia devices to pervade every aspect of society. Unfortunately screen sizes have not kept up and are limited to <5" diagonal preventing consumers from realizing the full potential of their multimedia devices. Projection technology based on novel microelectromechanical (MEMS) micromirrors capable of scanning a laser beams onto surfaces has been envisioned as a solution to address the screen size problem. The main advantages of scanning laser projection displays using MEMS technology is the potential for tiny, efficient,projection systems that can be embedded in almost any mobile communications or media device. A massive amount of research and development has been ongoing in the field of MEMS to realize these new displays.

## The Challenge of Silicon

Silicon remains the dominant structural material for MEMS serving adequately for diaphragm based pressure sensors and inertial accelerometers where stresses and operating frequencies are low, deformations are minimal, and direct interaction with environment is unnecessary. In one of the most widely anticipated MEMS applications—optical scanners, envisioned for use in novel scanned-beam display and imaging systems, the MEMS micro-mirror elements must deflect through relatively large displacements at high frequencies to, potentially, trillions of cycles.

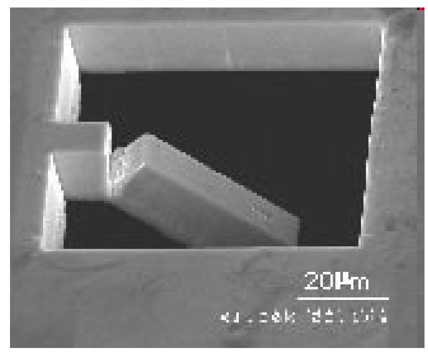

**Figure 1: Silicon cantilever after fatigue cycling**

The challenge with silicon and other materials derived from the semiconductor industry is making mirrors that are stiff enough to resonate at very fast speeds while at the same time permitting the mirror to deflect through a large enough angle to scan an adequate number of pixels in an image. Silicon can be made to vibrate at very high speeds, but the amount it can deform, is limited to a few degrees due to inherent material limits. This poses a severe challenge in using silicon MEMS mirrors in high resolution projection systems—particularly as image resolution keeps increasing. This chart outlines where the physical limitations of silicon make it unsuitable for resolutions greater than XGA:

**Table 1: Performance Requirements for Scanning MEMS Micromirror Display**

| | QVG | VGA | SVGA | XGA | XVGA | UXGA | HD |
|---|---|---|---|---|---|---|---|
| **# of horizontal pixels** | 320 | 640 | 800 | 1024 | 1280 | 1600 | 1920 |
| **# of vertical lines** | 240 | 480 | 600 | 768 | 960 | 1200 | 1080 |
| **peak scan angle for 1 $mm^2$ mirror** | 3.75° | 7.5° | 9.37° | 12° * | 15° | 18.75° | 22.5° |
| **scan speed for 60Hz frame rate (kHz)** | 7.2 | 14.4 | 18.0 | 23.0 | 28.8 | 36.0 | 32.5 |

***** deflection limit of silicon

## The Search for Alternative Materials

New materials are continuously being explored to circumvent the limitations of silicon. However, a wholesale change in materials was previously not a viable alternative because the manufacturing and test equipment and techniques are optimized for silicon and materials for semiconductor fabrication. Other materials explored remain limited to derivatives from semiconductor fabrication, but have shown great success in addressing the limits of silicon. For example, titanium foil based MEMS are being developed which show enhanced fracture resistant properties compared with silicon. Texas Instruments has successfully deployed titanium-aluminum alloys in their digital micromirror device and remains the most notable success of a MEMS system.

## Engineered Materials Provide the Solution

A novel approach, pioneered Mezmeriz's founders at Cornell University, has been the use of carbon fibers in MEMS. Fibers are the ultimate in engineered materials for high performance mechanical behavior. Specific materials property enhancements within structures can be achieved simply by varying the fiber orientation, volume, and material from which they are made and combined.

Carbon fibers exhibit exceptional mechanical properties across the board. In addition to being biocompatible, they are electrically and thermally conductive, possess the highest specific strength and stiffness of any material except carbon nanotubes, and are capable of enormous elastic deformations. Furthermore, they exhibit almost fatigue-free behavior under cyclic loading. Although typically used in large volumes, fibers intrinsically are MEMS scales (2-20 µm diameters) and their desirable properties are accentuated in sub-mm lengths (flaw-free regime).

The use of fibers in MEMS micro-mirrors translates to remarkable property enhancements compared with silicon:

**Table 2: Observed material properties for carbon-based and Silicon MEMS.**

| **Material Property** | **Silicon** | **Carbon Fiber** | **Importance of Material Property** |
| --- | --- | --- | --- |
| Young's elastic modulus (GPa) | 130 - 170 | **294 - 800** | Greater stiffer = **Faster oscillation** |
| Elastic stress limit (GPa) | < 1 | **4 - 7 Gpa** | Improved elasticity = **Larger deflections** |
| Density (kg/m^3) | 2330 | **1800** | Reduced weight = **Faster oscillation** |

Instead of developing a completely new materials technology that uses new processes and manufacturing techniques, Mezmeriz's solution was to introduce carbon fiber into the structures in such a way as to benefit from the strength and fatigue properties, while also leveraging the use of existing MEMS processing and equipment.

## New Designs with Carbon Fiber MEMS

The founders of Mezmeriz have demonstrated simple carbon-fiber based MEMS optical scanners fabricated using conventional MEMS processing techniques. Combining the low-cost manufacturing capabilities of MEMS with processes derived from textiles engineering and fiber science, Mezmeriz has developed unique, highly protected technology foreign to traditional MEMS designers and material scientists. Using contact lithography, and micromachining processes such as sequential etching and thin film deposition techniques, combined with proprietary fiber deposition techniques derived from textiles manufacturing, MEMS optical scanners have been fabricated from microscopic arrays of aligned 5 μm diameter carbon fibers.

Stiff and strong along their length, the fibers deflect through very large angles at high resonant frequencies allowing large scan angles and blisteringly fast speeds from the MEMS scanner. The resonant frequency is established by controlling the fiber lengths and number and mass loading of the mirror structure. Mezmeriz's novel carbon fiber integrated MEMS optical scanners can therefore attain both large scan angles and high speeds simultaneously—performance parameters that are mutually exclusive with silicon.

The exceptional mechanical behavior of carbon fiber based MEMS structure enables beam scanning capabilities previously impossible using silicon MEMS mirrors. The scan capabilities of the carbon fiber MEMS based projection system enables a *32 centimeterh HD display from a projection distance of less than four centimeter*.

The scanning capabilities of the carbon-fiber micro-mirror are not dependent on frequency; and the frequency of the fiber MEMS structures can be increased almost limitlessly simply by adding more fibers, varying their length and mass without affecting their scan and lifetime behavior. Therefore, a scanning mirror system built on carbon fiber enables a Moore's law type increase in image resolution for both image scanning and image capture systems.

## The Mezmeriz Solution

Mezmeriz's patented micromirror design and manufacturing technique makes it possible to build a microprojector that can be used in multiple applications. It will lead to embedded video projectors no larger than a camera phone, as well as to fully mobile theaters from MP3 and MP4 video players and personal-space presentation tools. Countless other future applications are possible when built upon the platform of MEMS built from engineered materials.

To learn more about the Mezmeriz carbon fiber micromechanical mirror system, please visit http://www.mezmeriz.com/.