Large-area applications of optical MEMS: micromirror arrays guide daylight, optimize indoor illumination

Volker Viereck, Qingdang Li, Andreas Jäkel, Hartmut Hillmer, University of Kassel, Germany

Future indoor light distribution of living and office spaces will improve significantly when large-area micromirror arrays are used in conventional double-glazed windows. In contrast to macroscopic solutions, such micromirror array-based solutions are nearly invisible, weatherproof, and maintenance free. Custom application across large areas requires an easy, low-cost, and reliable process, but also uses low-cost materials.

Micromirror arrays realize the goal of optimal daylight illumination without glare (figure 1) because windows equipped with these optical MEMS can tailor shade to the working space in future. Solar rays are guided for indirect lighting with one segment in the upper window illuminating the plant.

Figure 1: Photomontage demonstrates how rooms can be illuminated by daylight without glare

Large-area micromirror arrays enable translucent protection from solar glare while shading only desired areas. Because the structure dimensions cannot be resolved by the eye, the optical impression of these treated windows is similar to thin-film tinting, yet much more sophisticated (**figure 2**). Installation of micromirror arrays between the panes of double- or triple-glazed windows, protects the upgraded view against ill effects from scratching, temperature extremes, and moisture. Micromirror equipped glass panes can be easily installed in every conventional building, even in old and landmarked buildings.

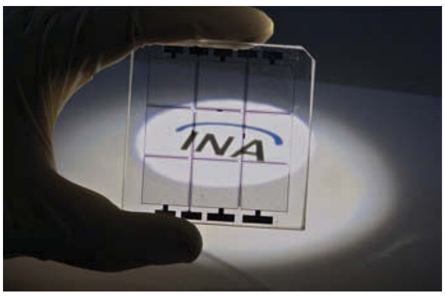

Figure 2: In the "open" position, the view through a micro mirror module is nearly undisturbed, in "closed" position the fill factor is about 95%

Technological implementation

Prototypes of these micromirror arrays were made as part of a feasibility study supported by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU). These micromirror enhanced modules have nine separately addressable subsegments and can be made to measure up to 30 cm^2 in total. Each array was produced by surface-micromachining conventional thin films and by micro-patterning technologies.

In each array, every single micro mirror element consists of a silicon-oxinitride carrier layer and an aluminium mirror layer. Standard float glass is used as substrate material, on which indium tin oxide (ITO) is sputtered as a planar transparent electrode. The micro mirror element "self assembles" by using tailored gradient stress in the carrier layer (**figure 3**).

With the application of discrete voltages between the mirror layer and the planar ITO electrode each mirror array can be moved within a prescribed angular range (**figure 4**). For example, groups of micro mirrors can be moved from a nearly 90° out-of-plane position to an aligned in-plane position with a voltage of only 80 V. Theoretical model calculations show that the micro mirrors can be continually adjusted to any angle up to 45° by varying the voltage applied. Below that angle the micro mir-

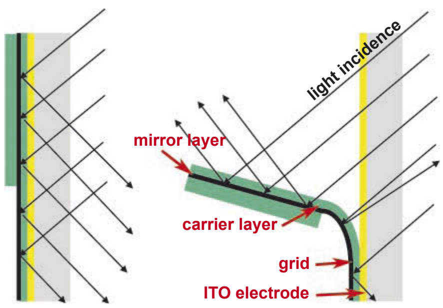

Figure 3: A cross section of a micro mirror element in "closed" position (left) and "open" position (right)

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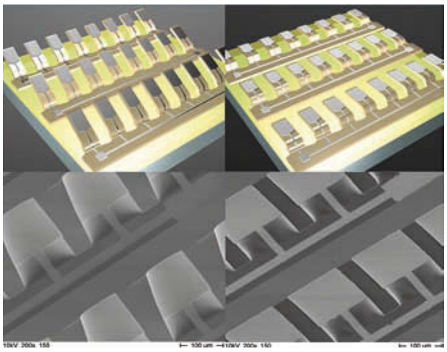

Figure 4: Schematics (top) and SEM micrograph (bottom) of micro mirrors in "mirror half open" and in "mirror closed" positions, respectively

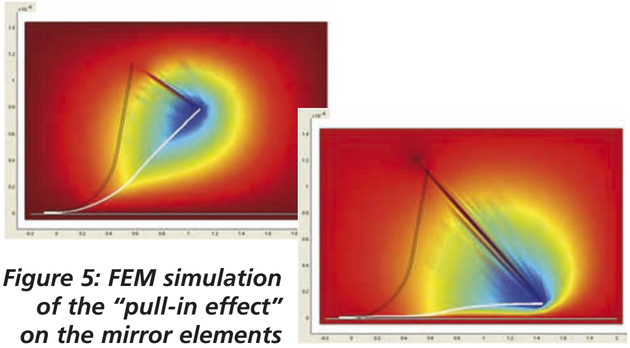

Figure 5: FEM simulation of the "pull-in effect" on the mirror elements

rors flap onto the substrate because of a "pull in effect", as shown in **figure 5**. The resulting angular range efficiently steers daylight as desired.

One micromirror module is illuminated from above in **figure 6**. In the left image, with no applied voltage, about 4000 micro mirror elements, each measuring 150 x 400 μm^2, reflect the incident light toward the spectator. In the right image, with applied voltage, the micro mirrors are repositioned to redirect the incident light. Power consumption during this actuated mode is less than 0.1 W/m^2.

Large-area mirror-array fabrication challenges

Today's mirror-array module fabrication process requires five deposition and three micro-patterning steps. The materials and the production processes must be specially coordinated to enable scaling onto large areas at a reasonable cost. These PECVD, PVD and sputtering techniques are commonly used in both large-area glass coatings and the photovoltaics industry. However, the micro patterning steps rely on conventional photolithography techniques, which may be replaced by printed photoresists.

The micromirror design allows a displacement of 5 µm between the structural layers. This is an important point for the process yield: currently the yield for modules having less than 2% of pixel errors is less than 50%. The performance goal is zero pixel errors within the direct field of vision. Modular mounting can achieve zero errors, but modularity requires a mechanical and electrical interconnection between each of the modules that does not draw the spectator´s attention.

Common controls lower production costs

Low-cost micromirror array production depends on common control of the thousands of mirrors as one group instead of addressing single mirrors individually. Micro mirrors in the arrays are interconnected by a very simple grid. Simulations of the Efficient Energy Conversion Group from the University of Kassel have shown that controlling segments of a size of about 1 dm^2 (about 150 000 micro mirrors) is sufficient for light steering and shading functionalities. Micromirror arrays can also be controlled independently as part of intelligent energy management systems.

Future micromirror array prospects

Micromirror arrays for consumer and commercial window applications have been developed in the laboratory with a scale size of some tens of square centimeters. The transfer to industrial production will be more challenging in the years ahead, especially because the process yield and the large-area micro patterning technologies are needed at lower costs.

However, considering the costs and the size development of today´s TFT displays with their concurrent quality improvement, the possibility of MEMS modules of a quarter of a square meter in size, from which much larger areas can be equipped, remains a realistic scenario.

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Figure 6: The left-hand image shows micro mirrors reflecting the incident light to the spectator ("mirrors open"). In the right-hand image ("mirrors closed") the mirrors redirect the incident light

Author contact:

Volker Viereck
Institute of Nanostructure Technologies and Analytics (INA)
University of Kassel
Heinrich-Plett-Str. 40
34131 Kassel
Germany
viereck@ina.uni-kassel.de
www.te.ina-kassel.de