A Compact, Low Cost, Phase Randomizing Device for Laser Illuminated Displays

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Abstract

A compact, low cost version of our phase randomizing deformable mirror for use in mass produced laser illuminated microdisplay-type picoprojectors is described. For this application, its speckle reduction performance is similar to our other more complex deformable mirror designs.

1 Background

DYOPTYKA has developed an innovative phase-randomizing deformable mirror for the reduction of speckle and other unwanted interference effects that can arise in laser illuminated displays. It offers a unique combination of advantages over alternatives such as moving diffusers with respect to speckle reduction performance, optical efficiency, electrical efficiency, size, speed, and manufacturability [1].

For several years we have supplied relatively small numbers of evaluation systems to prospective customers undertaking product development. However the design was not optimized for mass production. In preparation for the imminent commercialization of laser-illuminated microdisplay-type "picoprojector" displays we have redesigned our device for mass production, see Figure 1. Herein we describe the requirements, the design considerations arising, and performance evaluation.

2 Requirements

A common set of requirements collated from various prospective customers developing laser-illuminated LCoS and DLP picoprojectors include: reflectivity $\geq 98\,\%$, laser damage threshold $\geq 4\,\mathrm{W}$, actuation voltage $\leq 5\,\mathrm{V}$, power consumption $\leq 100\,\mathrm{mW}$, operational temperature range $-40...85\,^{\circ}\mathrm{C}$, shock tolerance $\geq 2500\,\mathrm{g}$, height $\leq 5\,\mathrm{mm}$, fully integrated control electronics, and price ≤ 10 USD each for an initial mass production quantity of 100 000 pieces.

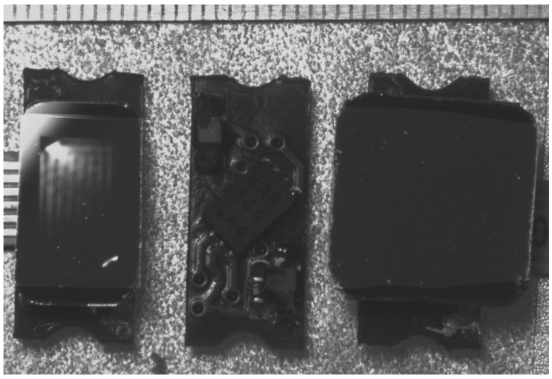

Figure 1: Different configurations of uDM2 beside a ruler with marks at 0.5 mm intervals. [Left] Deformable surface area of $3\,\mathrm{mm} \times 4.8\,\mathrm{mm}$ is active. Surface waves are partially visible. [Center] FR-4 PCB of dimensions $4.5\,\mathrm{mm} \times 10\,\mathrm{mm}$. 5.0 V microcontroller IC and multilayer piezoceramic actuator and sensor are visible. [Right] Larger mirror with $4.8\,\mathrm{mm} \times 4.8\,\mathrm{mm}$ deformable surface area (inactive.) All mirror coatings have $\geq 98\,\%$ reflection efficiency.

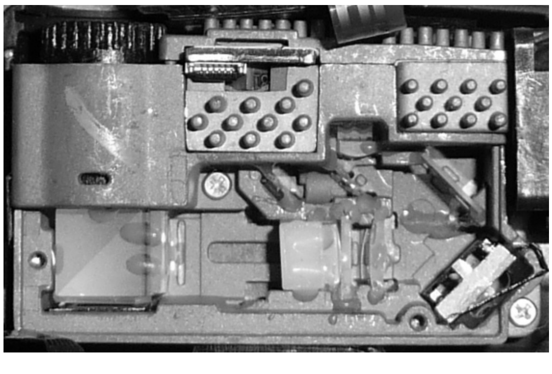

Figure 2: A prototype uDM2 (bottom right) located in the illumination optical system of an LCoS picoprojector. It is located before the fly's eye array pair and also serves to fold the optical path, replacing the conventional fold mirror which would otherwise be required for system compactness.

3 Design

At least one actuator is required to excite deformations of the mirror surface and at least one sensor is required so that consistent behaviour can be maintained over time. We used multilayer piezoceramic devices of size approximately $1\,\mathrm{mm}^3$ for both. We located these at diagonal corners of the mirror so as to leave enough space in between them for a small commercially-available, off-the-shelf, 5 V microcontroller IC that can source enough current for the actuator and with sufficient ADC resolution for the sensor signal. These components can be seen in Figure 1 [Center.]

In previous designs we used a ceramic PCB substrate which has a low coefficient of thermal expansion (CTE) and high stiffness. The increased material and processing costs relative to a more conventional substrate motivated changing to FR-4 laminate. A consequence of the higher CTE was that the parameters of closed-loop control system needed to be modified to operate over an increased range of stresses on the deformable mirror applied by the expanding and contracting PCB. A consequence of the reduced stiffness was the lowering of the average frequencies of actuation superimposed in the driving signal.

The deformable mirror substrate can be silicon or glass. The mirror coating can be protected silver or a dielectric stack for higher reflectivity but with higher processing cost. Different sizes of deformable mirror are possible for use at different locations: smaller when close to the laser sources, see Figure 1 [Left], or larger when within the homogenization optical system, see Figure 1 [Right.]

4 Evaluation

When used in our illumination and projection apparatus, see Figure 3 [Left], the uDM2 achieved a very similar reduction in speckle contrast ratio to our other deformable mirror designs. The ratio achievable depends on projection lens f/#, image magnification, wavelength, and viewing distance but in favorable conditions it can be $\leq 3\%$.

When operated such that the angular extent of randomized divergence from the deformable mirror was 5°, electrical power consumption was 96 mW and device temperature was stable at 40 °C in an ambient temperature of 23 °C after 72 h of continuous operation. Power consumption can be as low as 25 mW with a proportional reduction in angular extent.

Average reflectivity of $\geq 98\,\%$ across the visible wavelength range at an incident angle 45° was measured by the protected silver mirror coating manufacturer. We have not yet had the opportunity to evaluate the uDM2 against the other requirements listed in Section 2 but from our experience of other designs we are confident of meeting all of them.

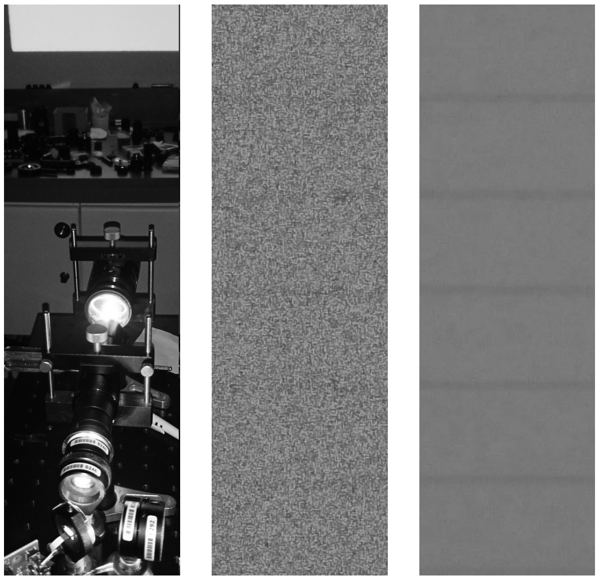

Figure 3: [Left] Illumination and projection apparatus used for evaluation of performance of uDM2 (bottom left.) [Center] Projected illumination with deformable mirror inactive, speckle pattern from writing paper surface is easily visible. [Right] Projected illumination with deformable mirror active, speckle pattern is greatly reduced.

The main difference in behaviour between the uDM2 and our other designs was observed to be more variation in angular extent over time but we do not consider this to be a problem in display applications where the deformable mirror is located within the illumination optical system.

5 Conclusions

We have developed a compact, low cost version of our phase randomizing deformable mirror for use in picoprojector display applications. Its speckle reduction performance is similar to our other more complex designs. We are working with our customers and manufacturing partners towards commencement of mass production in the near future.

References

[1] Shevlin, F., "Speckle reduction in laser-illuminated picoprojectors," in [*MOEMS and Miniaturized Systems XI*], Schenk, H., Piyawattanametha, W., and Noell, W., eds., *Proc. SPIE* **8252** (2012).