Dynamic Illumination for Spatio-temporal Integration of Unwanted Interference in Holographic Displays

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DYOPTYKA, Ireland.

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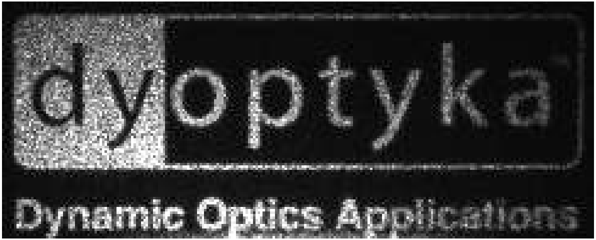
2018-04-27

Aims



CGH image displayed by LCoS SLM

- To observe unwanted interferences, including speckle, in *holographic* imagery formed using a spatial light modulator.
- To investigate whether our phase-randomizing *deformable mirror* can improve image quality.
- In an automotive *head-up display* as an example—because observed speckle is a function of a complete optical system.

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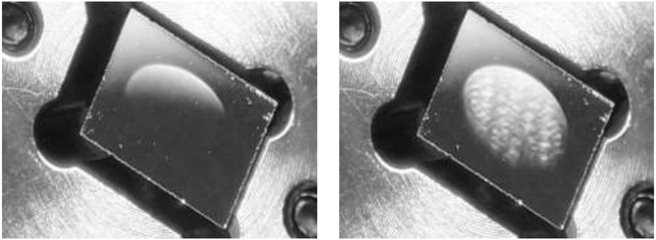

DM in inactive and active states

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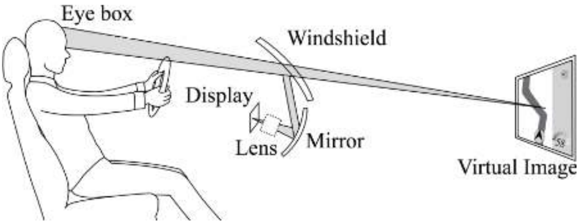

Typical automotive HUD *[Kim, 2016]*

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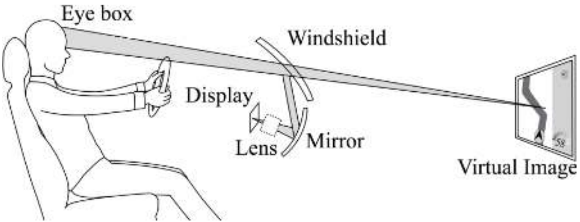

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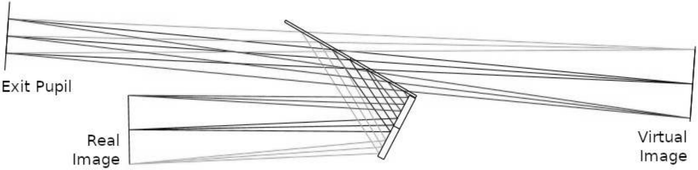
HUD Image Visibility

Low divergence



HUD optical system

[Zemax, 2018]

- Eye pupil misalignment with HUD exit pupil limits visible field.
- Eye box volume is proportional to *divergence* of real image.
- A *diffusing screen* at real image plane increases divergence.

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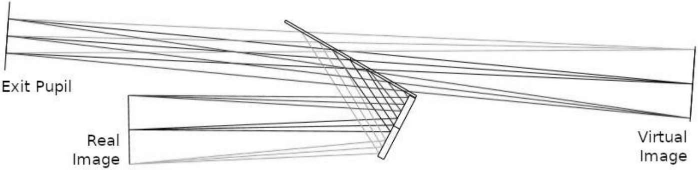

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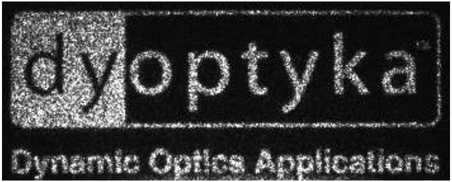
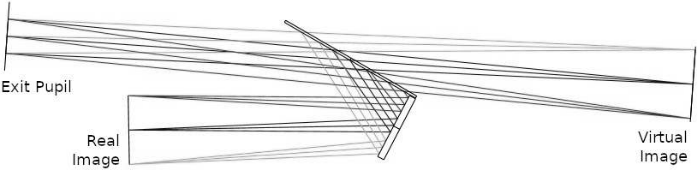


Higher divergence



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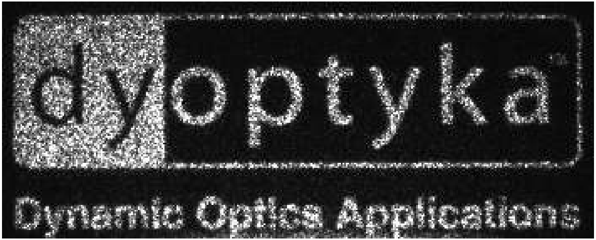
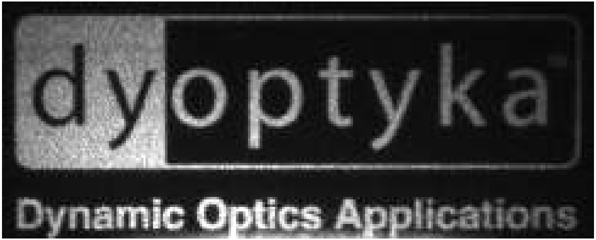
Diffusing screen considerations



Luminit Inc. surface diffuser, 20 deg *circular.*

- Diffusing screen worsens image quality: rough surface visible; and *speckle* with coherent illumination.
- Moving the diffusing screen is a very effective solution.
- However, mechanical motion may not be desirable: size, complexity, cost, power consumption, . . .
- Can *deformable mirror* be used instead?

Diffusing screen considerations



Diffuser rotating at 10,000 rev./min.

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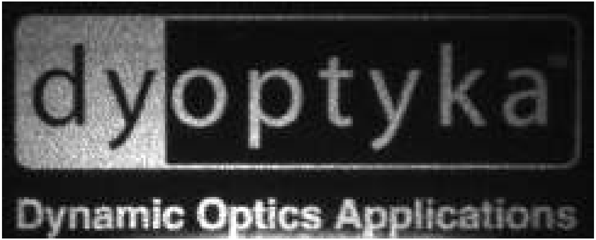

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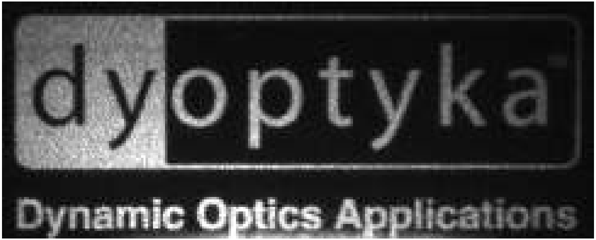

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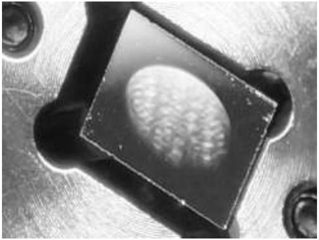
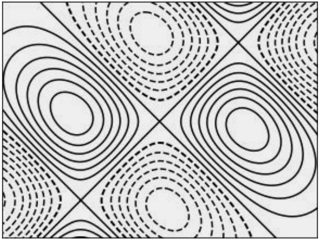
Deformable mirror: randomized phase



Surface waves



E.g. λ=100 µm, A=1 µm

- Convex and concave surface deformations at hundreds of kHz.
- Traveling and standing waves with no discontinuity of slope.

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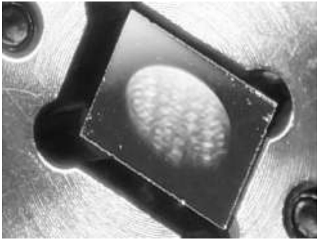

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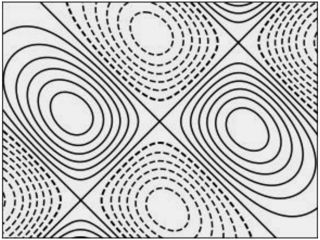

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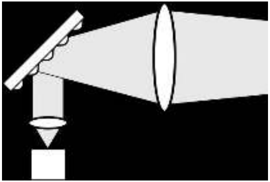
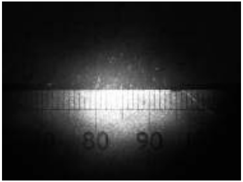
Deformable mirror: randomized divergence



Incidence e.g. $\varnothing 1$ mm

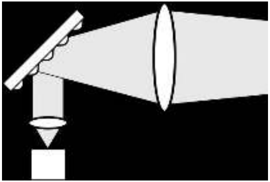


2 deg *divergence*

3 deg *divergence*

- Randomized divergence without scattering.
- Optically efficient, compact, alternative to a moving diffuser.

Deformable mirror: randomized divergence



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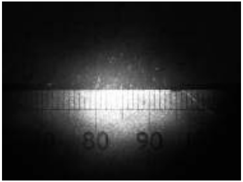

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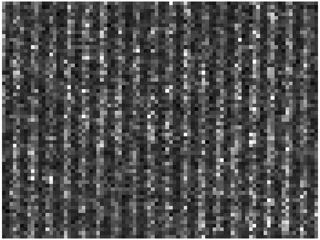
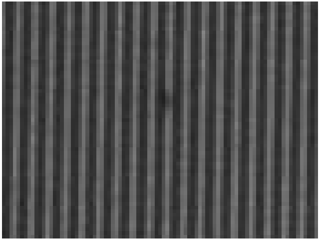
Deformable mirror: speckle reduction



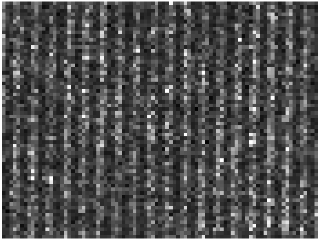
1 µs *pulse, DM inactive*



1 µs *pulse, DM active*

- Very fast, ... not a great advantage for most displays but it is for inspection (*throughput*) and measurement (*vibration.*)

Deformable mirror: speckle reduction



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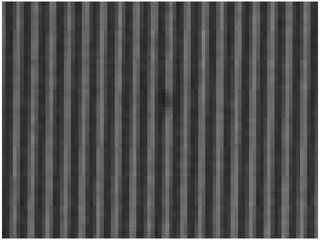

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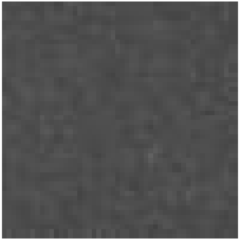
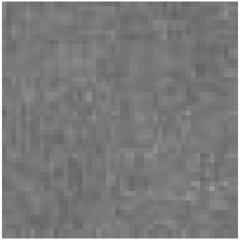
Deformable mirror: optical efficiency



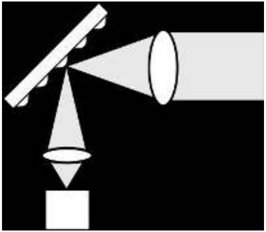
Diffuser,
$C_S = 6\,\%, I = 100\,\%$



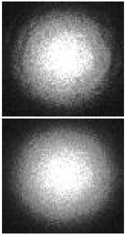
DM,
$C_S = 6\,\%, I = 157\,\%$

- For equal speckle contrast ratios, projection display imagery $> 50\,\%$ brighter with DM than with moving diffuser(s.)

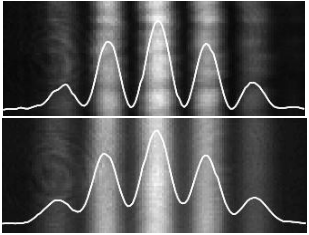
Deformable mirror: (pseudo-)collimation



Incidence e.g. $\varnothing 100\,\mu m$



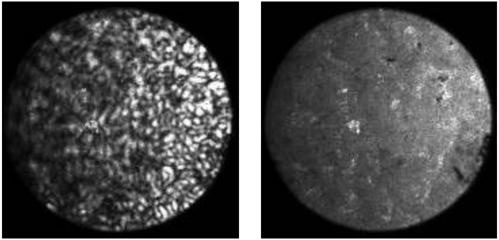
Beam dia.



Double slit fringes

- Beam quality preserved with spatial coherence reduced.

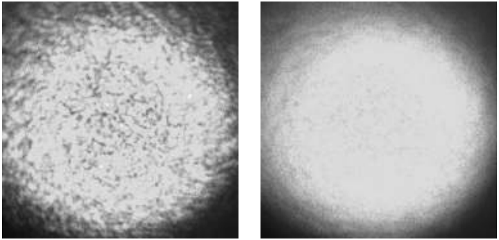
Deformable mirror: inter-modal dispersion



Exit face of 105 μm *multimode fiber*

- Efficient coupling into small lightguides.

Deformable mirror: inter-modal dispersion



Illumination from 105 μm *multimode fiber*

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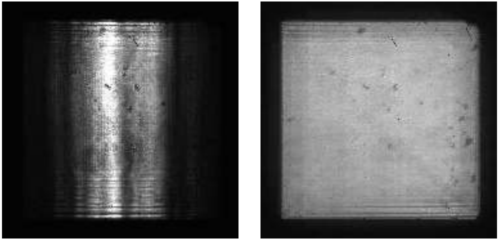
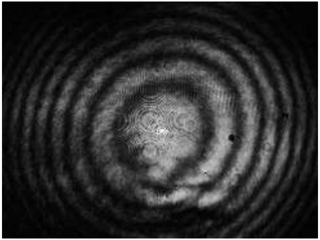
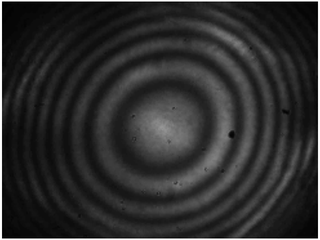


Exit face of 1 mm^2 *lightguide*

- Efficient coupling into small lightguides.

Deformable mirror: coherence preservation

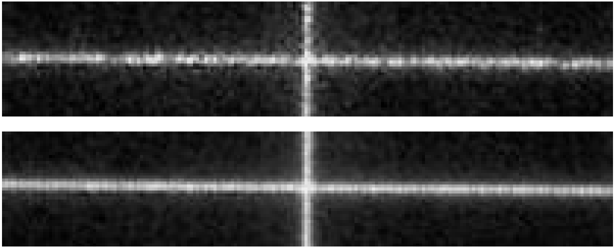




Michelson-type interferometer

- Although wavefront is randomized at high temporal frequency, interference fringes are stable.
- So too are diffraction patterns.
- What about computer-generated holograms? . . .

Deformable mirror: coherence preservation



DOE crosshair pattern on smooth surface

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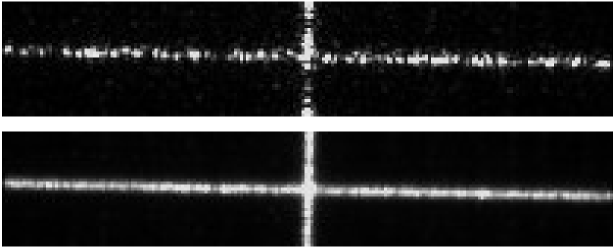
Deformable mirror: coherence preservation



DOE crosshair pattern on rough surface

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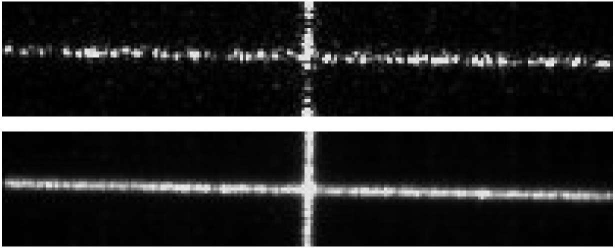

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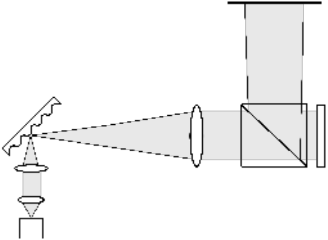
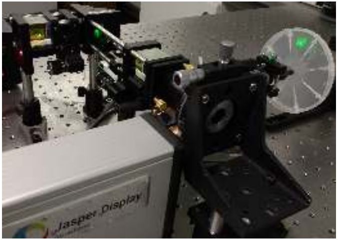
Computer-generated hologram display apparatus



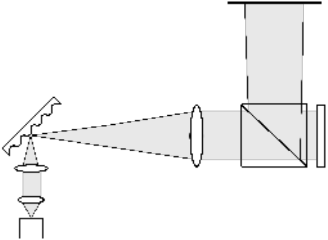
CGH LCoS display system



Apparatus

- Approx. $\varnothing 100\,\mu m$ spot focused onto surface of deformable mirror from highly coherent 532 nm laser.
- $f = 100\,mm$ lens collects and directs illumination through beamsplitter onto LCoS 1920×1080 pixel phase modulator displaying a computer-generated pattern.
- Hologram image formed on diffusing screen at distance determined by lens focus.

Computer-generated hologram display apparatus



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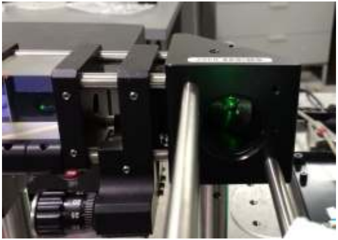

Spot on DM

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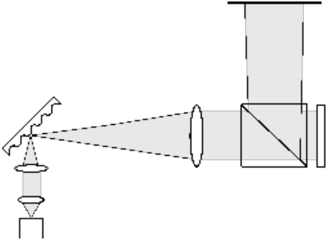
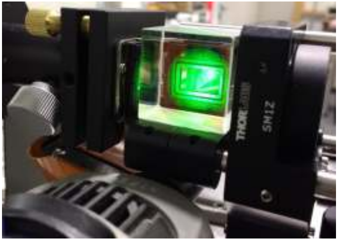


CGH LCoS display system



LCoS panel illuminated

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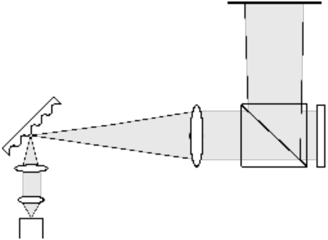
Computer-generated hologram display apparatus



CGH LCoS display system

Desired intensity image

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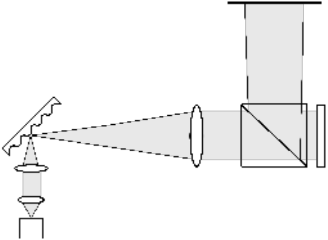
Computer-generated hologram display apparatus



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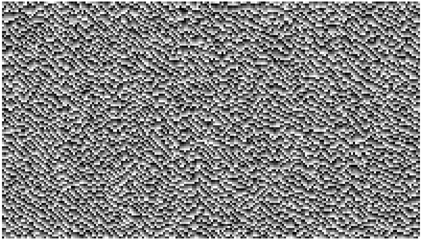

(Region of) CGH phase image

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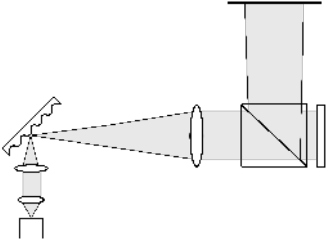

CGH LCoS display system

Hologram on diffusing screen

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Deformable mirror with surface diffuser

Diffusing screen, virtual image lens, camera at exit pupil

- Significant speckle when DM *inactive*, $C_S \approx 55\,\%$, $C_I \approx 10.4$
- *Small* improvement when DM *active*! $C_S \approx 39\,\%$, $C_I \approx 10.6$
- Moving the diffuser is much better, $C_S \approx 12\,\%$, $C_I \approx 10.0$
- Is the rough surface is being imaged? …

Deformable mirror with surface diffuser

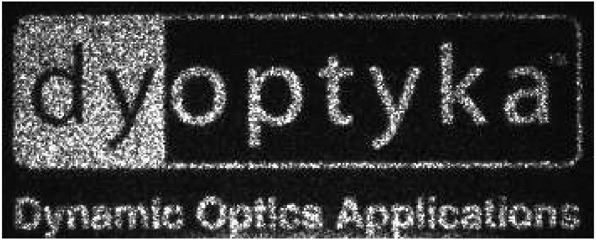

Image on Luminit Inc. 20 deg *diffuser, DM inactive.*

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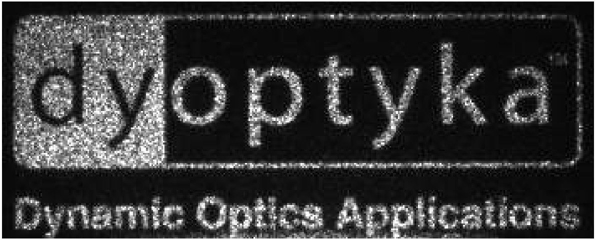

Image on diffuser with DM active

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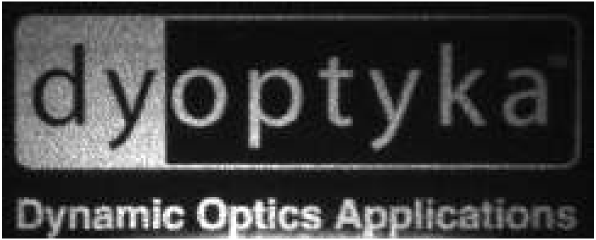

Image on diffuser rotating at 10,000 rev./min.

- Significant speckle when DM *inactive*, $C_S \approx 55\,\%$, $C_I \approx 10.4$
- *Small* improvement when DM *active*! $C_S \approx 39\,\%$, $C_I \approx 10.6$
- Moving the diffuser is much better, $C_S \approx 12\,\%$, $C_I \approx 10.0$
- Is the rough surface is being imaged? ...

Deformable mirror with surface diffuser

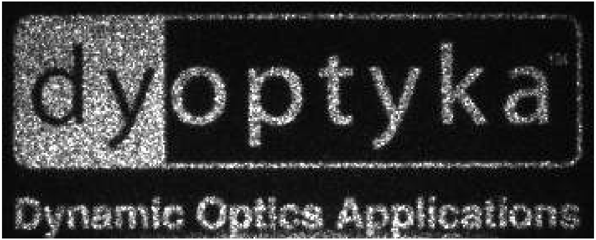

Image on diffuser with DM active

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Volume scatterers

PFA fluoropolymer, 2 mm *thickness, smooth surface.*

- Volume scatterers with smooth surfaces were investigated.
- Experimented with various easy-to-source materials such as silicone, polypropelene, and fluoropolymer.
- Fluoroware® wafer carrier found to have best transparency for required diffusion angle of approx. 20 deg.

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Deformable mirror with volume scatterer

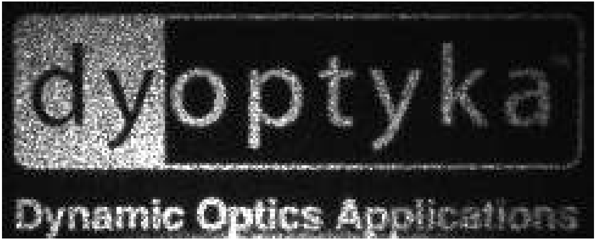

Image on PFA, DM inactive.

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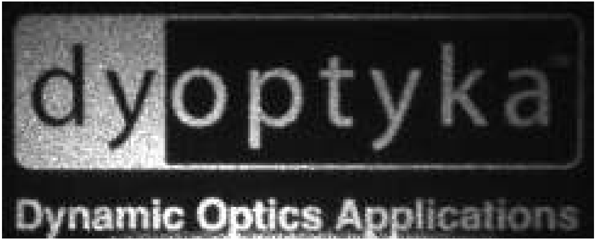
Deformable mirror with volume scatterer



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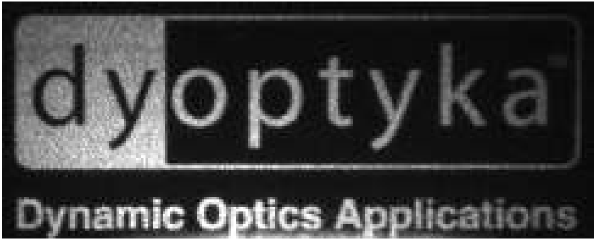

PFA rotating at 10,000 rev./min.

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Conclusions

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Acknowledgments

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