Optically Efficient Directional Illumination with Homogenization of Laser Incidence on Remote Phosphor

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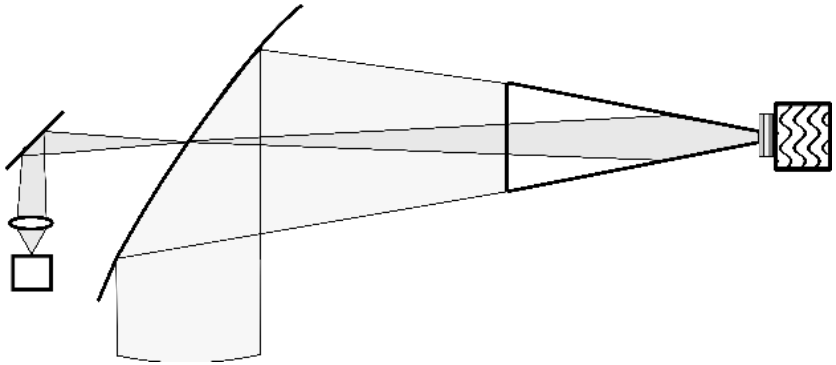
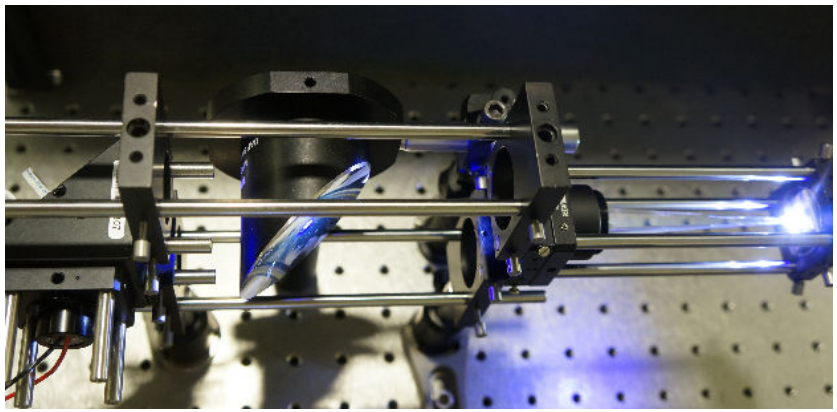
Concept and Experimental Apparatus

e.g. for automotive headlights, projection displays



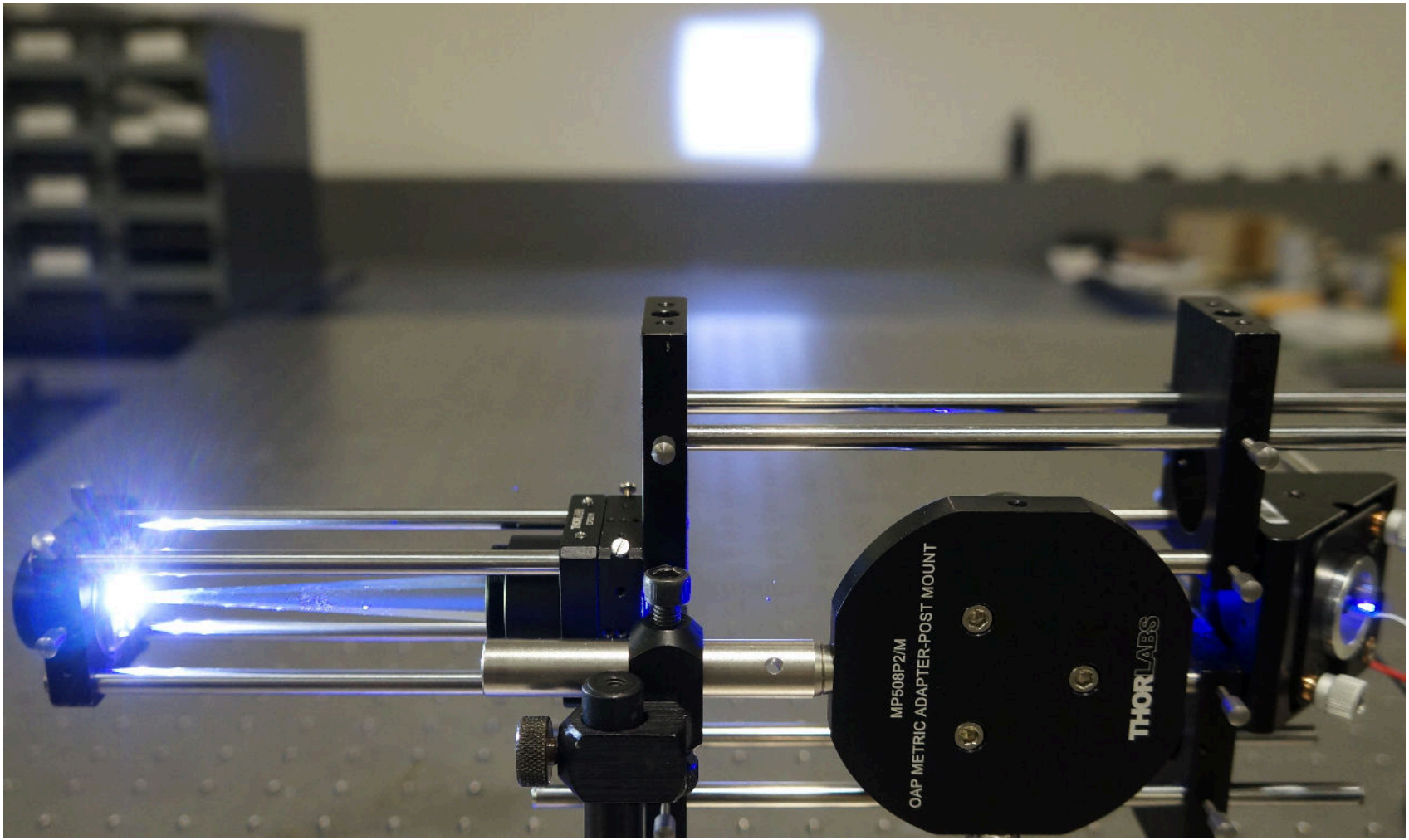
Concept



Apparatus

- Use a light guide to deliver high power illumination from 450 nm Blue LD into $1 \times 1\,\mathrm{mm}^2$ area of stationary, heatsinked, mirror-mounted Yellow phosphor.
- Light guide collection efficiency around 90% should be possible for Yellow emission and reflected Blue.
- $\varnothing 3$ mm hole loss approx. 0.36% for $\varnothing 50$ mm parabolic reflector; approx. 1.4% for $\varnothing 25$ mm parabolic reflector.

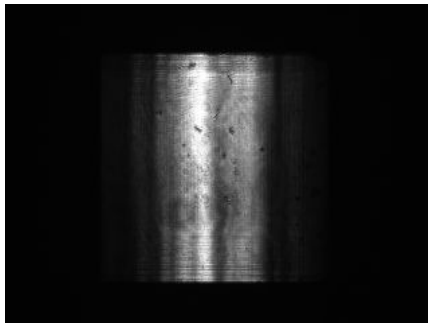
System operation



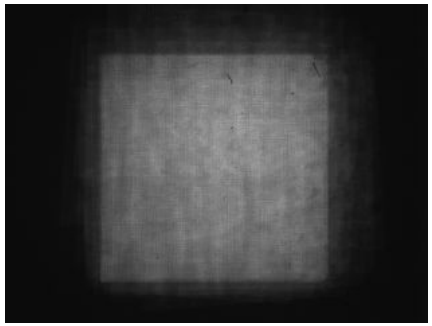
- "White" from $10 \times 10\,\mathrm{mm}^2$ light guide exit face projected by parabolic mirror of $f \approx 100\,\mathrm{mm}$ to $18 \times 18\,\mathrm{cm}^2$ at $180\,\mathrm{cm}$.

Homogeneity of *incident* LD illumination through LG

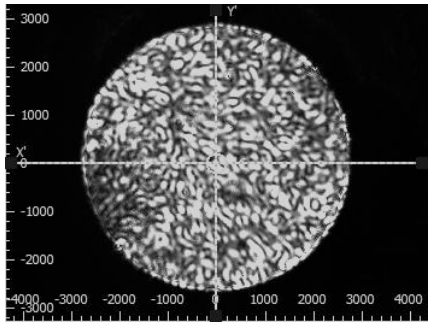
- Irregular incident intensity distribution onto phosphor causes hot spots (burning,) thermal gradients (cracking,) . . .



LD MM emission

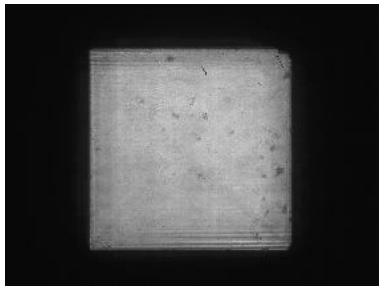


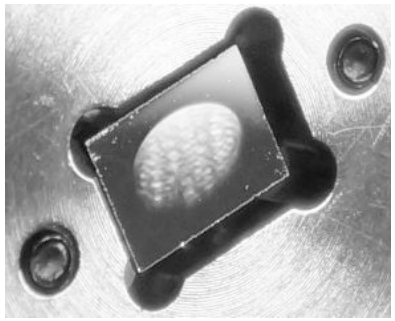
2 degree diffuser



MM optical fiber

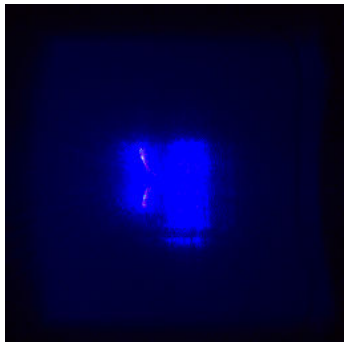
- Up to 25% more optically efficient coupling into light guide using *deformable mirror* instead of 2 degree diffuser.



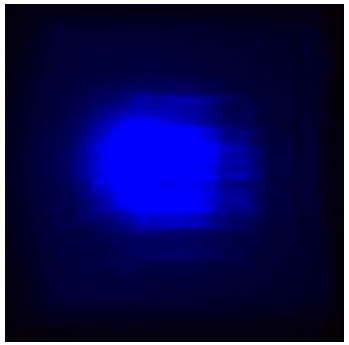


Homogeneity of *projected* LD illumination

- Irregular intensity distribution at $10 \times 10\,\mathrm{mm}^2$ exit face of light guide leads to irregular color temperature in projected area.

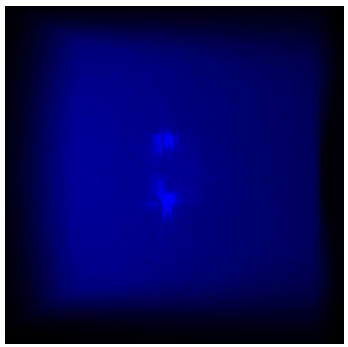


DM Off

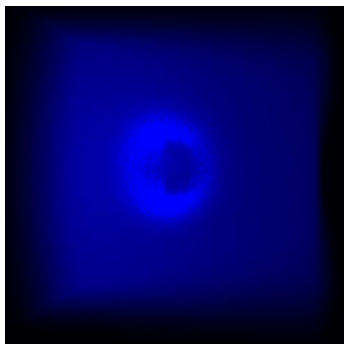


DM On

- DM low angle divergence is not enough to fill exit face. But additional scattering from ceramic powder phosphor does.

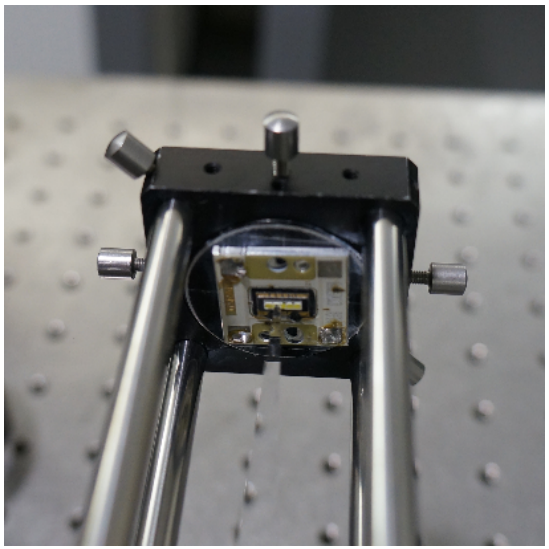


DM Off

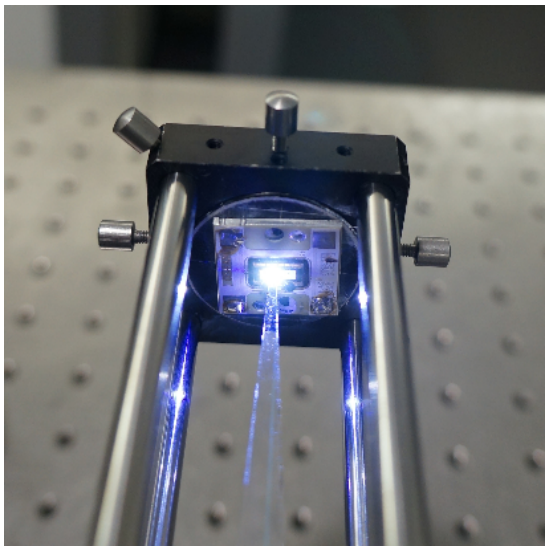


DM On

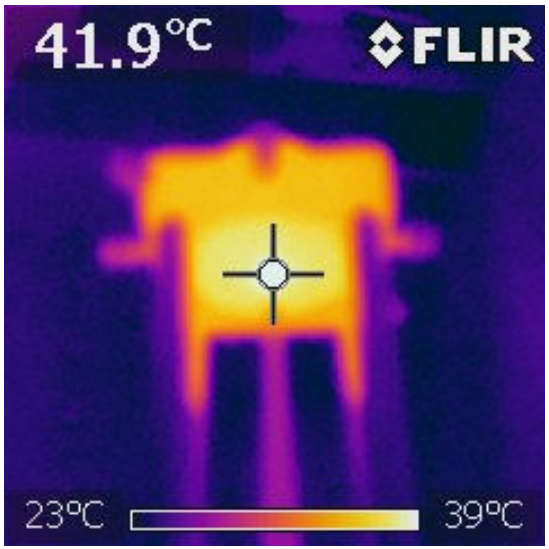
Ce:YAG ceramic powder phosphor [Osram, Germany]



LD off



LD on

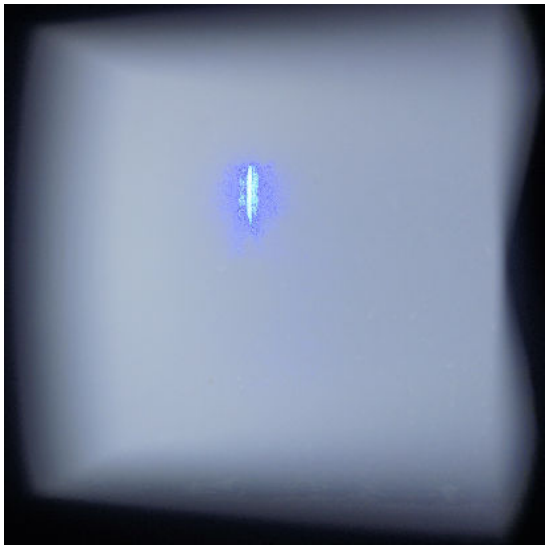


LD on, 6 W

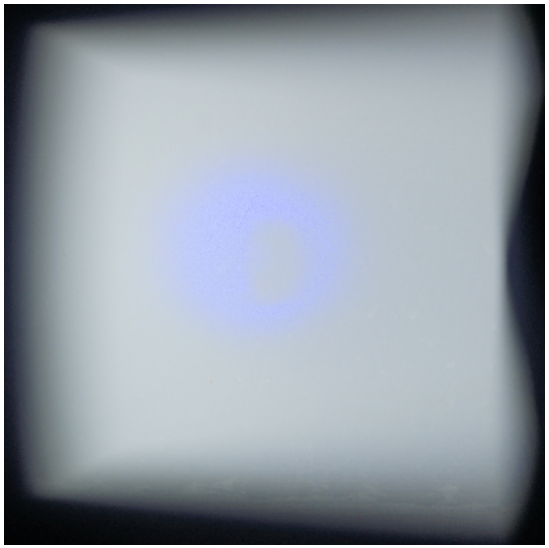
- Osram Ostar LED+CPP package mounted onto passive heatsink with thermal paste.
- Entrance face of light guide aligned with one of its $1 \times 1\,\mathrm{mm}^2$ CPP segments.
- Illuminance approx. 25 000 lx, measured within relatively homogeneous $18 \times 18\,\mathrm{cm}^2$ area at 180 cm.

Homogeneity of projected LD + CPP illumination

LED, 2700 K, 400 lm

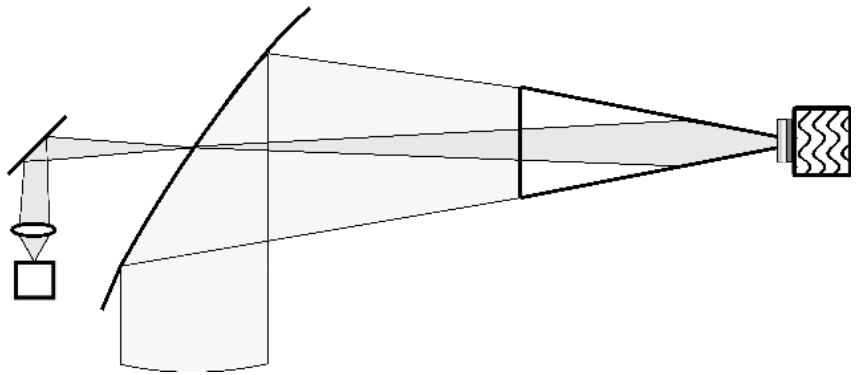


CPP, LD 6 W, *DM Off*



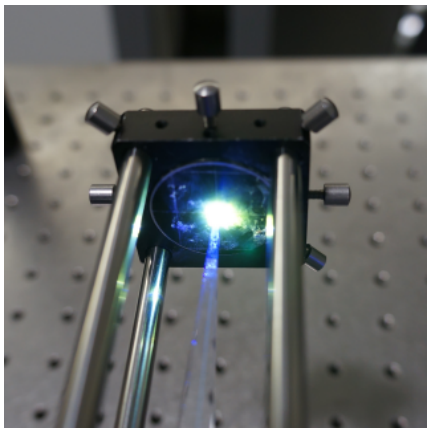
CPP, LD 6 W, *DM On*

- So concept works well with CPP. But CPP doesn't have best transmissivity for Yellow emission reflected by mirror.

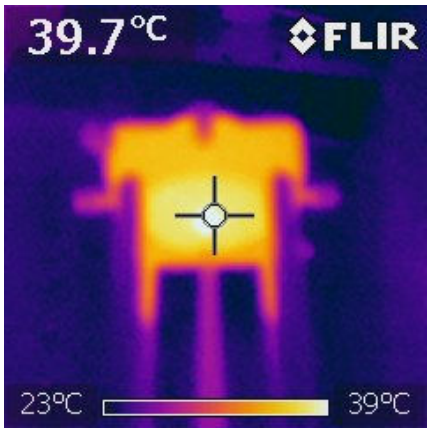


Ce:YAG Single Crystal Phosphor [NIMS, Japan]

SCP, $5{\times}5{\times}0.5\,\mathrm{mm}^3$



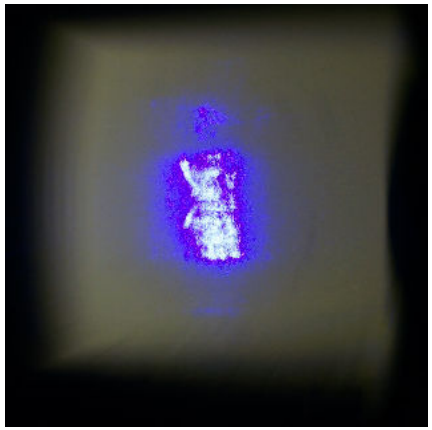
SCP, Al-coated



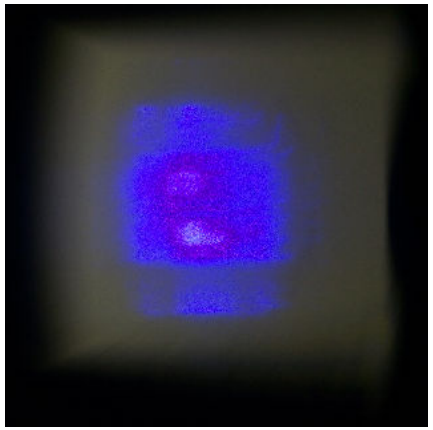
SCP, LD on, 6 W

- Highly transparent and heat resistant.
- Can be polished and mirror-coated.
- Internal QE: 97% at 21 °C, 90% 300 °C.
- External QE: 79% at 21 °C, 72% 300 °C.

Homogeneity of projected LD + SCP illumination

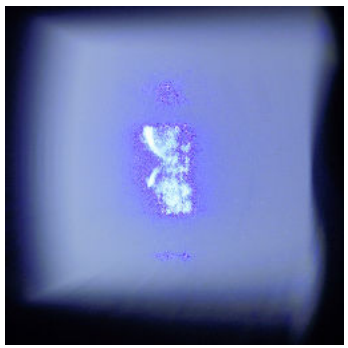


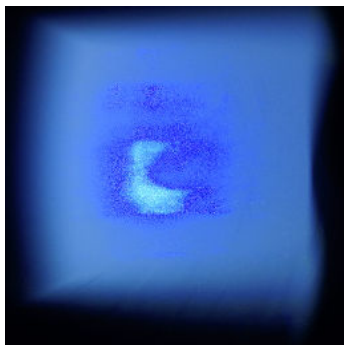
SCP, DM Off



SCP, DM On

- Very poor homogeneity because non-diffusing SCP does not scatter LD Blue to fill light guide exit face.
- Putting diffusing material at light guide entrance face helps homogeneity at the cost of reduced optical efficiency.

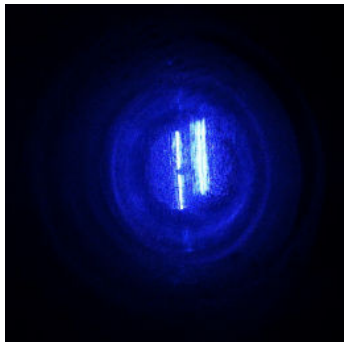




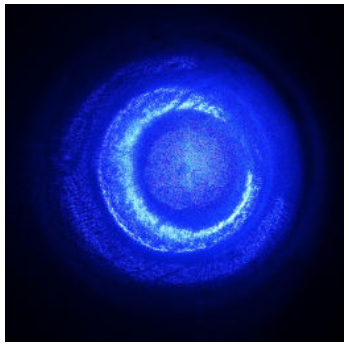
Current work

- Investigating *light guide designs* that amplify effect of DM for homogenization of LD Blue at *input* and *output* faces of LG *without diffusion.*

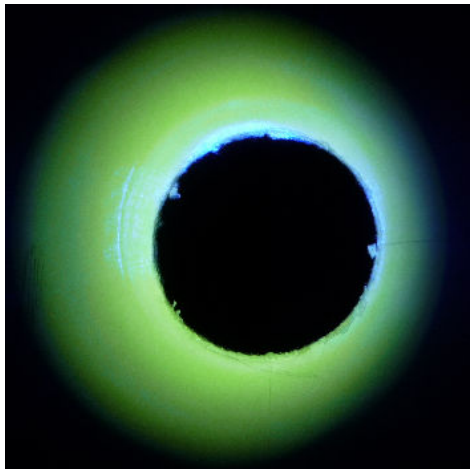
CPC+SCP



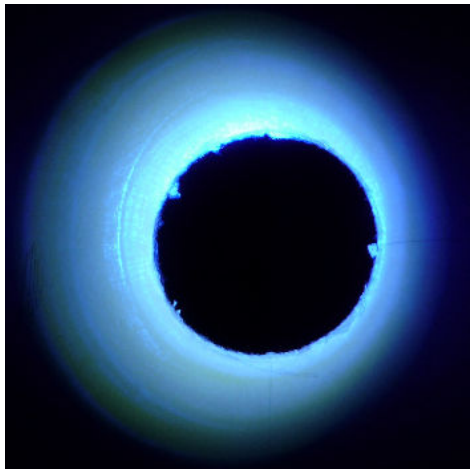
CPC, DM Off



CPC, DM On

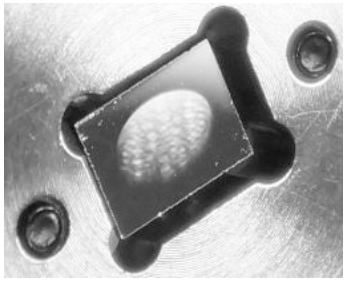


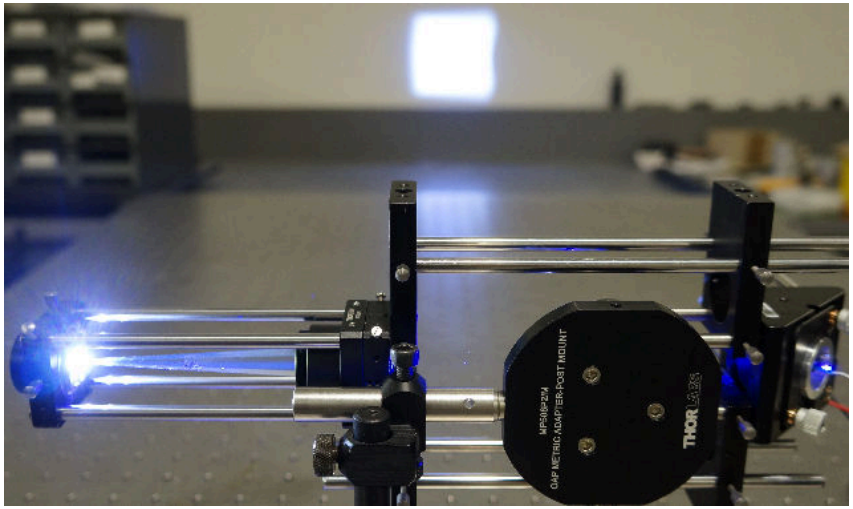
CPC+SCP, DM Off



CPC+SCP, DM On

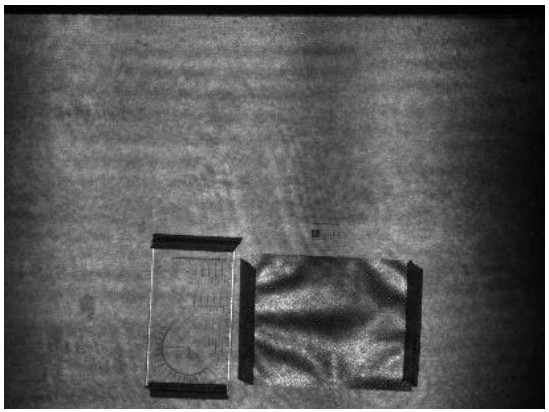
Conclusions



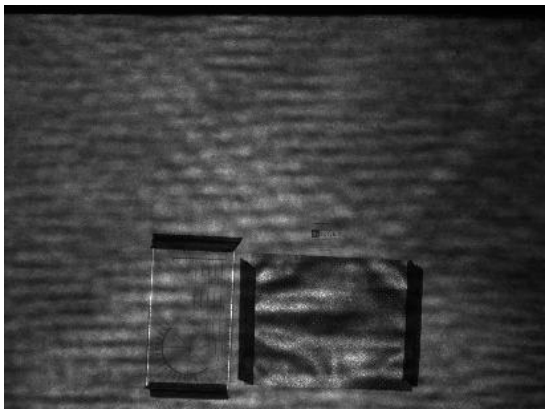


- With CPP, 25 000 lx and 40 °C at 6 W incident optical power.
- With SCP, should be $>$ 25 000 lx and $<$ 40 °C due to transparency—with appropriate light guide.
- Deformable mirror for homogeneity without diffusion losses.
- Deformable mirror reduces speckle arising with higher f/# projection optics required for longer distances.

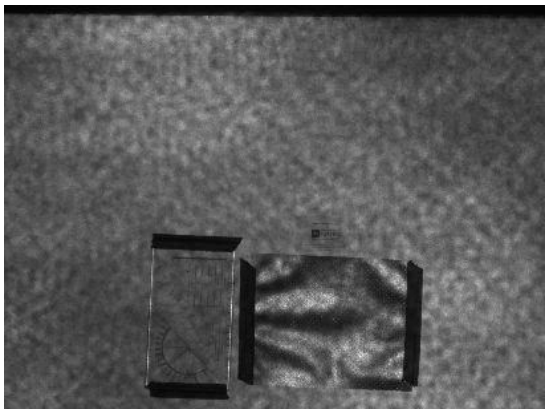
DM for Homogeneity + optical efficiency



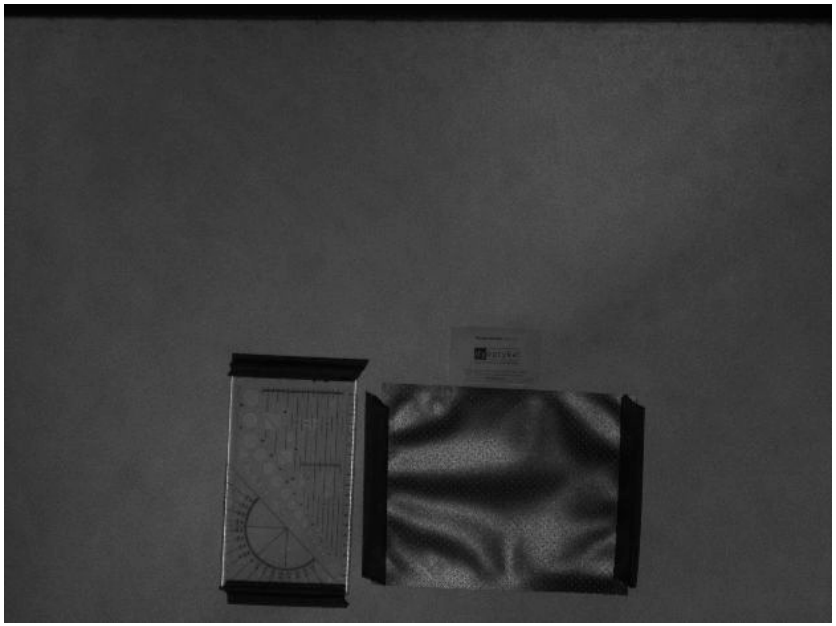
MM LD 445 nm, 25 ms



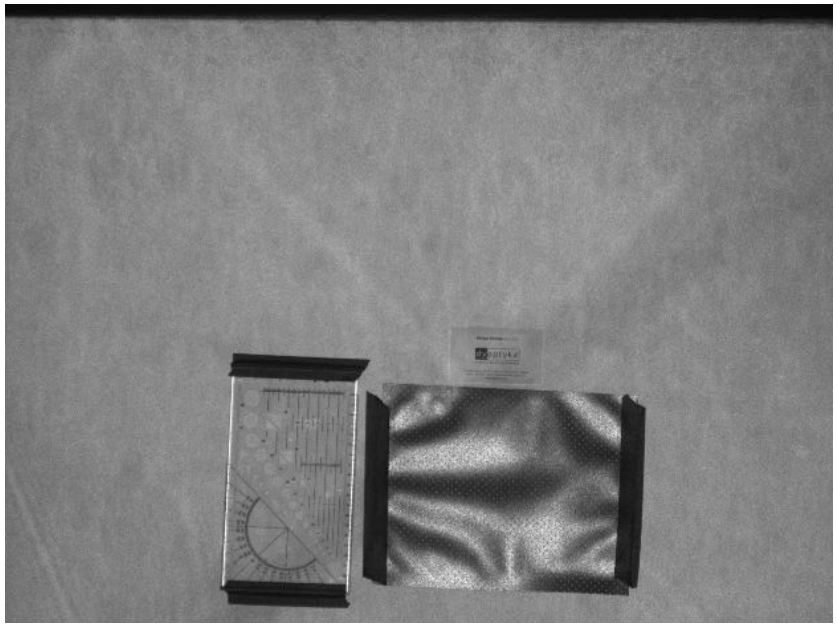
$1 \times 2^{\circ}$ *diffuser*, 25 ms



$2 \times 2^{\circ}$ *diffusers*, 75 ms

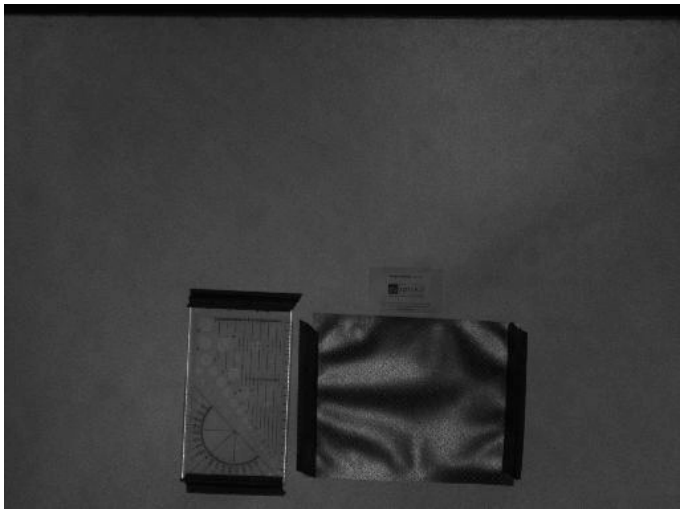


$2 \times 2^{\circ}$ *diffusers, 1 moving, GL 30%*

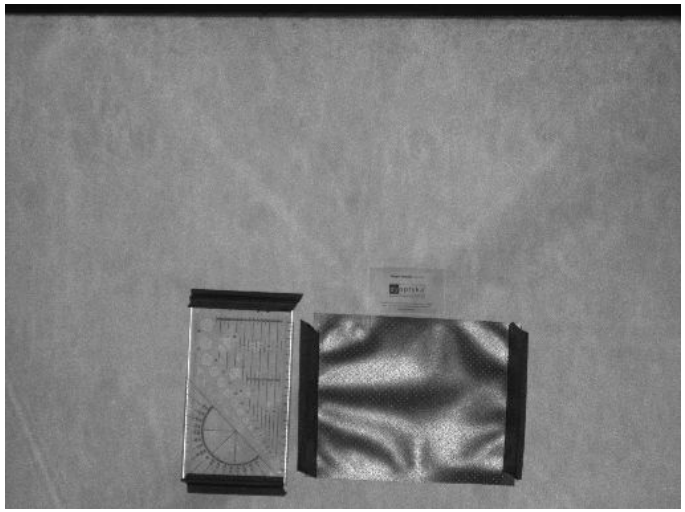


No diffuser, DM On, GL 47%

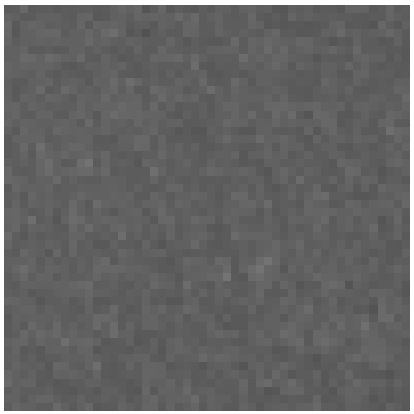
DM for speckle reduction + optical efficiency



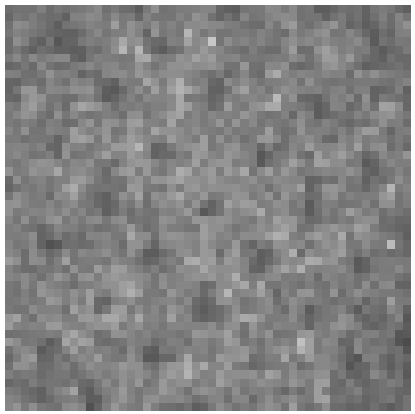
$2 \times 2^{\circ}$ *diffusers, 1 moving*



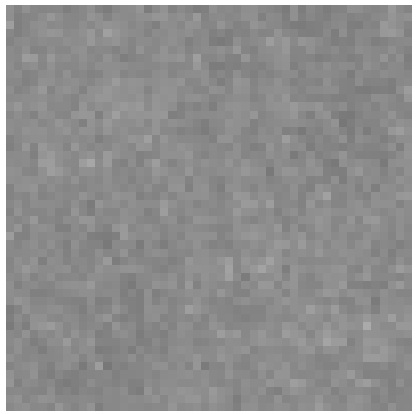
No diffuser, DM On



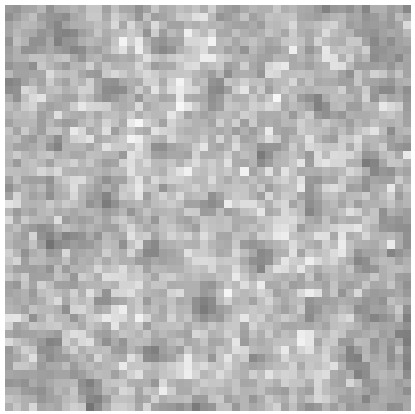
$K = 6\%$



$K = 16\%$



$K = 6\%$



$K = 16\%$

Acknowledgements

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Thank you! Questions?