Speckle Reduction With Multiple Laser Pulses

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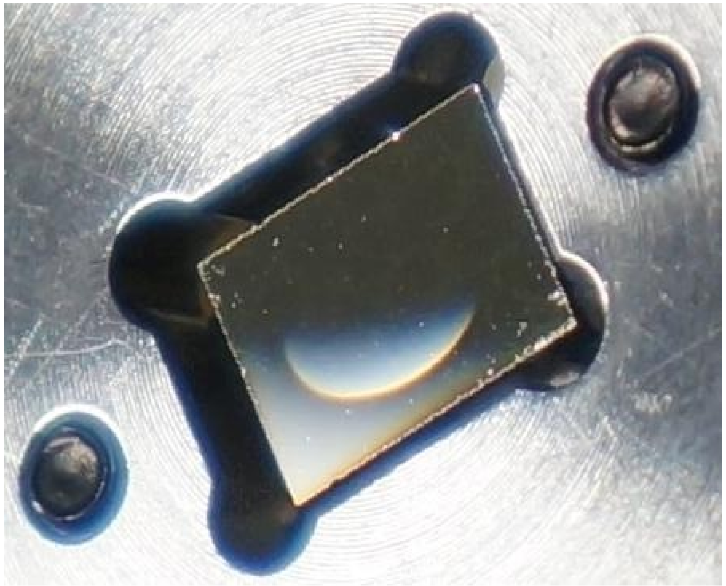
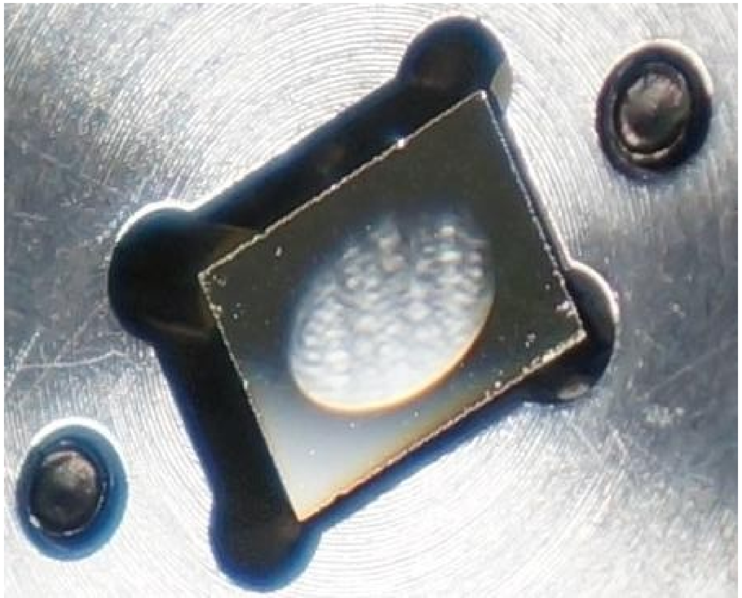
Dyoptyka device for speckle reduction: phase randomizing deformable mirror





- *High reflectivity, e.g. >99%.*
- *Randomized surface waves.*
- *Polarization preserving.*
- *Very fast actuation, e.g. 1 MHz.*

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Dielectric mirror coating reflectivity

EIS Optics
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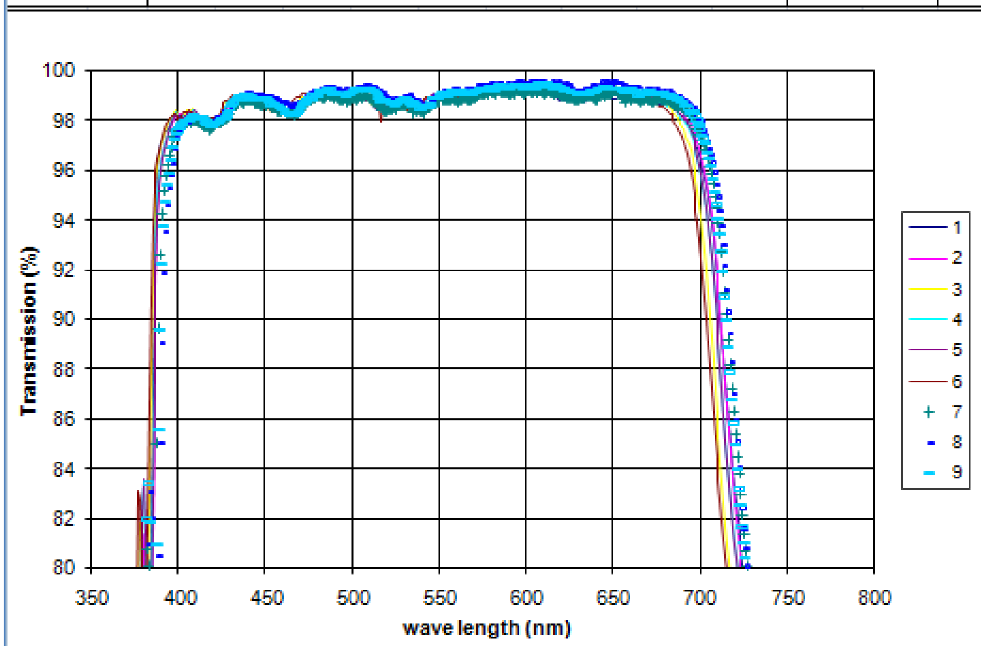
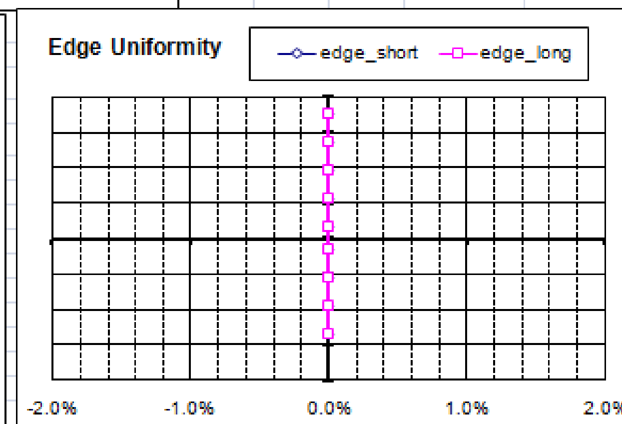
Spectral Measurement Report

material	Mir45	Side	2nd Side BT	Substrate:	
Machine:	BAK1358	9245	AOI: 45	Date:	2012/12/4 20:31
Instrument:	Lamda900		Pol.: q	Operator:	wy
Comment:				BT	

Open Data





Type		Value	r_b	r_e	ref	M1	M2	M3	M4	M5	M6			
Ravg	>	98	420	680		98.8	98.92	98.91	98.88	98.95	98.91	98.8	99.14	98.99
Rabs	>	92	420	680		98	98.09	98.13	98.08	98	97.98	97.66	97.9	97.77

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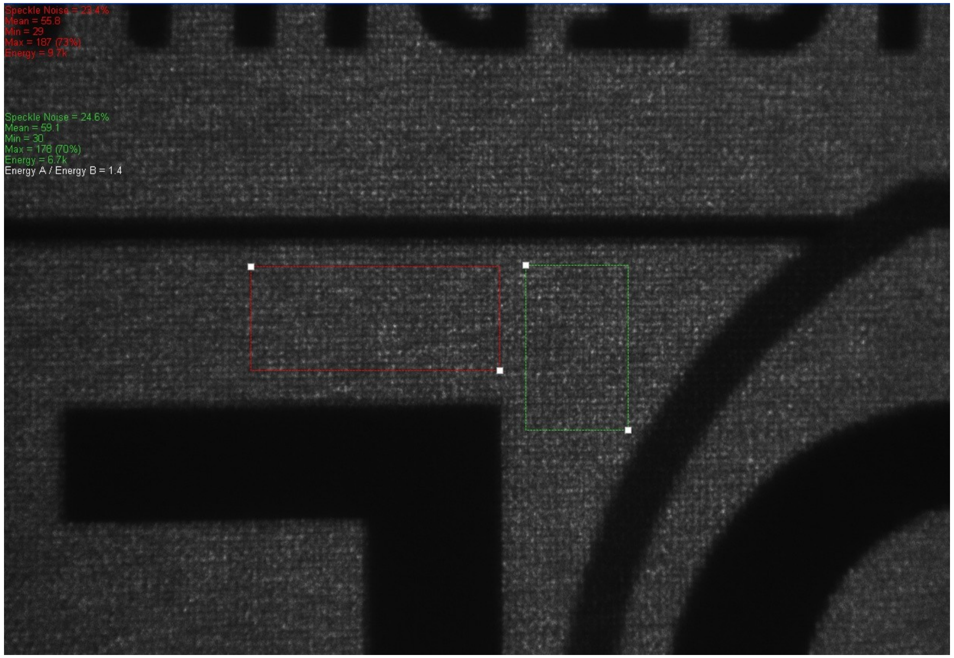
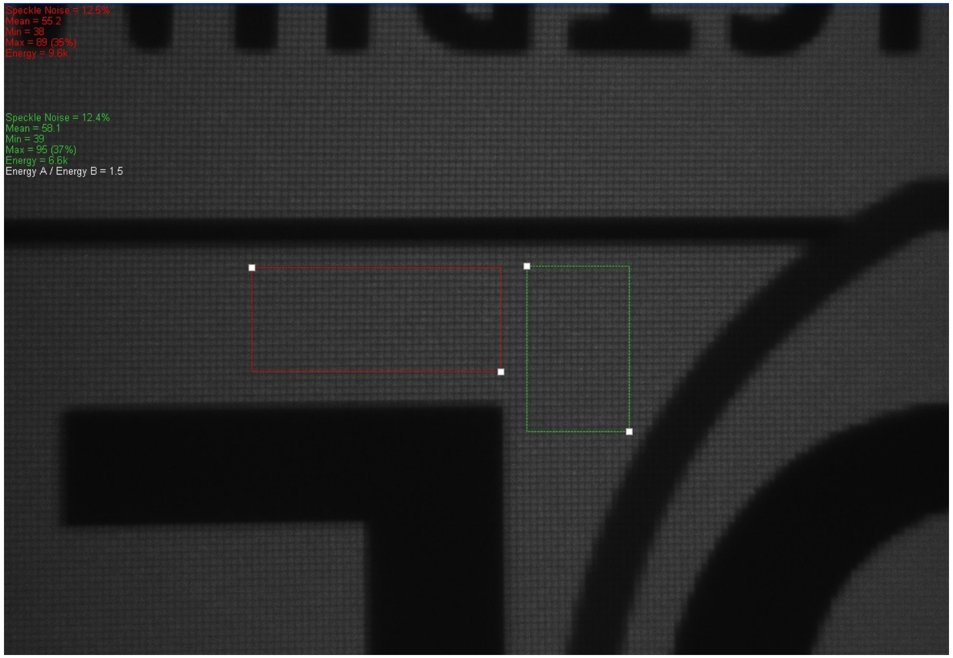
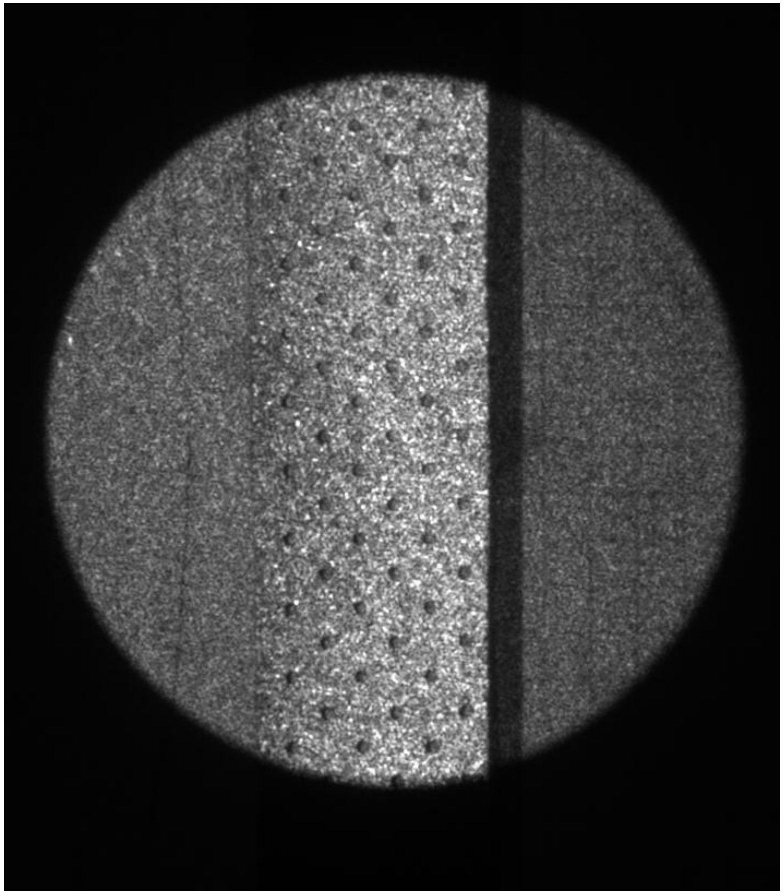
Speckle reduction applications: projection display and LCD-BLU

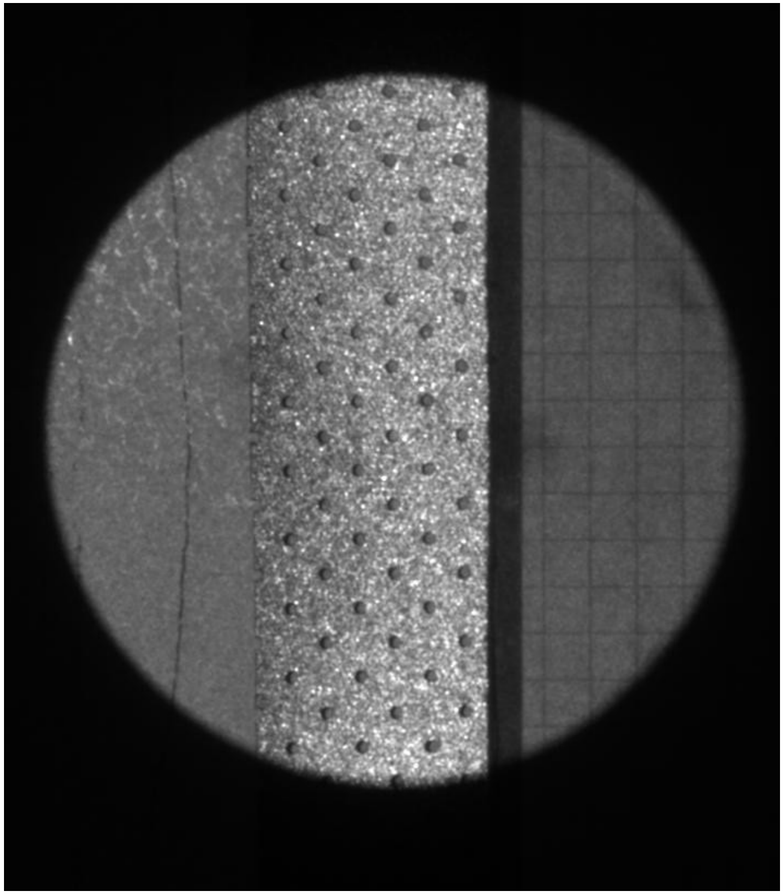




Laser -> Dyoptyka mirror -> DLP picoprojector

Speckle reduction applications: area illumination





Laser -> Dyoptyka mirror -> Lens -> 1,000 um fiber x 5 m -> Collimator -> Target (painted wall, rough metallic screen, paper.)

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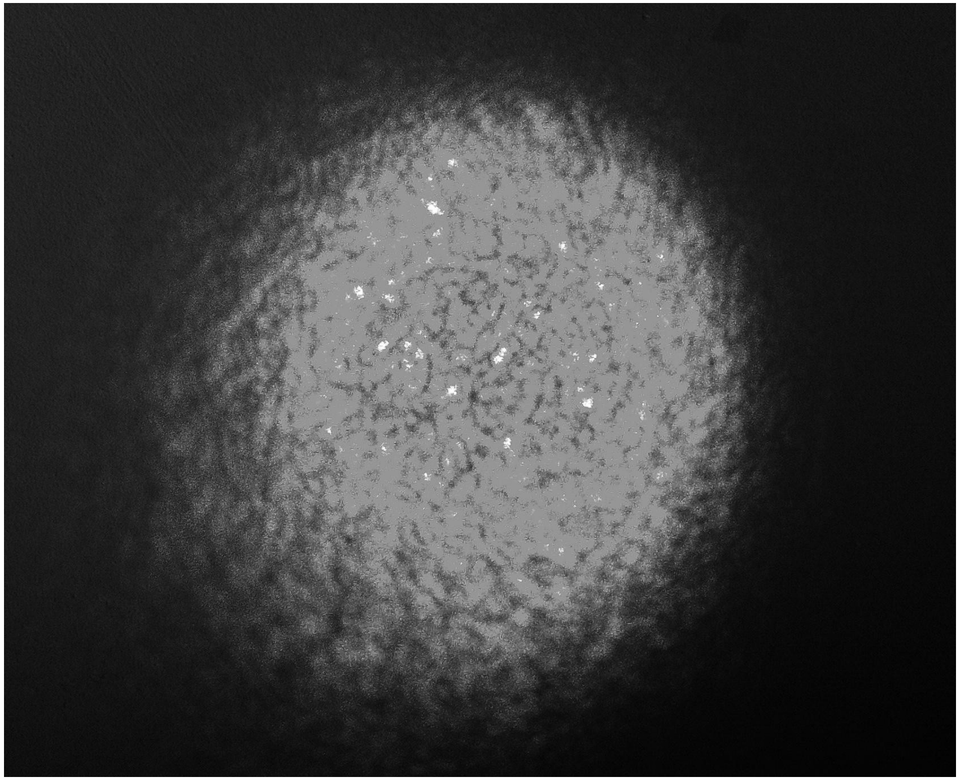
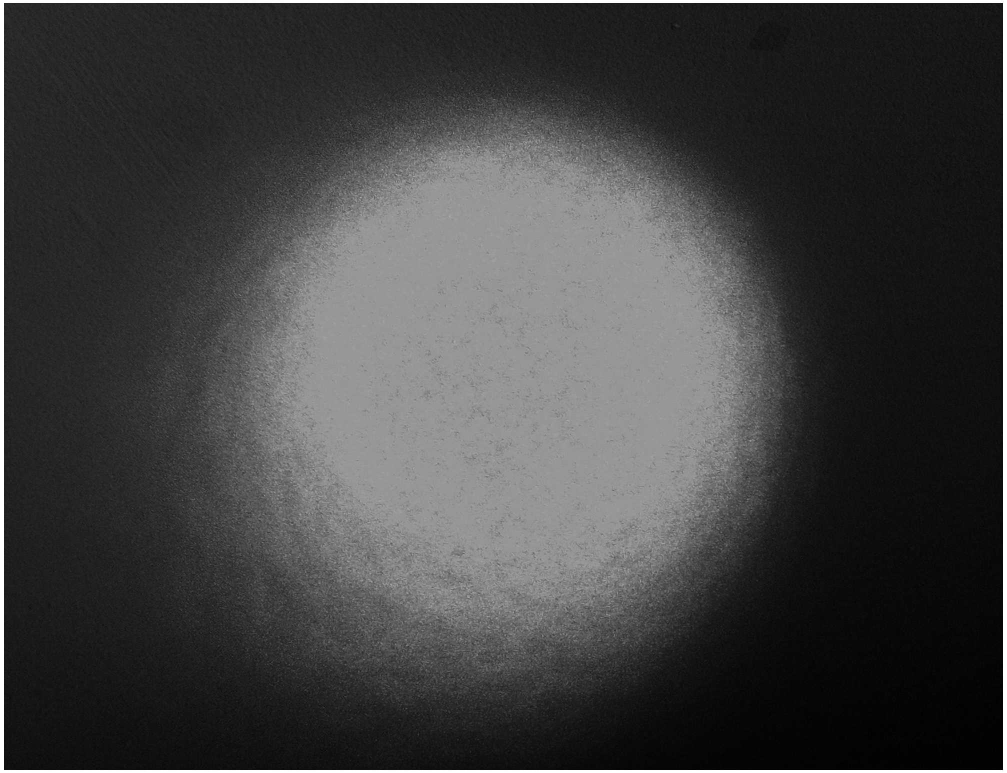
Speckle reduction applications: fiber mode mixing





Laser -> Dyoptyka mirror -> Lens -> 105 um multimode fiber x 3 m -> Painted wall.

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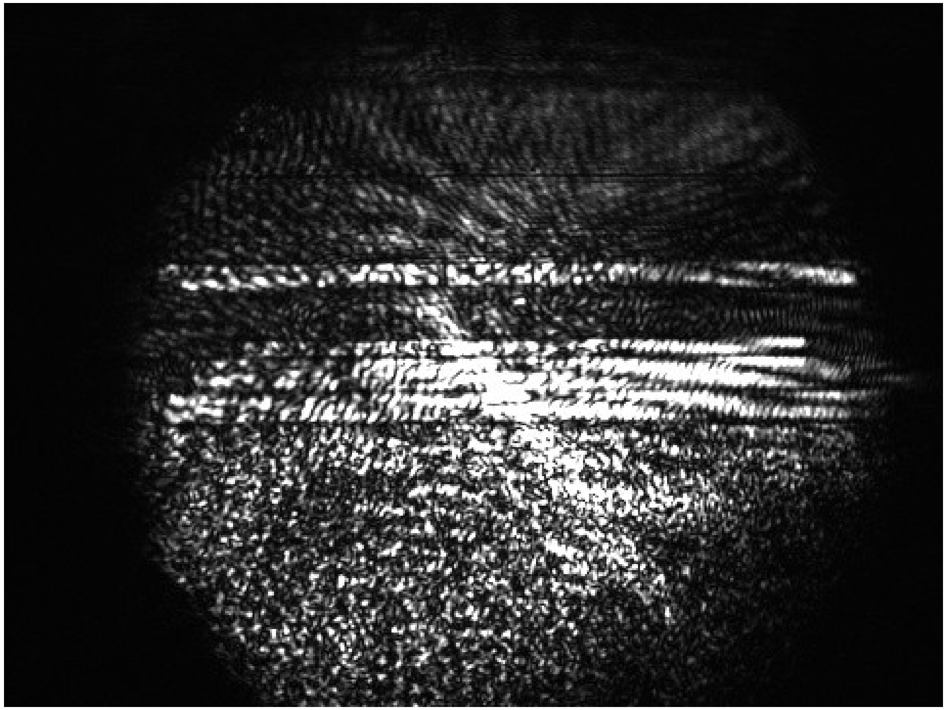
Speckle reduction applications: microscopy



Laser -> Dyoptyka mirror -> MOK microscope.
Pixel size at sample is 50 x 50 nm^2 !!!

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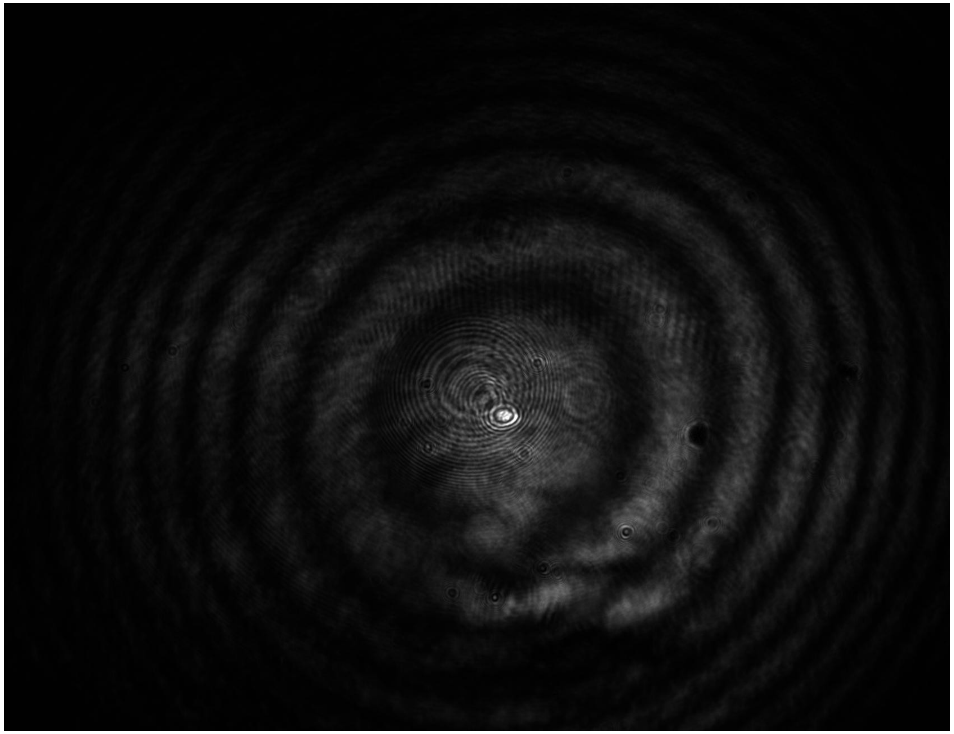
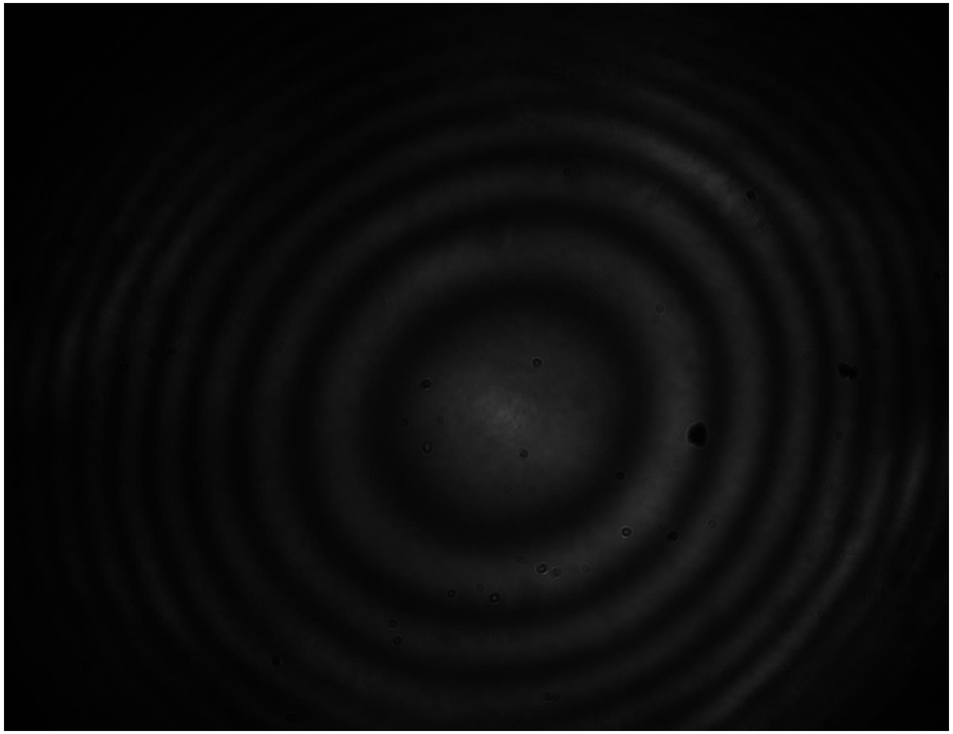
Speckle reduction applications: interferometry





Laser -> Dyoptyka mirror -> both interferometer arms.

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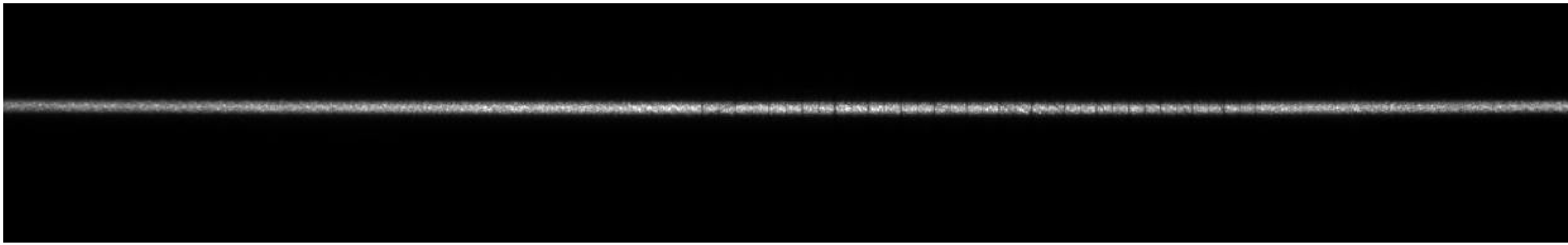
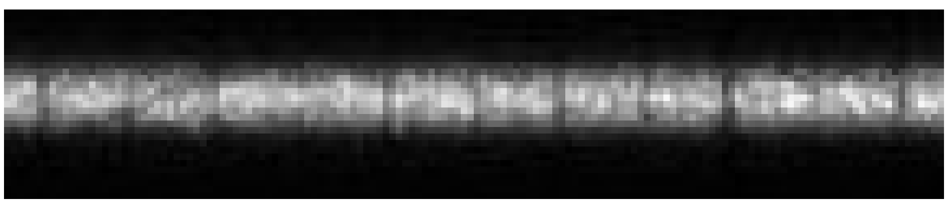
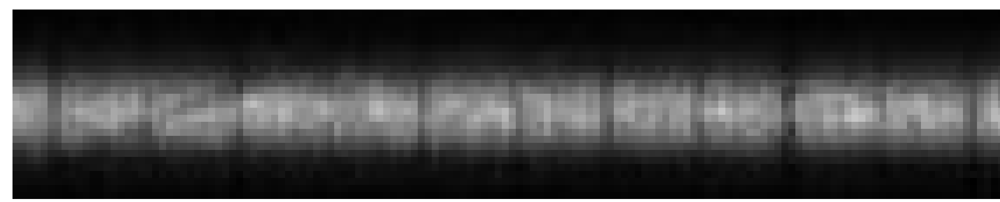
Speckle reduction applications: barcode reader







Laser -> Dyoptyka mirror ->
Line projection (1 m x 5mm) at 1 m distance.

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Speckle reduction applications:

Many others where Dyoptyka mirrors are being used:

- *From 415 nm to 10.6 um wavelengths*
- *From 1 mW to 100 W optical power*
- *From 1 mm to 30 mm beam diameters*

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Important characteristics of a speckle reduction solution

- *Performance*
- *Optical efficiency*
- *Size*
- *Power consumption*
- *Speed*
- *Cost*

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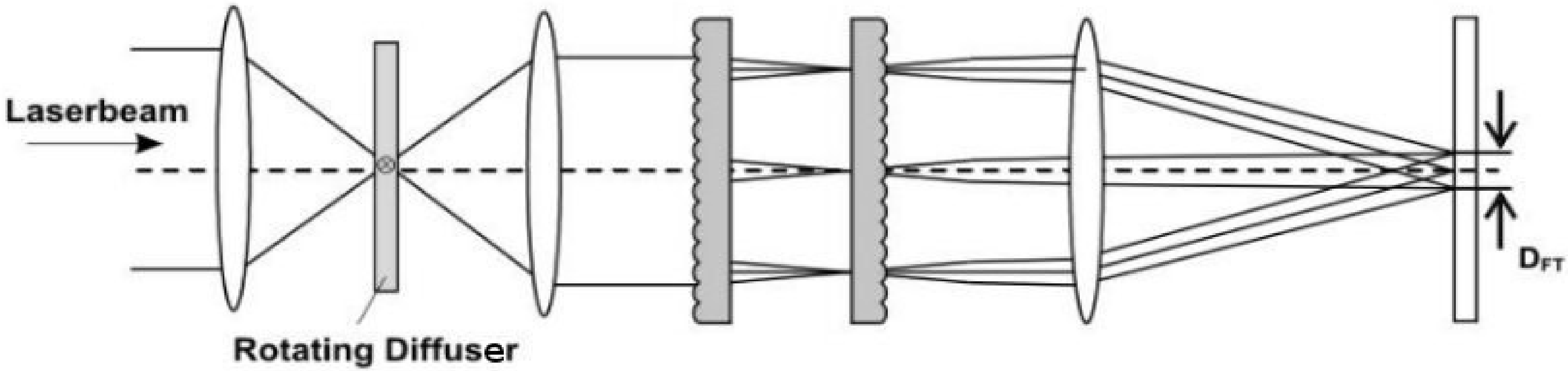
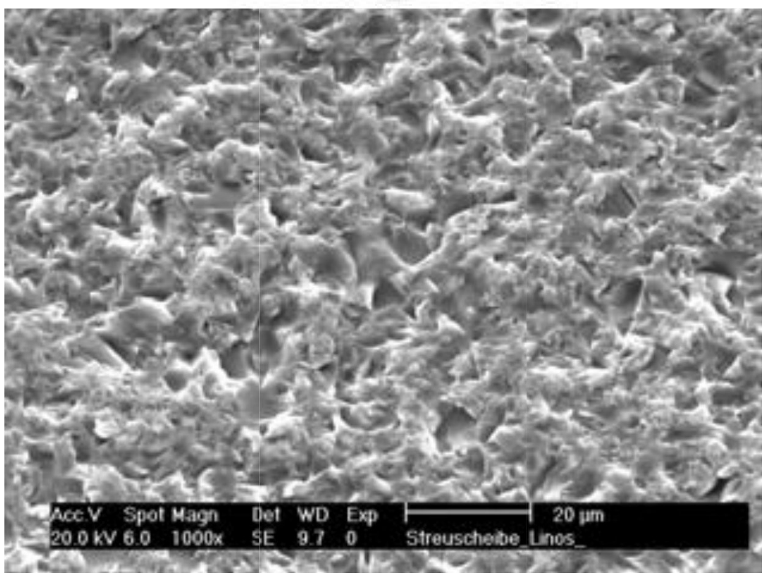
Conventional projection display approach:

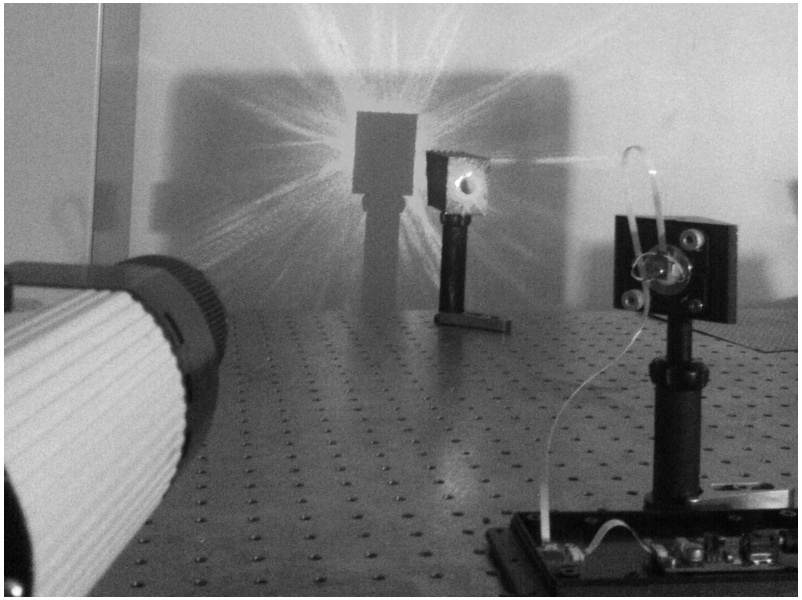
rotating diffuser in illumination optical system

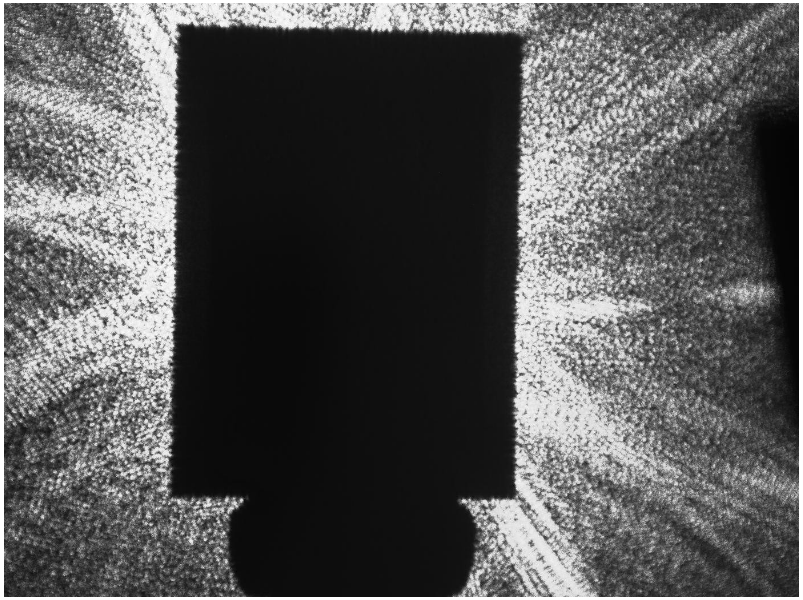




- *Performance: OK (could be better.)*
- ***Optical efficiency: very poor.***
- ***Size: very poor.***
- ***Power consumption: very poor.***
- ***Speed: very poor.***
- *Cost: OK.*

Engineered diffuser optical efficiency





- Higher angle scattering losses.
- Sub-optimal anti-reflection coating.
- Correlation lengths >> 100 um.

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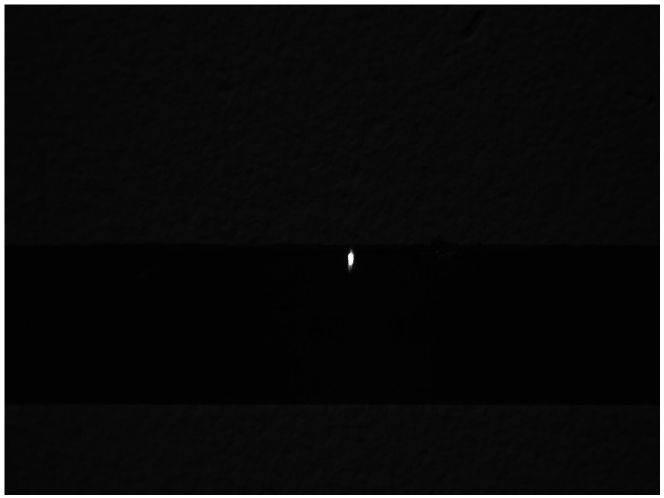
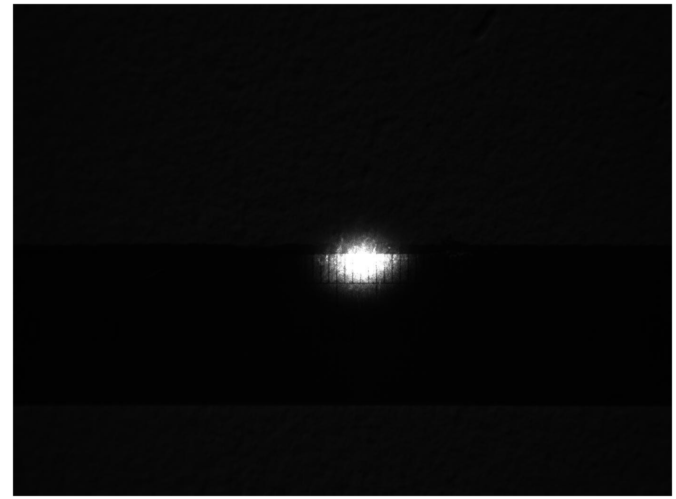
Dyoptyka mirror: low-angle, band-limited, randomized divergence

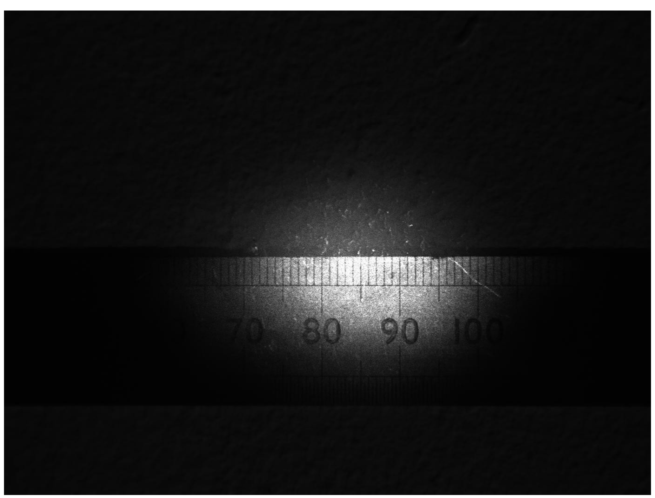
Mirror off:
no divergence.

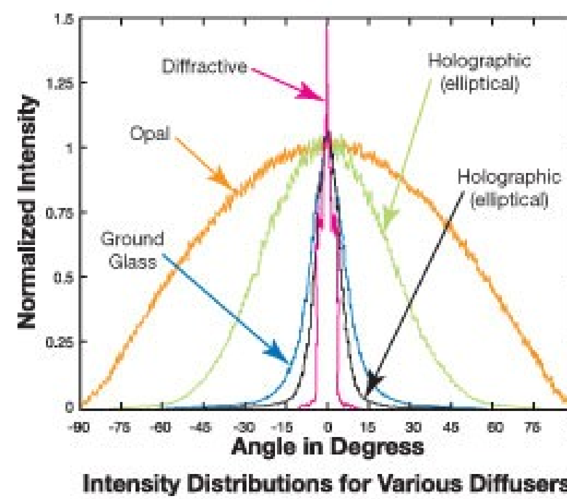




Mirror on, 1.8V:
divergence 0.5 deg.

Mirror on, 3.3V:
divergence 2.0 deg.





(Figure from Thorlabs.)

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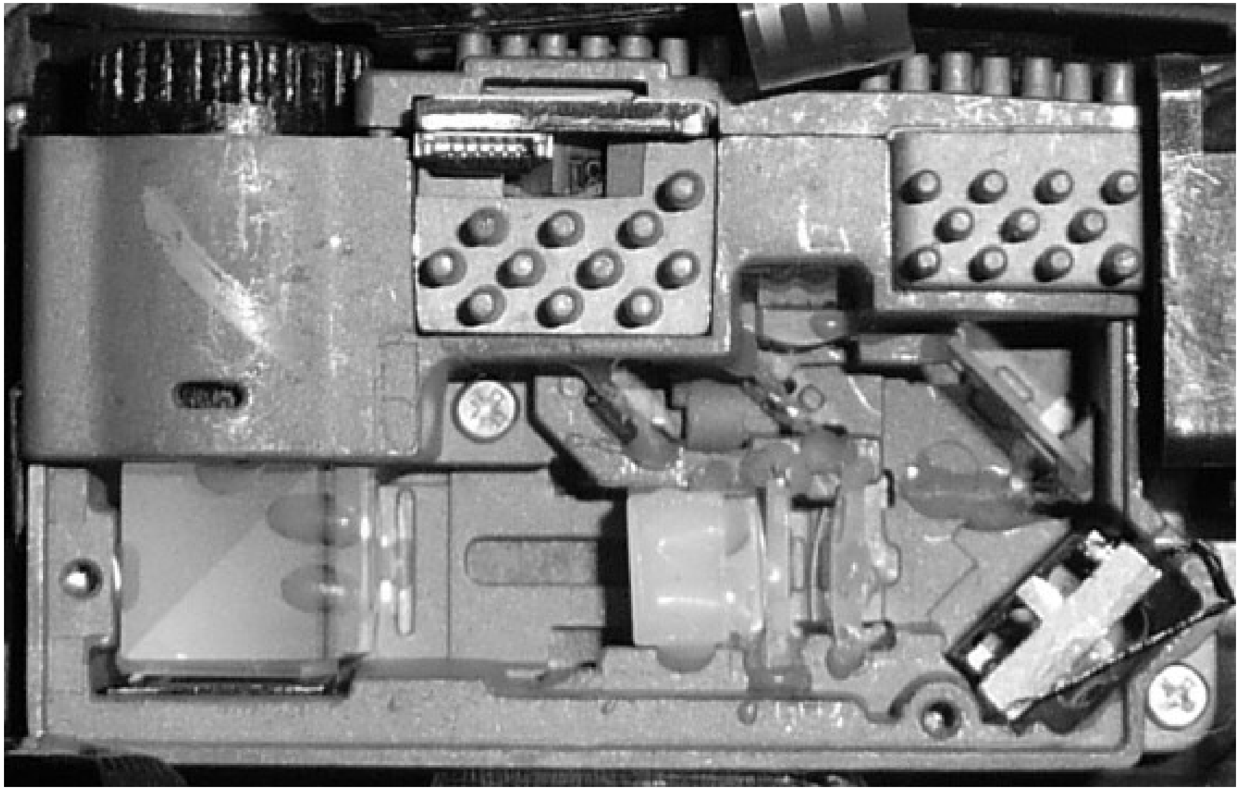
Dyoptyka mirror used instead of moving diffuser before/between microlens arrays



... or before homogenizing rod/pipe, optical fiber, LCD-BLU light guide, etc.

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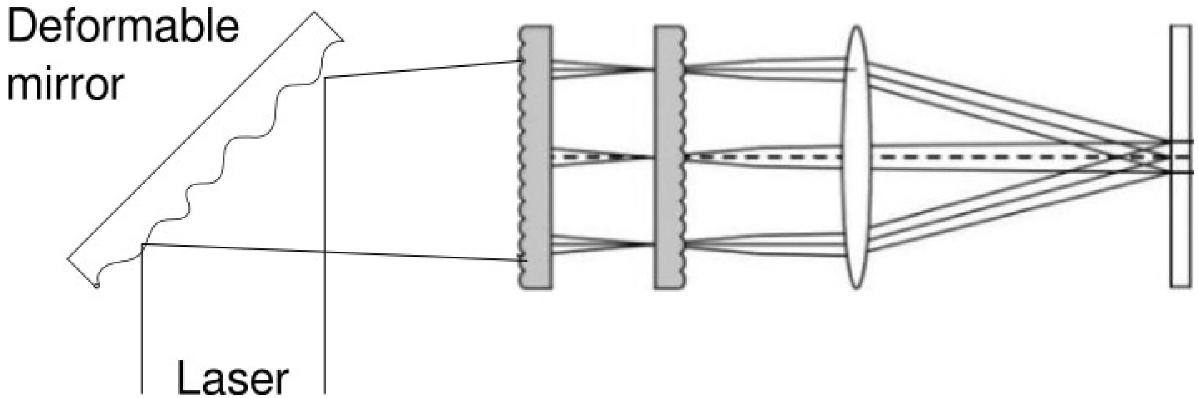
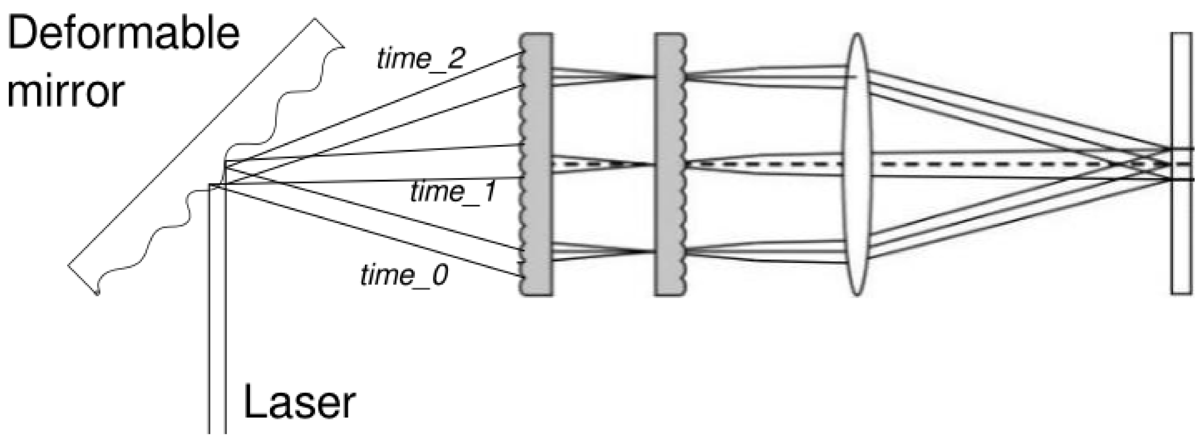
Dyoptyka mirror operation modalities



Full N.A. randomized divergence



Partial N.A. randomized divergence with fast tip/tilt

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Limits of speckle reduction

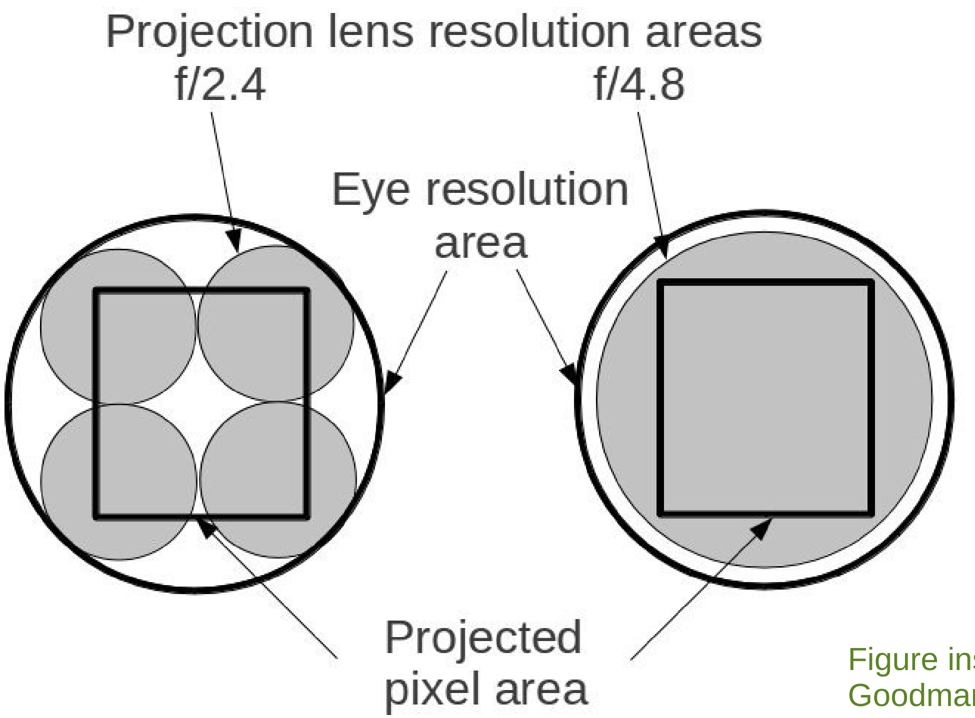

Figure inspired by Goodman (2007.)

*Minimum speckle contrast from a **single** coherent source proportional to: eye resolution / projection lens resolution.*

*Mutually-incoherent sources reduce speckle contrast further only if their **angular separation** is sufficient.*

Laser Diode Pulses in Projection Displays

[e.g. 1 us pulses. Short compared to microdisplay and eye. Not short enough to broaden linewidth.]

- *Optimize peak power and/or energy efficiency?*
- *Improve image contrast?*
- *Reduce rainbow effect?*
- ***Reduce speckle?***

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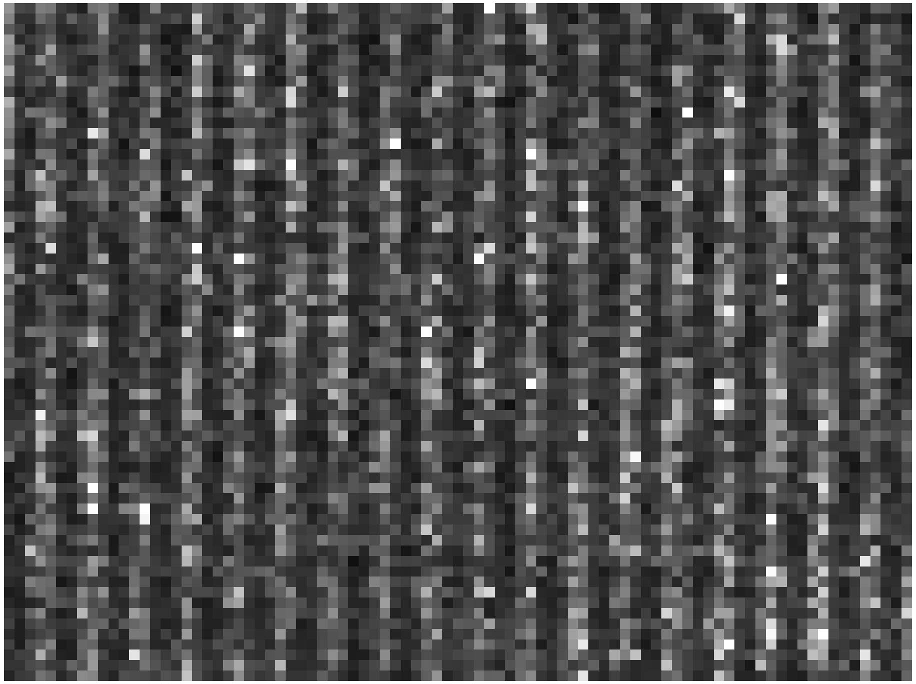
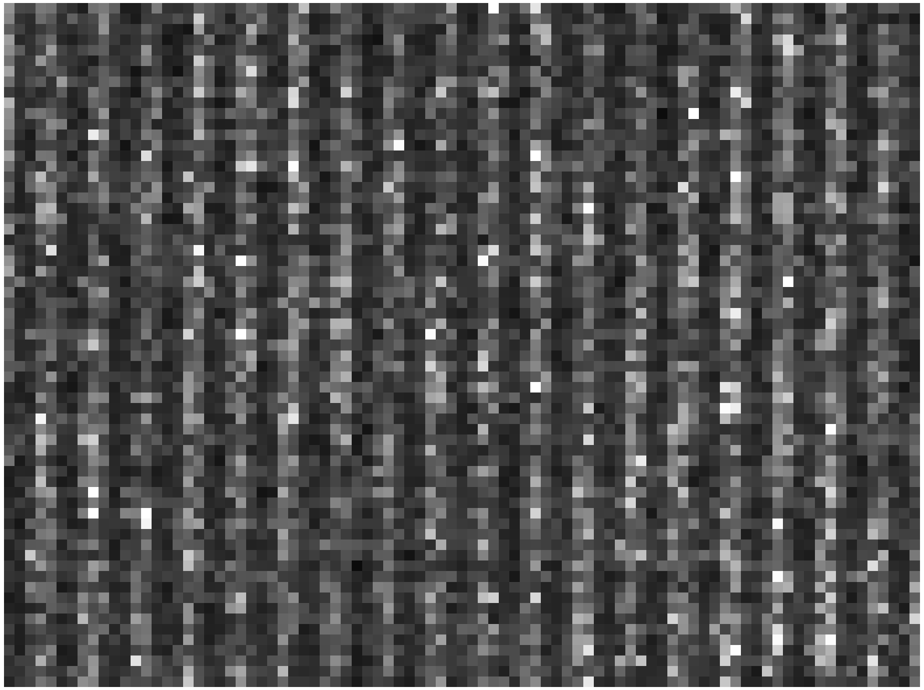
1 us pulse(s) with Dyoptyka mirror inactive



1 x 1 us pulse.
SCR 40.7%



25 x 1 us pulses, averaged.
SCR 40.7%

[SCR: 1 pulse == 25 pulses == CW with short coherence length == CW with long coherence length!]

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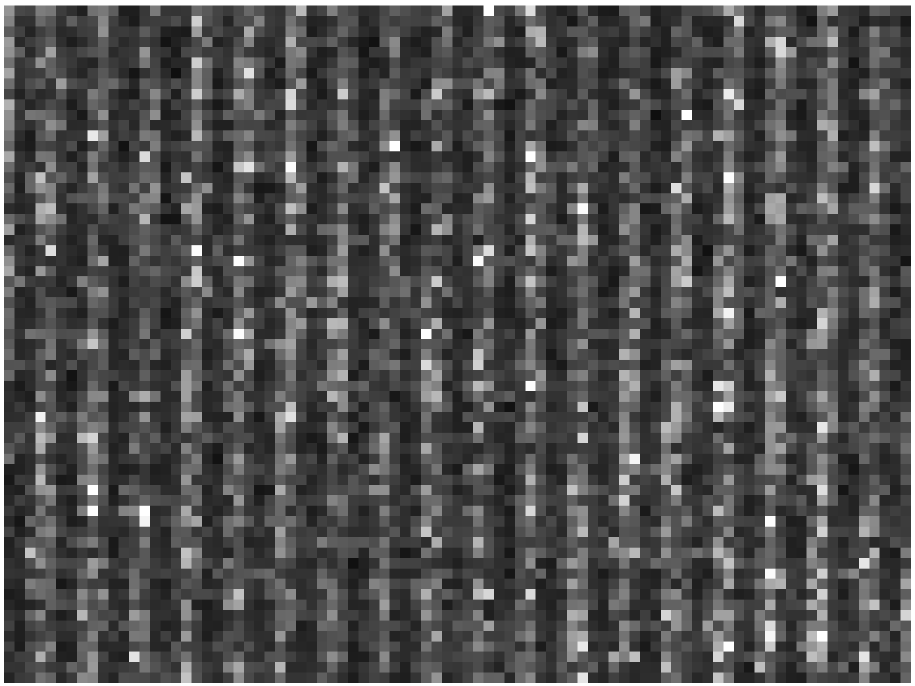
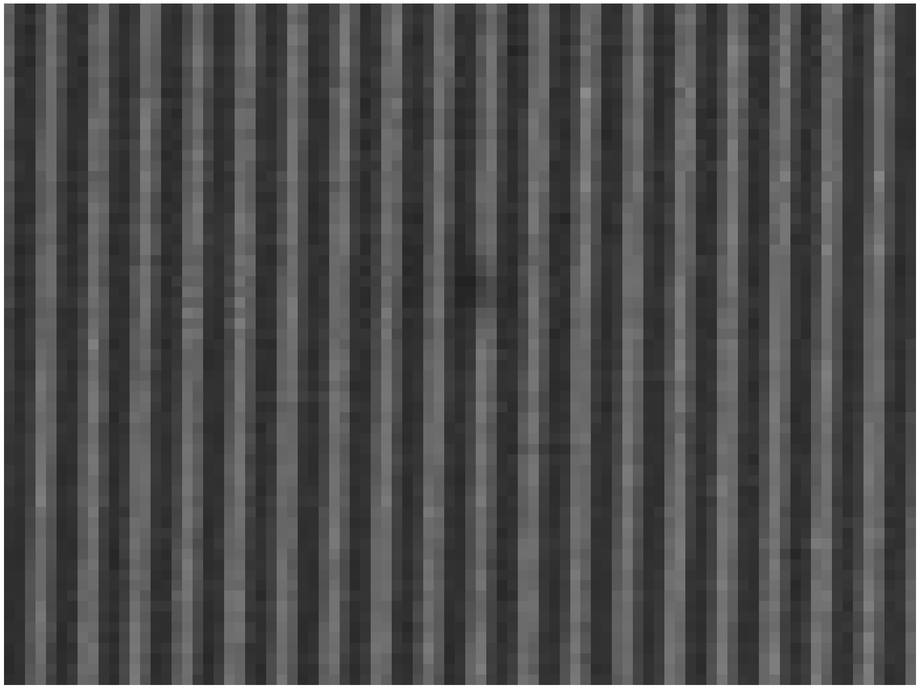
1 us pulse with deformable mirror inactive / active





Inactive: SCR 40.7%

Active: SCR 5.9%

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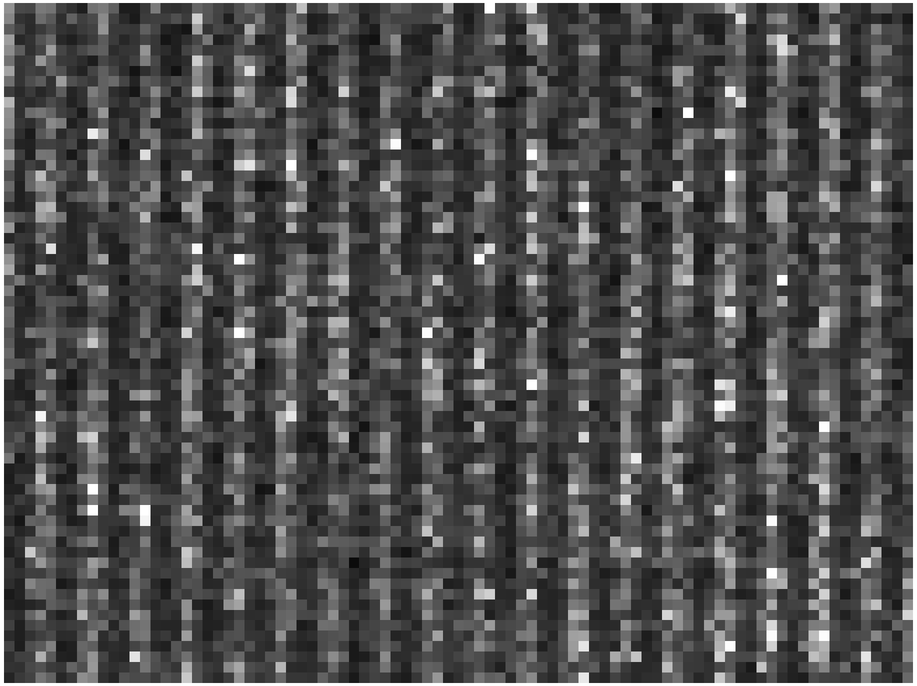
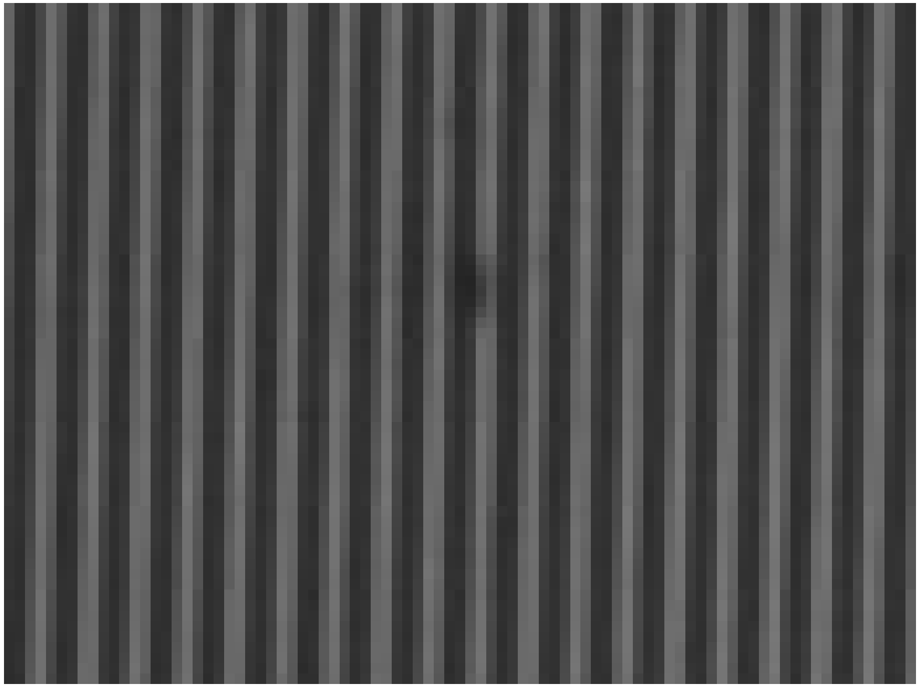
25 x 1 us pulses with deformable mirror inactive / active



Inactive: SCR 40.6%



Active: SCR 2.8%

[Active SCR: the same for both mirror operation modalities!]

Speckle Contrast Ratios

Pulses	DM Inactive	DM Active
1	40.72%	5.93%
1	40.75%	6.25%
1	40.65%	5.92%
1	40.70%	6.06%
1	40.82%	5.75%
1	40.73%	5.48%
1	40.85%	5.78%
1	40.84%	5.87%
1	40.71%	5.50%
4	40.63%	4.05%
9	40.60%	3.30%
16	40.58%	3.00%
25	40.56%	2.81%

Table 1: Speckle contrast ratios calculated for individual pulses (above) and sequences of pulses (below) with the deformable mirror (DM) inactive and active.

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Conclusions about Dyoptyka mirror performance with multiple pulses

- *Tip/tilt introduces sufficient angular separation between mutually-incoherent pulses from a single source to achieve same speckle reduction as from multiple sources.*
- *Because a larger f/# lens is required to allow appropriate angular separation, speckle reduction is equivalent between full N.A. and partial N.A. with tip/tilt operation modalities.*
- *So there's no benefit to speckle reduction.*
- *But power/energy efficiency, image contrast, and rainbow effect benefits may still apply.*

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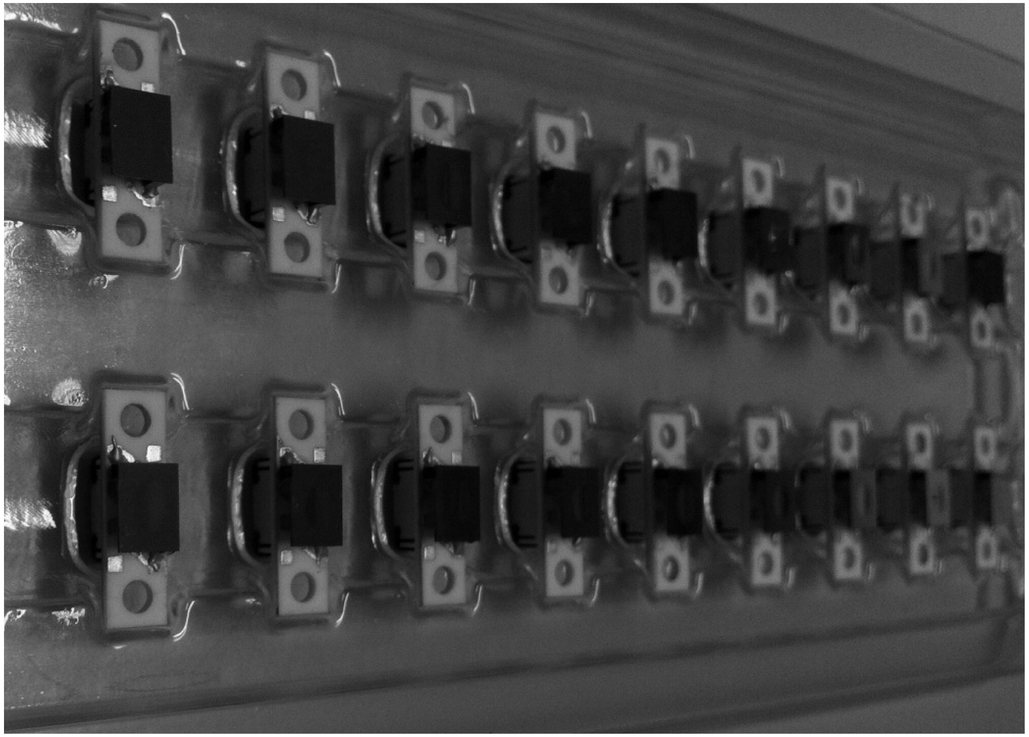
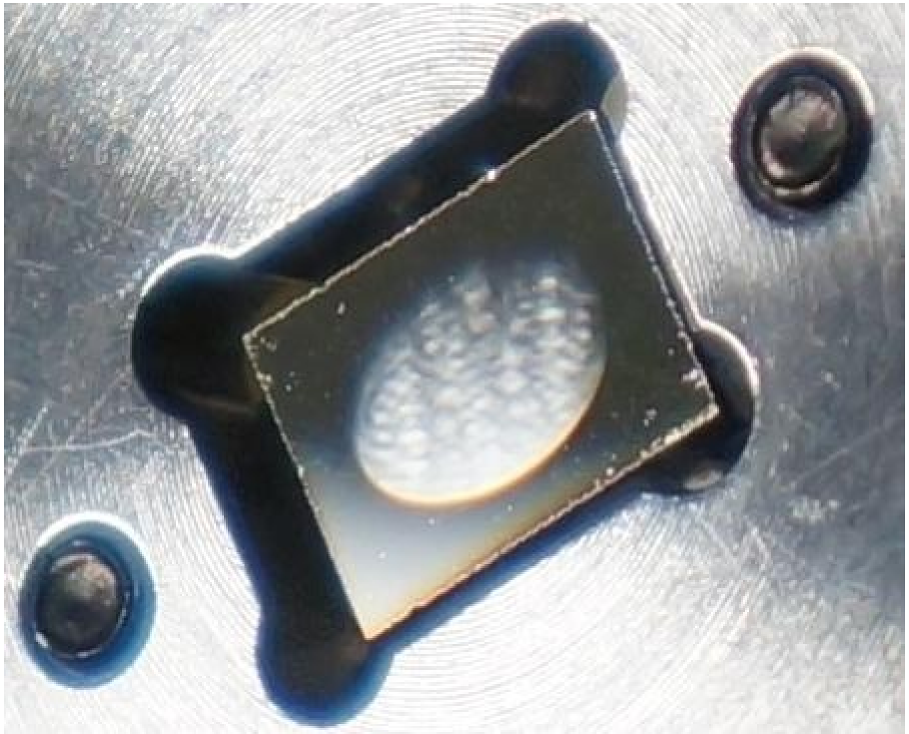
Thank You!





Questions?

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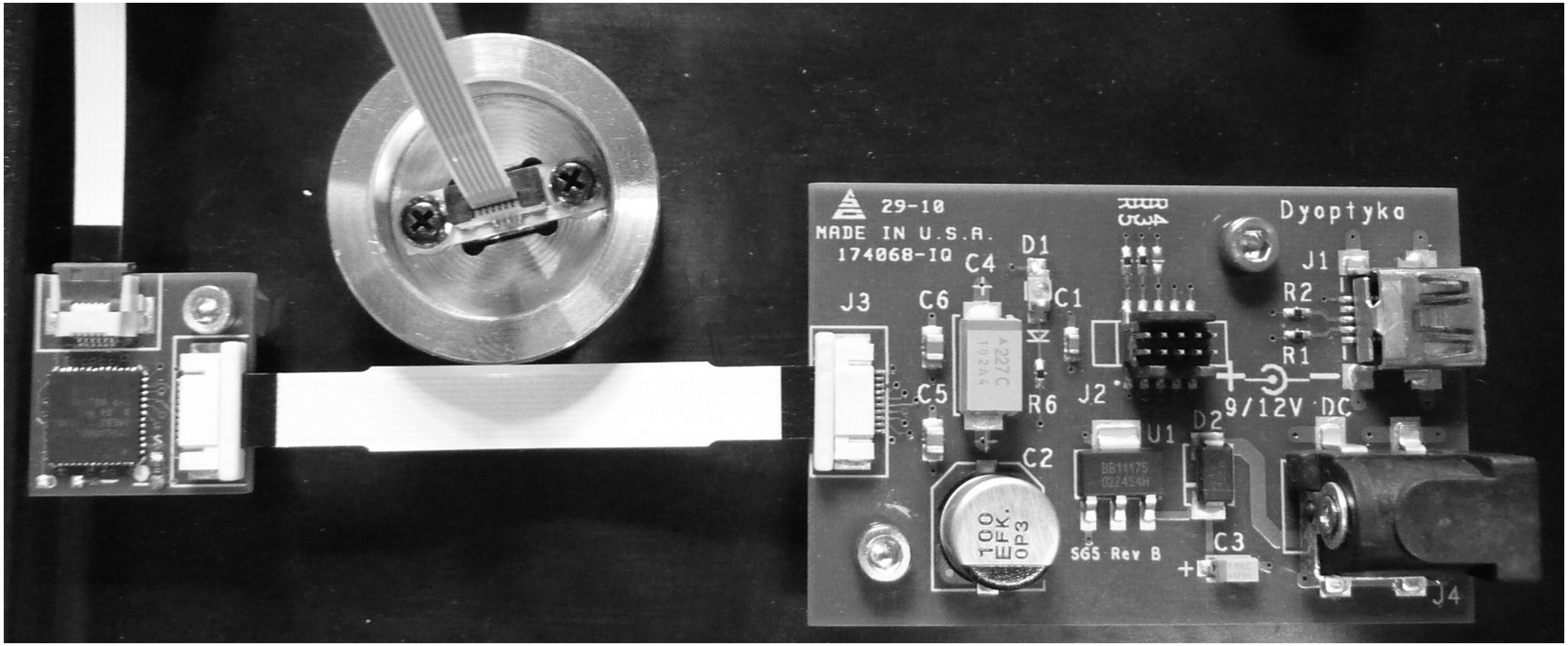
Availability



- *Evaluation systems with reconfigurable control electronics and PC-hosted reconfiguration software available now.*
- *Price is appropriate for consumer products in volumes as low as 1,000/month.*

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