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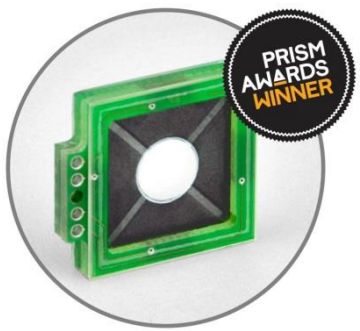

Compact and Reliable Speckle Reduction

Disclaimer: LSR-3000 Series (incl. LSR-5-17 and LSR-10-22) has been phased out as of July 21.

August 2017

Mark Ventura, Vice President Sales & Marketing

Optotune Switzerland AG | Bernstrasse 388 | CH-8953 Dietikon | Switzerland
Phone +41 58 856 3011 | www.optotune.com | sales@optotune.com

Agenda

- Introduction
- Active speckle reduction with CW lasers (oscillating diffusers)
  - Electroactive polymer based LSR
  - Reluctance force based LSR
  - Application examples
    - Light engine for laser projection
    - Micro/pico-projectors
    - Line generation
    - Fiber coupling
    - Microscopy
  - Available products

Optotune on one page

Established in 2008

Leader in tunable optics

27 sales partners in 30 countries

~70 employees in HQ in Zurich, Switzerland
~60 employees in Factory in Trnava, Slovakia

Two major businesses
- **Industrial**
- **Consumer**

Privately owned

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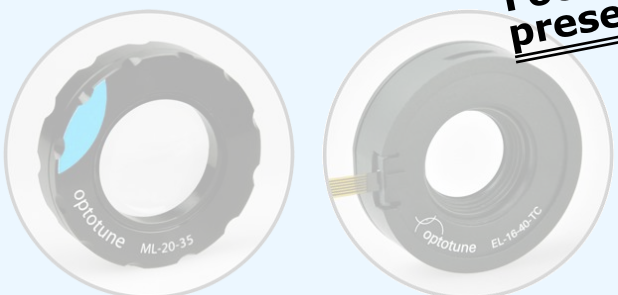
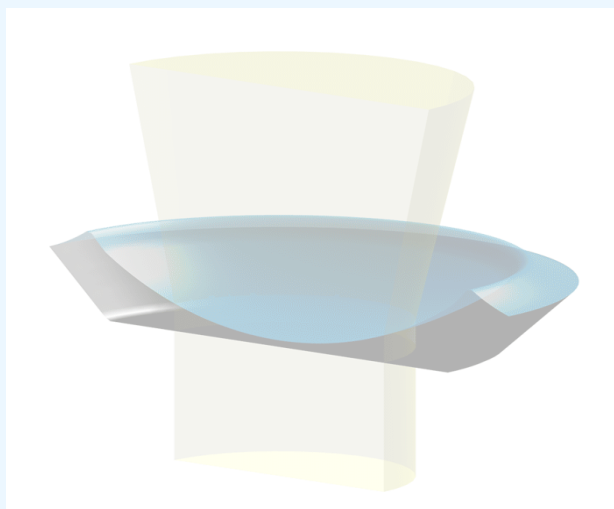
Optotune provides three core product lines

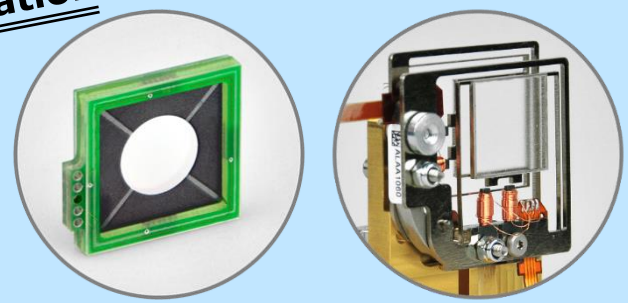
Focus tunable lenses

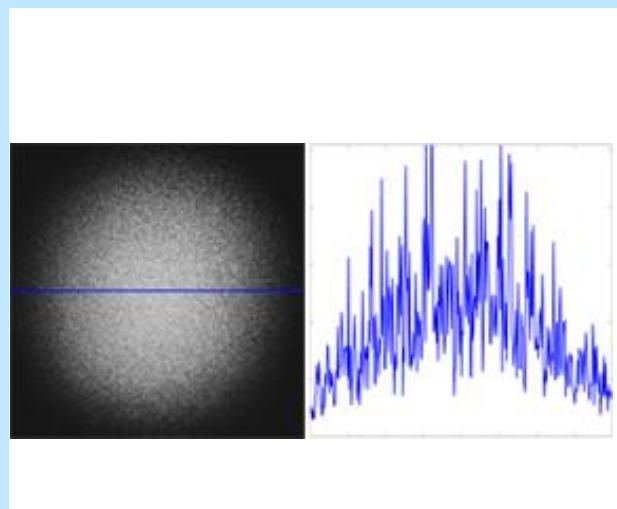




Laser speckle reducers

Focus of this presentation





Beam steering devices

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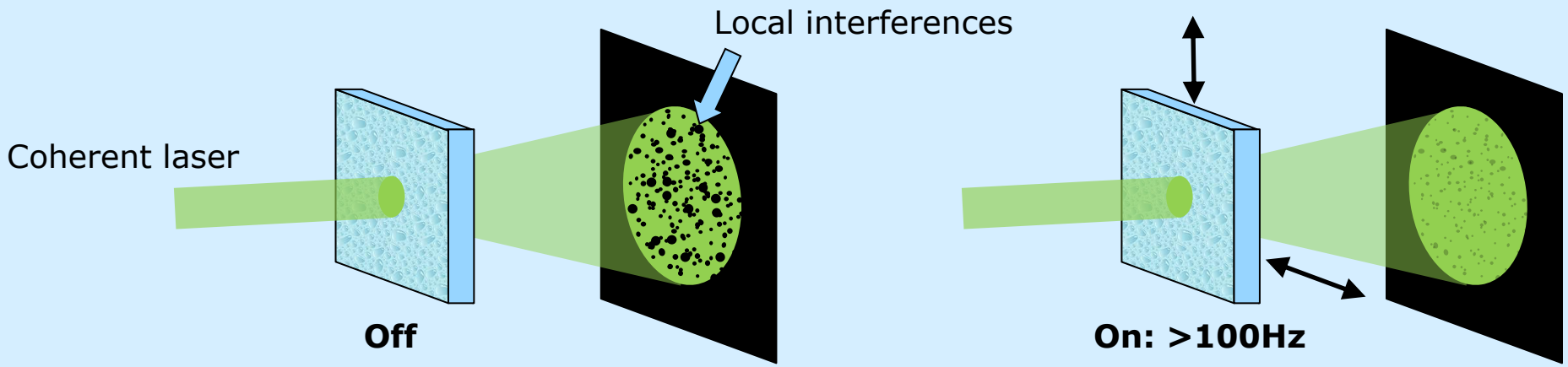
Speckle reduction principle: A moving diffuser is used to increase angular diversity

Principle



By moving a diffusor multiple speckle patterns are overlapped to reduce the perceived speckle noise

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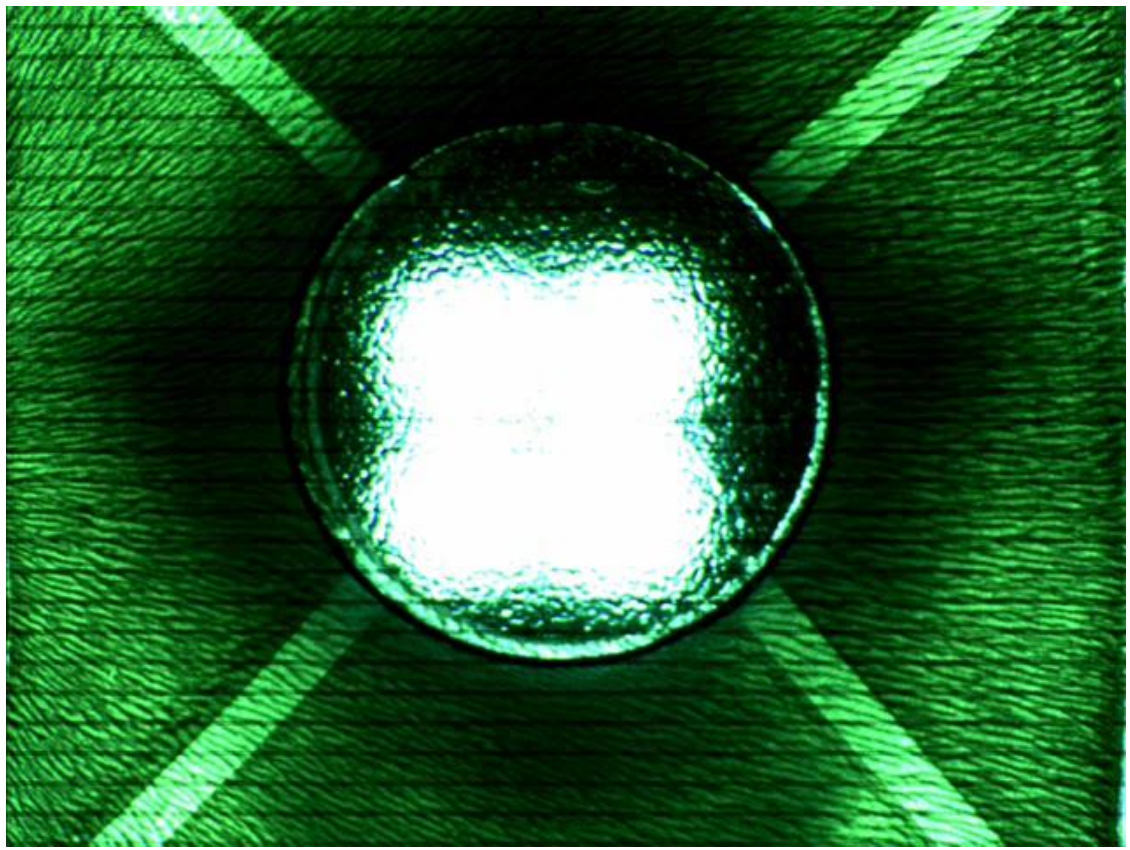
Electroactive polymer based LSR

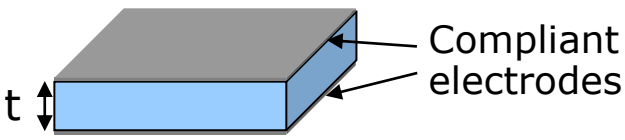
- Diffuser motion made visible with stroboscopic lighting



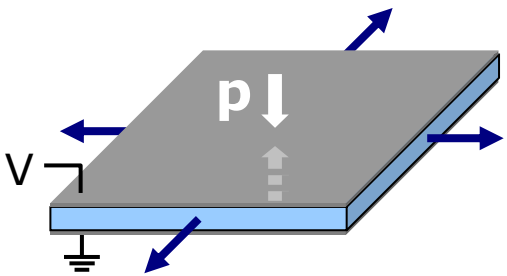
This video is available on www.optotune.com

Core technology: Electroactive polymers (EAPs)

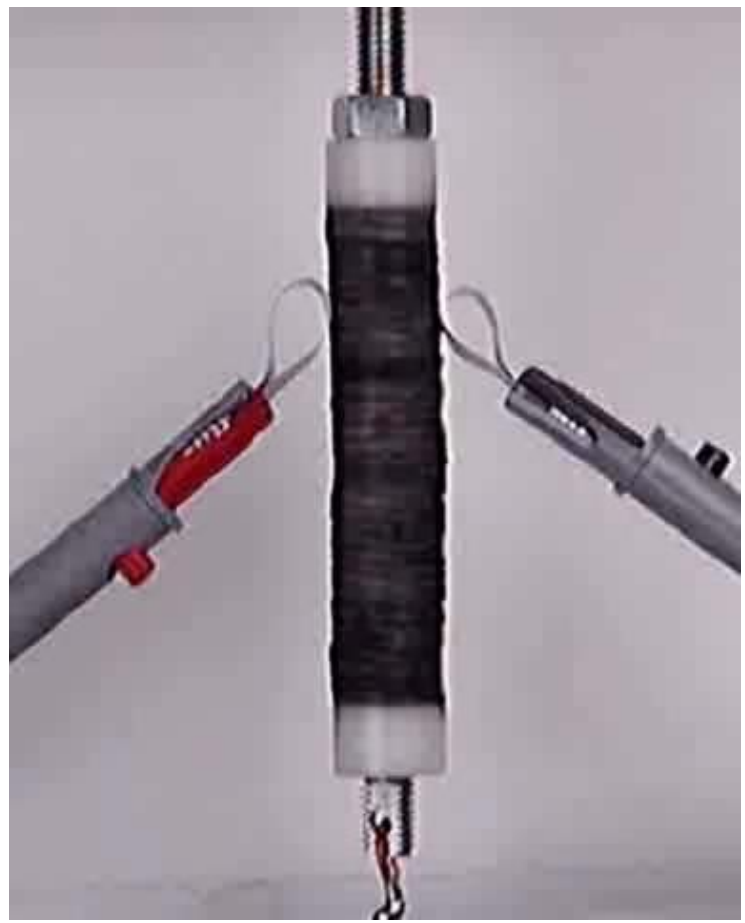
Voltage off



Voltage on



Deformation up to 20%



Advantages

- Large deformation
- Energy efficient
- Silent
- Highly precise

Applications

- Robotics
- Pumps
- Valves
- Energy harvesting

Optotune is first to apply EAPs in optics

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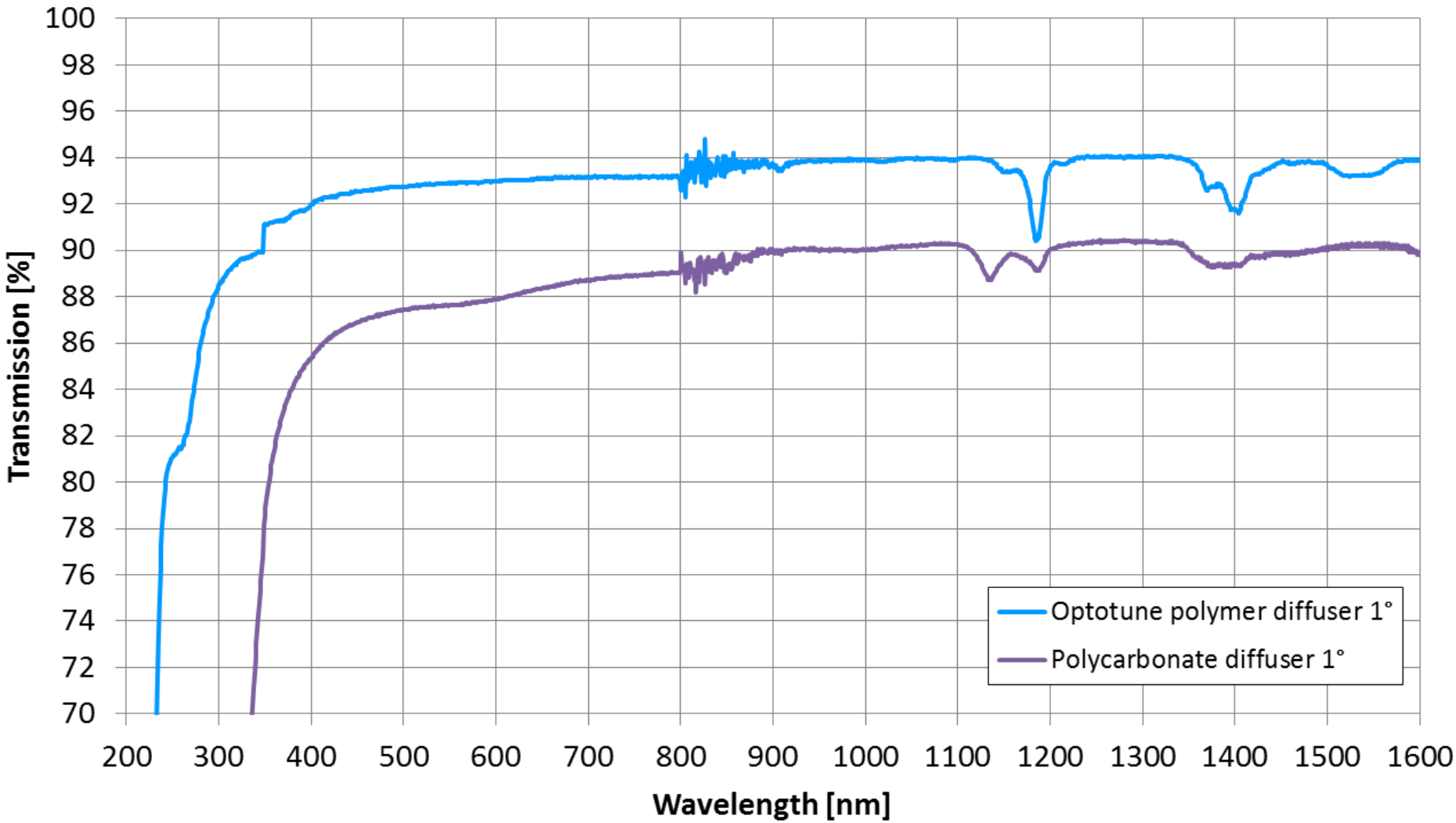
Optotune's proprietary polymers offer ~93% transmission @ >300W/cm² damage threshold



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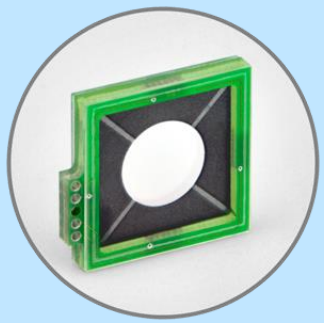
Comparison of EAP-based LSR & spinning disk

EAP-based LSR



+ Compact (1mm thickness possible, only a few mm added laterally)
+ 2D movement
+ Light weight
+ Vibration-free & silent
– High voltage (300V, but low power)
– Only thin & light diffusors
– Limited in size (10mm CA)
– Polymer membrane cannot be AR coated

Spinning disk diffuser

+ Off-the-shelf component
+ Well established technology
– Large size (circular disk & motor)
– Diffuser area on disk is factors larger than actually needed (expensive)
– Vibrations/noise
– Reliability issues due to mechanics
– Not suitable with flat top or elliptic diffusor

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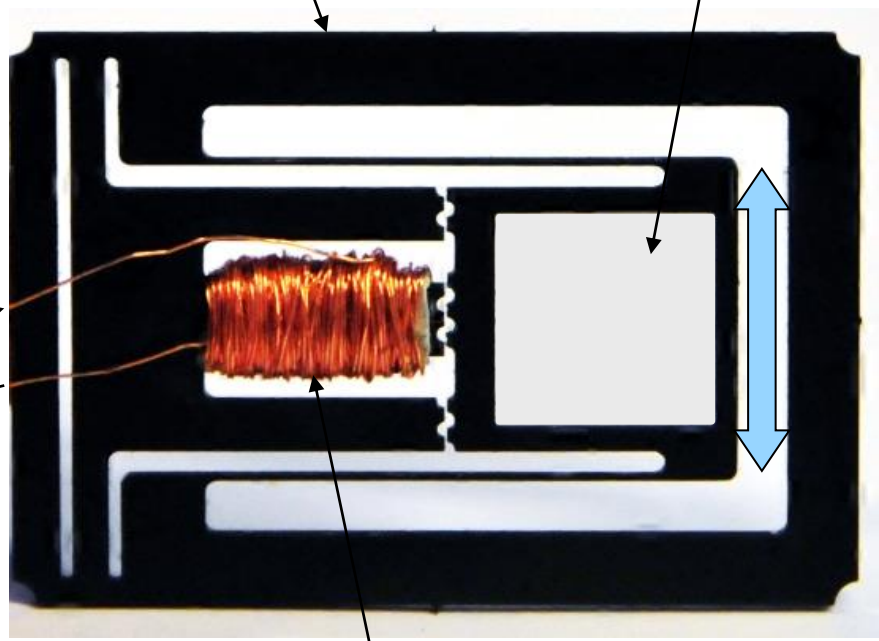
LSR based on reluctance force actuator

Thin steel structure

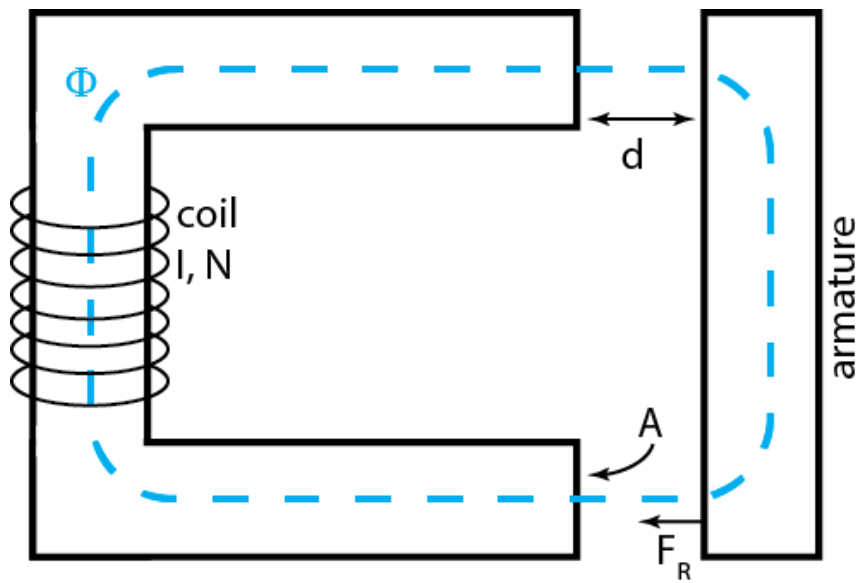
Diffuser of any material



Low voltage AC current

Coil

$$F_R = \frac{1}{2}\mu_0 A \frac{I^2 N^2}{d^2}$$



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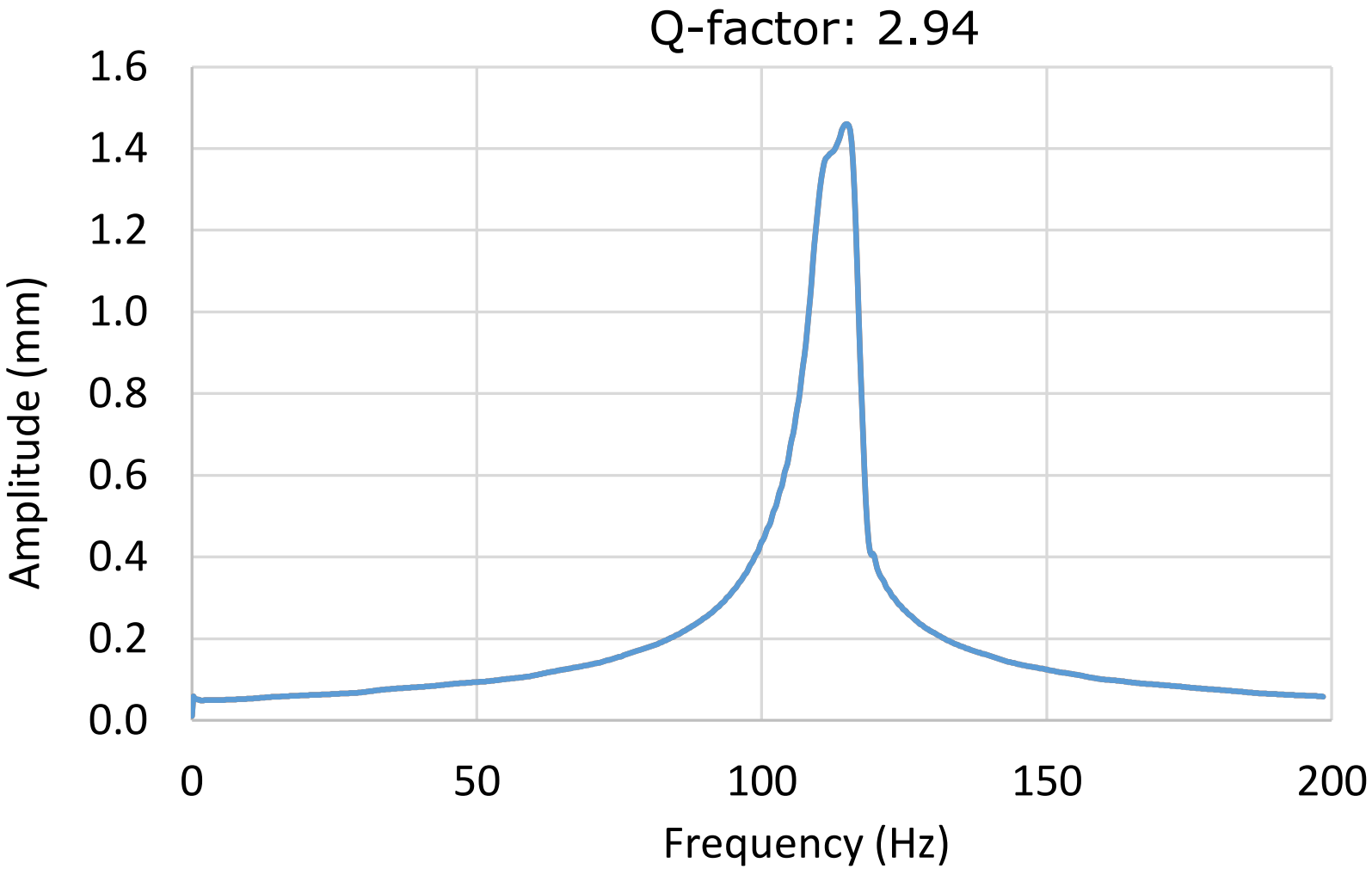
Very high Q-factor allows for large amplitude at low power



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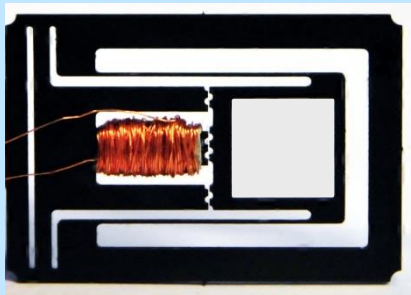
Comparison reluctance force LSR & spinning disk

Reluctance force LSR

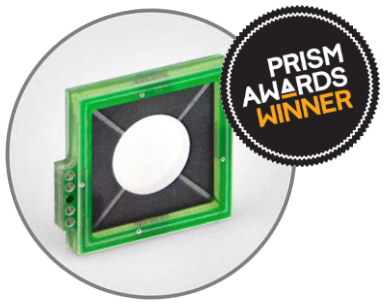


+ Compact
+ Very large diffusers possible (HUD)
+ Long lifetime (no friction)
+ Withstands harsh environments
+ Low power (high Q-factor)
+ Low cost
– Some vibration might be transferred (depending on mechanical mount)
– 1D linear movement (2D effect if 2 LSR are combined)

Spinning disk diffuser

+ Off-the-shelf component
+ Well established technology
– Large size (circular disk & motor)
– Diffuser area on disk is factors larger than actually needed (expensive)
– Not suitable with flat top or elliptic diffusor
– Vibrations/noise
– Reliability issues due to mechanics

Comparison of EAP & reluctance force-based LSR

	EAP-based LSR	Reluctance force-based LSR
		
Aperture	5 or 10 mm	18.5x18.5 mm
Diffuser type	Optotune polymer	Glass or polycarbonate
Transmission	93%	>98%
Oscillation type	2D (circular)	1D (linear)
Oscillation amplitude	300 um	800 um
Resonant frequency	300 or 180 Hz	~120 Hz (depends on diffuser weight)
Weight	3g	11g
Vibrations	None	Depends on mechanical mount
Cover glasses	Required	None
Operating lifetime	>2000h	>20'000
Electronics	5 VDC (EAP is pulsed with 300V)	5 VDC (coils are pulsed with current)

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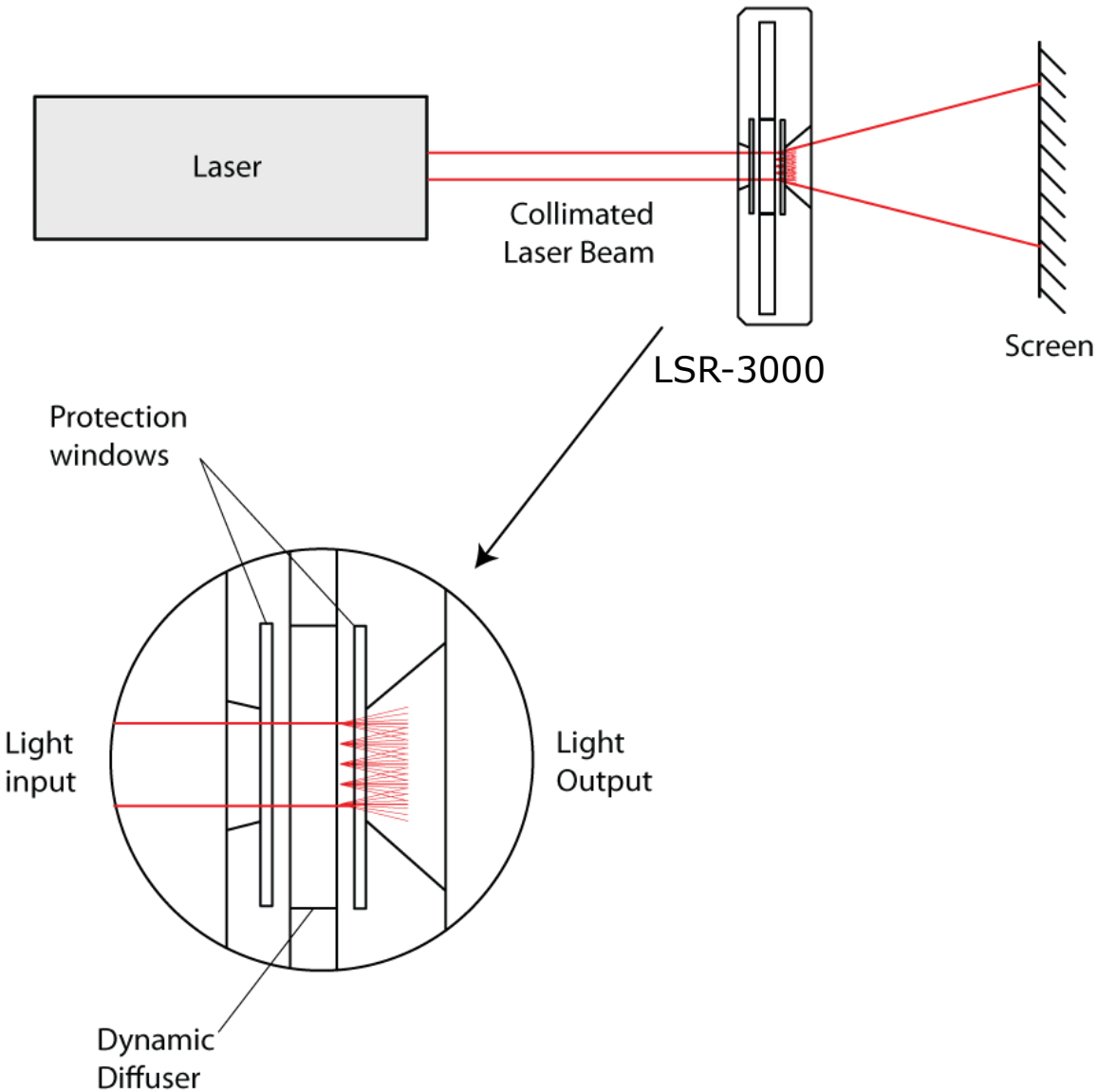
The issue of using diffusers



- Diffuser acts as a large number of point sources, each with the NA of the diffuser angle

  → increase in etendue

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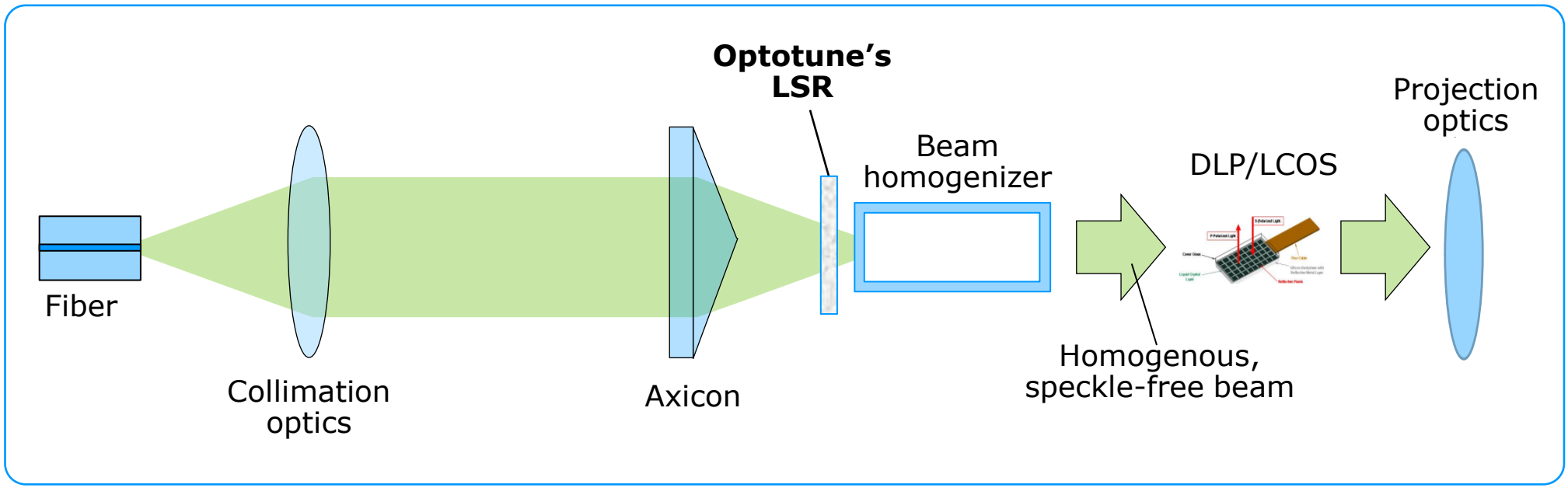
Example: Light engine for laser projector



- Effective speckle reduction has been shown using
  - an axicon as a focusing lens
  - Optotune's LSR
  - directly followed by a beam homogenizer
- Such a setup is compact, cost-saving and easy to align

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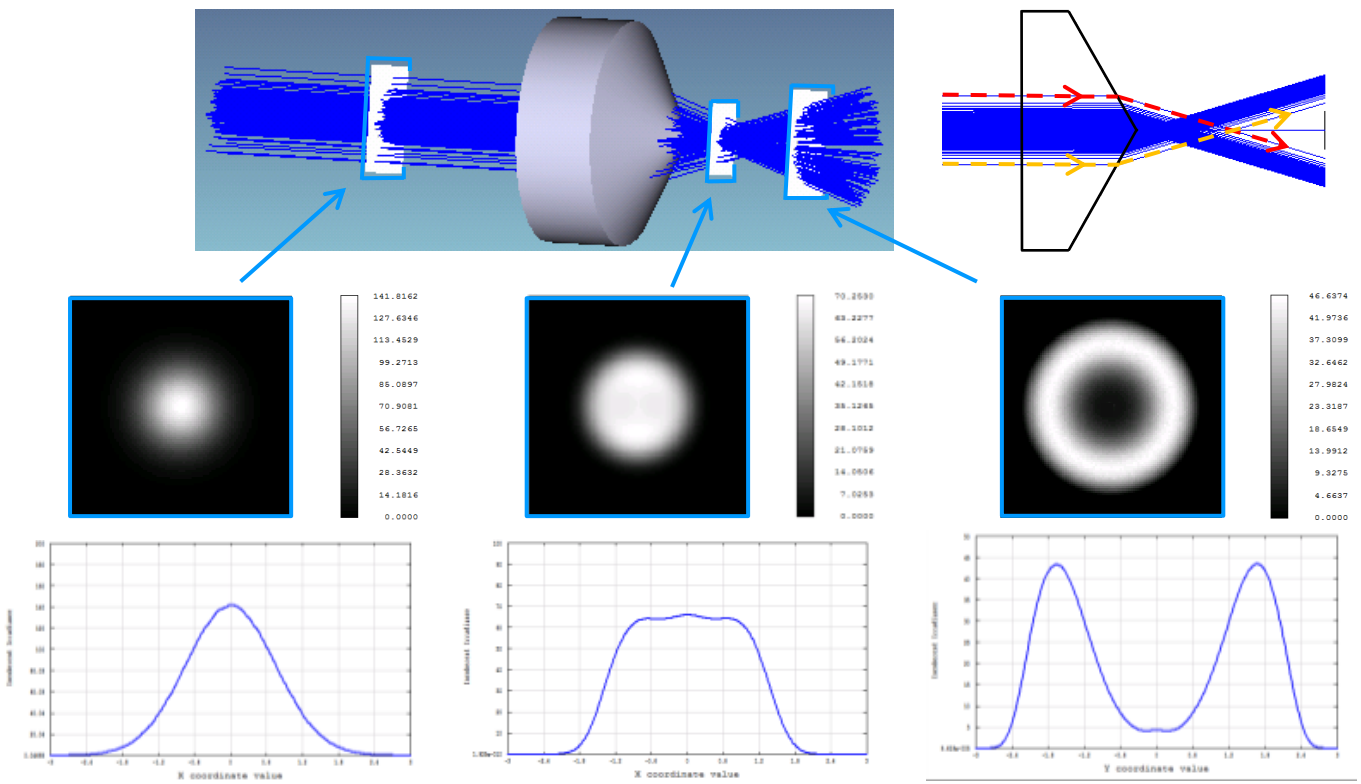
Benefits of an axicon for speckle-reduction

- Goal: Generate a homogenous, speckle-free beam before DLP/LCOS
- For optimal speckle reduction, a uniform angle distribution is beneficial
- However, most lasers have a Gaussian beam profile



Flat intensity AND angular distribution

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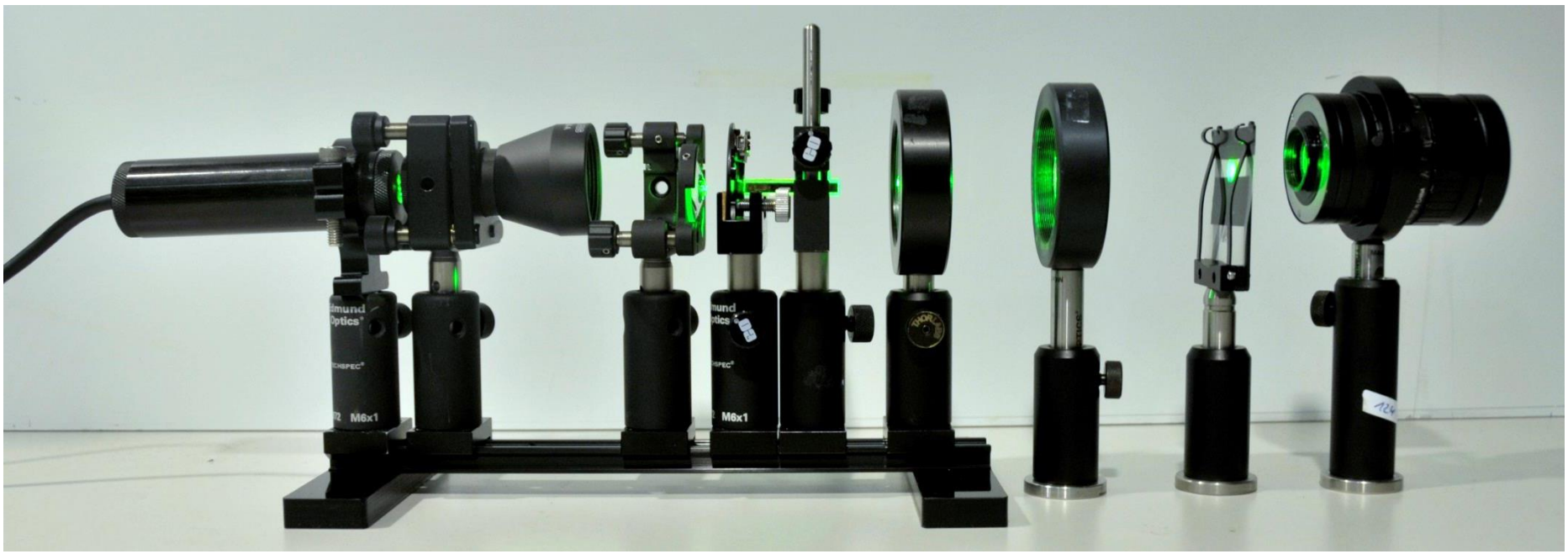
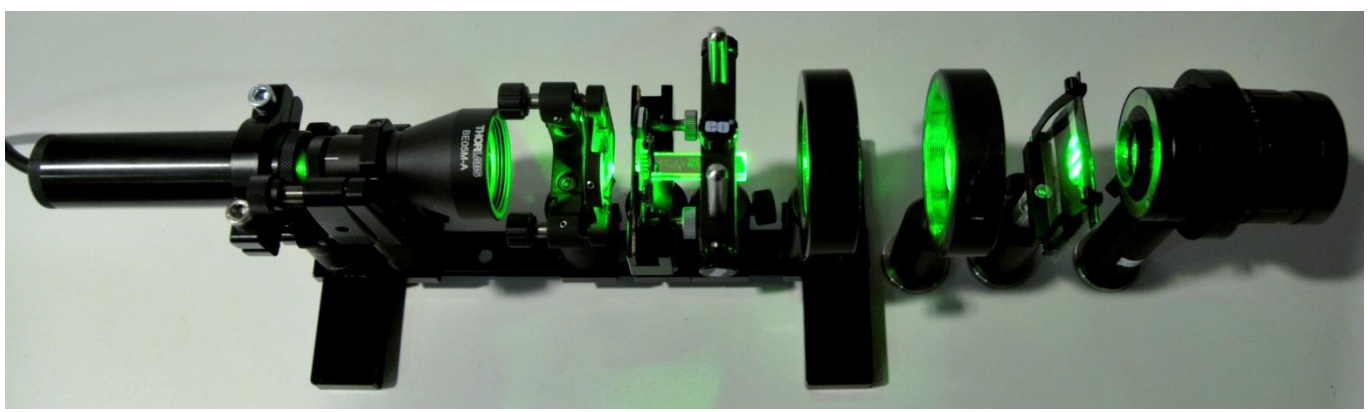
Exemplary setup (1/2)





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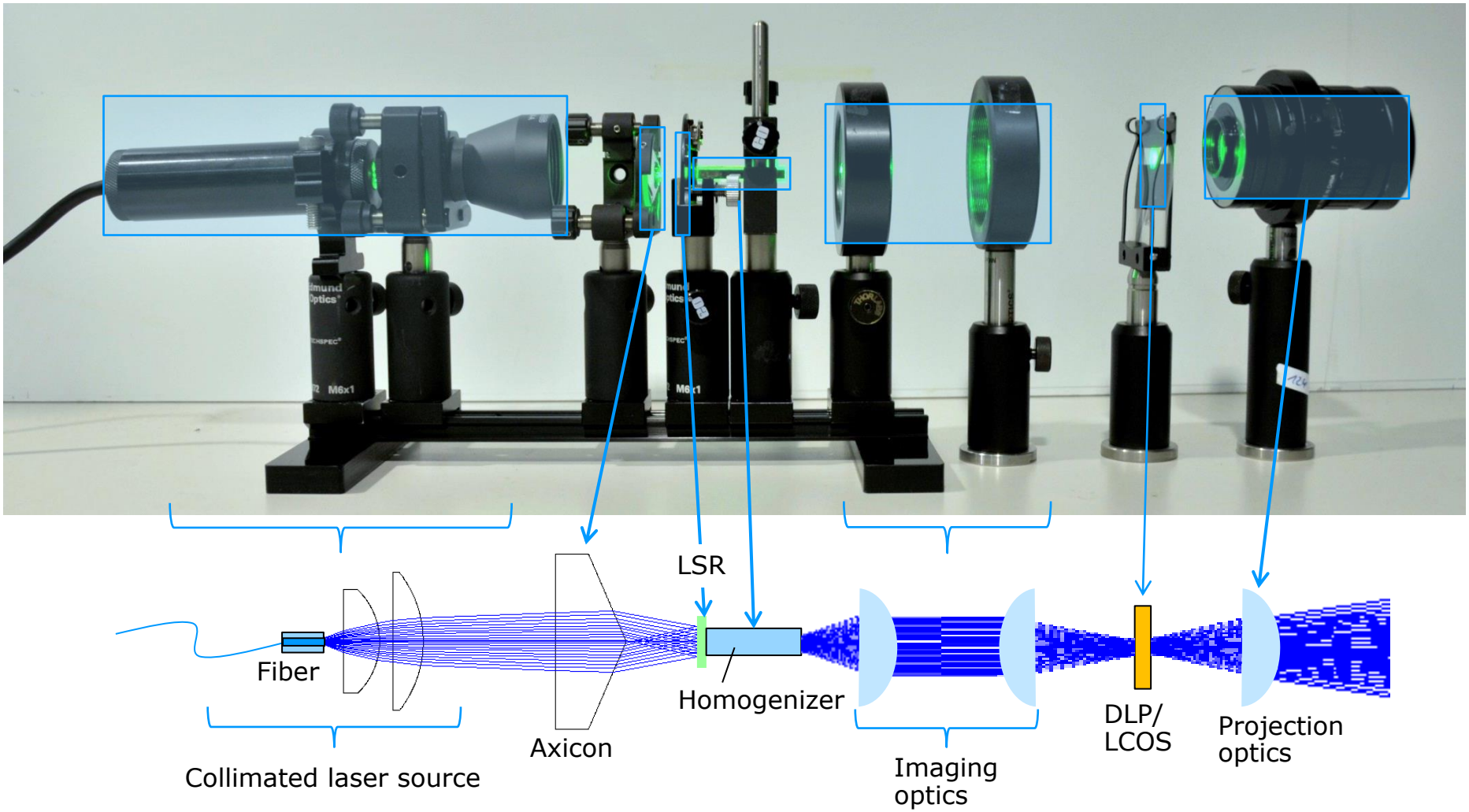
Exemplary setup (2/2)



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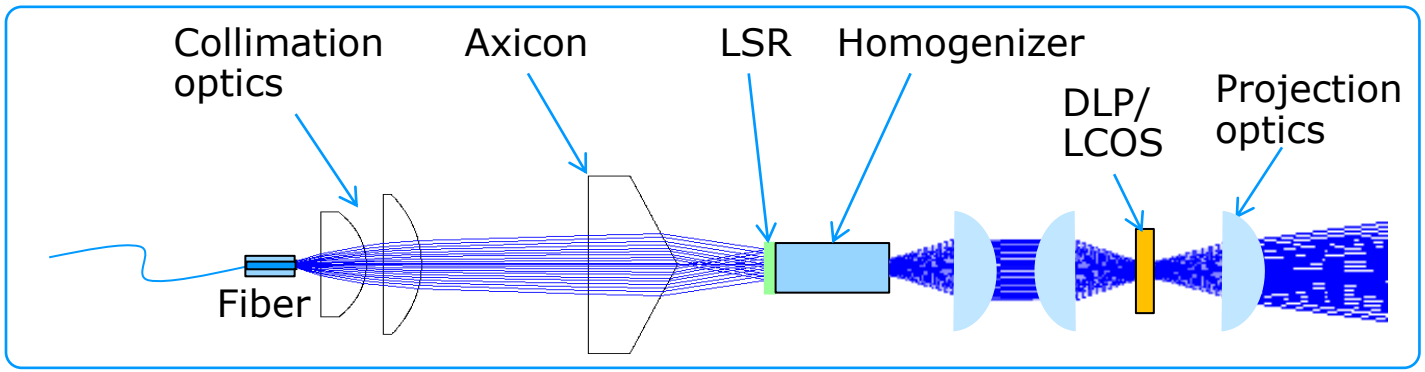
Design guidelines

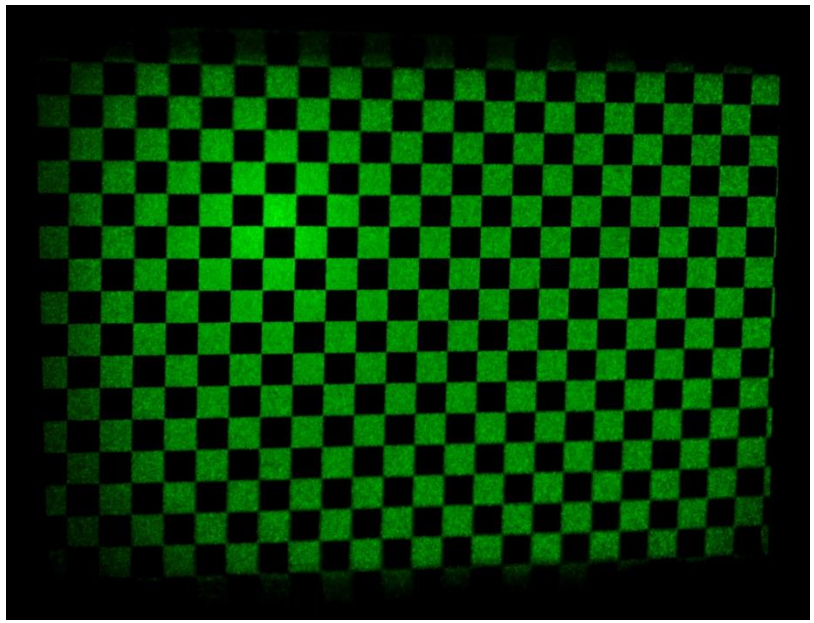


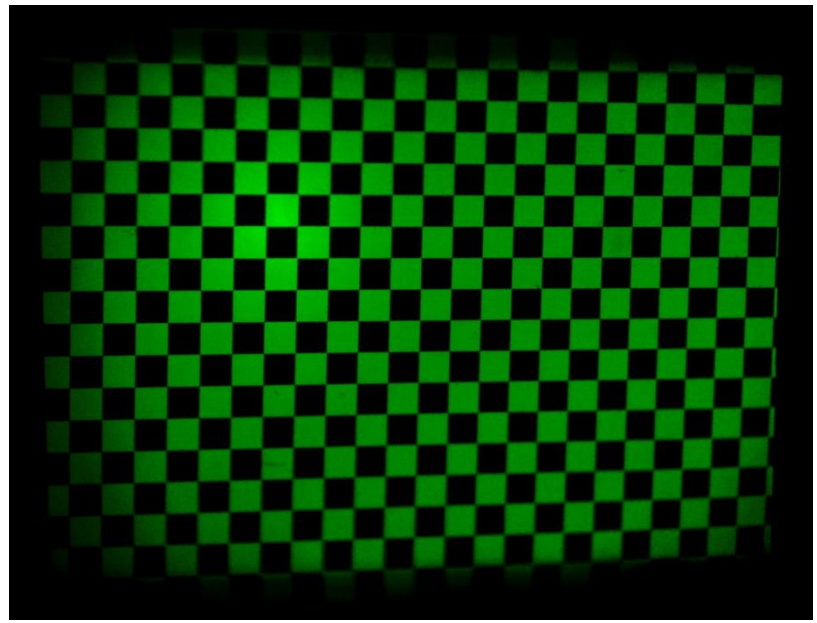
- The LSR should be placed as close as possible to the homogenizer rod
- The spot on the LSR should be slightly smaller than the aperture of the homogenizer rod
- The collimation optics should be chosen such that the collimated laser beam diameter is ~2 times the desired focus spot diameter
- The apex angle Θ* of the axicon should be chosen such that the angle incident on the LSR α_{in} fulfills: $\sqrt{{\alpha_{\mathrm{in}}}^2 + {\alpha_{\mathrm{LSR}}}^2} < \alpha_{\mathrm{accept.}}$;
  α_{LSR}: diffusion angle LSR, α_{in}: acceptance angle homogenizer

*$\Theta/2=90°-2\alpha_{\mathrm{in}}$

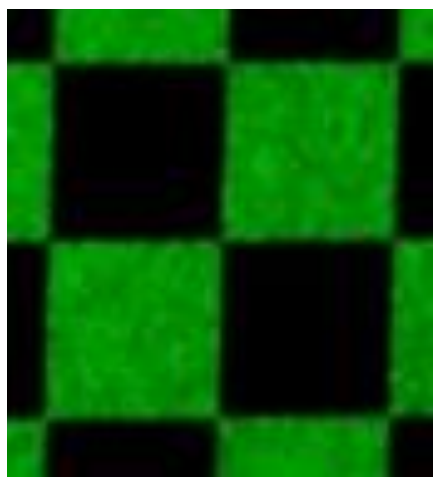
Exemplary performance of a despeckled laser projection system (1/2)

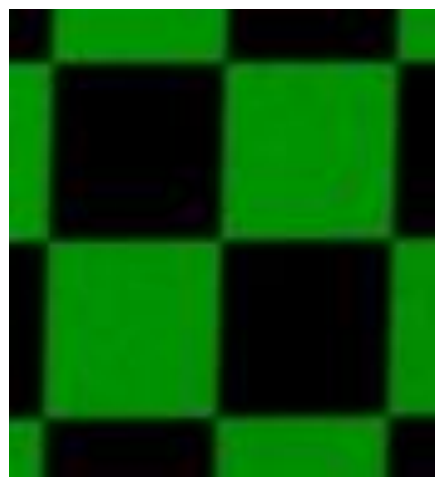
LSR off





LSR on



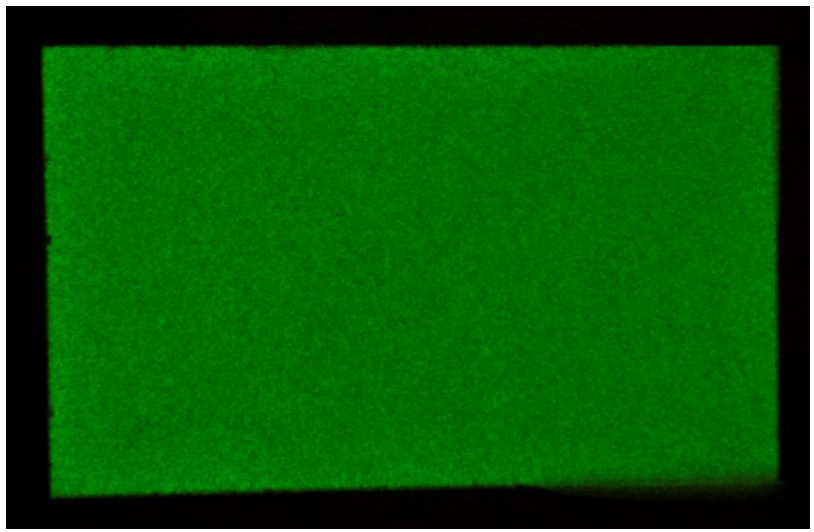


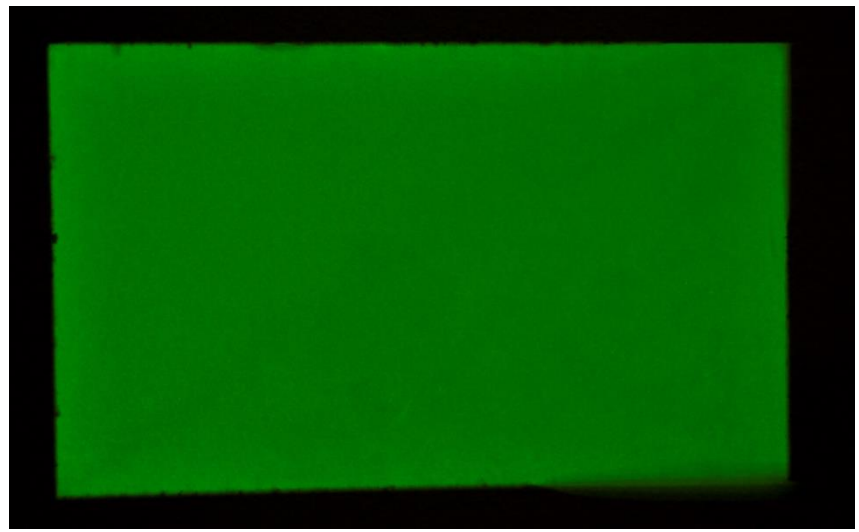
Camera settings:

- F-stop: f/8
- Exposure: 1/20 sec
- Focal length: 24 mm

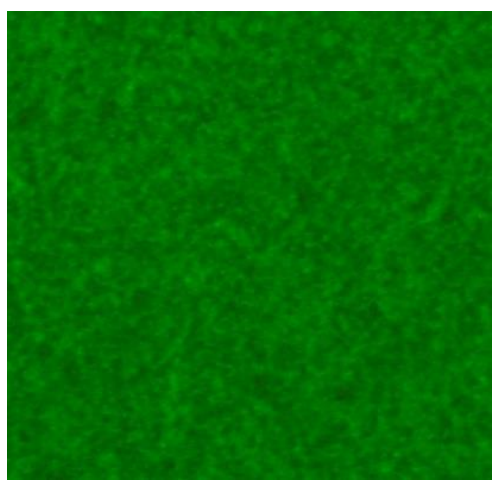
Exemplary performance of a despeckled laser projection system (2/2)

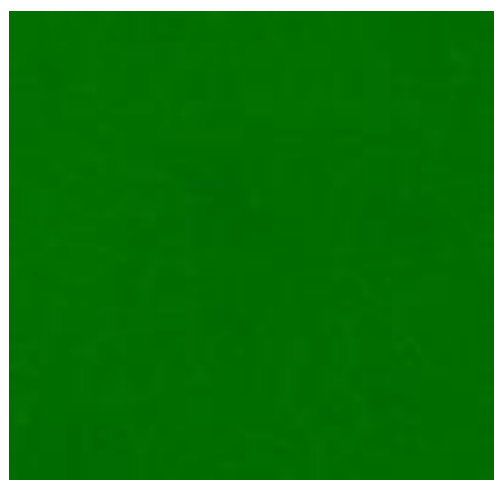
LSR off





LSR on





Camera settings:

- F-stop: f/4.2
- Exposure: 1/20 sec
- Focal length: 34 mm

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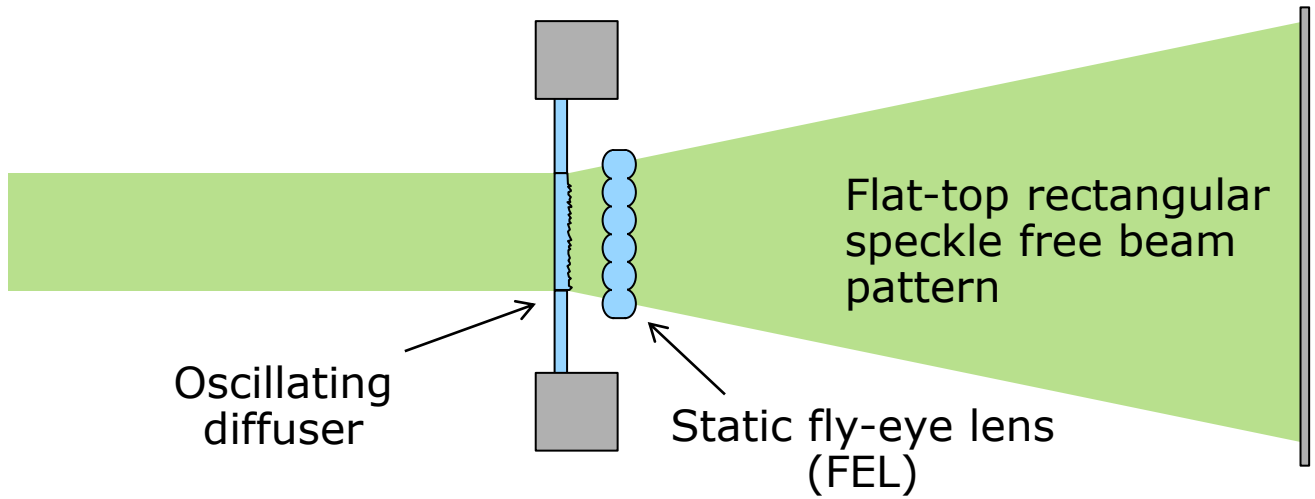
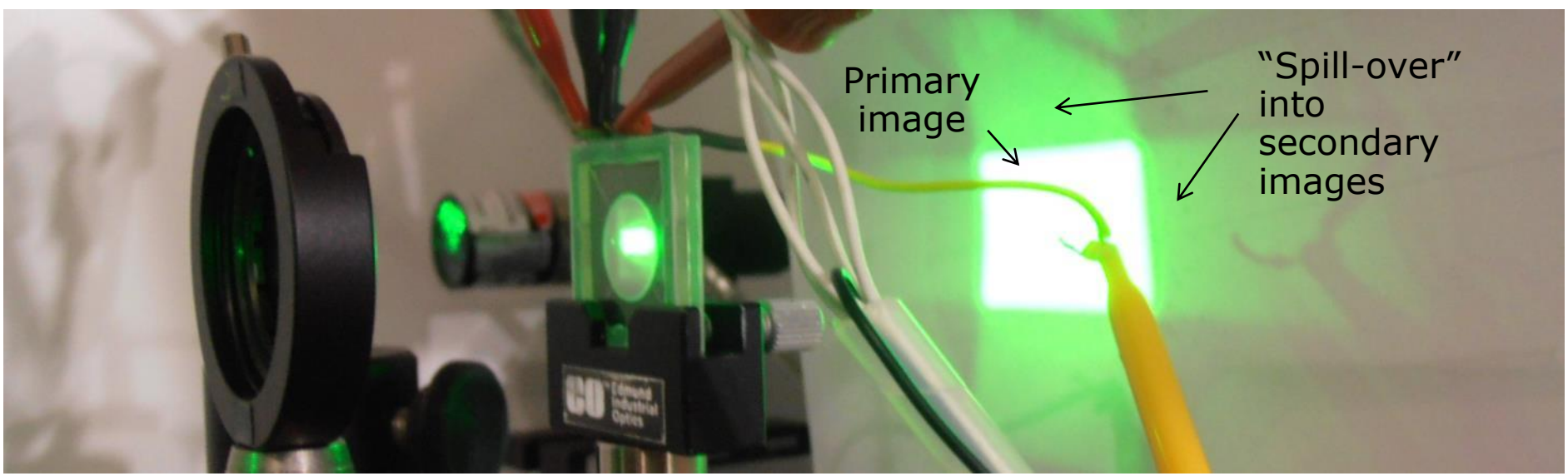
In compact projectors FELs can be used right after the diffuser



For high optical efficiency (minimum "spill-over"): Diffuser Angle <= acceptance angle of FEL



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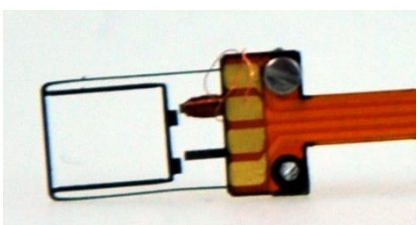
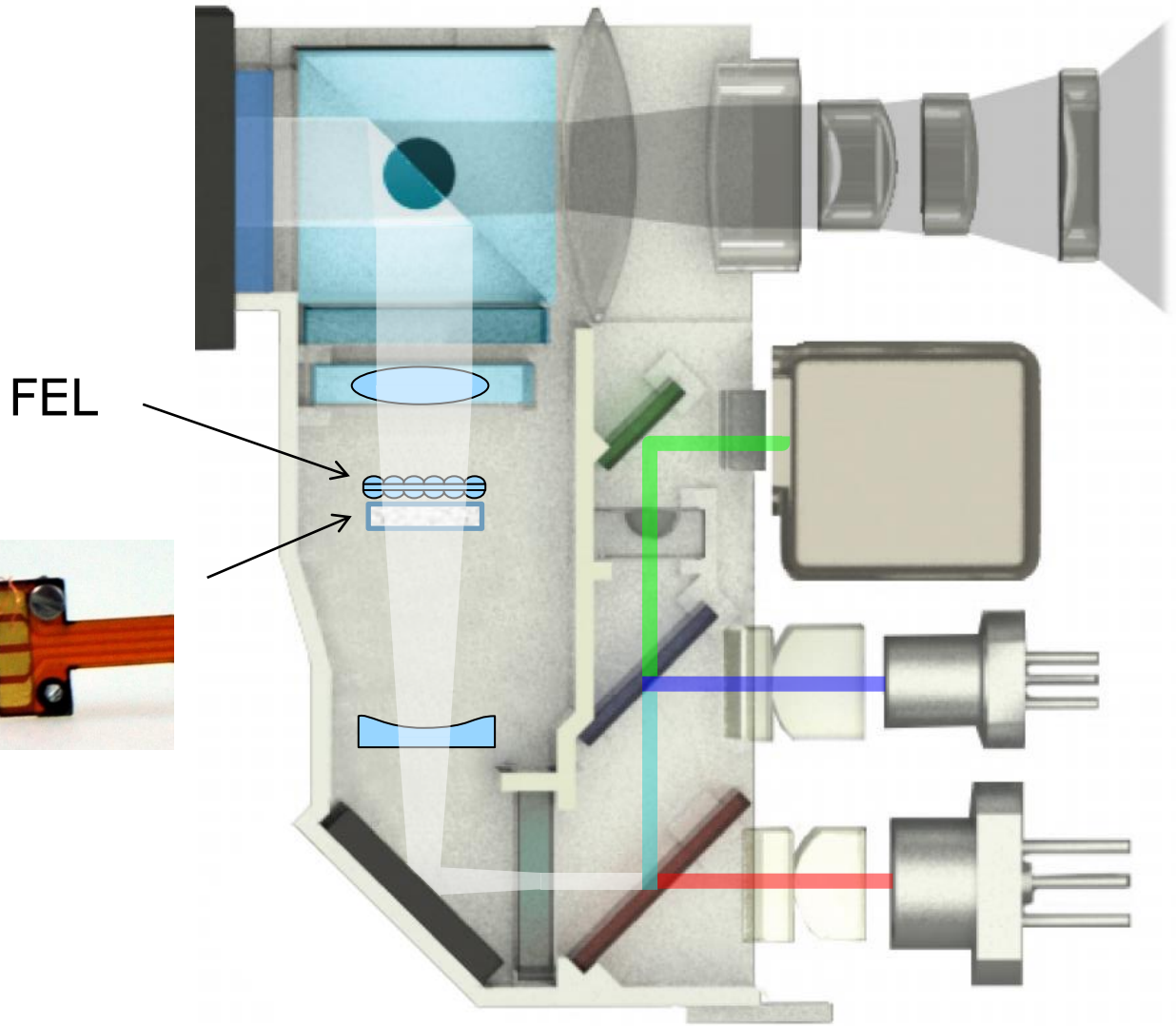
Typical configuration for pico-projectors





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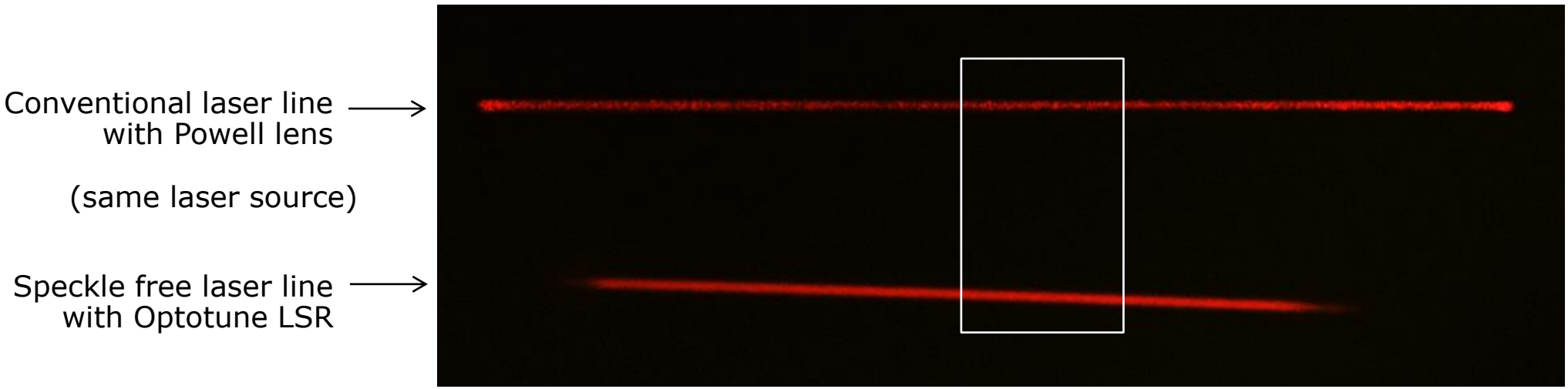
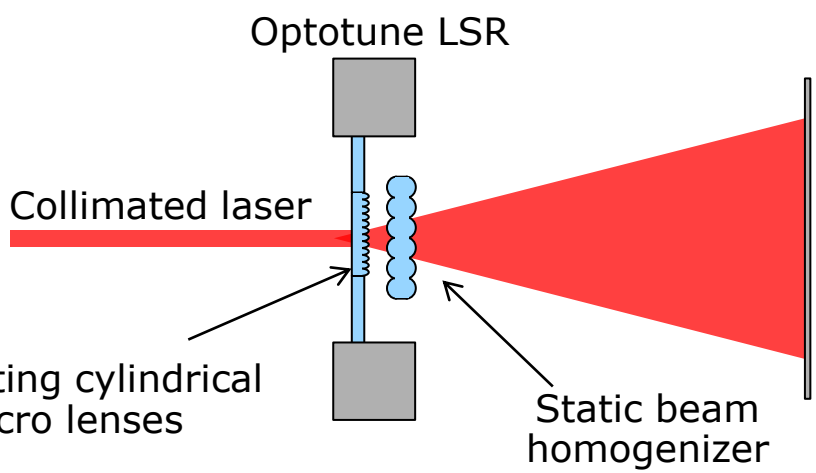
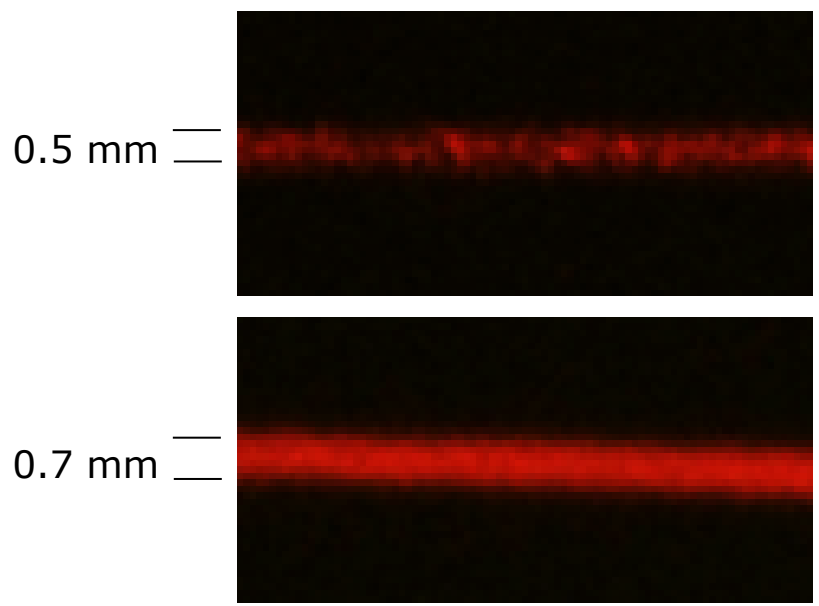
Speckle free uniform laser line (compared to standard line with Powell lens)







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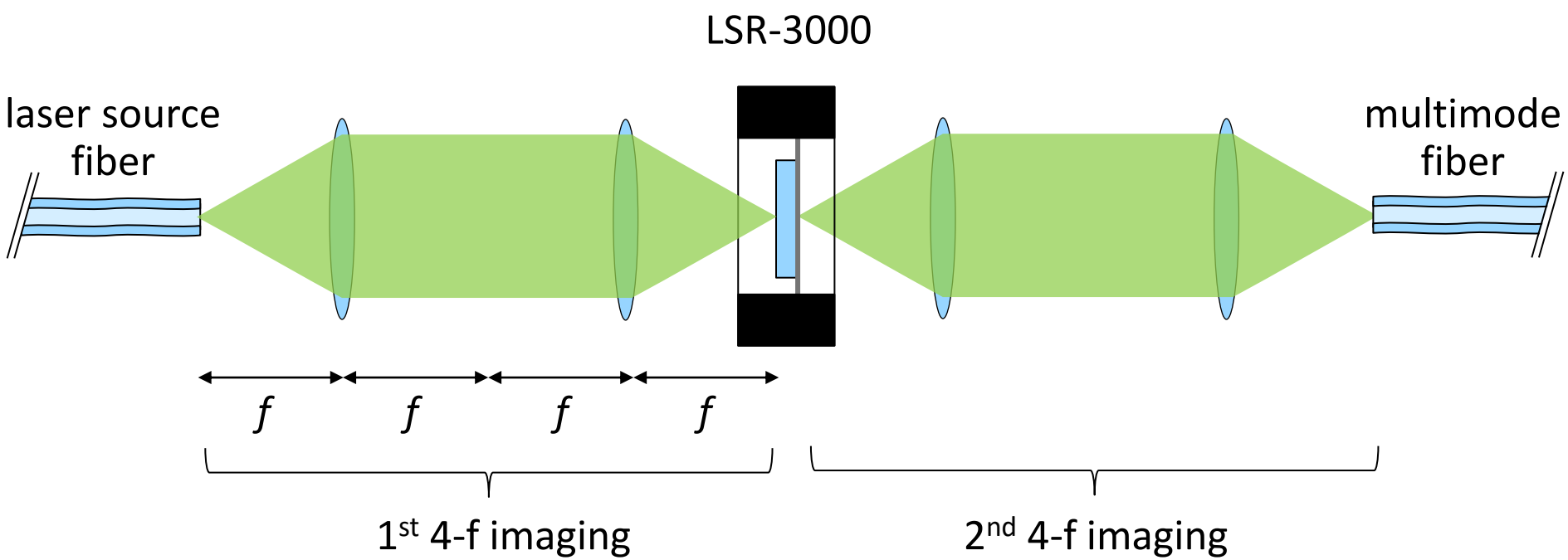
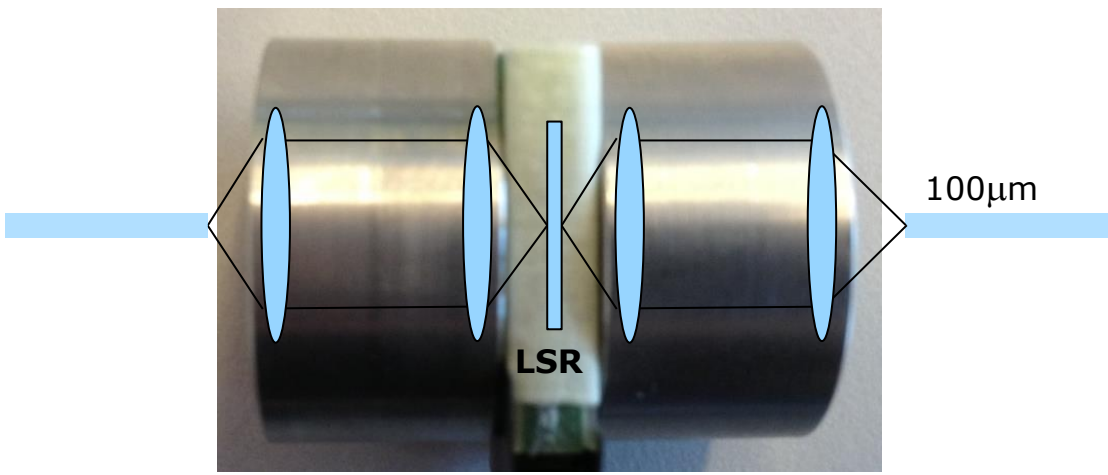
Fiber coupling:
Best layout is to image a spot on the diffuser

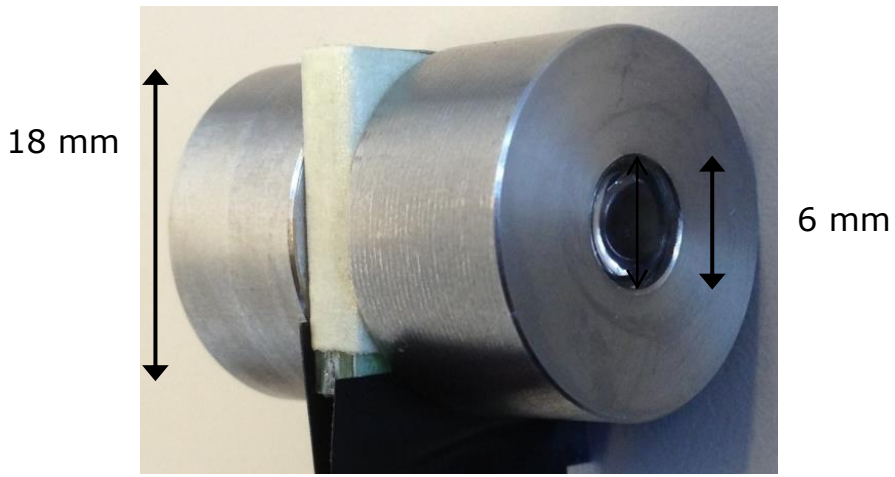


- Spot size on diffuser < diameter of fiber core
- No static diffuser allowed

Good speckle reduction shown with 75% efficiency

- Speckle reducer: LSR-5-17-17S-VIS with single 17° diffuser
- Fiber: 100µm core, 0.5 NA
- Off-the-shelf glass aspheres





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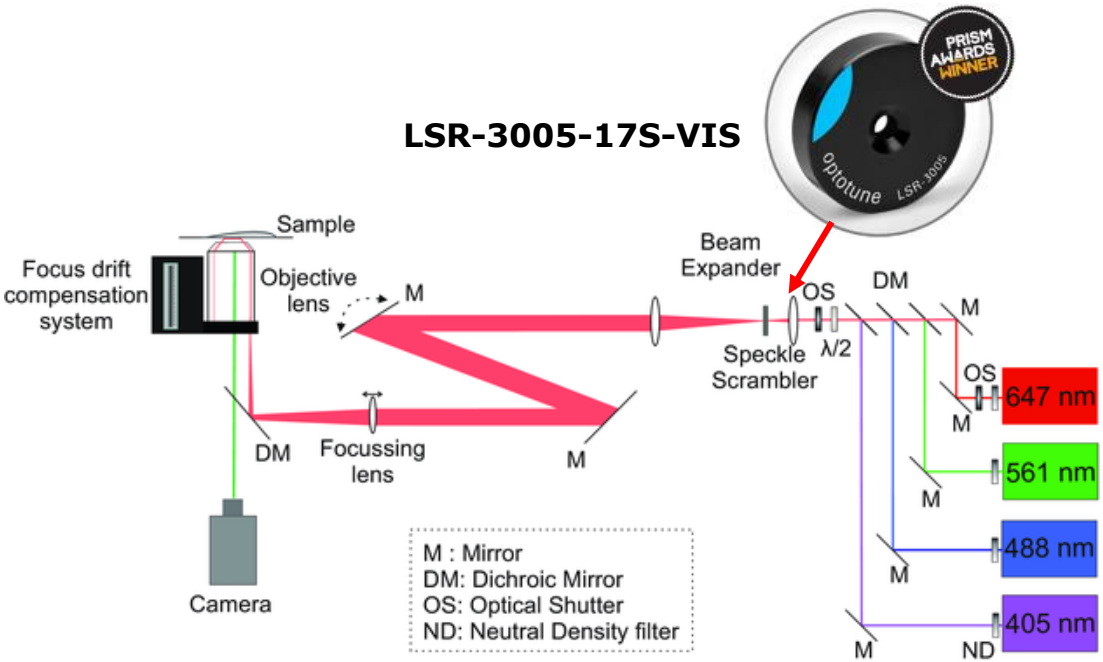
    - Microscopy
  - Available products

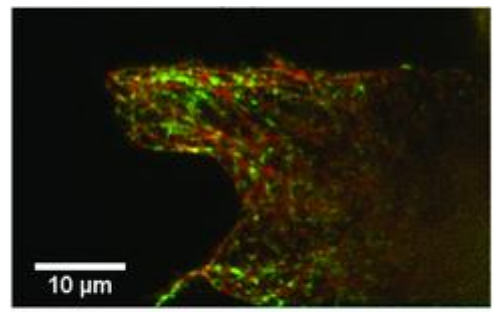
Optotune's LSR boosts image quality in super-resolution fluorescence microscope (STORM)

Setup:

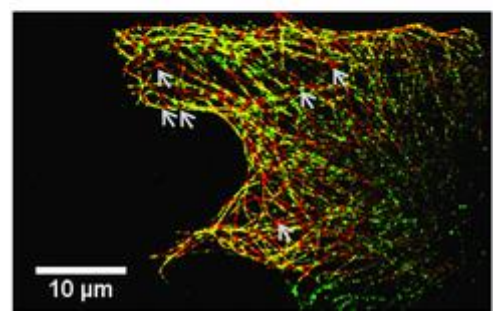
LSR-3005-17S-VIS



LSR off

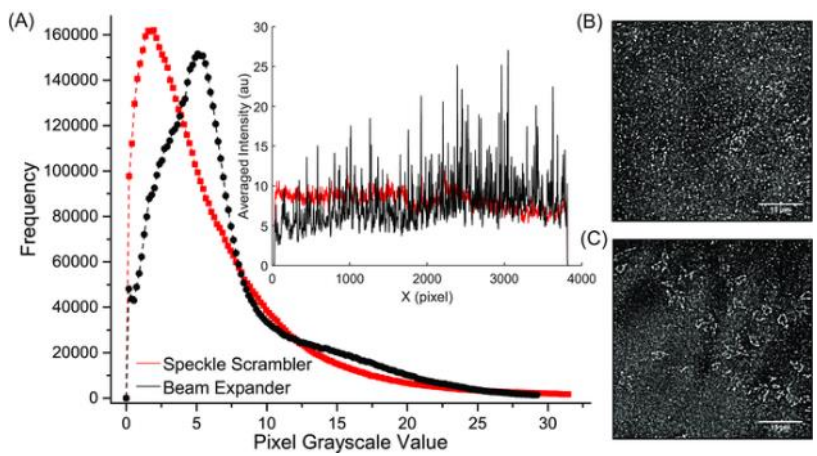


LSR on



MRC5 cells stained with Alexa Fluor 647

Distribution of pixel greyscale values:



Ref: P. Georgiades et al., Journal of Microscopy (2016), http://onlinelibrary.wiley.com/doi/10.1111/jmi.12453/full

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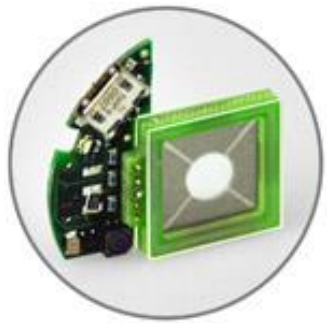
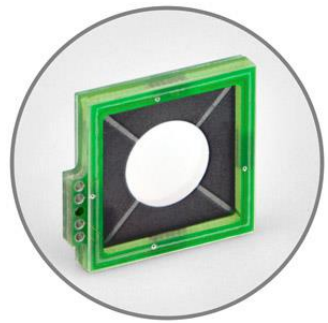
Agenda

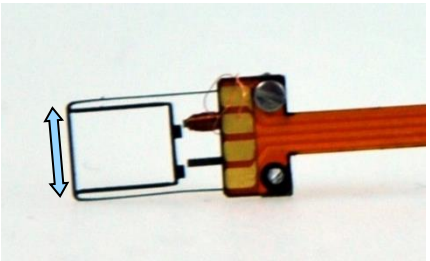
- Introduction
- Active speckle reduction with CW lasers (oscillating diffusers)
  - Electroactive polymer based LSR
  - Reluctance force based LSR
  - Application examples
    - Light engine for laser projection
    - Micro/pico-projectors
    - Line generation
    - Fiber coupling
    - Microscopy
  - Available products

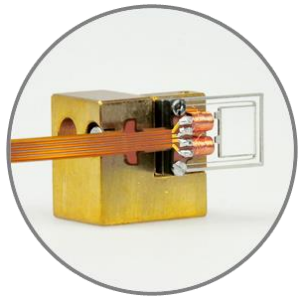
Available standard products based on EAP technology

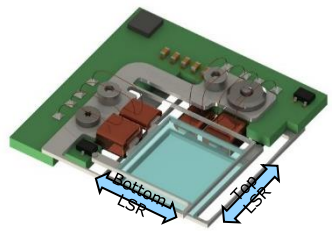
	LSR-3005	LSR-3010	LSR-5-17	LSR-10-22
				
Aperture	5 mm	10 mm	5 mm	10 mm
Size (Ø or L x H)	41mm x 8.8mm	48mm x 8.8mm	17mm x 3.8mm	22mm x 3.8mm
Standard diffuser angles*	6°, 12°, 17°, 24°			
Resonant frequency	300 Hz	180 Hz	300 Hz	180 Hz
Oscillation amplitude	300 um	400 um	300 um	400 um
Electronics	Integrated, CE certified	Integrated, CE certified	Optional, not certified	Optional, not certified

* A variety of circular and elliptical diffusion angles available upon request

Overview & status of reluctance-force LSRs



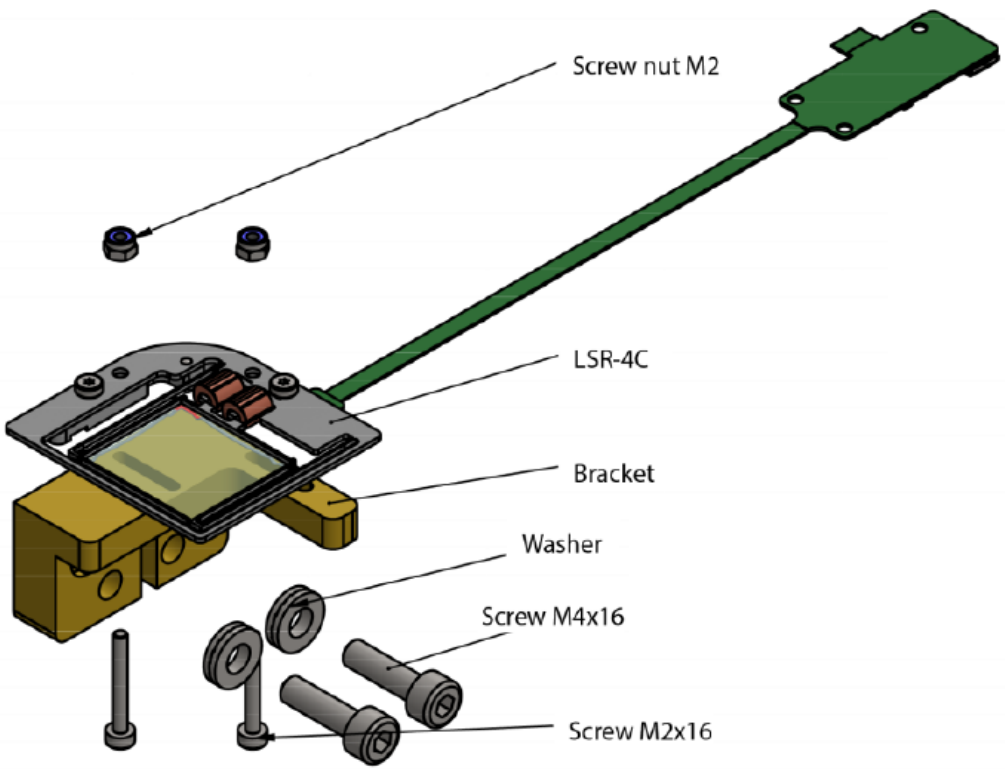




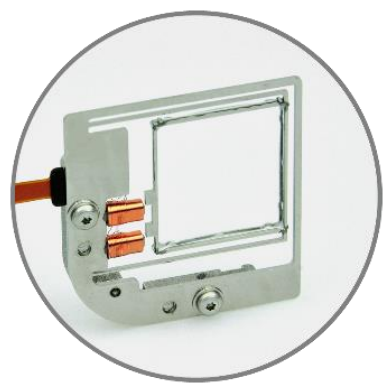
	Pico-projector	Line laser (µ-cylinder lens arrays)	Desktop-projector/ Laser TV	Cinema-projector	HUD
Diffuser [mm]	4.7x6.5	5x6	15x15	20x22	53x23
Aperture [mm]	4x5.5	5x5	12x12	18.5x18.5	50x20
Size [mm]	7x14x2	9.4x15.4x4	34x34x5	35x38x5	40x70x5
Oscillation	1D	1D	2x 1D	1D	2D
Amplitude [um]	400	400	800	800	1000
Frequency [Hz]	400	300	150	120	>60
Status	**Alpha**	**Beta**	**Alpha**	**Production**	**Concept**

LSR-4C options

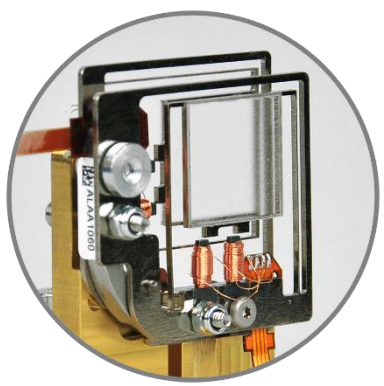
- 3 diffuser types available from Optotune
  - High-power coated fused silica: 8.5°
  - Uncoated glass diffusers: 10, 20°
  - Uncoated polycarbonate diffusers: 1, 5, 10, 20°
- Brass bracket available for prototyping



- Single or double configuration



LSR-4C-L



LSR-4C-LL

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Optotune Switzerland AG
Bernstrasse 388
CH-8953 Dietikon
Switzerland

Phone: +41 58 856 3000 | Fax: +41 58 856 3001
www.optotune.com | sales@optotune.com