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Focus-tunable lenses for endoscopy

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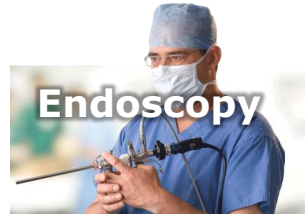
Dr. David Leuenberger, Senior Business Development Manager

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

Value proposition for endoscopes

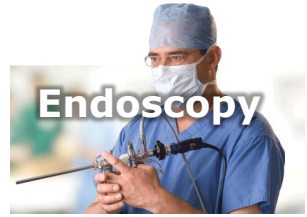


- Ever higher resolution endoscopy have decreasing depth of field.
  →A tunable lens allows to adjust the working distance from few mm to hundreds of mm.
- Current endoscopy systems with external cameras use a focusing/zoom rings that are hard to move with a single hand.
  → Push button focusing allows to do single-handed refocusing
- Current endoscopy system do not feature an auto-focus
  → Combining a tunable lens with a TOF distance sensor would provide real-time auto-focus.
- The high tuning speed of our lenses allow new functionalities:
  - Hyperfocal imaging through image stacking
  - 3D imaging from depth of focus

Agenda

- Our value proposition
- Optical functions enabled by tunable lens
  - Accommodation in proximal camera
  - Accommodation for chip-on-a-tip
  - Extended depth of field, Depth from focusing, Macro
- Standard products
- Reliability

Tunable lens in camera adapter



Rod lens relay

Illumination port
with fiber coupler

Eye
piece

Camera
adapter

Camera

Obj

Ocular

Iris

Image
sensor

EL-10-30-TC

Focus out

Focus in

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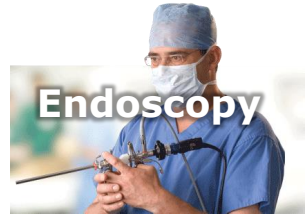
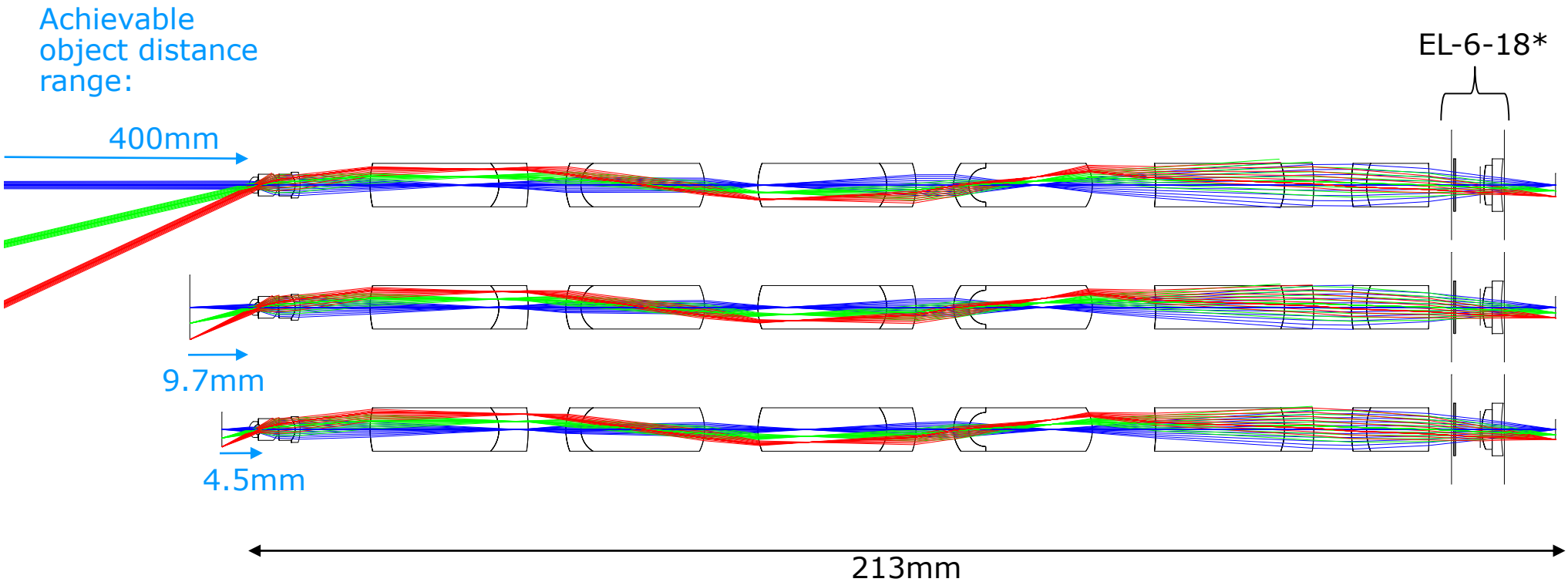
Example design for tunable camera adapter





*assumed EL-6-18 tuning range: BFL -385 … +55mm

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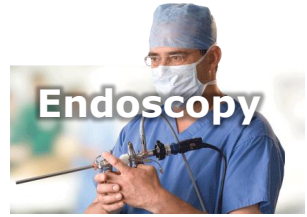
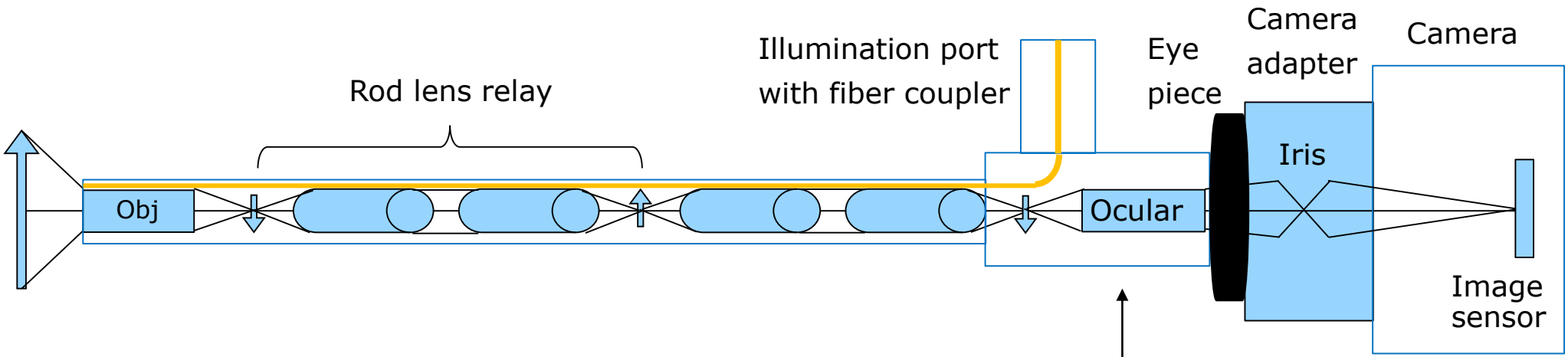
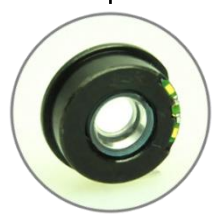
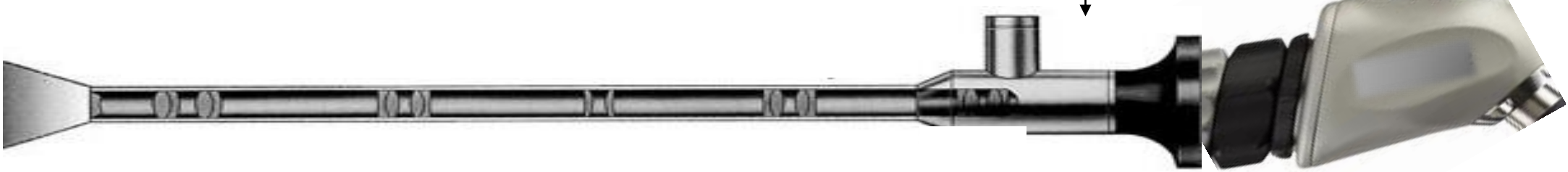
Small tunable lens in ocular







EL-3-10



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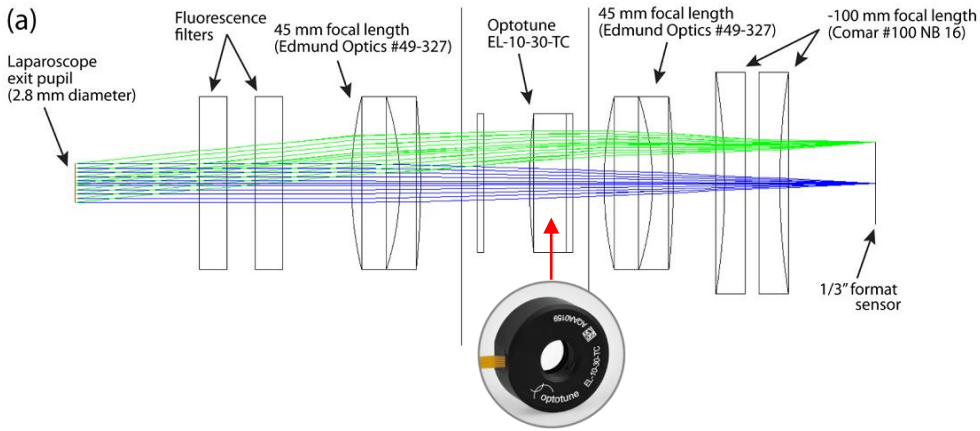
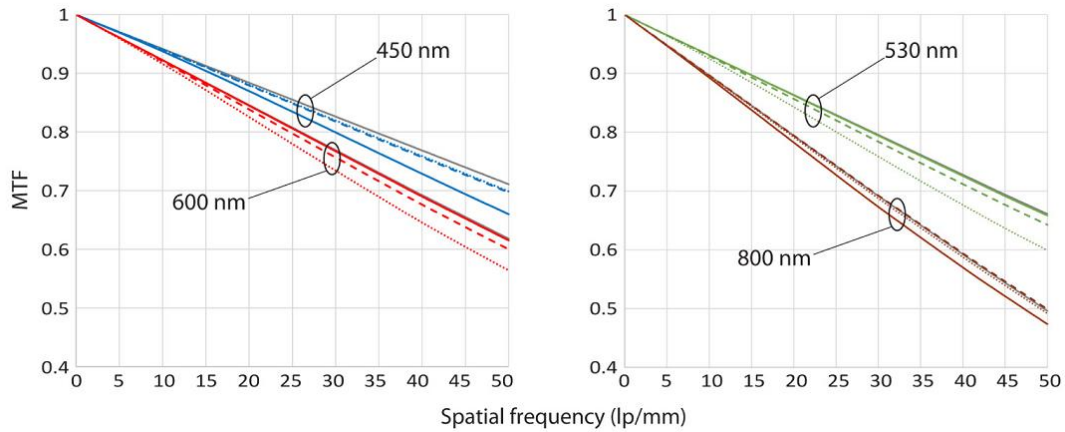
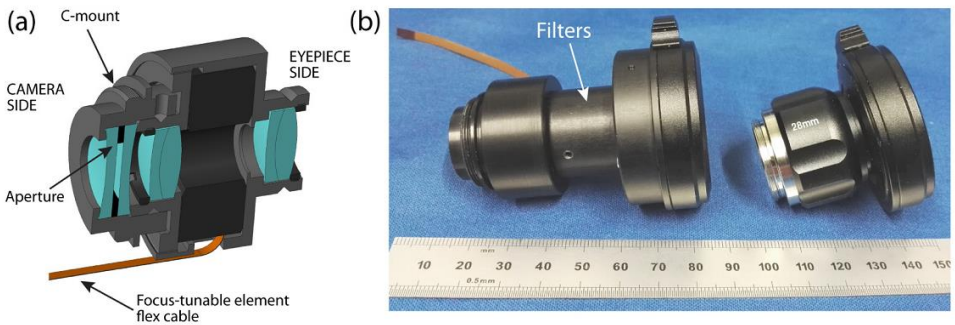
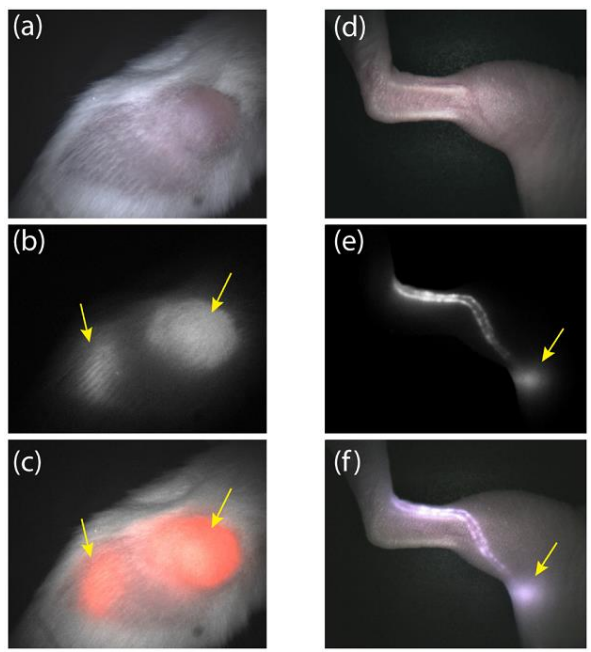
Example: Electrically tunable fluidic lens imaging system for laparoscopic fluorescence-guided surgery









***In vivo* evaluation of laparoscopic imaging. (a) White reflectance, (b) fluorescence and (c) combined fluorescence + white reflectance images of a subcutaneous tumor (right arrow), obtained with the TLS. Fluorescence signal of the probe accumulating in the kidney is also shown (left arrow). (d) White reflectance, (e) fluorescence and (f) combined fluorescence + white reflectance images of the left inguinal lymph node (arrows)**

https://www.osapublishing.org/boe/abstract.cfm?uri=boe-8-7-3232

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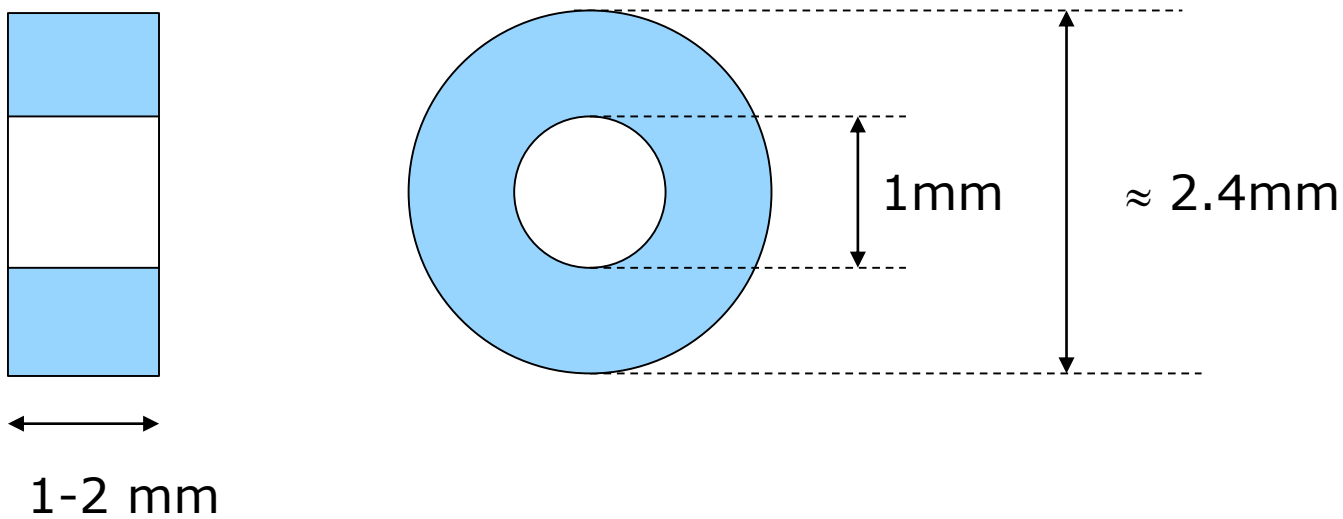
Optotune's lens technology can be miniaturized

- Optotune has the concepts and technology to build electrically tunable lenses that fit into the tip of an endoscope
- Target specs: 1mm CA, ≈2.4 mm OD, 1-2 mm thickness and >= ±18 dpt tuning range
- Please contact sales@optotune.com to learn more about custom lens developments



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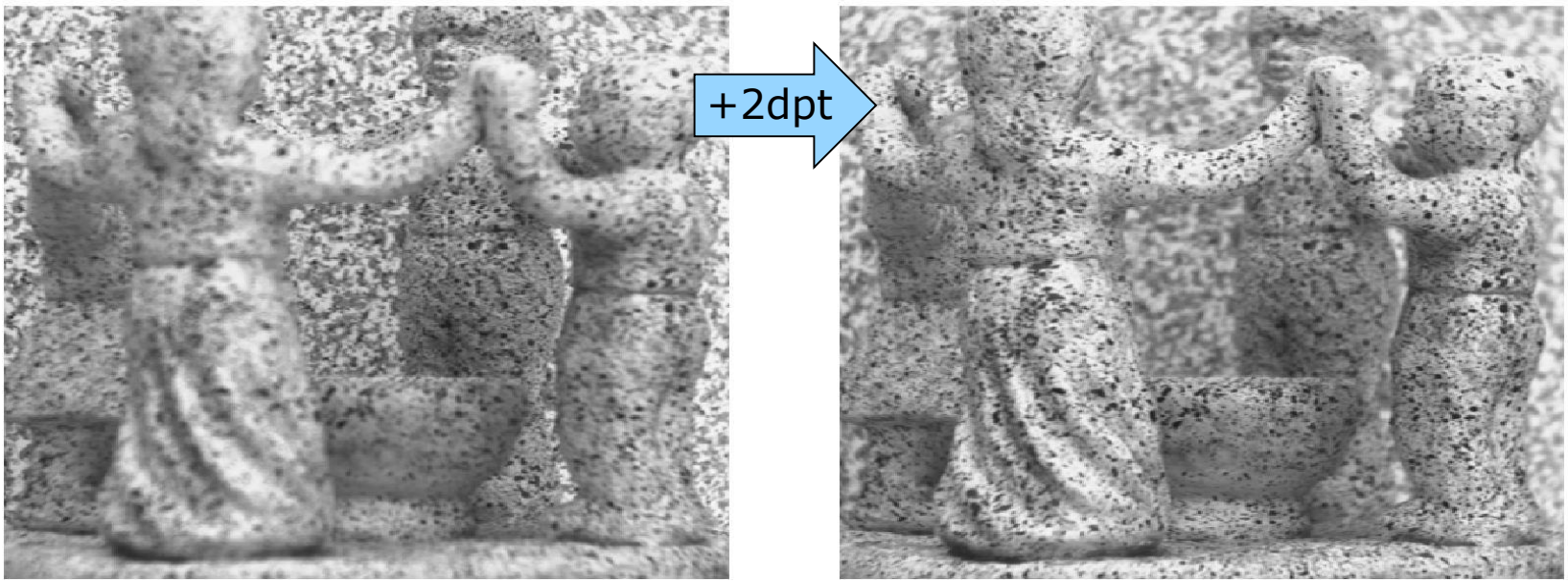
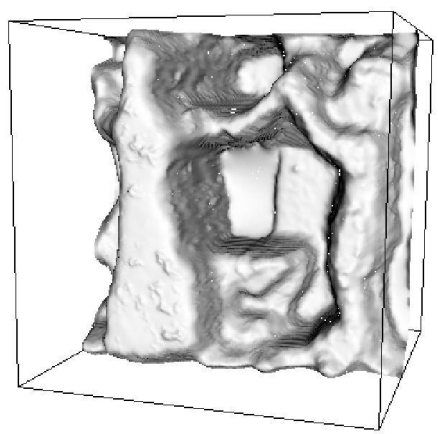
Depth from focus (DFF)

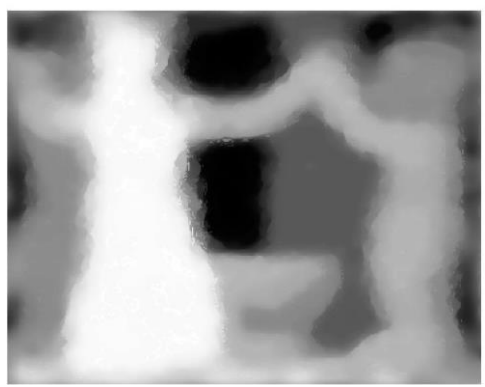
Focus on background

Focus on foreground



Depth map





Source: http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/FAVARO1/dfdtutorial.html

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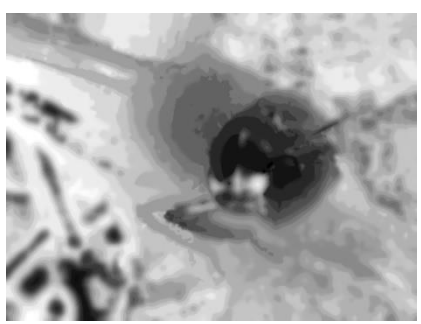
Focus stacking for “hyper-focus” images

Z-stack of e.g. 10 to 30 images*

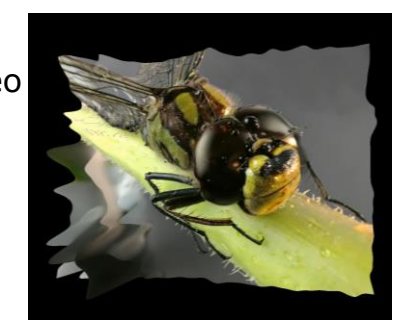
...

Rendered hyper-focus image**



Depth map

Video



*Ideally the number of frames to acquire is = Z-range / DoF **Rendered with Helicon Focus 6.7.1 software from 15 pictures (offline)

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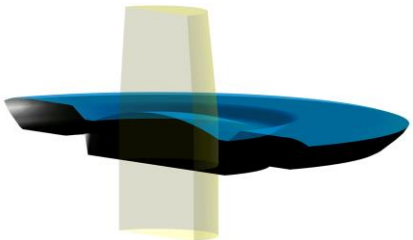
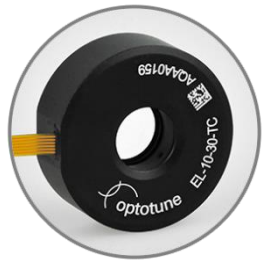
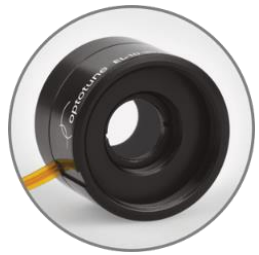
Optotune's electrically focus tunable lenses



	EL-3-10	EL-10-30-TC	EL-10-30-C(i)	EL-16-40	EL-10-42-OF
					
Focal power range*	-13 … 13 Dpt	8 … 22 Dpt	-1.5 … 3.5 Dpt	-2 … +3 Dpt	-10 … +10 Dpt
Clear aperture	3mm	10mm	10mm	16mm	16mm
Outer diameter	10mm	30mm	30mm	40mm	40mm
Wavefront quality RMS @525nm**	<0.15 / 0.15 λ	<0.25 / 0.5 λ	<0.15 / 0.25 λ	I: <0.15/ 0.5 λ II <0.25 / 0.5 λ	I: <0.25 / 2.5 λ II: <0.5 / 2.5 λ
Absolute focal power accuracy	N/A	< 0.1 Dpt	< 0.1 Dpt	< 0.1 dpt	< 0.1 dpt
Built-in sensors	None	Temperature	Temperature	Temp./Optical feedback	Temp./Optical feedback
Applications	Machine Vision Ophthalmology	Microscopy Ophthalmology	Machine vision	MV/Microscopy Ophthalmology	MV/Microscopy Ophthalmology

* Depends on selected optical fluid ** vertical / horizontal optical axis

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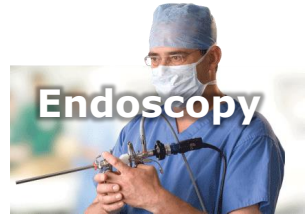
Auto-cleaving



- The EL-10-30 lens (in a sealed housing) has been tested by a 3rd party and survived 72 cycles of auto-cleaving (vapor, 140°C, 10 min).

Lifetime test of EL-10-30

Test	Test conditions	Status
Mechanical cycling	40 million full-range cycles (0 to 300 mA rectangular, at 10 Hz) 5 billion sinusoidal cycles at resonant frequency	Passed
High temperature test	85±2°C; rel. hum. <6% for 168 hours, non-operational	Passed
Temperature cycling test	-40°C / +85°C for 30 min each, 3 min transition time, 100 cycles	Passed
Damp heat cycling test	25°C / 55°C at 90-100% relative humidity, 3 hour transition time, 24h per cycle (9h plus transition time each), 18 cycles	Passed
Shock test:	800g for 1ms duration, 5 pulses in each direction (30 pulses in total)	Passed
Solar radiation test:	1120 W per m2 (IEC 60068-2-5), 8 h irradiation & 16 h darkness, 10 cycles	Passed

Polymer lenses can withstand high power!

- Only 0.1% absorption in VIS & NIR range
- The following tests were succesful with EL-10-30 (LD fluid)
  - 1070 nm, 200 W CW on a 3 mm beam diameter (equivalent to 2.2 kW/cm^2)
  - 1064 nm, 20 ns-pulsed at 50 kHz, 10 W average power on a 0.05 mm beam diameter (10 J/cm^2)
  - 355 nm, 20 ns-pulsed at 50 kHz, 7 W average power on a 0.05 mm beam diameter (7 J/cm^2)
  - 1064 nm, 12 ps-pulsed at 8.2MHz, 38 W average power on a 2 mm beam diameter (147 µJ/cm^2)
  - 850 nm, 140 fs-pulsed at 80 MHz, 3 W average power on a 6 mm beam diameter (0.13 µJ/cm^2)
  - 345 nm, 500 fs-pulsed at 200 kHz, 0.5 W average power on a 3 mm beam diameter (35 µJ/cm^2)
- Customized cover glasses are available

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shaping the future of optics

Optotune AG
Bernstrasse 388
CH-8953 Dietikon
Switzerland

Phone: +41 58 856 3000 | Fax: +41 58 856 3001

www.optotune.com | info@optotune.com