

## Fast Electrically Tunable Lens EL-10-30 Series



The curvature of this shape changing polymer lens is adjusted by applying current. The focal length is accordingly tuned to a desired value within milliseconds. Optotune offers three different types of housings of the EL-10-30. The compact 30x10.7 mm housing, a 30x20 mm housing with C-mount threads and the Industrial C-mount housing (Ci) with Hirose connector. For each housing there are different options to adapt the lens to your needs:

- High refractive (HR) liquid ( $n_D=1.559$ ,  $V=32$ ) & low dispersion (LD) liquid ( $n_D=1.300$ ,  $V=100$ )
- Diverse cover glass coatings
- Optional offset lenses

The table below summarizes the possible options for the three different housings. The overview of available standard products is summarized on page 2. At the end of this document you find a detailed explanation of the naming concept when ordering a customized EL-10-30.

Option	EL-10-30	EL-10-30-C	EL-10-30-Ci
Cover glass coatings	VIS <sup>1</sup> , NIR <sup>2</sup>	VIS, NIR, 1064 <sup>3</sup>	VIS, NIR, 1064 <sup>4</sup>
Optional offset lens	No	Yes	Yes

<sup>1</sup>400-700 nm broad band   <sup>2</sup>700-1100 nm infra-red broad band   <sup>3</sup>narrow band 1064 nm

The following table outlines the specifications of our standard electrically tunable lens EL-10-30. Cover glass coatings and tuning range can be adapted on demand.

Mechanical specifications	EL-10-30	EL-10-30-C	EL-10-30-Ci	
Clear aperture	10	10	10	mm
External diameter	30	30	Oval shape 48x30.5	mm
Thickness	10.75	24.6	24.6	mm
Weight	22.9	34.0	46.0	g
Connector length	300	100	1000 <sup>1</sup>	mm
Lifecycles (10-90% sinusoidal)	>1'000'000'000	>1'000'000'000	>1'000'000'000	
Temperature sensor & memory	-	Yes (SE97B)	Yes (SE97B)	

### Electrical specifications

Absolute maximum voltage	5	V
I2C supply voltage	3.3 (nominal), 3.6 (maximum)	V
Nominal control current with Lens Driver 4	0 to 250	mA
Absolute max. control current	0 to 400	mA
Power consumption	0 to 0.9 (nominal), 0 to 2.0 (absolute max.)	W
Response time (10%-90% step)	<2.5	ms
Settling time (typical at 30°C)	15 (rectangular step), 6 (controlled step)	ms

<sup>1</sup> Specified maximum Hirose cable length is 3m. Tests with 5m were successful, however the capacitance is 550pF (I2C bus specification is 400 pF max.).

### Optical specifications

	EL-10-30 (LD liquid)	EL-10-30-C & Ci (LD liquid)	
Focal tuning range @ 30°C <sup>2</sup>	+50 to +120	+100 to +200	mm
Dispersion (at 20°C)		1.302	
486 nm		1.300	
589 nm		1.299	
656 nm		1.298	
800 nm		1.297	
1065 nm		1.296	
1550 nm		100	
Abbe number V			
Wavefront error (@530 nm, 0 mA)	<0.25 / <0.5	<0.15 / <0.25	λ RMS
Optical axis vertical / horizontal			
Lens type		plano-convex	
Transmission spectrum		see Figure 7	
Optical damage threshold @ 1064 nm		10	kW/cm <sup>2</sup>
Centration		<2	arcminutes
Polarization		preserving	

### Thermal specifications

	EL-10-30 (LD liquid)	EL-10-30-C & Ci (LD liquid)	
Storage temperature	[-40,+85]	[-40,+85]	°C
Operating temperature <sup>2</sup>	[-20,+65]	[-20,+65]	°C

### Overview of available standard products

Standard products	Tuning range <sup>2</sup>	Refractive index	Cover glass coating	RMS wavefront error <sup>3</sup>	Integrated offset lens	Temperature sensor
EL-10-30-VIS-LD	+8.3 to +20 dpt	1.30	400 – 700 nm	<0.50 λ	No	No
EL-10-30-NIR-LD	+8.3 to +20 dpt	1.30	700 – 1100 nm	<0.50 λ	No	No
EL-10-30-C-VIS-LD	+5 to +10 dpt	1.30	400 – 700 nm	<0.25 λ	No	Yes
EL-10-30-C-NIR-LD	+5 to +10 dpt	1.30	700 – 1100 nm	<0.25 λ	No	Yes
EL-10-30-C-VIS-LD-MV	-1.5 to +3.5 dpt	1.30	400 – 700 nm	<0.25 λ	Yes (-150 mm)	Yes
EL-10-30-C-NIR-LD-MV	-1.5 to +3.5 dpt	1.30	700 – 1100 nm	<0.25 λ	Yes (-150 mm)	Yes
EL-10-30-Ci-VIS-LD	+5 to +10 dpt	1.30	400 – 700 nm	<0.25 λ	No	Yes
EL-10-30-Ci-NIR-LD	+5 to +10 dpt	1.30	700 – 1100 nm	<0.25 λ	No	Yes
EL-10-30-Ci-VIS-LD-MV	-1.5 to +3.5 dpt	1.30	400 – 700 nm	<0.25 λ	Yes (-150 mm)	Yes
EL-10-30-Ci-NIR-LD-MV	-1.5 to +3.5 dpt	1.30	700 – 1100 nm	<0.25 λ	Yes (-150 mm)	Yes

### Housings

The compact EL-10-30 is preferably mounted in a 30 mm ring holder. The relevant mechanical drawings are depicted below in Figure 1. Figure 2 shows the drawings of the C-mount housing. This housing has threads on either side and exhibits an M4 threaded hole in the housing for mounting on optical posts. Figure 3 shows the drawings of the industrial C-mount EL-10-30-Ci. This housing has an oval shape and no M4 threaded hole, however C-mount threads on either side like the C-mount housing. Apart from the housing and connector, the performance of the EL-10-30-C and EL-10-30-Ci are identical.

<sup>2</sup> Different focal tuning ranges available upon request. Guaranteed tuning range is reduced over operating temperature range by 0.07 dpt/°C.

<sup>3</sup> Wavefront error in RMS λ @525 nm, 0 mA current with optical axis horizontal (worst case)

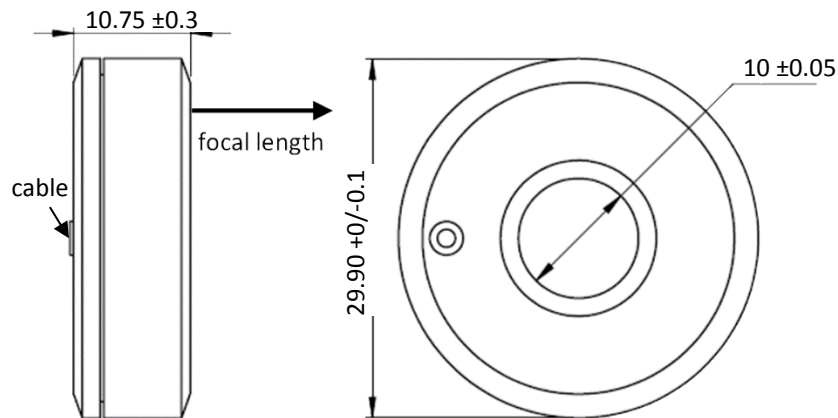


Figure 1: Mechanical drawing of the compact EL-10-30 (unit: mm).

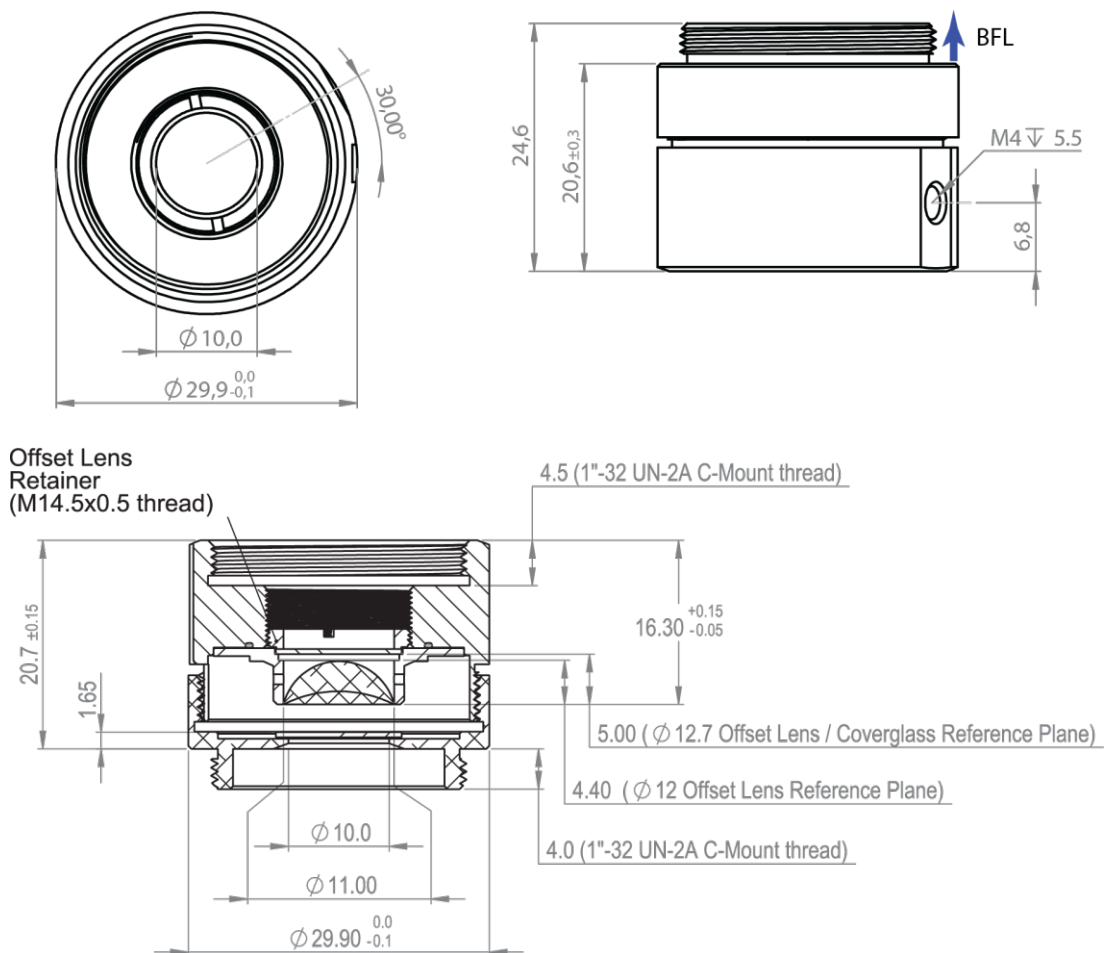


Figure 2: Mechanical drawing of the EL-10-30-C (unit: mm). The upper right panel shows the position of the M4 threaded hole for mounting of the EL-10-30-C

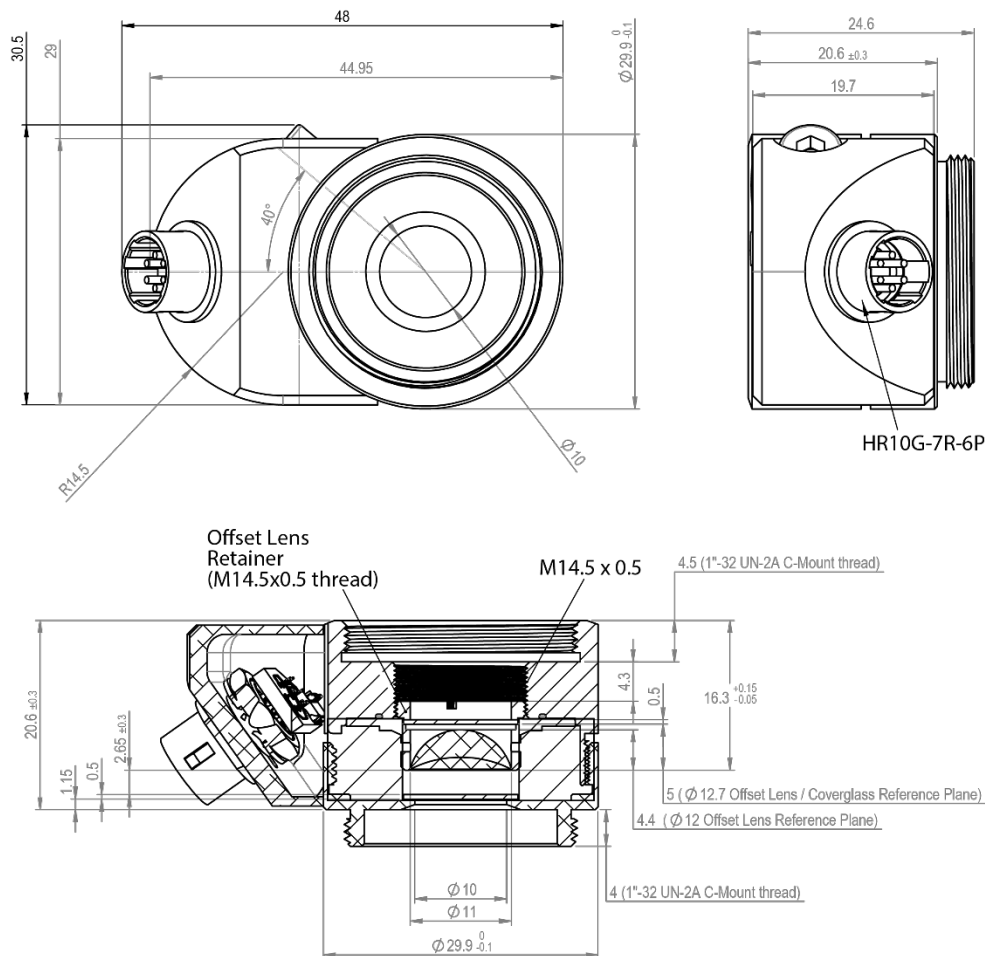
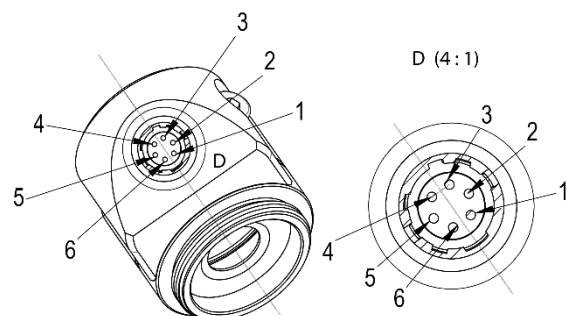


Figure 3: Mechanical drawing of the industrial C-mount EL-10-30-Ci (unit: mm).

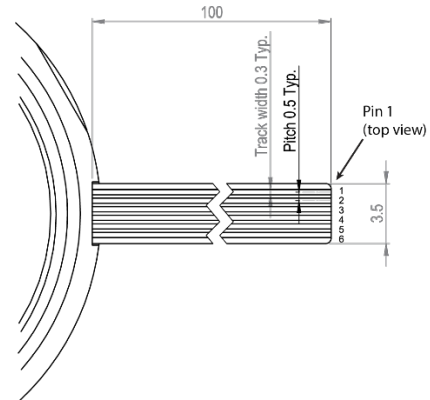
## Electrical connection

The compact EL-10-30 has a 30cm long cable for driving current through the lens. Here, the colored cable is the plus pole and the copper cable is the minus pole. The industrial design EL-10-30-Ci comes with a 6-pin Hirose connector. A 1m long cable to connect the EL-10-30-Ci to the EL-E-4i driver is available from Optotune (P/N CAB-6-100). The EL-10-30-C has a 10 cm long FPC connection, which is compatible with Molex 0.5mm pitch 6 way FPC backflip connector (P/N 503480-0600). Samples ship with an adaptor for easy soldering. Both the EL-10-30-C and -Ci feature an SE97B temperature sensor with 256 bytes of memory.

Pinning EL-10-30-Ci		
Position	Function	SE97B Pins
1	Lens (+ pole)	-
2	Lens (- pole)	-
3	SE97B Gnd	1-4
4	SE97B Vcc 3.3V	8
5	SE97B SCL	6
6	SE97B SDA	5

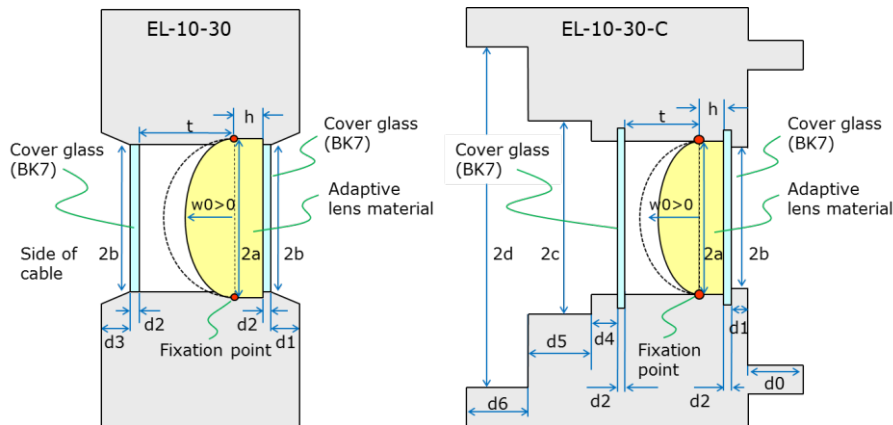


Pinning EL-10-30-C		
Position	Function	SE97B Pins
1	SE97B Gnd	1-4
2	Lens (- pole)	-
3	Lens (+ pole)	-
4	SE97B SDA	5
5	SE97B SCL	6
6	SE97B Vcc 3.3V	8



## Optical layout

Figure 4 contains the information needed to model the EL-10-30 lenses for simulation. A more detailed design guide and a ZEMAX plug-in is available at <http://www.optotune.com/downloads>.



		EL-10-30 [mm]	EL-10-30-C [mm]
a:	Semi-diameter of lens	5.5	5.5
b:	Outer semi-diameter 1 (clear aperture)	5.0	5.0
c:	Inner semi-diameter	-	7.0
d:	Outer semi-diameter 2	-	11.9
$w_0$ :	Central deflection of lens	In function of applied current	
$d_0$ :	Thickness outer thread	-	4
$d_1$ :	Distance from bottom cover glass to housing	1.15	1.15
$d_2$ :	Thickness of cover glasses	0.5	0.5
$h$ :	Constant zone of lens material	$2.45 \pm 0.3$	$2.65 \pm 0.3$
$t$ :	Cover glass distance	5	5
$d_3$ :	Distance from top cover glass to housing	1.1	-
$d_4$ :	Thickness holder ring	-	2
$d_5$ :	Distance from holder ring to housing	-	4.3
$d_6$ :	Thickness inner tread	-	4.5
Fixation point:	Lens edges always stay in the same axial position		

Figure 4: Optical layout of the EL-10-30 and EL-10-30-C with corresponding terminology.  
The optical design for the EL-10-30-Ci is identical to the C-mount version.

## Using offset lenses

In the EL-10-30-C and -Ci the protective cover glass can be replaced by an offset lens of 12 or 12.7-mm diameter. This allows shifting the focal length range to any desired value. For example, adding an offset lens with  $f = -150$  mm to the EL-10-30-C-VIS-LD will yield a focal length range of about -600 mm to infinity to +285 mm ( $1/f_{res} = 1/f_{EL-10-30} + 1/f_{offset}$ ). The design of the EL-10-30-C is optimized for good alignment of the tunable lens and the offset lens. The maximal thickness of the offset lens may be 4.7 mm.

## Working principle

The EL-10-30 is a shape-changing lens, as illustrated in Figure 5. It consists of a container, which is filled with an optical fluid and sealed off with an elastic polymer membrane. The deflection of the lens is proportional to the pressure in the fluid. The EL-10-30 has an electromagnetic actuator that is used to exert pressure on the container. Hence, the focal distance of the lens is controlled by the current flowing through the coil of the actuator.

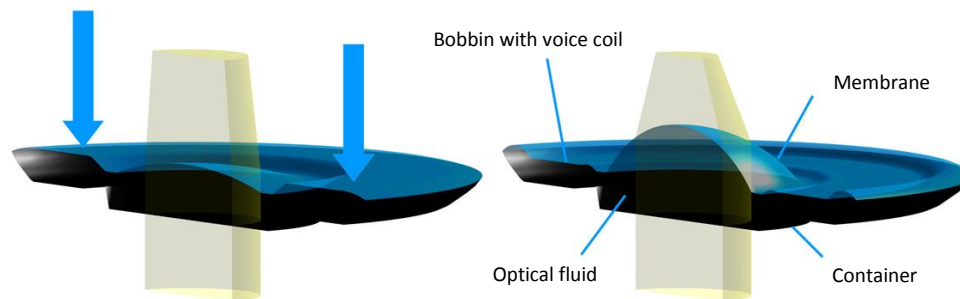


Figure 5: Working principle of the EL-10-30 series.

## Focal length versus current

The optical power of the EL-10-30 increases with current, shown in Figure 6. The starting point at zero current is set during production and can be varied from lens to lens, whereas the maximal value is 500 mm. The slope of the optical power is influenced by the mechanical properties of the membrane, which can also be varied on request to achieve different ranges. In open loop systems, a calibration of the lens with look-up tables is recommended. The focal length also depends on temperature, see paragraph *temperature effects*.

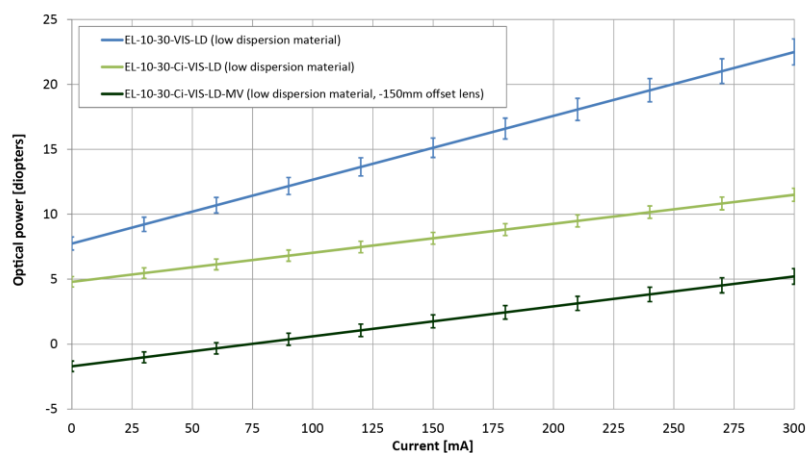


Figure 6: Relation of optical power to current for the most common EL-10-30 lenses at 30°C. The error bars show the standard deviation from lens to lens.

## Transmission range

Both the optical fluid and the membrane material are highly transparent in the range of 400 to 2500 nm. As the membrane is elastic it cannot be coated using standard processes, hence a reflection of 3 – 4% is to be expected. Cover glasses can be coated as desired. Figure 7 and Figure 8 show the transmission spectrum for our two standard broad-band coatings (visible and near infrared) as well as a custom narrow-band coatings:

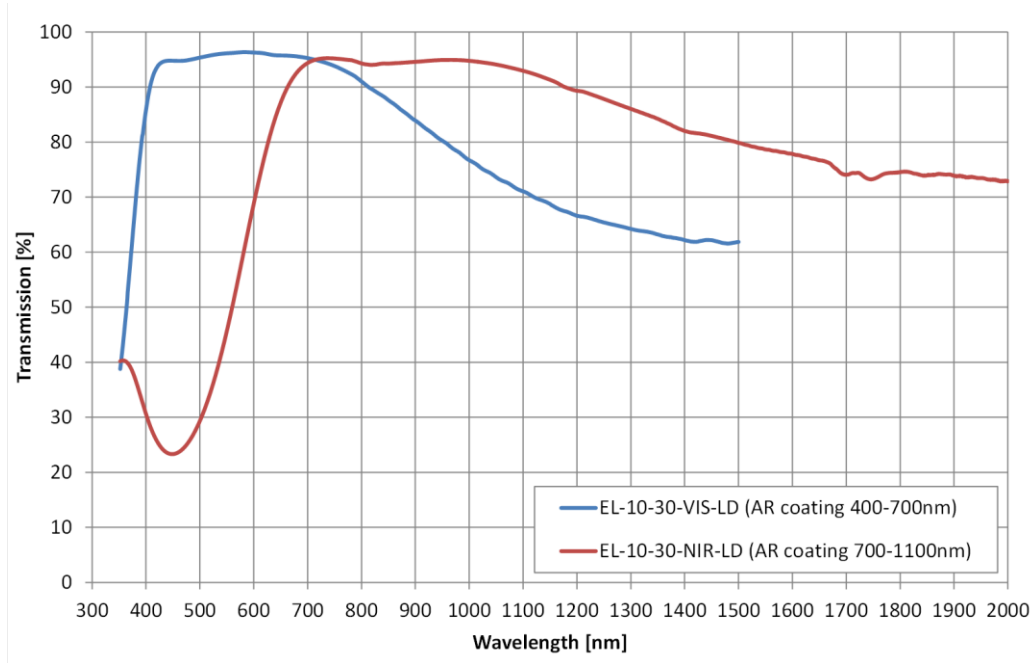


Figure 7: Transmission spectrum of the EL-10-30 for standard broad-band coatings.

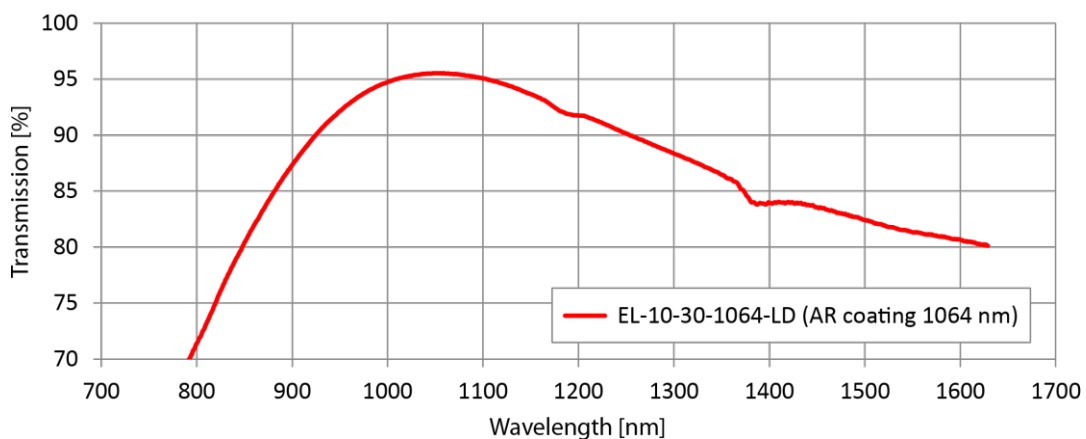


Figure 8: Transmission spectrum of the EL-10-30 for narrow-band 1064-nm coating.

The following graph (Figure 9) represents the transmission of the lens material only<sup>4</sup>, i.e. assuming perfect cover glasses.

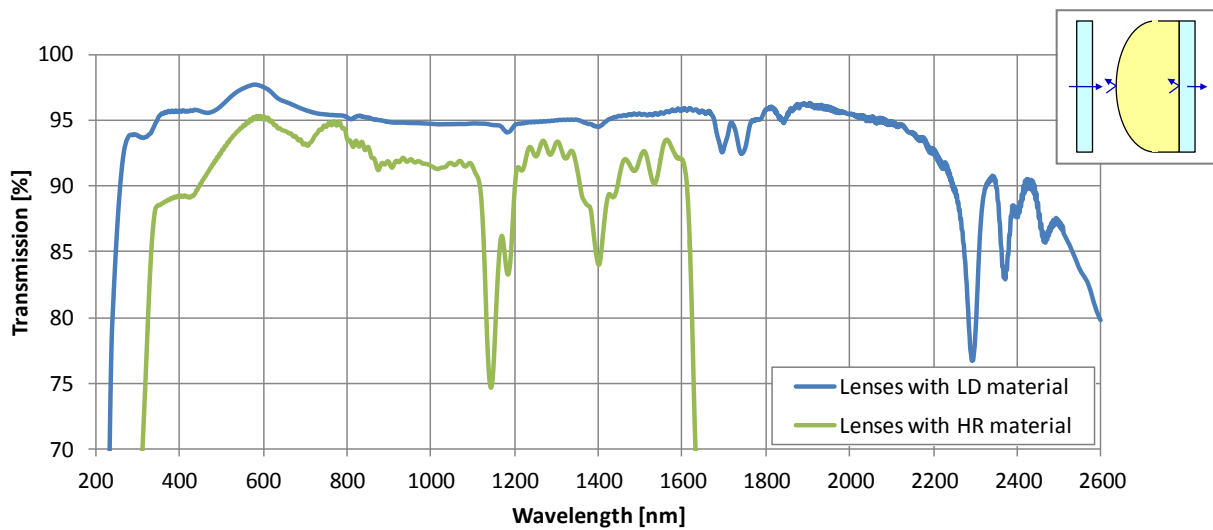


Figure 9: Transmission of the EL-10-30 assuming 100% transparent cover glasses.

Wavelength [nm]	EL-10-30-VIS-LD	EL-10-30-NIR-LD	EL-10-30-1064-LD
375	61.7	38.2	50.7
405	88.3	29.1	66.8
440	94.8	23.5	88.6
488	95.1	26.9	80.2
514	95.6	32.9	67.8
532	95.9	38.7	60.7
632	95.9	81.8	47.3
650	95.7	87.2	48.2
680	95.6	92.6	50.9
730	94.5	95.2	58.3
808	90.5	94.1	72.7
830	89.0	94.1	77.1
850	87.7	94.3	80.4
880	85.5	94.4	84.8
905	83.6	94.6	87.9
915	82.9	94.7	89.0
975	78.5	94.9	93.7
980	78.3	94.9	94.0
1030	74.9	94.4	95.4
1064	72.9	93.8	95.5
1070	72.7	93.7	95.4
1310	64.0	85.7	88.0
1540	NA	78.9	81.5
1550	NA	78.7	81.4

Table 1: Transmission values in percent of the EL-10-30 for common laser wavelengths

<sup>4</sup> The transmission of the „lens material only“ is put together from measurements of several lenses with differently coated cover glasses, whereas the three interfaces of „air to cover glass“ were removed mathematically.



## Laser damage measurements

The CW damage threshold of the lens material is  $10 \text{ kW/cm}^2$  for a wavelength of 1064 nm. Further measurements with CW and pulsed lasers have been performed with the following results:

- 1070 nm, 200 W CW on a 3 mm beam diameter (equivalent to  $2.8 \text{ kW/cm}^2$ )
- 980 nm, 75 W CW on a 1.5 mm beam diameter (equivalent to  $4.2 \text{ kW/cm}^2$ )
- 1064 nm, 12 ps-pulsed at 8.2 MHz, 38 W average power on a 2 mm beam diameter ( $147 \mu\text{J/cm}^2$ )
- 1064 nm, <15 ps-pulsed at 200 kHz, 50 W average power on a 7 mm beam diameter ( $650 \mu\text{J/cm}^2$ )
- 850 nm, 140 fs-pulsed at 80 MHz, 3 W average power on a 6 mm beam diameter ( $0.13 \mu\text{J/cm}^2$ )

For 532 nm, long term measurements (~22 days) show a degradation of the lens. The parameters of this measurement were: 7 ps-pulsed at 500 kHz, 1.15 W average power on a 2.4 mm beam ( $50 \mu\text{J/cm}^2$ ). For UV lasers (355 and 405 verified) damage is observed at relatively low laser power (e.g. 405 nm, 30 mW CW, 2 mm beam).

While no heating up of the lens is observed with the pulsed lasers, a 200 W CW laser does heat up the lens, resulting in a focus drift, which stabilizes after about 10 seconds. To avoid heating of the lens due to reflections hitting absorbing surfaces, it is advised to calculate such reflections and preferably not use more than 8 mm of the clear lens aperture.

## Wavefront quality

In principle, Optotune's focus tunable lenses exhibit a spherical lens shape (the nominal parameters can be found in the ZEMAX package, which is available for download on [www.optotune.com](http://www.optotune.com)).

As the membranes used are elastic, the lens shape is influenced by gravity. Results are summarized in Figure 10. With the lens lying horizontally (optical axis vertical), the RMS wavefront error of the EL-10-30 Series lenses is currently in the order of  $0.1 \lambda$  (measured at 525 nm), allowing for high quality imaging e.g. in microscopy. With the lens standing upright (optical axis horizontal) a Y-coma term must be added.

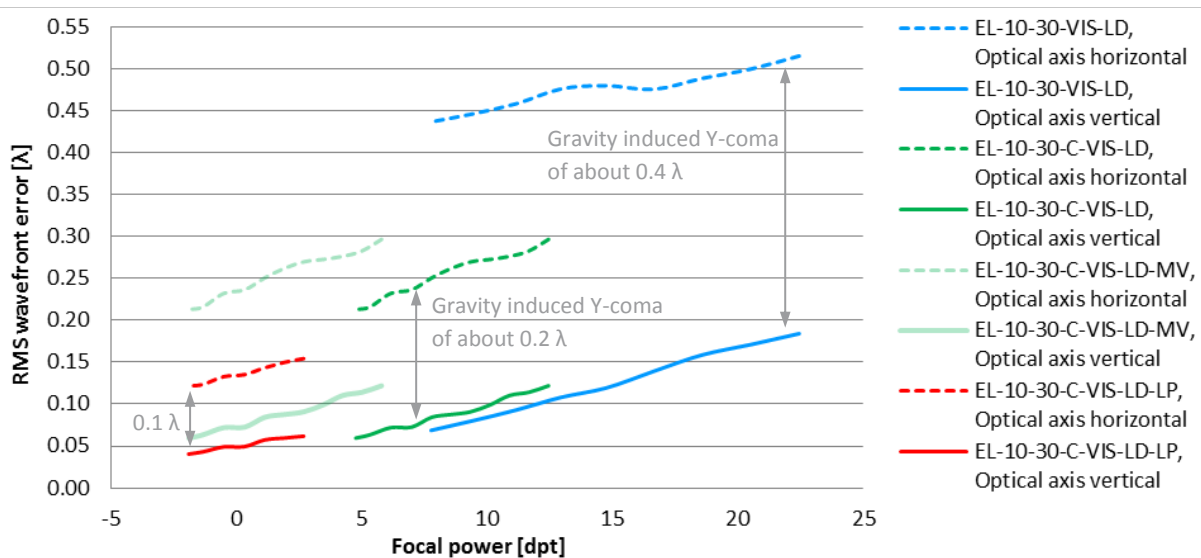


Figure 10: Wavefront measurement of typical EL-10-30-VIS-LD and EL-10-30-C-VIS-LD lenses at 525 nm and 80% of clear aperture, defocus, tilt & sphere excluded.

The gravity induced Y-coma term depends on the size of the lens, the density of the liquid and the mechanical properties of the membrane. While it is insignificant with lenses of apertures below 5 mm, it accounts for about  $0.1 \lambda$  for the C-mount LP-version,  $0.2 \lambda$  for the C-mount MV-version and  $0.4 \lambda$  for the compact version of the EL-10-30. The difference between the different variations of the EL-10-30 lenses is the design of the membrane.

The stronger membrane of the EL-10-30-C (with the LP version having the strongest membrane) reduces the gravity effect, however at the expense of focal tuning range (4 diopters for the EL-10-30-C-VIS-LD-LP, 7.5 diopters for the EL-10-30-C-VIS-LD and 14 diopters for the EL-10-30-VIS-LD, see Figure 6).

### Temperature effects

Heating up of the lens has two consequences: First, the refractive index of the optical fluid decreases. Second, the fluid expands in volume. While the first effect would increase the focal distance, the second effect reduces it. With the EL-10-30 design, the second effect prevails. The focal distance decreases by approximately 0.6 diopters per 10°C temperature increase.

This temperature effect is systematic and reproducible. This means the focal length can be controlled if the temperature is known. The EL-10-30-C and EL-10-30-Ci have a built-in temperature sensor (SE97B). The compact EL-10-30 does not have that sensor, but measuring the resistance of the coil (voltage divided by current) can serve as a proxy for the temperature in the lens. Heating up of the lens occurs at room temperature if driven at high currents or due to absorption of high power laser light. In such cases the lens is preferably mounted using heat-conducting metal clamps. For custom designs it is possible to balance the two temperature effects such that the focus shift becomes minimal at a certain focal length.

### Resolution and reproducibility

The step size of the focal power is limited by the resolution of the DAC of the current driver. For high precision applications a driver with 12 bits is recommended. As the relation between current and focal power is linear, the smallest step of e.g. the EL-10-30-C-VIS-LD about 0.0018 Dpt.

Unlike piezo systems, the EL-10-30 exhibits no hysteresis. The current through the coil induces a force, which is directly transferred onto the elastic membrane. There is no friction in the system. This means that at a constant temperature jumping between alternate current levels will always yield the same focal length. The effect of changes in temperature are described above. For the EL-10-30-Ci lenses, Optotune's Lens Driver 4 offers a focal power mode, which makes use of calibration data stored in the lens (EEPROM of the SE97B). The absolute reproducibility achieved over an operating temperature range of 10 to 50°C amounts to typically 0.1 diopters. More details on the focal power mode are provided in the Lens Driver manual.

### Resistance and Inductance of the driving coil

In principle, the EL-10-30 can be driven using a DC voltage (e.g. even a simple battery) or a current source. However, the focal length of the lens depends on the current flowing through the coil and the resistance of the coil changes with temperature (12.5 Ohm at 25°C). That is why, for highest stability, it is recommended to use a current source. Note that this temperature effect is visible within seconds and has nothing to do with the expansion of the optical fluid described above, which is on the order of minutes. For AC operation, the inductance of the coil, which depends on frequency, is an important parameter. Both the resistance and inductance are shown in Figure 11.

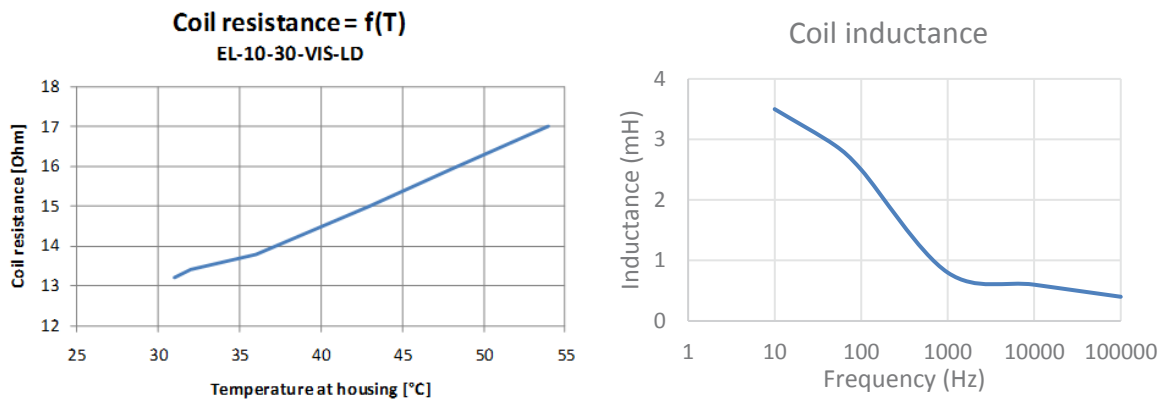


Figure 11: The left plot shows the coil resistance as a function of temperature. On the right, inductance versus frequency is shown.

### Recommended drivers and power supplies

Optotune provides its own high-precision USB drivers with a resolution of 0.1 mA. It includes the I2C readout of the temperature sensor, which can be used for temperature compensation.



There are also many alternative off-the-shelf products available to control the EL-10-30:

- Precision constant current driver for laser diodes with external control via 0-5 V analog signal (e.g. Edmund Optics NT56-804 or NT84-355)
- For high precision applications (0.1 mA resolution) with manual control: TTi QL355
- For high precision applications (0.1 mA resolution) with USB/RS232 computer control: TTi QL355P
- For low precision applications (1 mA resolution) with manual control: TTi EL301R
- For low precision applications (1 mA resolution) with USB computer control: Quakko HY3005DP  
<http://shop.vendio.com/Evan2002/item/2041700966/?s=1282809362>

The lens can also be driven using pulse width modulation (PWM) with a frequency between 20 kHz and 50 kHz. Another very useful component is the ADN8810 programmable precision current source of Analog Devices, which features 12 bits of resolution and can be controlled with an SPI interface.

### Response time

The rise time on a current step is in the range of 2-4 ms, depending on the step size. However, it takes about 15 ms until the lens has fully settled. Figure 12 shows the optical response on a current step measured with photodiode. The measurements were performed at room temperature.

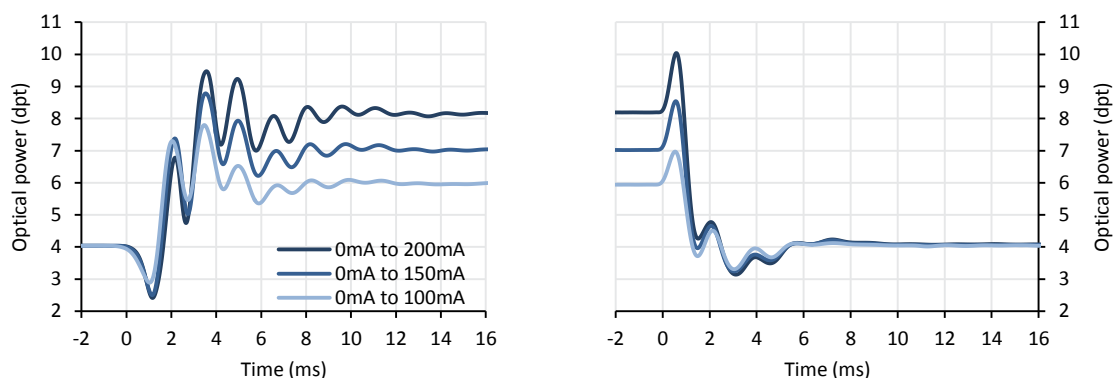


Figure 12: Typical optical response of the EL-10-30-C to a current step.

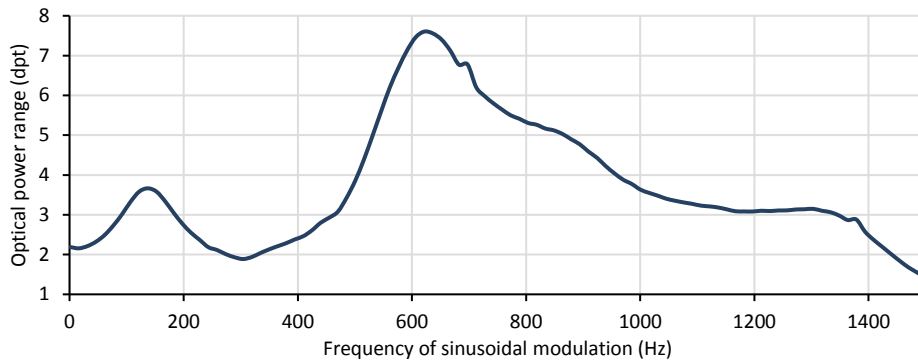


Figure 13: Typical frequency response of the EL-10-30-C with current oscillating from 50 to 150 mA.

This system is slightly over-damped and the frequency response in Figure 13 shows a resonant frequencies at about 150 and 600 Hz. To achieve a shorter settling time, however, it is better to remove these frequencies from the step function. Also, settling time can be improved by applying an overshooting step function. Tests show that the dynamics of the lens is similar in both directions and across different current ranges. The fact that the step down to 0 mA settles faster with the EL-10-30-C is because the actuator actually hits the housing. It is generally recommended to operate above 10mA at all times to avoid this effect, as it may shorten the lifetime of the lens. With an optimized driving signal, the settling time is reduced below 5ms. Figure 14 shows an example of the response behavior with a driving signal filtered with three low-pass filters (300 Hz) in series. The following graph shows the optical response on a current step measured using two photodiodes. For faster response times, please also consider the smaller electrical lens EL-6-18, which is about 50% faster.

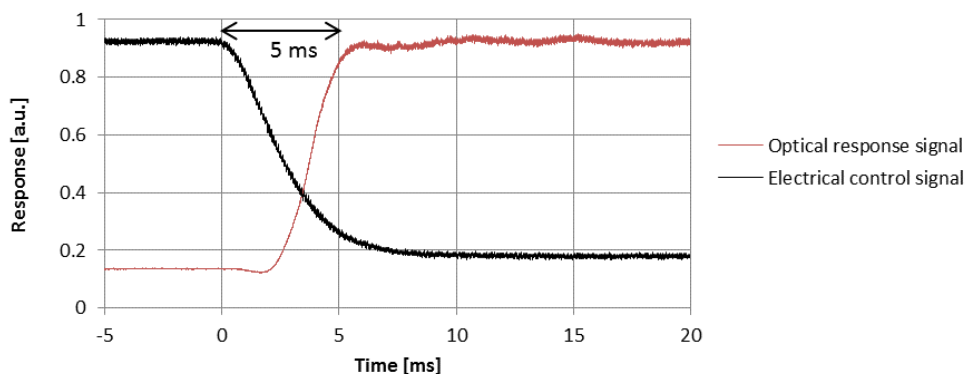


Figure 14: Optical response of the EL-10-30-C-LD-LP to a current step from 50 mA to 250 mA with a driving signal filtered with three low-pass filters (300 Hz) in series.

Another way to attenuate the oscillations seen in Figure 12 is by using standard passive elements. The circuit is illustrated on the left of Figure 15. It is analogous to a LC-low-pass filter used in loudspeakers, with a slew rate of 12 dB/octave (second order). Since the impedance of the EL-10-30, -C and -Ci is similar, the circuit is applicable to all members of the EL-10-30 series. On the right of Figure 15, the optical response of the EL-10-30-LP to a rectangular current step (10%-90%) is shown. The parameters of the LC-circuit correspond to a cut-off frequency of 165 Hz, showing good damping behavior. As a trade-off, the response time is slightly increased to about 5 ms.

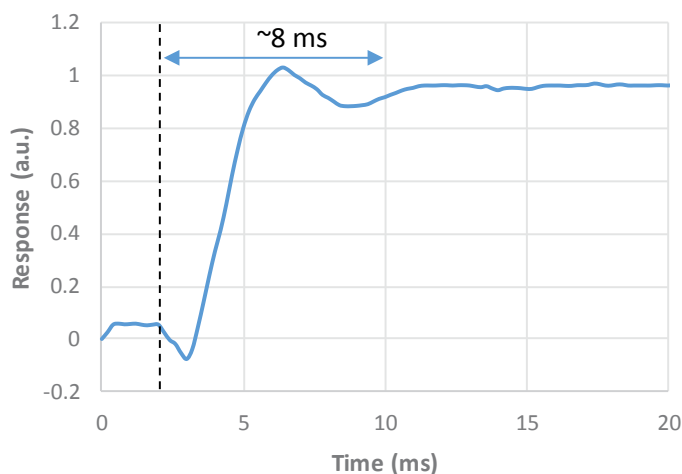
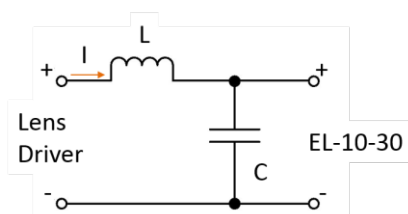


Figure 15: Filter circuit based on passive elements. The current output of the Lens Driver is connected on the left and the lens on the right side. In this example  $C = 94 \mu\text{F}$  and  $L = 10 \text{ mH}$ , giving in a cut-off frequency of 165 Hz.

### Atmospheric pressure and low temperature performance

By working principle, the atmospheric pressure has no influence on the lens. This has been validated down to values of  $10^{-4}$  mbar. Furthermore, the EL-10-30 with LD material is suitable for low temperature operation. The lens is tunable down to temperatures as low as 230 K. The response time of the lens increases for lower temperatures (e.g. 3 s at 250 K and 60 s at 230 K). For temperatures below 220 K the lens freezes but no damage was observed in tests down to 10 K. The transmission of the lens is independent of the operating temperature.

### Autofluorescence

The EL-10-30 with LD material is not auto fluorescent and can be used for fluorescence microscopy.

### Life time

The EL-10-30 has passed relevant environmental and accelerated aging tests as outline in Table 2.

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

**Solar radiation test:**

Passed

1120 W per m<sup>2</sup> (IEC 60068-2-5), 8 h irradiation & 16 h darkness, 10 cycles

Table 2: Environmental tests performed with the EL-10-30.

**Mounting possibilities for the compact EL-10-30**



G024503000, LI-NOS - Qioptiq



G061042000, LI-NOS - Qioptiq



KM200V/M, Thorlabs



NT57-977, Edmund Optics



NT64-564, Edmund Optics



NT03-676, Edmund Optics

**Ordering information for custom versions of the EL-10-30**

For custom versions, please use the following concept for part numbers:

**EL-10-30-H-AR-MAT-APP- (F<sub>min</sub>/F<sub>max</sub>)**

H = Leave blank for compact housing

C: C-mount housing with FPC connector

Ci: Industrial C-mount housing with Hirose connector

AR = VIS: visible broad-band anti-reflection coating (400 – 700 nm)

NIR: near broad-band infrared anti-reflection coating (700 – 1100 nm)

1064: narrow-band anti-reflection coating at 1064 nm

NOC: No coating

MAT = HR: high refraction lens material ( $n_D = 1.559$ )

LD: low dispersion lens material ( $n_D = 1.300$ )

APP = MV: Machine vision option: Includes -150 mm offset lens for a total focal tuning range of -600 mm to infinity to +170 mm

LP: Laser processing option: Includes -150 mm offset lens and an optimized membrane for a total focal tuning range of -600 mm to infinity to +400 mm

f<sub>min</sub> = minimum focal length

f<sub>max</sub> = maximum focal length

**Example:** EL-10-30-VIS-LD-(+80/+300) refers to a custom electrical tunable lens of 10 mm aperture and 30 mm outer diameter (compact housing) with anti-reflection coating for visible light, low dispersion lens material and a focal tunable range from +80 to +300 mm.

**Customization**

Optotune's lens technology can be adapted to your needs. Table 3 provides a range of possible parameters.

Clear aperture (A)	From 2 mm to 55 mm
Range of focal length	From $-A$ to infinity to $+A$
Response time	As little as 1 ms
Lens shapes	Spherical, from convex to flat to concave, whereby the other side of the lens may be a static free form  Cylindrical shapes are possible as well
Cover glasses	BK7, fused silica, sapphire, plastics (PC, PMMA, COC)
Coatings	For cover glasses only

Table 3: Lens parameters that can be customized.

Note: Not all criteria can be met at once. For example, larger apertures based on the same EL-10-30 principle are slower and more power consuming. As an alternative, a mechanical design could be used similar to Optotune's ML-20-35 or ML-25-50, which requires no holding power and can easily be motorized.

### Exchanging the offset lens of the EL-10-30-C Series

The EL-10-30-C is shipped with a planar cover glass or with an integrated offset lens (MV version), which is held in place by a retainer ring. The cover glass or offset lens can easily be exchanged by hand following the procedure outlined below. Please note that this is preferably done in a clean room or under a flow hood to avoid dust entering the tunable lens.

1. Loosen the retainer ring carefully with a small screw driver
2. After about 5 rotations turn the lens with the ring pointing down so no dust can get into the lens
3. Take out the cover glass / offset lens with the retainer ring. Prepare the new cover glass or lens.
4. Turn the lens again, but be careful, that no dust gets inside. Carefully drop the new cover glass or lens (planar side should usually look down towards the lens) inside using tweezers.
5. Put the retainer ring in by hand
6. Tighten the retainer ring with a screw driver. Be careful not to scratch the glass.

IMPORTANT: At the end, do not exert much torque ( $<1$  Nm) as this might damage the tunable lens.



## Safety and compliance

The product fulfills the RoHS and REACH compliance standards. The customer is solely responsible to comply with all relevant safety regulations for integration and operation.