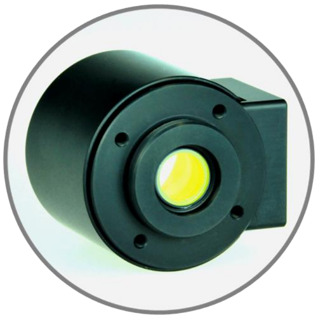

Electrically Tunable Lens EL-10-42-OF

The working principle of Optotune's EL-10-42-OF with integrated optical feedback is based on the well-established shape-changing flexible lens. The curvature of the lens is adjusted by applying an electrical current. The focal length is accordingly tuned to a desired value within milliseconds. The EL-10-42-OF has an integrated optical feedback, measuring the optical power of the lens in real-time. Optimal control is guaranteed in combination with the EL-E-OF-A electronics. As a consequence, reproducibility and focus stability is extremely high which makes Optotune's EL-10-42-OF the perfect choice for laser processing applications.

Main specifications

Clear aperture	10	mm
Optical power: tuning range	-2.0 to +2.0	dpt
Optical power: pointing stability (+/- STD)	< +/- 0.002	dpt
Optical power: repeatability (+/- STD)	< +/- 0.005	dpt
Optical power: long term stab. 8h (+/- STD)	< +/- 0.01[1]	dpt
Lateral spot shift over full tuning range	< 45	µRad
Lateral long term drift at fixed focal length	< 5	µRad
Wavefront error (@525 nm, 0 mA)	< 0.25	λ RMS
Lens type	plano-convex	
Transmission wavelengths (94% transmission)	532[2] and 1064 +/- 6	nm
Long term radiation damage @ 1064 nm: 40 mJ/cm^2 at 20 kHz	No effect after 2000 h (ongoing)	
Damage threshold[3] @ 1064 nm: 125 ns-pulsed at 50 kHz 10 ps-pulsed at 50 kHz Damage threshold @ 532 nm: 1 ns-pulsed at 300 kHz 10 ps-pulsed at 50 kHz	 2.6 2.05 0.19 0.11	 J/cm^2
Response time (10%-90% step)	12 (controlled)	ms
Typical speed of focus change	6000	mm/s
Focal length resolution	Continuous (depends on control electronics)	
Lifecycles (10%-90% sinusoidal)	>1'000'000'000	
Weight	90	g
Heater set temperature	47	°C
Operating temperature	10 to 40	°C
Storage Temperature	-20 to 80	°C

Parameters in combination with f = 160 mm f-theta lens[4]

Max z-tuning range	100	mm
Repeatability (10%-90% step)	< 250	µm
Long term drift over 3h	< 500	µm

Electrical specifications

Max lens power consumption	1.5	W
Max lens current	350	mA
Max heater power consumption	12	W
Heater resistance @ 25°C	25 +/- 10%	Ohm
Voltage Vcc	3.3	V
LED power supply @ 1.5V	30	mA

[1] Mainly due to residual temperature effects
[2] Contact sales@optotune.com for further information
[3] Characterization done by Inspire AG and IWF/ETH Zurich
[4] See laser processing application note for further details

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Housing

The EL-10-42-OF comes with a black metallic housing. The rectangular shaped part of the housing at the side includes the electrical connections. Four M3 thread holes located at the front surface of the housing are designated for mounting. A typical assembly is shown in section *Alignment and mounting*. The Ø40.0 mm and Ø25.5 mm diameter flank is tightly tolerated (ISO tolerance g6) and suitable as an alignment feature. The included Teflon washer provides thermal isolation and has to be placed between the EL-10-42-OF and an external holder.

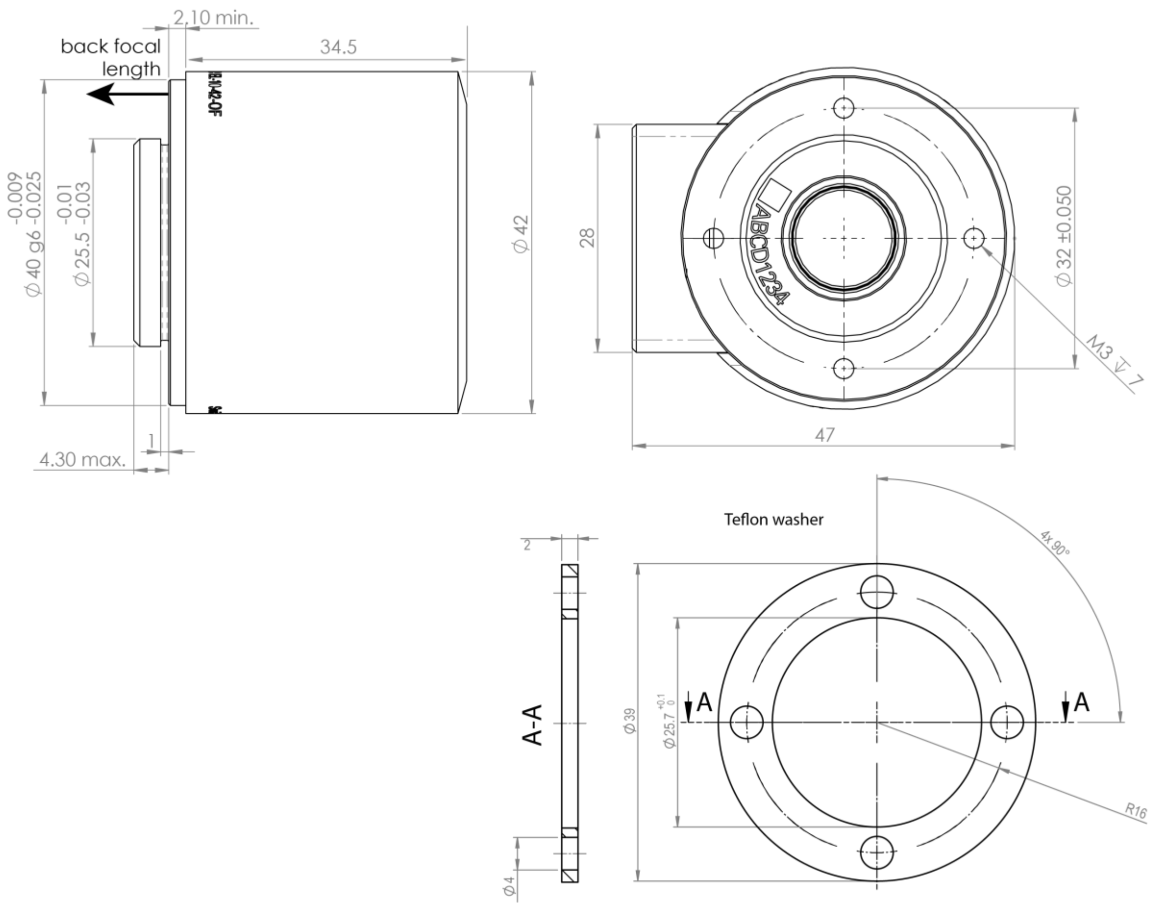

Figure 1: Mechanical drawing of the EL-10-42-OF (unit: mm). Four M3 thread holes are available four mounting. The Teflon washer has a thickness of 2mm and its flatness is tolerated within +- 0.05 mm.

Electrical connection

The electrical connection of the EL-10-42-OF consists of two female 1.5 mm AMP Mini CT connectors with 6 and 8 pins (see e.g. www.te.com, No. 292207-6 and 292207-8). The detailed pin-out is summarized in the table below.

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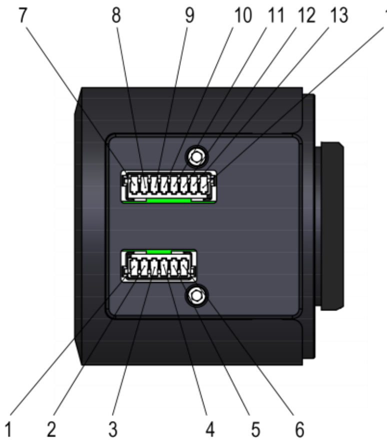

Figure 2: Electrical connections of EL-10-42-OF. Both connectors are of type 1.5 mm AMP Mini CT.

Pinning					
Position	**Function**	**Value**	**Position**	**Function**	**Value**
1	GND	-	8	Control current -	-
2	Heater in	Max. 12W	9	GND	-
3	Heater out	-	10	LED + Anode	30 mA @ 1.5V
4	I²C SDA	Digital signal	11	LED – Cathode	-
5	I²C SCL	Digital signal	12	Photodiode Common Cathode GND	-
6	Vcc	3.3V	13	Photodiode Anode back	Typ. 100 µA
7	Control current +	0..350 mA	14	Photodiode Anode front	Typ. 100 µA

Optical power versus current

The optical power of the EL-10-42-OF increases with increasing current, shown in Figure 3. The working principle is based on Optotune's well-established technology of electrically tunable lenses. The core that forms the lens contains an optical fluid, which is sealed off with an elastic polymer membrane. An electromagnetic actuator is used to exert pressure on the container and therefore changes the curvature of the lens. By changing the electrical current flowing through the coil of the actuator, the optical power of the lens is controlled.

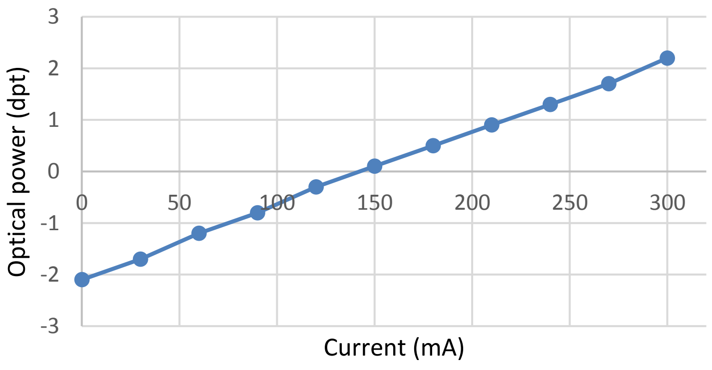

Figure 3: Typical data showing the linear relation between optical power (in diopters) and electrical current.

Optical feedback signal

The basic idea to establish an optical feedback is to detect light passing through the lens, emitted by a built-in LED. Two photodiodes (front, back) detect the light from the LED and emit a photo current between 0 and ~100 µA, see left panel of Figure 4. The slopes of the two signals, red and blue lines, are different. Yet, the photo currents are both proportional to the actual optical power (diopters) of the lens. With subsequent electronics these

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currents are converted into a signal of several volts through trans-impedance amplifiers and the normalized difference (V1-V2)/(V1+V2) of the two voltages V1 and V2 is calculated. As a result, a linear relation between the normalized voltage and the optical power of the lens is established (see right panel of Figure 4). The signal is independent of intensity fluctuations due to the normalization.

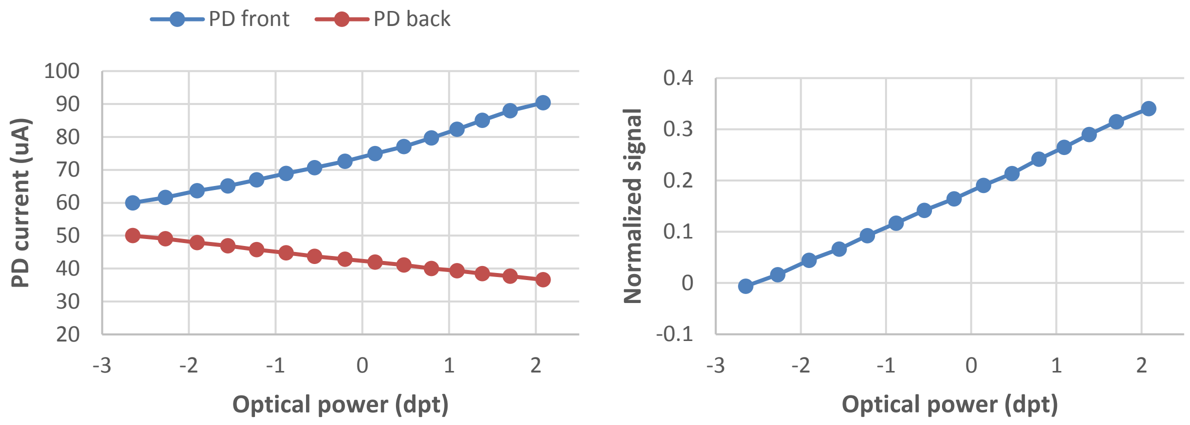

Figure 4: The left panel shows the dependency of photo current versus optical power of the lens. The red and blue lines are the signals from the two photo diodes. Both signals show linear dependency but have a different slope. The right panel presents the normalized signal which is proportional to the optical power.

Alignment and mounting

An important aspect when mounting the EL-10-42-OF is to ensure proper alignment with respect to the optical axis. Figure 5 shows an implementation of a holder plate. For detailed dimensioning in your design, we can provide a CAD file of the holder. We propose a scheme that utilizes the part of the smaller diameter of the lens which is specified with low tolerance (ISO g6). The through hole of the holder plate has the corresponding DIN tolerance H8. The lens is screwed from the front onto the holder plate. This guarantees best alignment with respect to the optical axis. The elongated holes give the rotational freedom to align the connectors, since the relative position of the connectors and the screw holes vary from lens to lens. For best thermal isolation, a Teflon washer (included in the package) has to be placed between the lens' front face and the holder. Also, it is recommended to use plastic screws to fix the lens. In Figure 5, the lens is rotated such that the connectors point to the side.

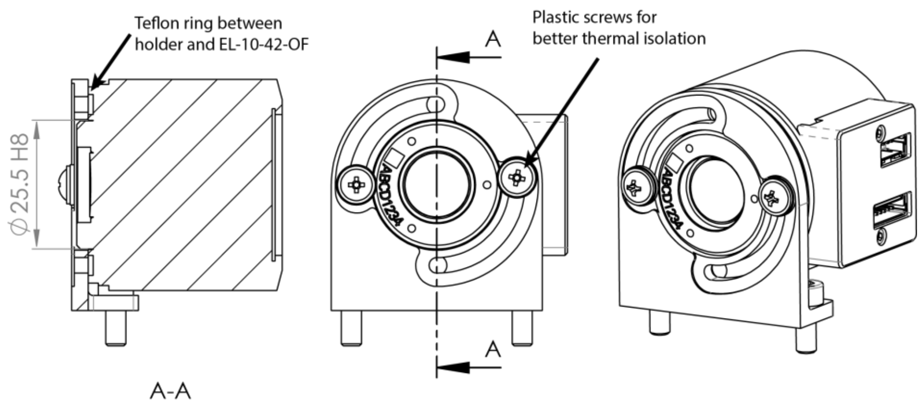

Figure 5: EL-10-42-OF on a holder plate. The smaller diameter servers as the alignment feature to guarantee precise alignment with respect to the optical axis. Two screws coming from the front hold the lens in place. The elongated holes allow for rotation of the lens to place the connectors in the preferred position. In this example the connectors point to the side.

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Bode diagram

In order to characterize the dynamics of the EL-10-42-OF itself, which behaves similar to a mass-spring system, it is common to measure the Bode diagram. It contains both the magnitude of the frequency response and the phase shift. The result is shown in Figure 6 which is applicable as a generic model for the EL-10-42-OF. Lens to lens variations are negligible. The first resonance peak is at 200 Hz and in the same region the phase shift reaches -90° and continues to lower values. The diagram gives an indication of the physical limit of the lens' maximum control speed, which will be around 100 Hz (half of the resonance frequency).

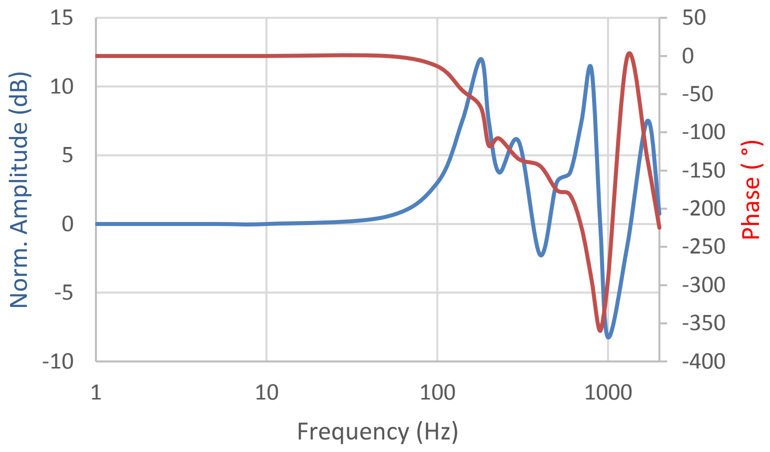

Figure 6: Bode diagram of the EL-10-42-OF. The amplitude is normalized to the DC limit (constant current) and shows a resonance at 200 Hz (blue curve). The phase shift is shown in red.

Temperature stabilization

In order to have highest focus stability, the EL-10-42-OF has to be operated at a fixed set temperature of 47 °C. By default, this is guaranteed when using the EL-E-OF-A controller board. An integrated heater element keeps the set temperature constant by using the lens' temperature sensor as feedback signal. When the lens is initialized, it requires a finite amount of time until the set temperature is reached. In Figure 7, the most extreme conditions are shown with an environmental temperature of 10°C and 40°C. As one can see, it takes approximately 4 and 6 minutes, respectively, to reach the set temperature. The power supply operates at 24V. After a short time, indicated by the red and blue arrows, the lens is set to maximum current (300 mA), in order to see the effect of additional heat input. Even for the 40°C environmental temperature only a small increase of about 2°C is visible, which is the desirable result.

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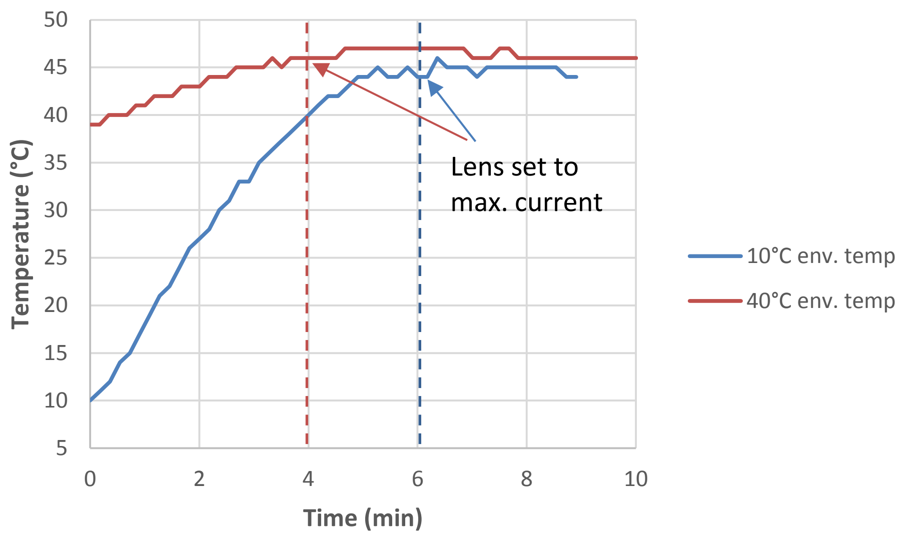

Figure 7: Initial heating phase when the lens is initialized. Depending on the two (extreme) environmental temperatures 10°C and 40°C, it takes approximately 4 and 6 minutes (dashed vertical lines) until the set temperature is reached. The additional heat input when setting the lens to 300 mA is negligible.

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.

For more information on optical, mechanical and electrical parameters, please contact sales@optotune.com.

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