Applications in Ophthalmology

July 2017

Dr. David Leuenberger, Business Development Manager

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

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
  - Progressive lens emulation fitting glass
Founded 2008

Leader in tunable optics

25 sales partners in 30 countries

70 employees

HQ located in Zurich, Switzerland

Privately owned
Optotune provides three core product lines

Focus tunable lenses

Laser speckle reducers

Beam steering devices
Expansion of product portfolio over the years
## Our vision: Enable optical innovations

By delivering key components

- Tunable lenses
- Laser speckle reducers
- Beam steering devices

Based on platform technologies

- Membranes & liquids
- Electroactive polymers
- Reluctance force actuators
Expertise in house from R&D to production
Optotune’s market focus

**Laser projection**
- High-resolution, speckle-free projections
- Ultra-compact solution with no mechanics
- Low power consumption

**Machine vision**
- Focus within milliseconds
- Working distances from infinity to 50mm
- Maximal flexibility

**Laser processing**
- Fast control of Z-axis
- Compact, reliable design with less mechanics
- Easy to integrate

**Medical**
- Compensation of visual defects
- Continuous adjustment in real-time
- +/- 20 diopters spherical, +/- 10 diopters cylindrical

**Microscopy**
- Axial focusing over several 100um within milliseconds
- Backward compatibility with several types of microscopes
- Speckle-free laser illumination

**Custom design**
- What is your application?
# Key medical application

<table>
<thead>
<tr>
<th>Microscopy</th>
<th>OCT</th>
<th>Handheld spectroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applications</strong></td>
<td><strong>Eye OCT</strong></td>
<td><strong>Raman spectroscopy</strong></td>
</tr>
<tr>
<td>Confocal microscopy</td>
<td>2-Photon microscopy</td>
<td></td>
</tr>
<tr>
<td>2-Photon microscopy</td>
<td>Light-sheet microscopy</td>
<td></td>
</tr>
<tr>
<td>Light-sheet microscopy</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Value proposition</strong></td>
<td><strong>Switch between retina</strong></td>
<td><strong>Increase signal</strong></td>
</tr>
<tr>
<td>3D imaging</td>
<td>and cornea.</td>
<td><strong>strength → faster, more accurate</strong></td>
</tr>
<tr>
<td>Fast tuning</td>
<td></td>
<td><strong>measurement</strong></td>
</tr>
<tr>
<td></td>
<td>Higher lateral resolution</td>
<td></td>
</tr>
</tbody>
</table>
### Key medical application

<table>
<thead>
<tr>
<th></th>
<th>Endoscopy</th>
<th>Ophthalmology</th>
<th>Dental cameras</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applications</strong></td>
<td>Rigid endoscopy</td>
<td>Subjective refractive measurement (Phoropter)</td>
<td>CAD/CAM systems</td>
</tr>
<tr>
<td><strong>Value proposition</strong></td>
<td>Focus-on-demand Auto-focus</td>
<td>Compact size (wearable)</td>
<td>Higher image quality (speckle-free)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quicker measurement</td>
<td>Auto-focus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost effective</td>
<td>Image stabilization</td>
</tr>
</tbody>
</table>

---

9
Agenda

- Company presentation

- Products & Technology

- Trends in Ophthalmology

- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
# Optotune’s electrically focus tunable lenses

<table>
<thead>
<tr>
<th>Model</th>
<th>Focal power range*</th>
<th>Clear aperture</th>
<th>Outer diameter</th>
<th>Wavefront quality RMS @525nm** ***</th>
<th>Absolute focal power accuracy</th>
<th>Built-in sensors</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL-10-30-TC</td>
<td>8 … 22 Dpt</td>
<td>10mm</td>
<td>30mm</td>
<td>&lt;0.25 / 0.5 λ</td>
<td>&lt;0.15 dpt</td>
<td>None</td>
<td>MV OCT</td>
</tr>
<tr>
<td>EL-10-30-C(i)</td>
<td>-1.5 … +3.5 Dpt</td>
<td>10mm</td>
<td>30mm</td>
<td>&lt;0.15 / 0.25 λ</td>
<td>&lt; 0.1 dpt</td>
<td>Temperature</td>
<td>MV Microscopy</td>
</tr>
<tr>
<td>EL-10-42-OF</td>
<td>-2 … +2 Dpt</td>
<td>10mm</td>
<td>42mm</td>
<td>&lt;0.15 λ</td>
<td>0.008 dpt (temp. contr.)</td>
<td>Temp./Optical feedback</td>
<td>Laser marking</td>
</tr>
<tr>
<td>EL-16-40-TC-5D</td>
<td>-2 … +3 Dpt</td>
<td>16mm</td>
<td>40mm</td>
<td>I: &lt;0.15 / 0.5 λ</td>
<td>&lt; 0.1 dpt</td>
<td>Temp./Optical feedback</td>
<td>MV/Microscopy Ophthalmology</td>
</tr>
<tr>
<td>EL-16-40-TC-20D</td>
<td>-10 … +10 Dpt</td>
<td>16mm</td>
<td>40mm</td>
<td>II: &lt;0.25 / 0.5 λ</td>
<td>&lt; 0.1 dpt</td>
<td>Temp./Optical feedback</td>
<td>MV/Microscopy Ophthalmology</td>
</tr>
</tbody>
</table>

* Depends on selected optical fluid  
** vertical / horizontal optical axis  
*** class I: high-mag, microscopy  
class II: standard grade
Focus tunable polymer lenses are reliable

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

<table>
<thead>
<tr>
<th></th>
<th>LSR-5-17</th>
<th>LSR-5-17-E</th>
<th>LSR-10-22</th>
<th>LSR-10-22-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture</td>
<td>5 mm</td>
<td>5 mm</td>
<td>10 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Size (Ø or L x H)</td>
<td>17mm x 3.8mm</td>
<td>17mm x 3.8mm</td>
<td>22mm x 3.8mm</td>
<td>22mm x 3.8mm</td>
</tr>
<tr>
<td>Standard diffuser angles*</td>
<td>6°, 12°, 17°, 24°</td>
<td>6°, 12°, 17°, 24°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resonant frequency</td>
<td>300 Hz</td>
<td>300 Hz</td>
<td>180 Hz</td>
<td>180 Hz</td>
</tr>
<tr>
<td>Oscillation amplitude</td>
<td>300 um</td>
<td>300 um</td>
<td>400 um</td>
<td>400 um</td>
</tr>
<tr>
<td>Electronics</td>
<td>No</td>
<td>Yes, not certified</td>
<td>No</td>
<td>Yes, not certified</td>
</tr>
</tbody>
</table>

* A variety of circular and elliptical diffusion angles available upon request
## New generation of ultra-thin steel LSRs

- All-in-one platform for easy handling
- Can be designed more compact for OEMs

<table>
<thead>
<tr>
<th></th>
<th>Pico-projector</th>
<th>Cinema-projector</th>
<th>HUD (Planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser [mm]</td>
<td>6.5x4.7</td>
<td>18.5x18.5</td>
<td>53x23</td>
</tr>
<tr>
<td>Aperture [mm]</td>
<td>5.5x4</td>
<td>17x17</td>
<td>50x20</td>
</tr>
<tr>
<td>Size [mm]</td>
<td>7x14x2</td>
<td>39x39x5</td>
<td>40x70x5</td>
</tr>
<tr>
<td>Oscillation</td>
<td>1D</td>
<td>1D</td>
<td>2D</td>
</tr>
<tr>
<td>Amplitude [um]</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Frequency [Hz]</td>
<td>400</td>
<td>130</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Status</td>
<td>Alpha Series</td>
<td>In Production</td>
<td>Planned</td>
</tr>
</tbody>
</table>

Under development

In production
Working Principle based on Membrane and Fluid

Videos available on www.optotune.com
The focal power \((D = 1/f)\) of Optotune’s lenses is controlled by current.

Note: This curve varies from lens to lens. However, it is reproducible once calibrated.
Currently three optical materials available

<table>
<thead>
<tr>
<th></th>
<th>High refraction liquid</th>
<th>Medium refraction liquid</th>
<th>Low dispersion liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive index ((n_D @ 589.3nm))</td>
<td>1.56</td>
<td>1.38</td>
<td>1.30</td>
</tr>
<tr>
<td>Abbe number V</td>
<td>32</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Transmission range (&gt;90%)</td>
<td>330 – 1600nm</td>
<td>350 – 1600nm</td>
<td>240 – 2200nm</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-5° - 85°C</td>
<td>-20° - 120°C</td>
<td>-20° - 85°C</td>
</tr>
<tr>
<td>Toxicity</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Color stability (yellowing)</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

- Monochromatic applications with large tuning range
- Illumination systems based on lasers or LEDs
- Polychromatic imaging, laser processing
Membrane & Fluid is Transparent >90% from 240 – 2200nm

Transmission of the EL-10-30 assuming 100% transparent cover glasses.
Response time of \( \sim 10\text{ms} \)

**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.

Oscillation mode → fast image stacking

Low-pass filtered:

- 5 ms
Tuning range and wavefront quality

Measured at 525 nm and 80% of clear aperture, defocus, tilt & sphere excluded.

Precision optics quality can be achieved
Polymer lenses can withstand high power!

- Only 0.1% absorption in VIS & NIR range
- The following tests were successful with EL-10-42-OF (LD fluid, high-power coatings)

<table>
<thead>
<tr>
<th>Damage threshold @ 1064 nm:</th>
<th>2.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 ns-pulsed at 50 kHz</td>
<td>2.05</td>
</tr>
<tr>
<td>10 ps-pulsed at 50 kHz</td>
<td></td>
</tr>
<tr>
<td>Damage threshold @ 532 nm:</td>
<td>0.19</td>
</tr>
<tr>
<td>1 ns-pulsed at 300 kHz</td>
<td>0.11</td>
</tr>
<tr>
<td>10 ps-pulsed at 50 kHz</td>
<td></td>
</tr>
</tbody>
</table>

- Customized cover glasses are available
Open loop operation with temp. calibration

“I need a lens with f=125mm”

Set f=125mm in lens driver software

Command sent to lens driver to set f=125mm

Temperature compensated control current to adjust lens to f=125mm

Lens calibration table and temperature read by lens driver

Lens calibration curve stored on lens internal memory

EL-10-30-C including NXP temperature sensor SE97B with internal memory

f=125mm

Lens characterization f vs T vs I

“..."
Optotune has developed a platform for 2D beam-steering.
## Optotune on-going beam-steering product development

<table>
<thead>
<tr>
<th></th>
<th>MR-15-30- ('Scuti')</th>
<th>MR-7-10- ('Scutini')</th>
<th>MR-5-5- ('Mizar')</th>
<th>Tunable prism (TP-12-16)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary mirror/aperture size [mm]</strong></td>
<td>15</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td><strong>Mechanical tilt (° half angle)</strong></td>
<td>25</td>
<td>4</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td><strong>Mech. Repeatability RMS typical</strong></td>
<td>30-100 μrad</td>
<td>T.B.D</td>
<td>1.7 mrad</td>
<td>Depends on actuator</td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
<td>30x19</td>
<td>10x10x2.7</td>
<td>5x5x4</td>
<td>16x12</td>
</tr>
<tr>
<td><strong>Position feedback</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Engineering samples available</td>
<td>Alpha proto</td>
<td>Alpha proto</td>
<td>Engineering samples available</td>
</tr>
</tbody>
</table>
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
  - Applications in Ophthalmology
    - Compact Phoropter-like module
    - OCT
    - Perimeter
    - ‘Fogging’ in auto refractometers
Trends:

- Combine different functionalities into one single compact instrument

  - Precision Laser System with integrated 3D OCT (e.g. AMO CATALYS®)

  - Corneal topographer + OCT (e.g. Zeiss Atlas 9000)

  - Corneal topographer + pupillometer (e.g. TOPCON CA-200F Corneal Analyser)

  - OCT + Fundus imaging by confocale laser scanning + eye tracking (Heidelberg Engineering)
Trends

- Portable instruments
  - Handheld refractometer by Adaptica
  - Plus Optix Vision Screener

- More robust to transport, less calibration required \( \rightarrow \) no movable parts
- Multi-spectral devices \( \rightarrow \) requiring low dispersion optics (c.p. Optotune Abbe number of 100).
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
## Ophthalmology - How it works

<table>
<thead>
<tr>
<th>Application</th>
<th>Optotune value proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Ophthalmoscope</td>
<td>Change of magnification</td>
</tr>
<tr>
<td>Slit-lamp</td>
<td>Autofocus of auxiliary camera</td>
</tr>
<tr>
<td>Phoropter</td>
<td>Spherical lens+2 Stokes cylinder replaces lens wheels (compact)</td>
</tr>
<tr>
<td></td>
<td>Fast tuning</td>
</tr>
<tr>
<td>Surgical microscope</td>
<td>Autofocus/ superposition of real image and OCT display</td>
</tr>
</tbody>
</table>
## Ophthalmology - How it works

<table>
<thead>
<tr>
<th>Application</th>
<th>Optotune value proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundus camera</td>
<td>Autofocus</td>
</tr>
<tr>
<td>Wavefront Aberro-meter</td>
<td>Autofocus</td>
</tr>
<tr>
<td>Perimeter</td>
<td>Replace trial lens to adjust for eye correction</td>
</tr>
</tbody>
</table>
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
    - OCT
    - Perimeter
    - ‘Fogging’ in auto refractometers
Trends
Smaller, lighter, cheaper

Mechanical phoropter
Automatic phoropter
Compact phoropter
Phoropter glasses

REICHERT ULTRAMATIC
NIDEK RT-5100
DOMS PHOROSTAR 600

7 kg
3.5 kg
600 g
200 g

A million lenses in one:
Achieve +/-20 diopters with a single tunable lens
Schematics of compact phoropter module

- 1st cylinder lens mounted on a rotational actuator
- 2nd cylinder lens mounted on a rotational actuator
- Electrical tunable lens
- Casing
- Front plate
Success stories - Adaptica

VisionFit™ - the unique wearable adaptive refractor for the most advanced subjective sight examination.

The Adaptive Lenses Stack
1. Adaptive Spherical Lens
2. Adaptive Cylindrical Lens
3. Adaptive Aberration Lens
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
Focusing on different focal planes within the eye

Spectral Domain OCT configuration

Typical SD-OCT setup with added capability to switch between front and back plane of eye.
Extended scan-range

- Overcoming trade-off between lateral resolution and axial field of view.

**Trade-off between lateral resolution and axial field of view.**

- **a)** focusing optics with low NA,
- **b)** focusing optics with a high NA and
- **c)** sample focusing optics with a high NA and an extended axial field of view due to an axial focus scan using the Optotune EL-10-30-C
New applications – Dynamic-focus SS-OCT

- Dynamic-focus SS-OCT system with a long axial imaging range
- Enhanced penetration depth and improved lateral resolution along the whole imaging depth
- High-resolution images of the human anterior eye chamber were demonstrated
- The developed system showed higher penetration depth than the commercial OCT systems
- Demonstrated, for the first time, the measurement of sulcus-to-sulcus distance in normal human eyes with OCT.
- The authors have a significant financial interest in Carl Zeiss Meditec, Inc. and Optovue

Fig. 1 Schematics of dynamic-focusing swept-source optical coherence tomography (SS-OCT) system. Cir, circulator; MP, miniprojector; EL, electrical lens; and L1–L7 as the lens number from 1 to 7.

Fig. 7 Imaging of the anterior segment of a normal human subject. (a) and (b) Dynamic-focus SS-OCT images without and with annotation, (c) images obtained with 40 MHz ultrasound biomicroscopy (UBM), and (d) image obtained with Visante TD-OCT. Both SS-OCT and Visante TD-OCT operate at the 1310-nm wavelength. CCT, central corneal thickness; ACD, anterior chamber depth; and PD, pupil diameter. Scale bars are 500 μm for all images.

J.P. Su et al, Journal of Biomedical Optics 126002-7 December 2015 • Vol. 20(12)
Microscope-integrated intraoperative OCT

Surgical guidance using iOCT feedback

- Optotune’s electrically tunable lens EL-10-30-NIR-LD allowed real-time adjustment of the OCT focal plane to maintain parfocality with the microscope view.

- Potential for iOCT-guided maneuvers and clinical decision-making in ophthalmic surgery.
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
Success stories - Perimeter

ML-30-46:
- 28mm CA
- +/- 8dpt Tuning Range
Agenda

- Company presentation
- Products & Technology
- Trends in Ophthalmology
- Applications in Ophthalmology
  - Compact Phoropter-like module
  - OCT
  - Perimeter
  - ‘Fogging’ in auto refractometers
‘Fogging’

- The *Fogging* allows the patient to view the target clearly and minimizes the interference with accommodation even in high astigmatism.

- The fast response from the Optotune EL is ideally suited to implement ‘fogging’.

![NIDEK AR-1 AUTO REFRACTOMETER](image)

![Typical fixation target](image)

![Graph showing response and time](image)
# Lifetime test of EL-10-30

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