Applications in Ophthalmology

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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
Optotune on one page

Established in 2008

Leader in tunable optics

27 sales partners in 30 countries

~80 employees in HQ in Zurich, Switzerland
~70 employees in Factory in Trnava, Slovakia

Two major businesses
- Industrial
- Consumer

Privately owned

Vision Systems Innovator Award 2016 >
Swiss Economic Award 2014 >
No. 1 Startup in Switzerland 2011 >
Prism Award 2011 >
Swiss Technology Award 2010 >
Winner of Venture 2008 >
ETH Spin-off 2008 >
Optotune provides four core product lines

**Focus tunable lenses**

**Laser speckle reducers**

**Extended pixel resolution actuators**

**2D mirrors**
Expansion of product portfolio over the years
Focus tunable lenses

- Apertures from 3 to 30mm
- Fast response of ~5ms
- Low dispersion ($V > 100$)
- Long lifetime $> 10^9$ cycles
- High repeatability $< 0.1$ dpt
Our vision: Enable optical innovations

<table>
<thead>
<tr>
<th>Enables product innovation</th>
<th>By delivering key components</th>
<th>Based on platform technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Compact &amp; fast autofocus</td>
<td>• Tunable lenses</td>
<td>• Membranes &amp; liquids</td>
</tr>
<tr>
<td>• 3D laser processing</td>
<td>• Laser speckle reducers</td>
<td>• Electroactive polymers</td>
</tr>
<tr>
<td>• Laser-based cinema</td>
<td>• Beam steering devices</td>
<td>• Reluctance force actuators</td>
</tr>
</tbody>
</table>
Expertise in house from R&D to production

Materials Research  Optical Design  Mechanical Design

Prototyping  Testing  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>![Microscopy Image]</td>
<td>![OCT Image]</td>
<td>![Handheld Spectroscopy Image]</td>
</tr>
</tbody>
</table>

### Applications
- Confocal microscopy
- 2-Photon microscopy
- Light-sheet microscopy
- Eye OCT
- Tissue OCT
- Raman spectroscopy

### Value proposition
- 3D imaging
- Fast tuning
- Switch between retina and cornea.
- Higher lateral resolution
- Increase signal strength → faster, more accurate measurement
## Key medical application

<table>
<thead>
<tr>
<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>
</tr>
<tr>
<td><strong>Value proposition</strong></td>
<td>Focus-on-demand</td>
<td>Compact size (wearable)</td>
</tr>
<tr>
<td></td>
<td>Auto-focus</td>
<td>Quicker measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost effective</td>
</tr>
</tbody>
</table>
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# Optotune’s electrically focus tunable lenses

<table>
<thead>
<tr>
<th></th>
<th>EL-3-10</th>
<th>EL-10-30-TC</th>
<th>EL-10-30-C(i)</th>
<th>EL-16-40</th>
<th>EL-10-42-OF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focal power range</strong></td>
<td>-13 ... 13 Dpt</td>
<td>8 ... 22 Dpt</td>
<td>-1.5 ... 3.5 Dpt</td>
<td>-2 ... +3 Dpt</td>
<td>-10 ... +10 Dpt</td>
</tr>
<tr>
<td><strong>Clear aperture</strong></td>
<td>3mm</td>
<td>10mm</td>
<td>10mm</td>
<td>16mm</td>
<td>16mm</td>
</tr>
<tr>
<td><strong>Outer diameter</strong></td>
<td>10mm</td>
<td>30mm</td>
<td>30mm</td>
<td>40mm</td>
<td>40mm</td>
</tr>
<tr>
<td><strong>Wavefront quality RMS @525nm</strong></td>
<td>&lt;0.15 / 0.15 λ</td>
<td>&lt;0.25 / 0.5 λ</td>
<td>&lt;0.15 / 0.25 λ</td>
<td>I: &lt;0.15 / 0.5 λ</td>
<td>II: &lt;0.25 / 2.5 λ</td>
</tr>
<tr>
<td><strong>Absolute focal power accuracy</strong></td>
<td>N/A</td>
<td>&lt; 0.1 Dpt</td>
<td>&lt; 0.1 Dpt</td>
<td>&lt; 0.1 dpt</td>
<td>&lt; 0.1 dpt</td>
</tr>
<tr>
<td><strong>Built-in sensors</strong></td>
<td>None</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temp./Optical feedback</td>
<td>Temp./Optical feedback</td>
</tr>
</tbody>
</table>

* Depends on selected optical fluid  
** vertical / horizontal optical axis
Focus tunable polymer lenses are reliable

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<th>Test conditions</th>
<th>Status</th>
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</table>
| 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  |
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</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>
2D tiltable mirror

- Large deflection (+/- 25°)
- 15mm clear aperture
- Compact
- Precise
- Status: prototype
Tunable prism

- Compact
- Intuitive alignment
- Low dispersion ($V > 100$)
- In transmission
Optotune has developed a platform for 2D beam-steering.

Unique in terms of mirror size and tilt angle.
# 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>Primary mirror/aperture size [mm]</td>
<td>15</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Mechanical tilt (° half angle)</td>
<td>25</td>
<td>4</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Mech. Repeatability RMS typical</td>
<td>30-100 µrad</td>
<td>T.B.D</td>
<td>1.7 mrad</td>
<td>Depends on actuator</td>
</tr>
<tr>
<td>Footprint</td>
<td>30x19</td>
<td>10x10x2.7</td>
<td>5x5x4</td>
<td>16x12</td>
</tr>
<tr>
<td>Position feedback</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Status</td>
<td>Engineering samples available</td>
<td>Alpha proto</td>
<td>Alpha proto</td>
<td>Engineering samples available</td>
</tr>
</tbody>
</table>
**XPR for extended pixel resolution**

**Optotune Products**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical performance</td>
<td></td>
</tr>
<tr>
<td>Clear aperture size</td>
<td>25 mm</td>
</tr>
<tr>
<td>Glass window movement angle</td>
<td>0.225°</td>
</tr>
<tr>
<td>Transition time</td>
<td>1.1 to 1.3 ms</td>
</tr>
<tr>
<td>Drive current</td>
<td>&lt;450 mA</td>
</tr>
<tr>
<td>Sound pressure</td>
<td>21 dBA</td>
</tr>
</tbody>
</table>

**Benefits**

- Fast transition time
- Long lifetime
- High resolution with small optics and chip size
- Fully pre-calibrated at 50 & 60Hz for temperatures up to 75°C

**Applications**

**High-resolution projection**

**Super-resolution imaging**

![Diagram of high-resolution projection](image)

![Diagram of super-resolution imaging](image)
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  ▪ 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 → no movable parts
- Multi-spectral devices → requiring low dispersion optics (c.p. Optotune Abbe number of 100).
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# Ophthalmology - How it works

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<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) 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

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<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>
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Trends

Smaller, lighter, cheaper

Mechanical phoropter
Automatic phoropter
Compact phoropter
Phoropter glasses

A million lenses in one:
Achieve +/-20 diopters with a single tunable lens

REICHERT ULTRAMATIC
NIDEK RT-5100
DOMS PHOROSTAR 600

7 kg
3.5 kg
600 g
200 g
Phoropter

Schematics of compact phoropter module
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
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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.
Overcoming 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

\[
FOV_{axial} = \frac{2\lambda}{\pi NA^2}
\]

\[
\Delta x = \frac{2\lambda}{\pi NA}
\]
EL-10-30-C allows enables a swept source OCT system to image the whole eye.

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

![Schematic diagram of dynamic focusing swept-source optical coherence tomography (SS-OCT) system.](image)

**Fig. 1** Schematics of dynamic-focusing swept-source optical coherence tomography (SS-OCT) system. Cir, circulator; MP, minipjector; 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.
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
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Success stories - Perimeter

ML-30-46:
- 28mm CA
- +/- 8dpt Tuning Range
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‘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’.

![Typical fixation target](image)

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

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