Optics in Horticultural Lighting

- Lighting for plants – design approaches
- Optics for horticultural lighting
- Reference design
Horticultural lighting

• Plants consume light and need photons for photosynthesis

• The amount and ratio of different wavelengths determine how, and how fast plants grow and produce crop

• Can mimic daylight integral and provide stable, optimized growing conditions for each plant

• Types of lighting: top lighting, vertical farming, intra-canopy lighting
Why LED in horticultural lighting?

Lower radiated heat
- Lights closer to plants → more dense farms
- Lower water consumption

Superior optical control
- Better control of where the light goes
- No wasted energy off target

Sustainability
- Long lifetime of luminaires
- Lower maintenance costs

Free control of spectral content
- Better match of spectra to plant’s needs
- By species / growth stage

→ more dense farms
→ Lower water consumption
Why OPTICS with LED?

• With the right optics LED light can be focused on the plants

  Narrow beam angle:
  • gives a higher PPFD (for plants that require deeper penetration of light inside the foliage)

  Wider beam angle:
  • has a potentially lower PPFD but can be compensated by lowering the luminaires
  • Potential cause of shadowing problems
  • has a lower foliage penetration

  Asymmetric beam angle:
  • New possibilities: vertical plane, off-plant installations
It’s important to optimise system ROI

- LEDs have longer lifetime compared to traditional HPS lightsources
  - LED 90% @25,000h, 85% @50,000h
  - HID 50% survival at 20,000h

- LEDs use 30% less electricity
  - No savings if additional heating is needed

- Spectrum optimisation
  - Higher yield
  - Healthier crop

- LEDs have lower output, therefore light should be focused only on plants to maximise PPFD
  - Correct choice of optics is very important
  - Optimise for the number of luminaires and DLI

- LEDs have around 2.5-5x investment cost
  - Optics will help to improve PPFD -> Maximise ROI and potential to reduce #luminaires
Design key questions

Successful grow light fixture is the sum of its components!

<table>
<thead>
<tr>
<th>Component</th>
<th>Affecting</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDs Driver</td>
<td>PPF &amp; Spectral Power</td>
<td>• Generating enough photons?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Correct ratio of photons?</td>
</tr>
<tr>
<td>Optics</td>
<td>PPFD (min, max, uniformity)</td>
<td>• Are the photons going where they are consumed?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distance required between luminaires</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distance required between luminaire &amp; plants?</td>
</tr>
<tr>
<td>All</td>
<td>PPF/J, W/m², W/kg (efficacy)</td>
<td>• How efficient installation?</td>
</tr>
</tbody>
</table>
Different types of lighting

Top lighting - greenhouses
- General hall/greenhouse lighting from the ceiling
- Retrofitting old HPS, modifying spectral content of light
- Challenges: light concentration on plants, uniformity and constant quality of light spectrum, high amount of power needed

Top lighting – vertical farming
- Emerging trend – illumination from top at a close distance
- Challenges: uniform intensity and spectral distribution, plants shading each other, photosynthetic efficiency (PPF/W), heat

Intra-canopy lighting
- Illumination on the side or inside the plants
- Possible with LEDs (HPS too hot)
- Challenges: uniform PPFD, good color uniformity (if continuous/wide spectrum), spectrum fit to the rest of lighting, light direction
What LEDiL optics for what type of lighting?

<table>
<thead>
<tr>
<th>Top lighting - greenhouses</th>
<th>Beam examples</th>
<th>Optic examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optics: 60-90deg low/mid bay (beam depends on installation height) with a slight batwing for uniform illuminance</td>
<td><img src="image" alt="Beam examples" /></td>
<td><img src="image" alt="Optic examples" /></td>
</tr>
</tbody>
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<tr>
<th>Top lighting – vertical farming</th>
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<tr>
<td>Optics: VSM, CY, WWW, STRADA-C, STRADA-S or other &gt;90deg optics, FLORENCE-3R with LED clusters for plants requiring a high DLI</td>
<td><img src="image" alt="Beam examples" /></td>
<td><img src="image" alt="Optic examples" /></td>
</tr>
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<th>Intra-canopy lighting</th>
<th>Beam examples</th>
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<tr>
<td>Optics: VSM, STRADA-S, STRADA-FT and other forward throw beams (TF, NHS, T2, T3)</td>
<td><img src="image" alt="Beam examples" /></td>
<td><img src="image" alt="Optic examples" /></td>
</tr>
<tr>
<td>Potential: ZT25/ZT45 or WAS beams as an additional light installed in corridors for illumination of bottom parts of plants</td>
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</tbody>
</table>
High bay optics for horticultural top lighting

No Optics

Not Recommended
- Optics will greatly increase PPFD and are worth the cost
- Optics focus light on plants

Simple Optics

Lowest Cost
- Reflector/film improves PPFD and uniformity
- Enables wider range of mounting heights

Individual Optics

High Performance
- Good uniformity
- Improved mixing for multi-color systems
Maximize your usable efficacy

- Focus light energy where it’s needed
  → Greater yield with less electrical power

- Uniform intensity and spectral distribution
  → Healthier and more productive plants

- Optics help focus the light on the plants, allowing either:
  - greater crop yield and shorter grow cycles
  - reduced BOM costs of the luminaire
Chemical resistance

PMMA versus PC

• In general PMMA is more resistant than PC to chemicals such as ammonia

• The chemical resistance of Makrolon® depends on:
  • the concentration of the substance
  • the temperature
  • the contact time
  • the internal stresses of the polycarbonate sheet

• We strongly recommend thorough testing to ensure the chemical is fully compatible with the product, LEDs and other components.

• Check chemical resistance in the LEDiL Installation Guide
Why LEDiL?

• Wide range of modular designs available for all types of horticultural lighting
  • Efficient single lenses and arrays, IP solutions, uniform colour mixing and various light distributions
  • Optimized results with the latest LEDs
  • Reduced luminaire BOM costs

• LEDiL horticultural optics help to focus light/photons on the plants resulting in:
  • Greater PPFD using less power
  • Greater crop yield
  • Shorter growing cycles

• Uniform light and spectral distribution produces healthier and more productive plants
LEDiL IP High Bay & Linear lenses

Easier and cheaper solutions with up to IP67 for horticultural lighting

<table>
<thead>
<tr>
<th>HB-IP-2X6 &amp; -G2</th>
<th>HB-2X2MX</th>
<th>HB-2X2MXS</th>
<th>STELLA</th>
<th>FLORENCE-3R-IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB-IP-2X6-RS</td>
<td>HB-2X2MX-M</td>
<td>HB-2X2MXS-M</td>
<td>STELLA-HB-HP</td>
<td>FLORENCE-3R-IP-Z90</td>
</tr>
<tr>
<td>HB-IP-2X6-M</td>
<td>HB-2X2MX-W</td>
<td>HB-2X2MXS-WW</td>
<td>STELLA-HB-WWW</td>
<td>FLORENCE-3R-IP-Z60</td>
</tr>
<tr>
<td>HB-IP-2X6-W</td>
<td>HB-2X2MX-WWW</td>
<td>HB-2X2MXS-WWW</td>
<td></td>
<td>FLORENCE-3R-IP-O</td>
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<tr>
<td>HB-IP-2X6-WW</td>
<td></td>
<td></td>
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<td>PMMA upon request</td>
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<tr>
<td>HB-IP-2X6-O</td>
<td></td>
<td></td>
<td></td>
<td>3x11 mid power modules</td>
</tr>
<tr>
<td>Up to 5050 size HP</td>
<td>Up to 7070 size Ultra HP</td>
<td>Up to 7070 size Ultra HP</td>
<td>Up to 30mm LES COB</td>
<td>MP, HP</td>
</tr>
</tbody>
</table>
2X2Mx®

Versatile platform in PMMA & Silicone

- Compatible with ultra-high-power LEDs up to 7070 package sizes
- Can be used with clusters of smaller LEDs
- Both PMMA and silicone versions provide ingress protection up to IP67
- Modular structure enables wide compatibility and easy modification
- World class ecosystem support with a range of PCB’s and heat sinks available from LEDiL’s 2X2MX Ecosystem Partners
VIRPI

25-up multi-lens family with high power density

- High power LEDs arrayed in a small footprint
- 5 by 5 cluster delivering high lumen output in a compact package
- Perfectly balanced precision and power for horticultural lighting

**Features**

- 74.9 x 74.9 mm, H 9.4 mm
- 25 High-Power LEDs in a tight array
- 3 different beam angles to optimise for different installation heights (S-14°, M-28° and W-42°)

**Typical Applications**

- High PPF designs
- Consumer applications
- Horticultural lighting

**Compatibility**

- Up to 3535 size LED packages
FLORENCE-3R-IP

Ingress protected lens for mid-power LEDs and clusters

- Up to IP67 rated PC/PMMA lens for low & mid bay lighting
- Protected against moisture and constant dust
- 90°, 60° and oval beams similar to original FLORENCE-3R

Features
- 321 x 79 mm
- Integrated silicone gasket
- Sturdy fastening with screws to ensure up to IP67 rating
- Highly efficient modular lighting
- Third party heatsinks and PCB modules readily available

Compatibility
- Compatible with Zhaga book 7 three-row modules (L28W6) and similar
- Compatible with flat-package mid-power LEDs (primary) or High power LEDs such as Oslon SSL series
- Can be used with single LEDs or clusters
DAHLIA
Highly efficient linear platform for horticultural lighting

- Extremely uniform lighting on the growth area resulting in optimal growing conditions
- High power density by 120 closely spaced lenses
- IP65 rated with easy to clean smooth surface

**Features**
- 320 x 80 mm
- Comes with a silicone seal for IP65
- Made of PMMA (good chemical resistance)
- Sturdy fastening with 14 screws
- Adopts easily into design with 1-4 channels and varying number of LEDs per channel
- PPFD deviation 10 % over the growth area

**Typical Applications**
- Horticultural top lighting

**Compatibility**
- Typical horticultural 3535 HP LEDs (e.g. Osram Oslon SQ Horti, Luxeon SunPlus 35 Line LEDs)
DAHLIA ecosystem

LEDiL®

- DAHLIA optics for precise light control
- FLORENCE-3R-IP optics for cost efficient cluster based design
- Heatsinks designed to be compatible with LEDiL optics
- Standard and custom light engines
HB-IP-2X6-G2

Cost effective version of HB-IP-2X6 optimized for 5050 LED packages

- Mechanically compatible with LEDIL IP-2X6 series
- Level of ingress protection to be confirmed, targeted for up to IP67
- Excellent cutoff and light control

**Features**
- 173 x 71.4 mm
- Made from PMMA
- Comes with a silicone seal
- Mounted with 8 screws
- Contain pockets for connectors, PCB screws & other components
- Typical light output up to 8000 lm

**Typical Applications**
- Industrial lighting
- High bay
- Flood light

**Compatibility**
- Optimized for flat high power 5050 size LED packages
- Compatible with up to 5050 size LED packages
PETUNIA2

Improved version optimised for latest horticultural LEDs

- Compact solution for plant top lighting – especially for consumer products
- PETUNIA2 is a direct replacement of PETUNIA with main physical measures staying the same. Only the size of single optic is slightly bigger.
- Smooth mixing of color at short distance resulting in a uniform growing light for plants

**Features**

- 29.5 x 46.5 mm, H 7.4 mm
- 12-up lens
- Made from PMMA
- Special multi-lens designed for good uniformity with multiple types of LEDs
- Easily optimized spectra with different LEDs

**Typical Applications**

- Horticultural lighting

**Compatibility**

- Optimized for Oslon SSL horticultural LEDs
- Compatible with up to 3535 size LED packages e.g. Oslon Square (PETUNIA is not)
Supplemental toplighting with DAHLIA

- Goal was to create HPS supplemental light to increase DLI and improve spectral content of the light

- Designed to achieve over 90% PPFD uniformity across the 6 meter growing tray while reducing power consumption

- LEDiL’s new DAHLIA optic was chosen to direct light on the flowering plants while reducing luminaire size and BOM cost

- 90x Oslen Square Hyper Red and 30x Oslen Square Gen3 White were used

- Mechatronix CoolBlock HC-01-3X11-B heat sink
Illumination results

- 36 DAHLIA modules in three lines
  - Distance: 2.35 m
  - Spacing: 3.1 m
  - Power: 195.3 W / module
  - PPF: 489 µmol/s / module
  - Efficacy: 2.505 µmol/J

- Results at center tray
  - Min 25 µmol/m², Max 27 µmol/m²
  - Average PPFD 26 µmol/m²
  - PPFD uniformity on grow tray 95.3%

- Results at first and last tray
  - Min 15 µmol/m², Max 27 µmol/m²
  - Average PPFD 23 µmol/m²
  - PPFD uniformity on grow tray 67.2%
Conclusion

- DAHLIA reference design achieved the set goals
  - Uniformity over 90% except at the edges of the greenhouse
  - Uniformity at the edges can be improved by reflectors on the side of the building

- Optics also helped focusing light on the plants and reduced significantly light spread outside grow platforms

- This reference design was created for supplemental lighting and daylight filling but modular light engine design scales easily into higher PPFD requirements
Thank you. Questions?