

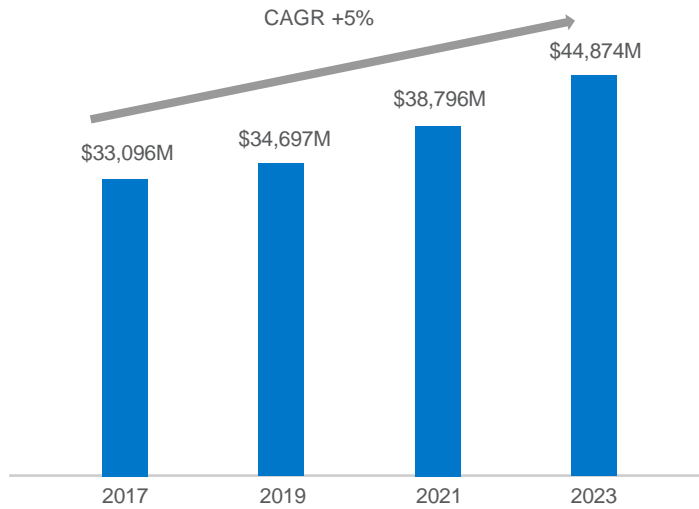
Horticulture Lighting Solutions



Market

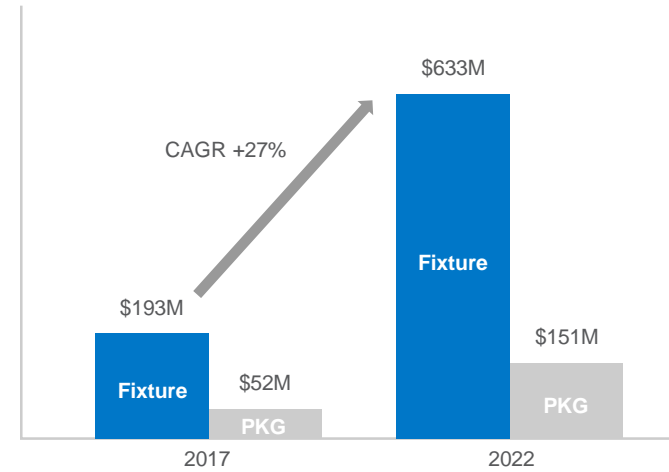
Horticultural LED market expected to grow rapidly

General LED Lighting Market



Source: LEDinside (2019)

Horticultural LED Lighting Market



Source: LEDinside (2018)

Background

The growth of horticultural LED market is driven by 3 factors



Transition to
highly efficient LED lighting



Demand for fresher,
healthy, and organic food



Legalization of
medical & recreational cannabis

LED Penetration

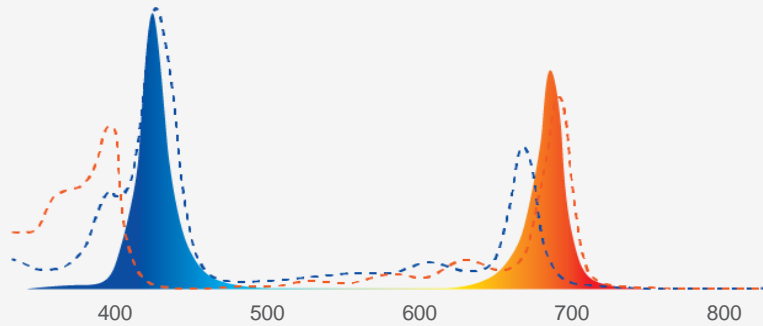
Penetration rate of LED is still low in horticulture market

	Fluorescent	MH	HPS	Conventional LED (Narrow Spectrum)	
Market Share		90%		10%	
Product Specification	Efficacy ($\mu\text{mol}/\text{J}$)	1	1.4	1.8	> 2.5
	Heat	Low	High	High	Low
	Lifetime (hrs.)	< 20,000	<20,000	< 30,000	> 50,000
	Warm-up Time	Short	Long	Long	Short
	Design Flexibility	Low	Low	Low	High
	Lighting System Cost	Low	Low	Low	High
	Spectrum Controllability	n/a	n/a	n/a	Low
	Visibility (Human Eye)	Good	Good	Good	Bad

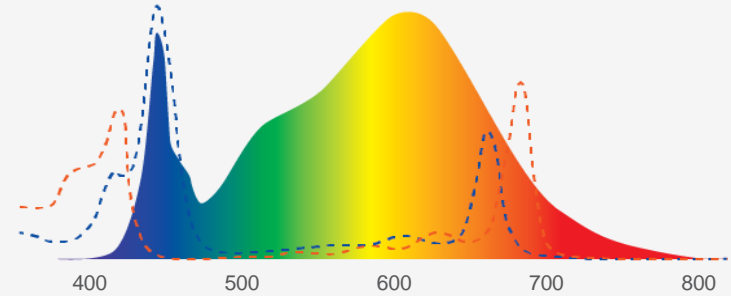
Full Spectrum LED

Full spectrum is recent trend with more cost-effective, productive, & favorable solution

Conventional Narrow Spectrum

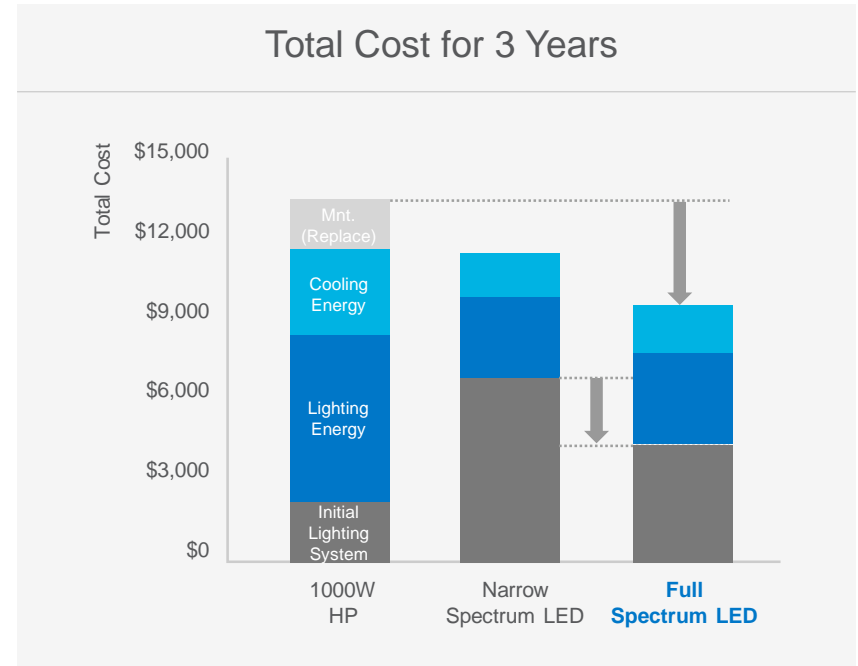
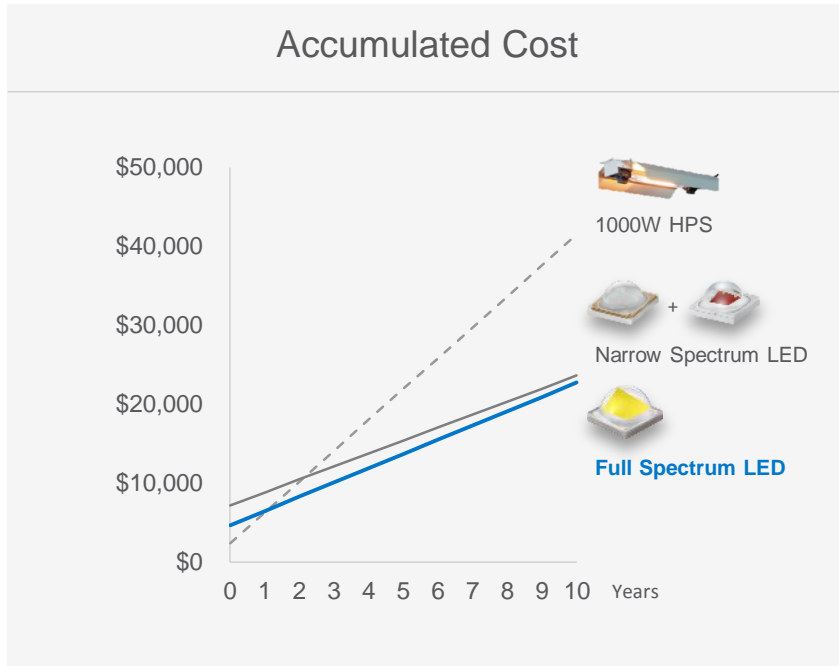


Full Spectrum



More Cost-effective Solution

Full spectrum reduces initial lighting system and operating costs

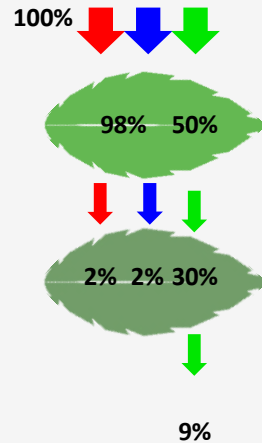


※ Unit Price: HPS (\$400 x 6ea), Narrow (\$1200 x 6ea), Full (\$780 x 6ea) / Lifetime: HPS (2k hrs.), Narrow (60khrs), Full (60k hrs.) / Electricity Rate : \$0.1 per kWh

More Productive Solution

Full spectrum promotes balanced plant growth by improving various aspects

Photosynthesis



1. Kozai, Ohmsya Pub P227 (2015)
2. Jindong, Plant Cell Physiol. (1998)

Anti-disease



1. Kudo, SRI Res Rep. (2009)
2. Kudo, Horti Res, (2013)
3. Kudo, SRI Res Rep. (2010)

Nutrition



More Favorable Solution

Full spectrum enables easier detection of diseases & pleasant work environment

Narrow Spectrum



Full Spectrum



Key Considerations

There are three key considerations in horticulture lighting

Spectrum

Optimized spectrum ensures healthier and balanced plant growth

Efficacy

High PPF/W enables increased plant growth using less energy

Reliability

Horticulture environment requires higher level of reliability and stability

Why Samsung LED

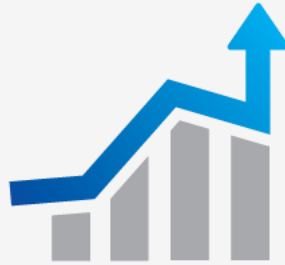
Samsung Horticultural LED line-up created with the key considerations in mind

Freedom in Spectrum



Spectrum of infinite possibilities
enabling purpose driven plant growth

Industry Leading PPF/W



The highest efficacy increasing yield
of crops and saving operation cost

Enhanced Quality

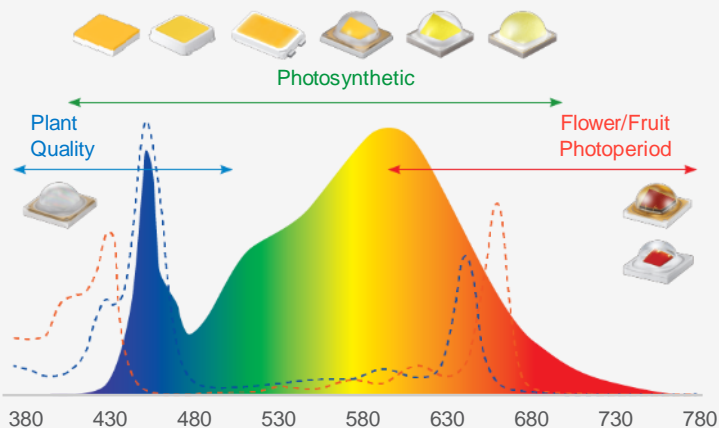


Industry proven reliability under
harsh horticulture environmental
conditions

Spectrum of Infinite Possibilities

A wide selection of LEDs and simulation tool provide freedom of spectrum design

LED Selections



Simulation Tool



Experiment on Full Spectrum

- Plants: Butterhead Lettuce, & Oak Leaf
- Environment: 24°C, RH 70%, On/Off=16/8 hrs., hydroponic
- Test Period: 10 days
- Variable: Light spectrum (narrow vs. full) **with same PPF**

※ Experiment was repeated 3 times with different batches for reproducibility



Narrow Spectrum



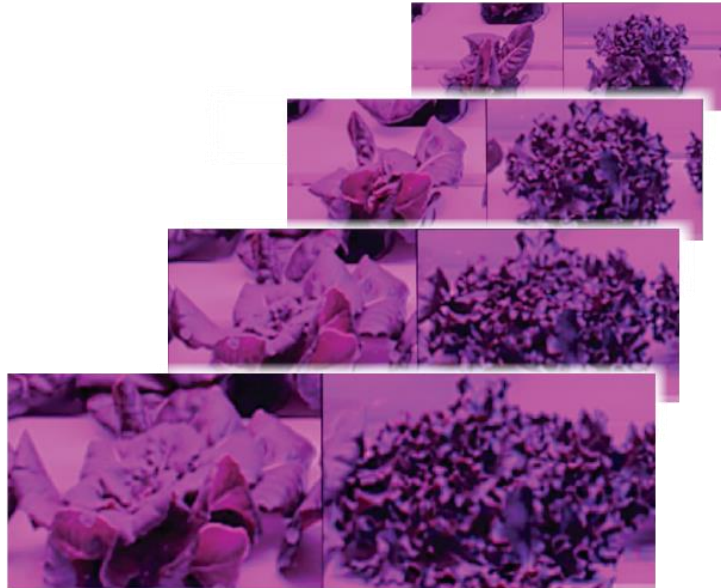
Full Spectrum



Experiment on Full Spectrum

10% higher fresh weight was obtained with full spectrum

Narrow Spectrum



Full Spectrum

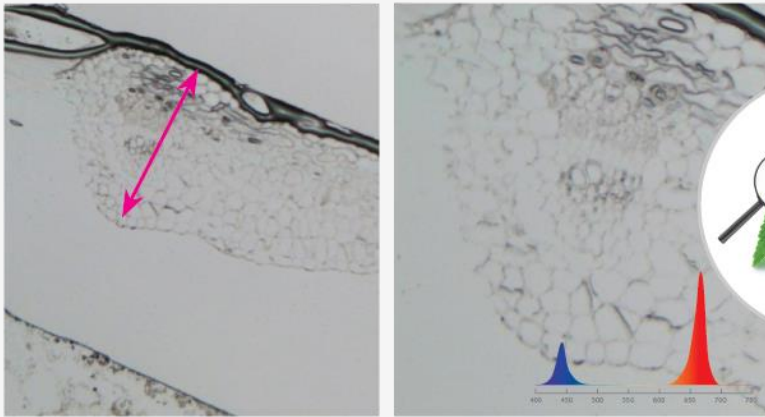


Experiment on Full Spectrum

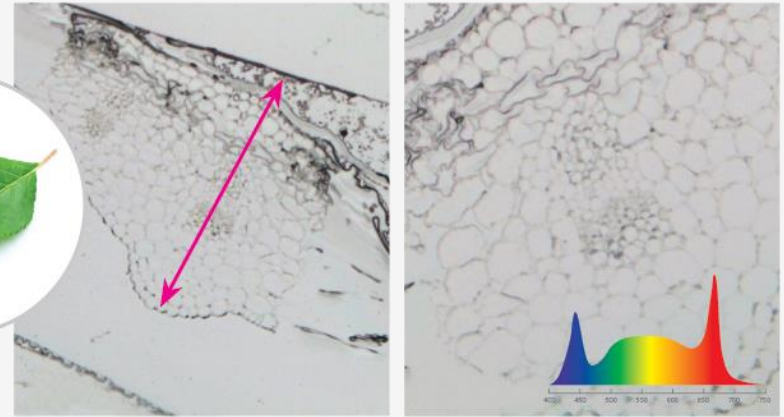
Full spectrum can improve quality of plants as well

- Cross-sections of the leaves under narrow spectrum vs. full spectrum were compared
- Thicker leaf and well-formed structures (xylem, phloem, etc.) were obtained with full spectrum

Narrow Spectrum



Full Spectrum



Spectrum Engineering

Color, taste, and immunity can be optimized with spectrum engineering

Color

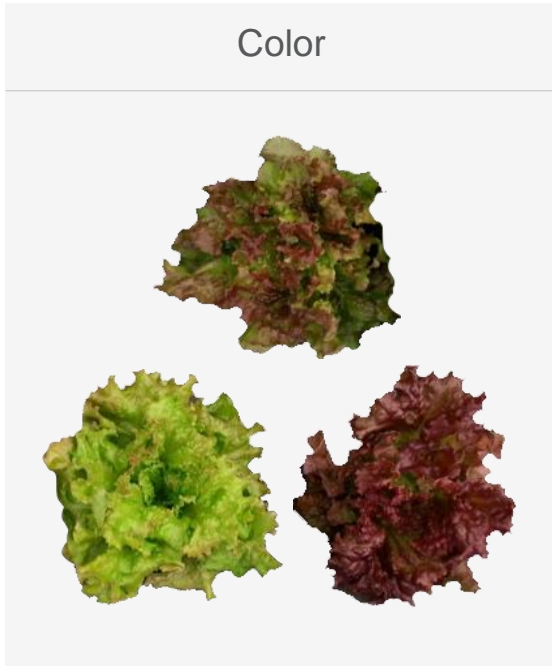


Image : Univ. of Guelph

Taste



Image : Plenty

Immunity

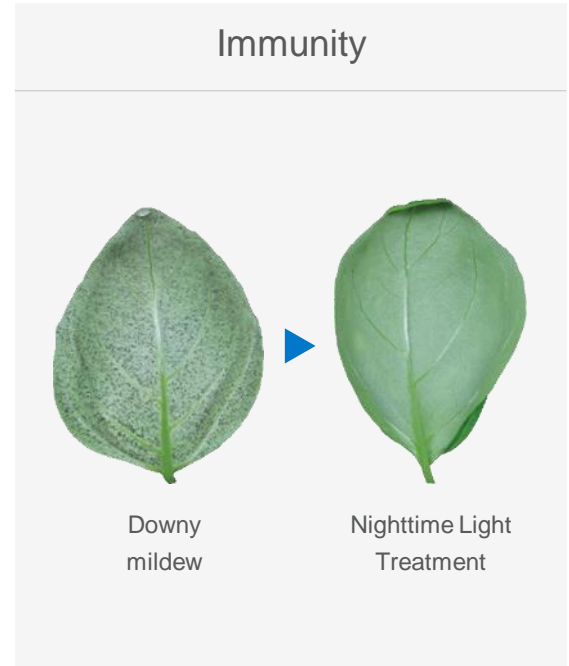


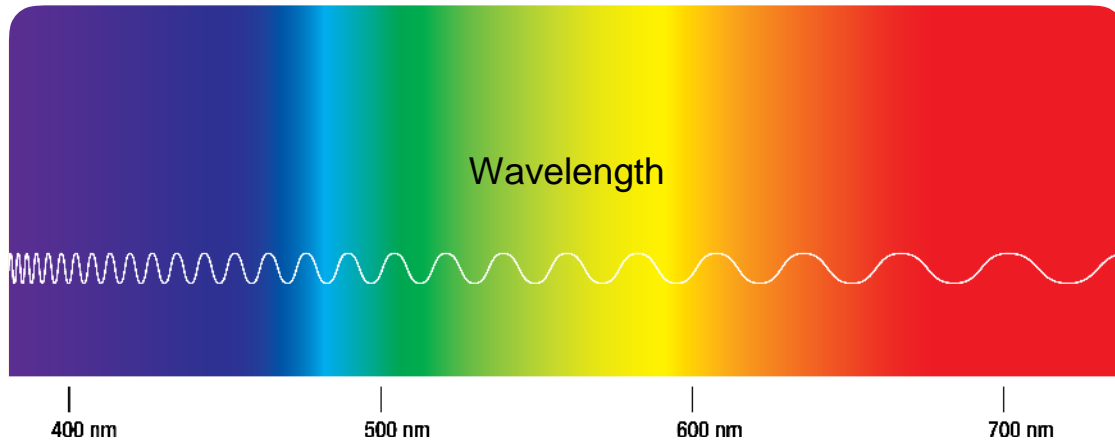
Image : Lighting Research Center

Figure-of-Merit

PAR (Photosynthetic Active Radiation): 400-700nm

PPF (Photosynthetic Photon Flux): Amount of photons in PAR ($\mu\text{mol/s}$) $\leftrightarrow \text{Im}$

PPE (Photosynthetic Photon Efficacy): PPF/Watt efficiency ($\mu\text{mol/J}$) $\leftrightarrow \text{Im/W}$



High Efficacy LED

LED efficacy is key to succeed in horticulture application
→ Samsung provides industry leading high efficacy LEDs

		LM301H	Company A	Remark
Form Factor (mm ²)		3.0x3.0	3.0x3.0	-
25°C 65mA 5000K CRI80	PPF (μmol/s)	0.56	0.51	+10%
	PPE (μmol/J)	3.10	2.86	+8%



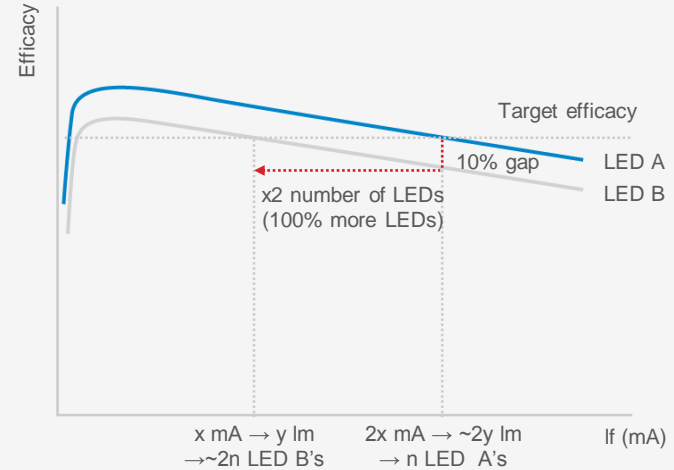
Saving in Lighting System Cost

Initial lighting system cost can be significantly reduced with high efficacy LED

- Target PPF > 800 $\mu\text{mol/s}$
- Target PPE > 2.80 $\mu\text{mol/J}$

	Company A	LM301H
Series x Parallel	17S x 80P	17S x 37P
IF (A)	6	6
IF/LED (mA)	75	162
VF (V)	47.0	47.8
Watt (W)	282.0	286.8
PPF ($\mu\text{mol/s}$)	815	822
PE ($\mu\text{mol/J}$)	2.89	2.87
Number of LEDs	1360 ea.	629 ea.

54%↓



Saving in Operation Cost

A huge amount of electrical energy can be saved with high efficacy LEDs

FLUENCE



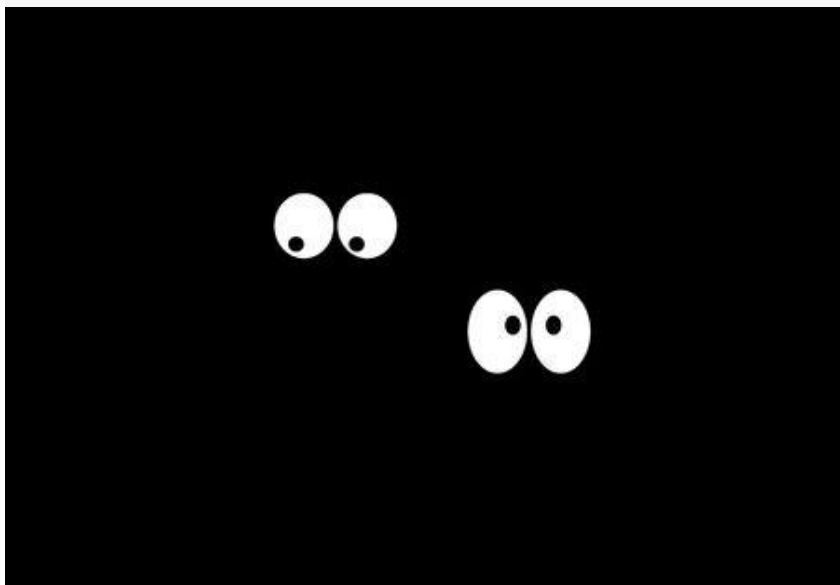
plenty



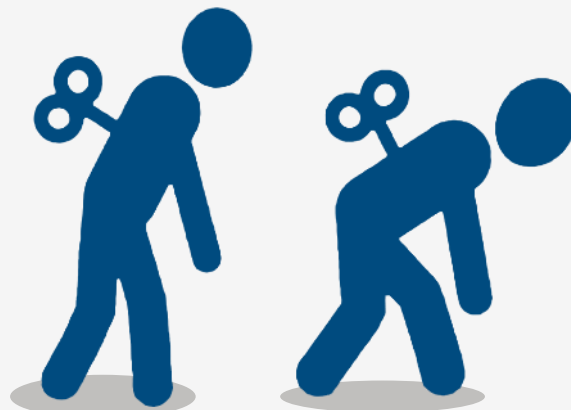
LED Failure Modes

Blackout and performance degradation over time are typical failure modes

Blackout



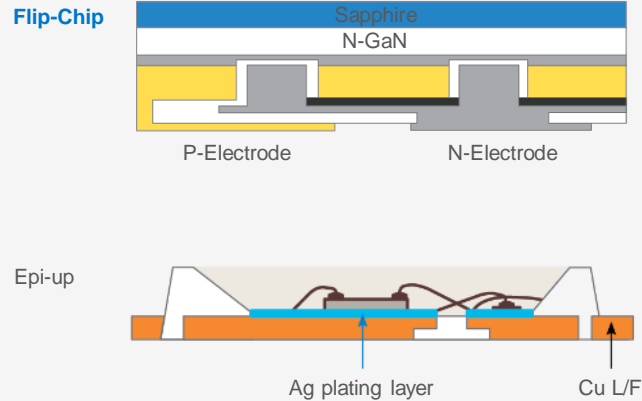
Performance Degradation



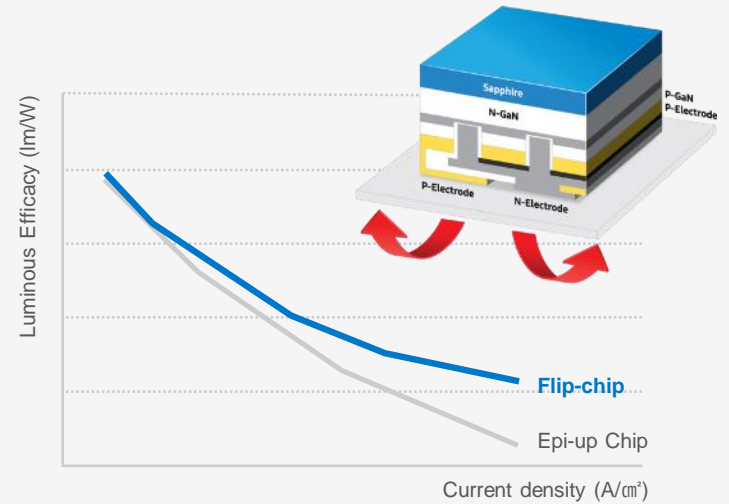
Advanced Flip Chip Structure

Flip-chip LEDs prevent potential wire-open and blackout failure

Wire-free Flip Chip Structure



Excellent Heat Management



High Sulfur Environment

Performance degradation of LEDs can be caused by chemical exposure



N, P, K, Mg, S, Ca



Conventional Package

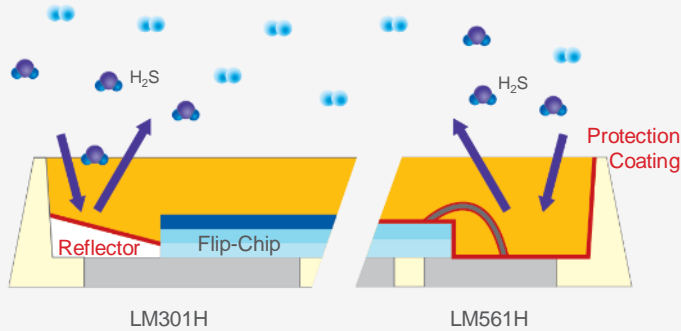


- Ag in wire or electrodes can be tarnished when exposed to H₂S
- $2\text{Ag} + \text{H}_2\text{S} + 1/2\text{O}_2 \rightarrow \text{Ag}_2\text{S} + \text{H}_2\text{O}$ (Ag₂S causes PPF degradation)

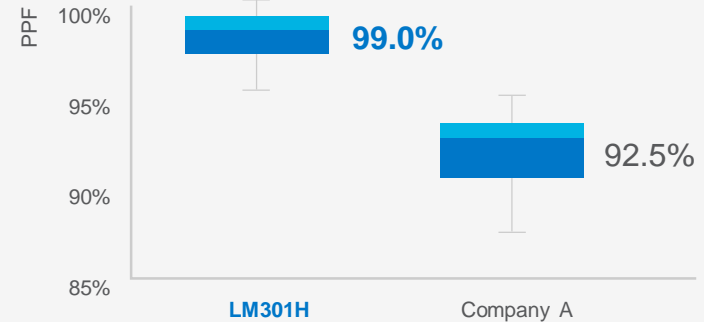
Superior Sulfur Resistance

LED with protection schemes is necessary to maintain PPF, Spectrum, etc.

Horticulture LEDs with Protection Schemes



H₂S 15ppm, 25°C / 75% humidity for 504 hrs.



※ IEC Pub.68-2-43

Main Applications

Vertical Farming



* Crops: Lettuce, Herb → Small (short) Size, Short Life Cycle
* LED Requirements: High Efficacy, Thermal Dissipation↓, Cost↓




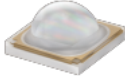


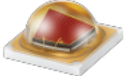

Greenhouse Farming



* Crops: Tomato, Pepper, Cucumber → Tall Size
* LED Requirements: High power, Size↓, Weight↓

Vertical Farming Solution


- Crops: Lettuce, Herb, etc.
- LED Lighting Requirements: Efficacy \uparrow , & Thermal Management

	White LED			Color LED				
								
	LM301H	LM561H	LM301H ONE	LH351H Blue (450nm)	LH351H Red (630nm)	LH351H Deep Red (660nm)	LH351H Deep Red (660nm) V2	LH351H Far Red (730nm)
PPF ($\mu\text{mol/s}$)	0.56	0.51	0.49	2.80	1.57	2.32	2.63	*1.96
PPF/W ($\mu\text{mol/J}$)	3.10	2.84	2.75	2.80	2.14	3.12	3.73	**2.91
Footprint (mm^2)	3.0 \times 3.0	5.6 \times 3.0	3.0 \times 3.0	3.5 \times 3.5				

*BPF, **BPF/W

Greenhouse Farming Solution

- Crops: Tomato, Pepper, Cucumber, etc.
- LED Lighting Requirements: Cost↓, Size/Weight↓

	White LED					Color LED				
										
	LH241H	LH281H	LH351H-B	LH351H-C	LH351H-D	LH351H Blue (450nm)	LH351H Red (630nm)	LH351H Deep Red (660nm)	LH351H Deep Red (660nm) V2	LH351H Far Red (730nm)
PPF (μmol/s)	2.51	2.59	2.48	2.56	2.58	2.80	1.57	2.32	2.63	*1.96
PPF/W (μmol/J)	2.52	2.65	2.51	2.60	2.69	2.80	2.14	3.12	3.73	**2.91
Footprint (mm ²)	2.4 × 2.4	2.8 × 2.8		3.5 × 3.5				3.5 × 3.5		

*BPF, **BPF/W

Thank you