

LEDs

Hidden features

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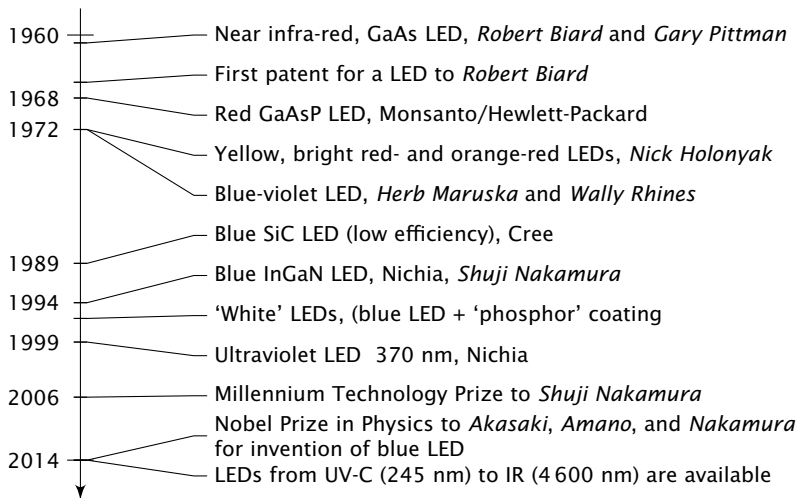


Outline

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 - History
 - LEDs as electronic components
 - LED drivers

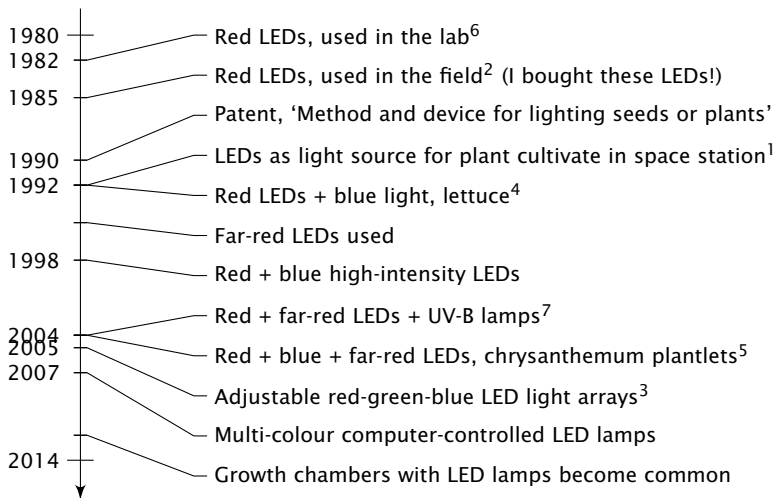
- 2 LED as light sources for plant cultivation
 - Properties
 - LED-based commercial growth lamps

Recent LED technology timeline



LEDs in plant research timeline (not exhaustive)

As light sources for plant growth or its regulation



LEDs as electronic components

Binning

- When semiconductors are fabricated the resulting parts have some variability.
- One production step is testing and classification into “bins”.
- The fabrication process has a certain yield of good-enough parts.
- For CPUs, the maximum achievable clock rate without overheating might be a reason for putting them in bins corresponding different part numbers.
- For white LEDs the best known binning is into colour temperature ranges (given in K).
- For white LEDs also binning for light-output efficiency is usual (lowest efficiency can be 50% of that of the best bin).
- The best performing parts have a premium price.

LEDs as electronic components

Expected life

- Depends on LED type (technology/wavelength) (e.g. UV-B LEDs have a shorter life than VIS ones).
- Depends on operation conditions (e.g. high temperature, current surges).
- In other words on both thermal and electronic design of the appliance or circuit.
- Many electronic parts are available in commercial, industrial and military subtypes. This is usually the result of binning and packaging (e.g. ceramic vs. plastic)
- Components' rated life is specified at a certain specific set of operation conditions.
- Pushing the limits (e.g. over-clocking a CPU) is risky.

LEDs as electronic components

Luminous efficacy and lighting efficiency

- Luminous efficacy in lumens per watt of radiation is of no use for plant growth, as it is based on human vision.
- Luminous efficacy describes how bright we see light of a certain colour.
- Lighting efficiency in lumens per watt of electrical energy is also based on human vision.
- It describes how bright we see the light produced relative to the electrical energy used.
- Best white LEDs are now as efficient as HPS lamps, SON lamps can still be a bit more efficient.

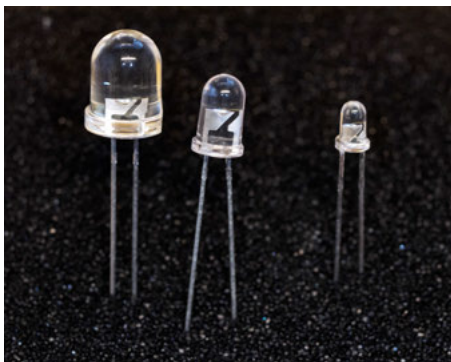
LEDs as electronic components

Efficiency

- Best physical measure of efficiency to use in photobiology is the ratio between number of photons produced and amount of electrical energy used.
- Some types of LEDs, emitting specific colours are inherently more energy efficient than others.
- Energy efficiency has been improving rapidly, which means that state-of-the-art LEDs are usually the most efficient.
- Efficiency of the LEDs will be higher than that of a whole system because the driver circuitry is not perfectly efficient.
- *Be careful with efficiency data in brochures! Definitions are sketchy and quantities sometimes miss-named or irrelevant.*

LEDs as electronic components

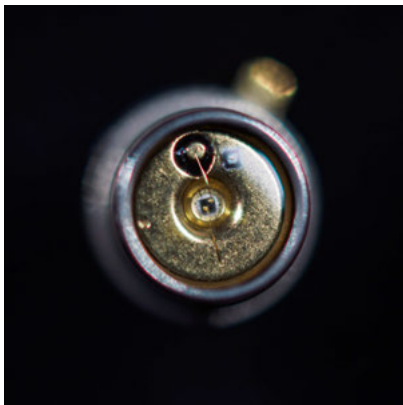
Single die LEDs



Some very common types of epoxy packages 8 mm, 5 mm, and 3 mm in diameter. In the photograph clear packages, but most common were tinted packages.

LEDs as electronic components

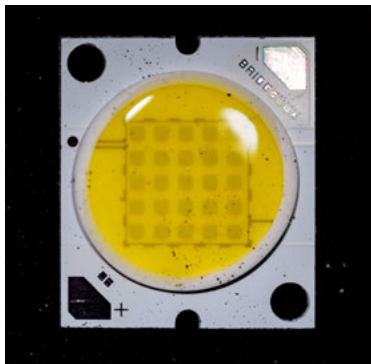
Single die LEDs: Close up



First commercial UV LED (370 nm) from Nichia. Wires connected to chip are visible. On the side there is a diode for protection.

LEDs as electronic components

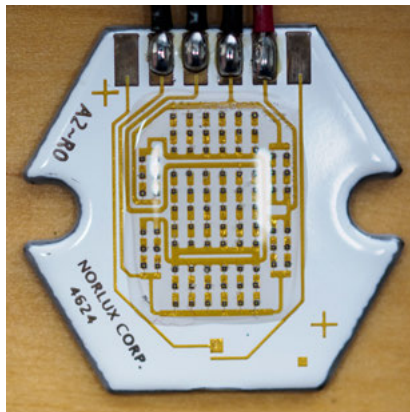
Blue LED dies and yellow 'phosphor' = 'white' LED



These arrays are 19 mm \times 19 mm, a similar one released by Cree in 2014 (not shown), type CXA2590, is rated at 130 W.

LEDs as electronic components

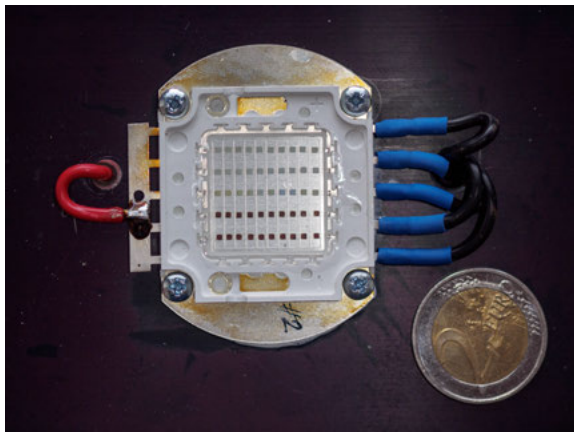
Red-green-blue array



This 10-years' old array contains $30 + 30 + 30$ dies, for a total light output of 130 lumen from 12 W of electric power.

LEDs as electronic components

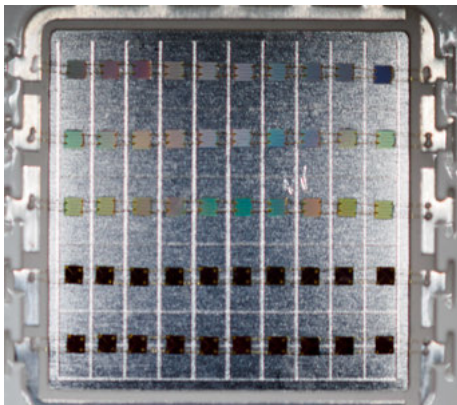
Array with bare LED dies, five independent channels



Custom assembled 5-colour LED array, 50 W total, 50 pieces of 1 W LED dies.

LEDs as electronic components

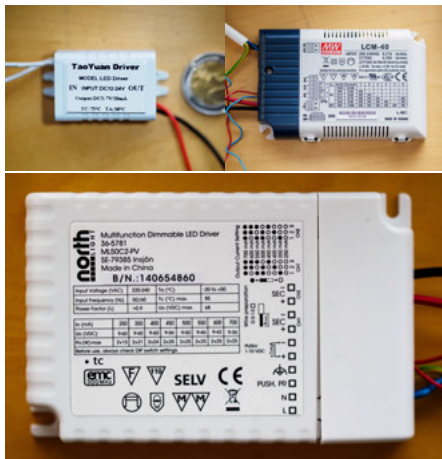
Same LED array: Close up



Wires along each row of chips connected in series can be seen running horizontally.

Off-the-shelf LED drivers

Discrete current limit settings



Used for LED illumination as components, cost 2 € to 50 € each.

Programmable power supply

Precision and stable current regulation 1 mA to 30 A



As used in electronics' labs and workshops, cost 300 € to 700 €.

Important properties of light sources

Spectrum The colour of light. Has been discussed frequently. *I will skip it today.*

Spatial distribution Well understood. *I will skip it today.*

Lifetime Very long for LED lamps with good electrical and cooling design. *I will skip it today.*

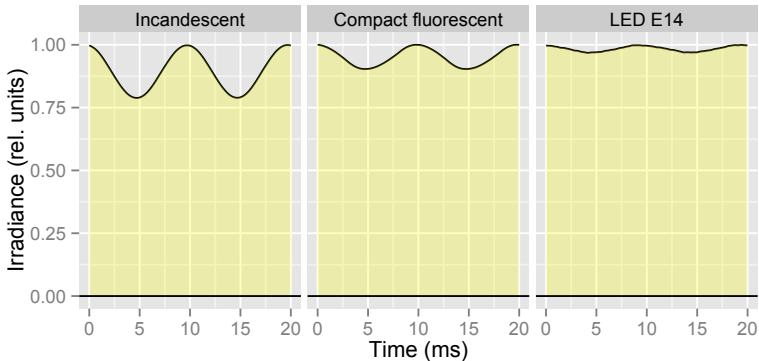
Temporal variation Seldom discussed but worthwhile thinking about.

Temperature dependence Important when lamp temperature is not constant.

Electrical noise Seldom discussed but should be taken into consideration.

Temporal variation

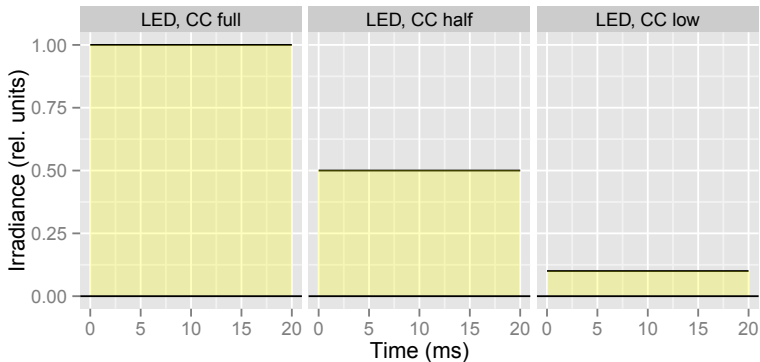
Common household lamps (examples)



The variation in output is the result of the frequency of the AC mains supply (50 Hz, 1 cycle = 20 ms), but as light is emitted both on the + and - half cycles, the light output frequency is 100 Hz.

Temporal variation

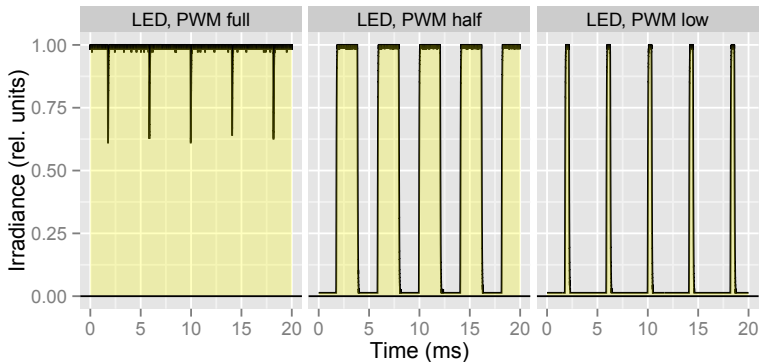
Constant current (CC) dimming of LEDs



Constant current (CC) dimming is achieved by limiting the current through the LED. Light output remains constant (even with some cheap drivers to within 1% or better).

Temporal variation

Pulse-width-modulation (PWM) dimming of LEDs



Pulse width modulation (PWM) consists in quickly switching LEDs on and off. In this example the frequency used is 250 Hz and the duty cycle of the 'square' wave is varied.

Temperature response

Effect on light output

LED Higher light output at low temperature. Expect an increase of around 10–15% with a decrease of 50 C.

Fluorescent Much lower light output at low temperature. For 'normal types' a decrease of 75% with a decrease in temperature from 30 C to -5 C is not uncommon.

Electrical 'noise'

What is it?

- *Electromagnetic interference* (EMI) is used to refer to the disturbance that affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source.
- The design and placement of LED drivers (as well as ballasts for discharge lamps) can be important when using sensitive instrumentation in a growth chamber.
- Not considered EMI, but noise entering instrumentation through a shared mains circuit can also causes problems.
- The susceptibility of instrumentation depends also on how the instruments themselves are designed.

Types of LED growth lamps

Spectral properties

- Mono-, di-, trichromic LED lamps with fixed spectrum
 - usually red + blue, occasionally red + green + blue, if dimmable, all channels dimmed in parallel
- Broad-spectrum lamps with fixed spectrum
 - a few channels, but at least some channels emit a broad spectrum, if dimmable, all channels dimmed in parallel
- Multi-channel lamps with variable spectrum (channel mixing ratio)
 - 5 to 10 narrow band channels independently dimmable

Types of LED growth lamps

Cooling

- Passive cooling by radiation and convection
→ aluminum case with fins (no moving parts)
- Active cooling by forced convection
→ fans (moving parts)
- Active water cooling
→ (re-)circulating water, usually with pump and heat exchangers

Broad-spectrum lamps

Several different but fixed spectra available



Valoya broad spectrum R150 plant-growth lamp.
Photo: Valoya Oy www.valoya.com

What some of you want to know

Can we simulate sunlight with LEDs?

- The technology exists.
- You would need custom assembled LED arrays, but they are easy to get.
- Would be rather difficult to get irradiance levels similar to sunlight.
- If you want to also use LEDs as a source of UV-B radiation it would be extremely expensive (> 1000 € for 25 mW), and they would not last much more than 1000 hours at full power.
- My advice for a system like the solar simulators, just wait, probably two or three years, maybe even longer for UV-B.

Things to take into account

- For normal controlled environments, the technology is mature enough, but be very careful with your choice.
- For LED lamps used in plant research, requirements are different than for commercial plant growing, as much as it was the case for older types of lamps.
- How to measure efficiency has to be considered carefully, as the end-product is not the light itself.
- Inconsistent specifications for plant-growth LED lamps make comparisons difficult.

Things to take into account

- In the case of PWM dimming little is known of how and how much it may affect plant growth and “behaviour”.
- In a multichannel system, using PWM will cause a huge and very fast temporal variation in the spectrum.
- Using PWM, dimming down to 1% can be usually achieved.
- Using CC dimming with LED arrays, it is normally possible to go down to only about 10%.
- I do not know what is the current situation but a couple of months ago the then current design for some new Heliospectra lamps worked using a combination of methods: CC dimming down to 10% and PWM below 10% (not a good design in my opinion).

References

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The End

Research group <http://blogs.helsinki.fi/senpep-blog/>

Software <http://r4photobiology.wordpress.com/>

Instrumentation <http://openinstruments.wordpress.com/>

I thank Prof. Dr. Jörg-Peter Schnitzler and Dr. Andreas Albert for suggesting the I would give a talk about LEDs. I also acknowledge the financial support of the organizers of the conference and of the Academy of Finland (decision 252548).

Thanks for listening!