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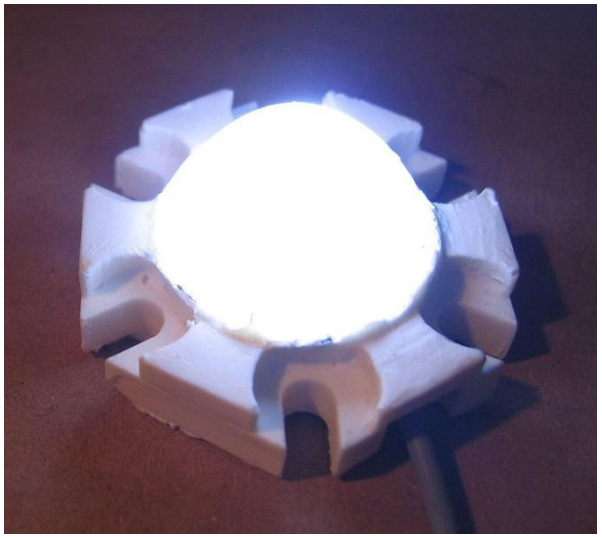
LIGHT&LIGHTING LABORATORY

Tailored lighting with freeform optics

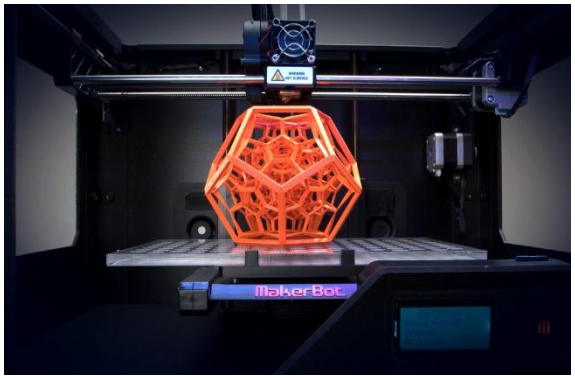
Youri Meuret

The LED: A revolutionary component

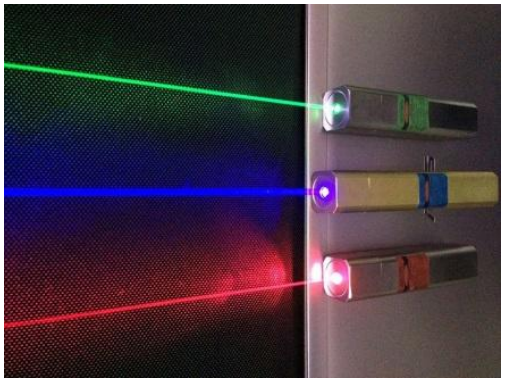


Other technologies that could revolutionize the lighting industry

Freeform optics

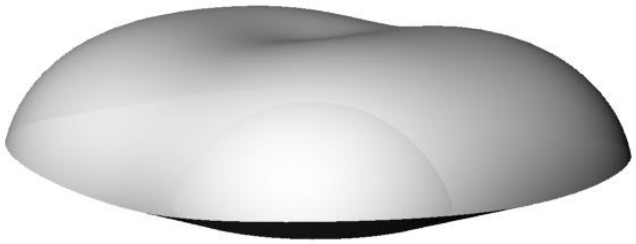


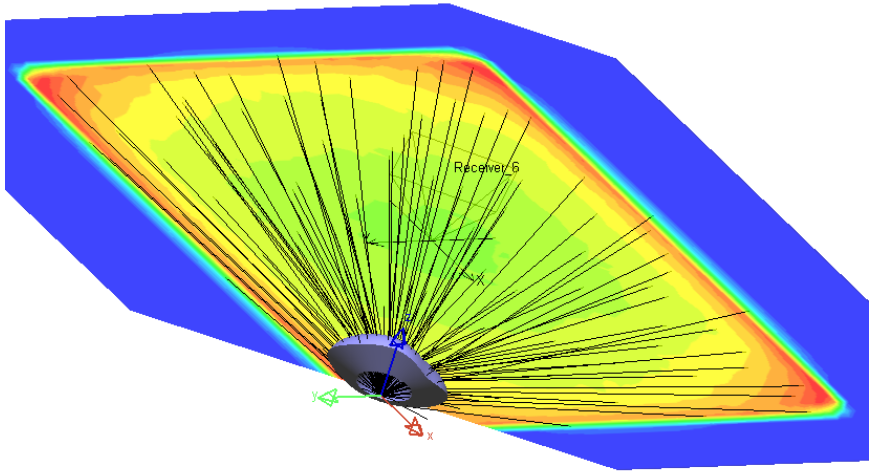
3D printing



Laser diodes

A freeform optical component …

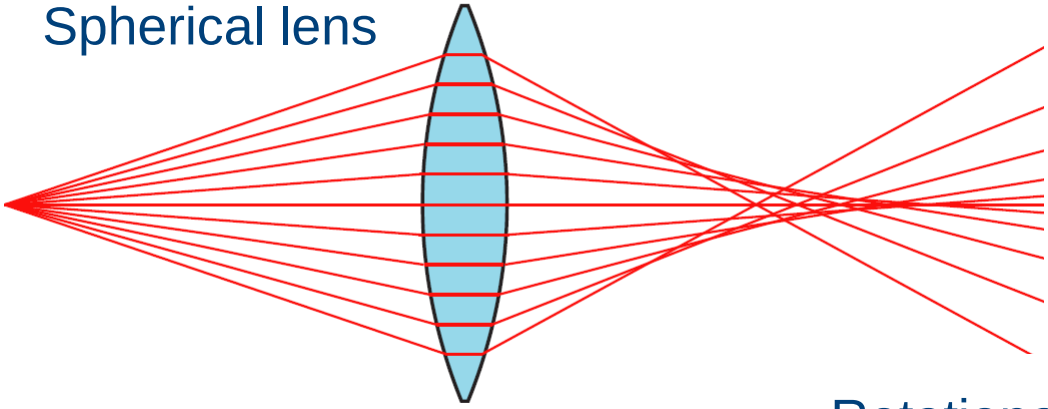




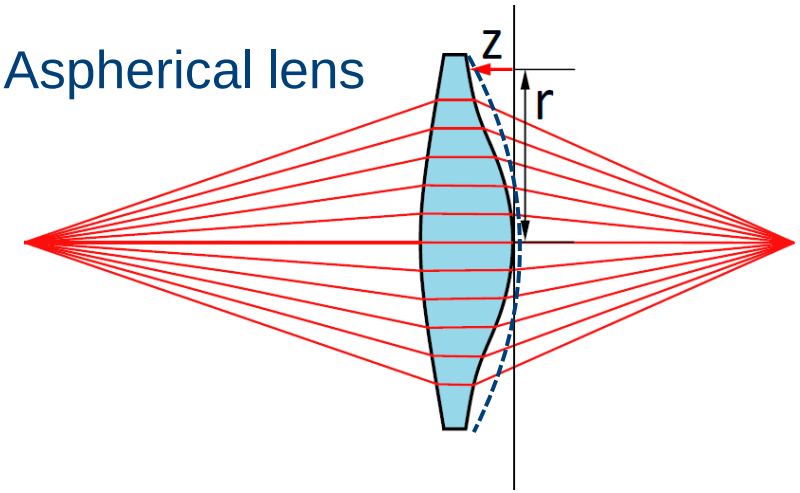
… is a lens or reflector of which
the shape is fully determined by the optical functionality and which is not limited by any symmetry constraint

Imaging systems typically use rotational-symmetric lenses

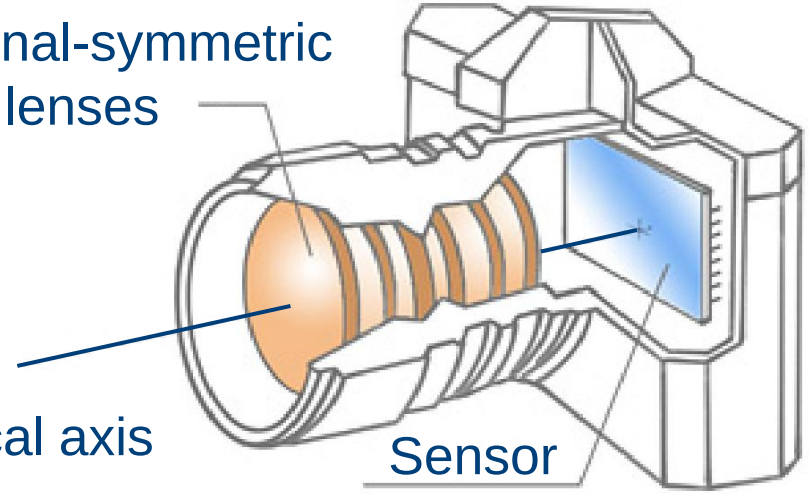
Spherical lens



Aspherical lens



Rotational-symmetric lenses



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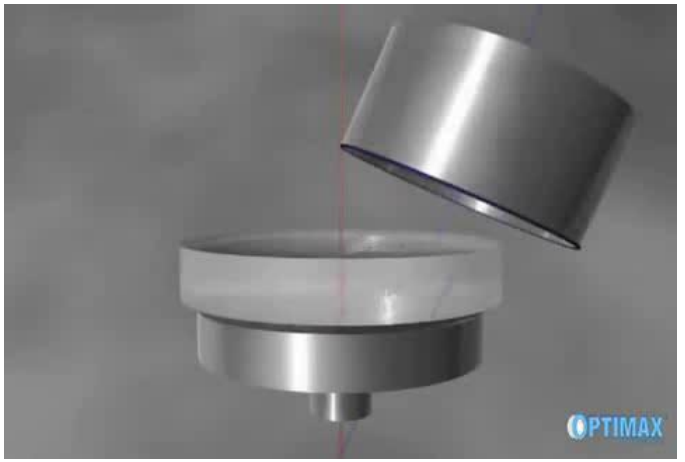
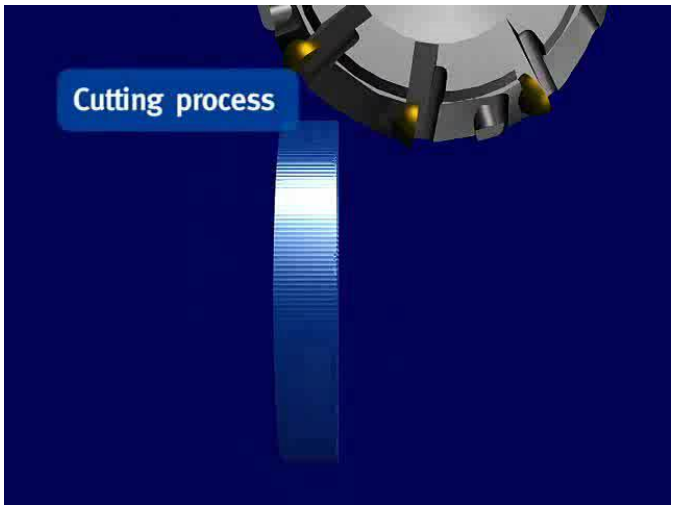
F. Duerr, Y. Meuret, and H. Thienpont. *Potential benefits of free-form optics in on-axis imaging applications with high aspect ratio*. (2013)

The main reason lies in their fabrication process

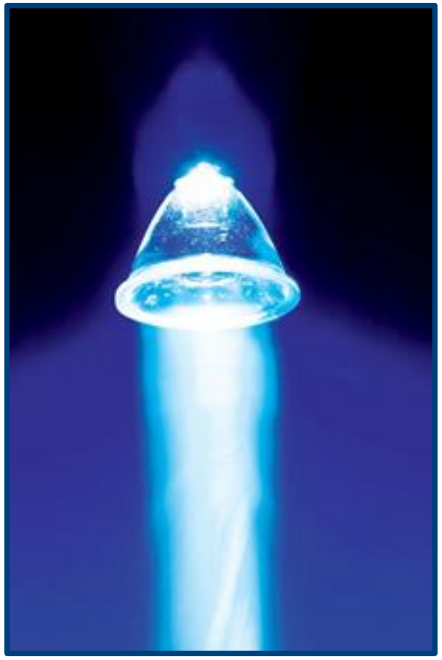
Polishing of a spherical lens



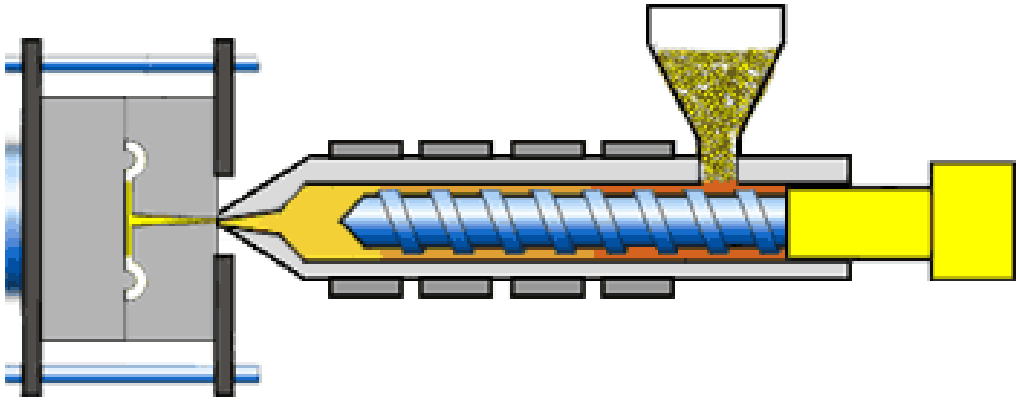
Fabrication of a freeform lens in glass



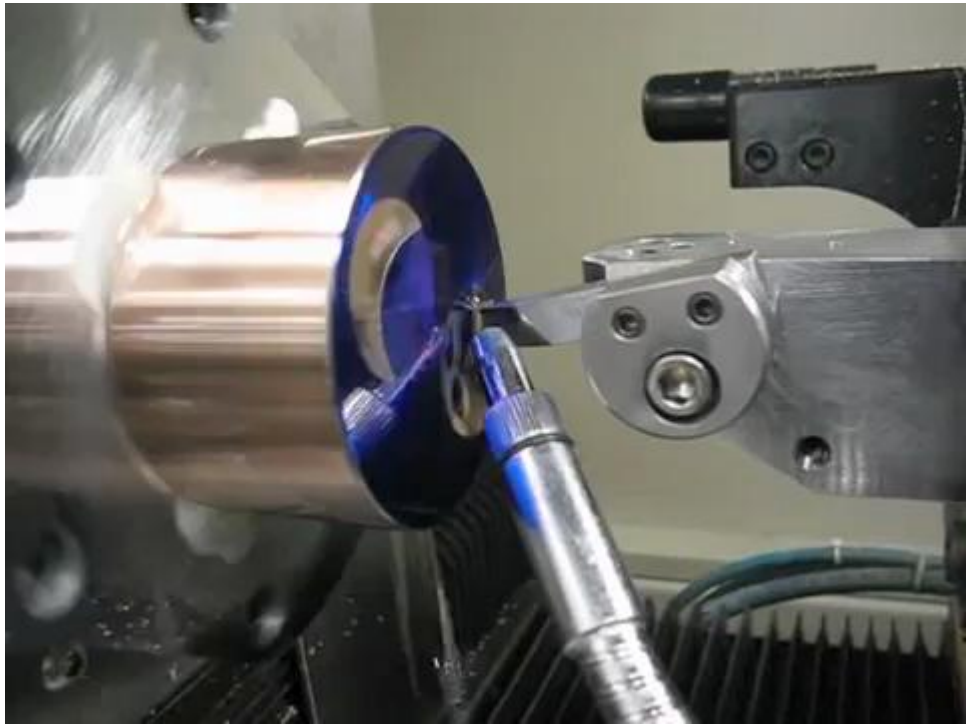
Illumination systems typically also use rotational-symmetric lenses



The cost of a plastic freeform component is not much more expensive than that of a (rotational-) symmetric component



Fabrication of a freeform mould with high-precision diamond machining



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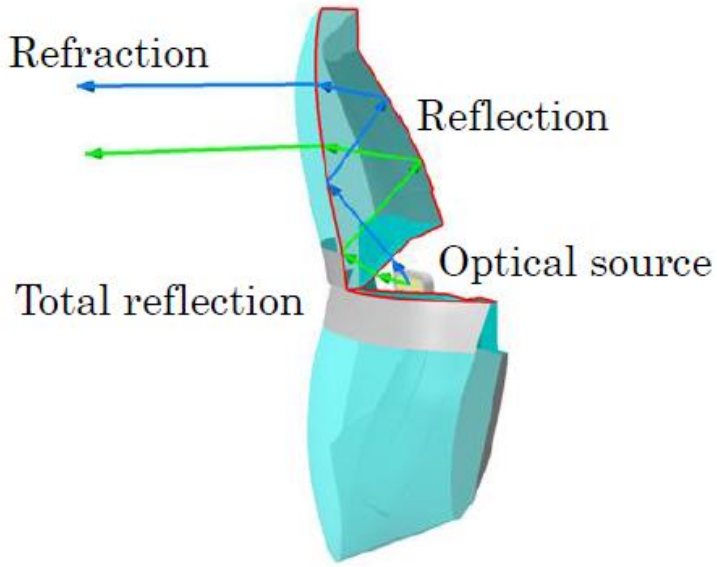
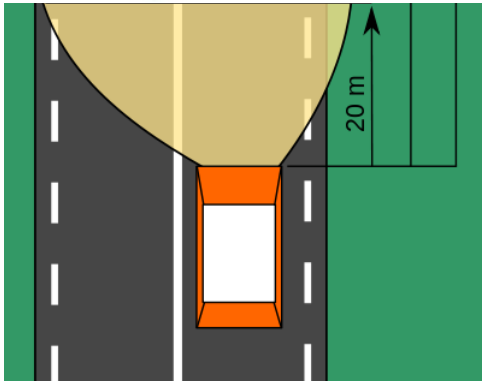
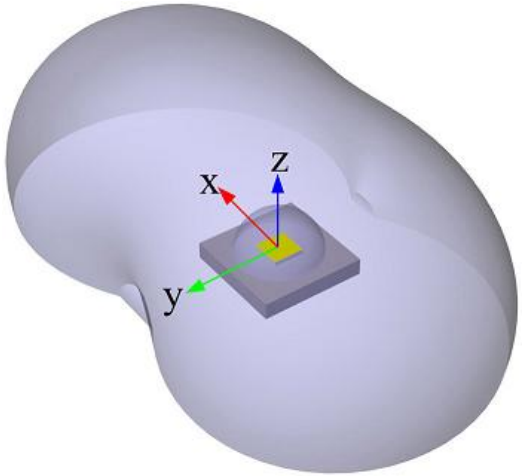
Commercial use of freeform optics (1)

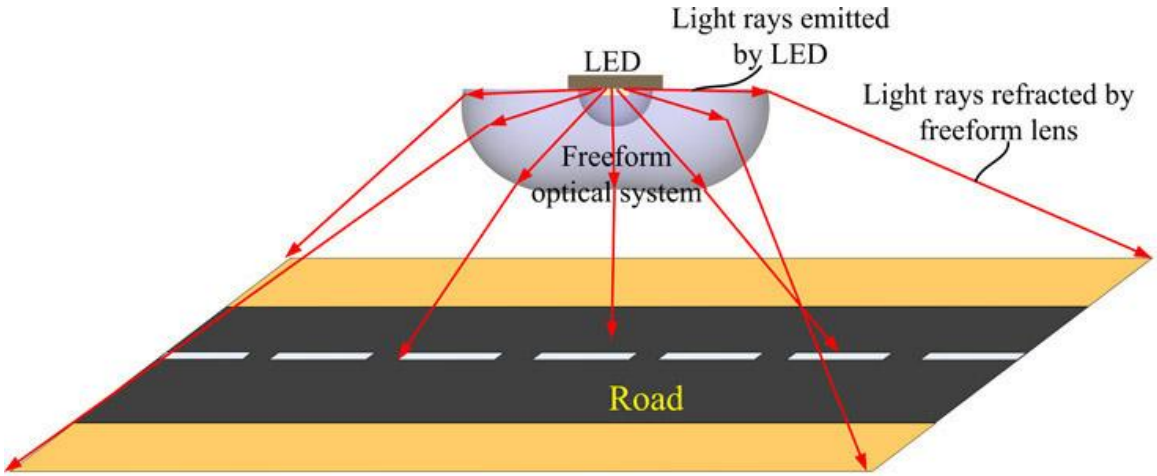




Source: News Release, Stanley Electric CO., LTD

Commercial use of freeform optics (2)





“Energy-saving LED light sources,” 30 March 2011, SPIE Newsroom

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Why are freeform optics still not a mainstream technology ?

3 personal views

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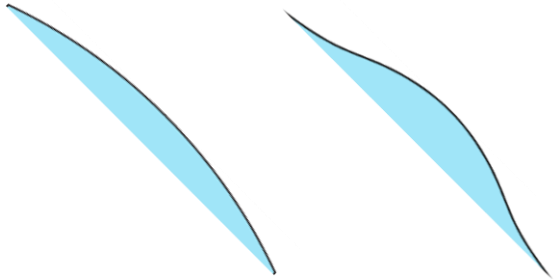
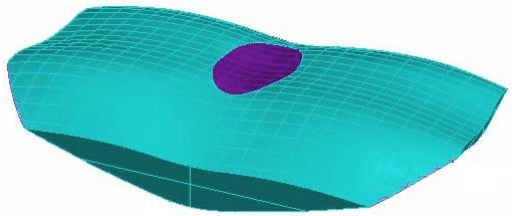
Reason 1

Optical design is far from trivial

	Rotational-symmetric optical components	Freeform optics
		
# necessary parameters to describe surface	1 2 - 10	20 - 1000
Design strategy	Optimization	→ Optimization (limited) → Direct design algorithms

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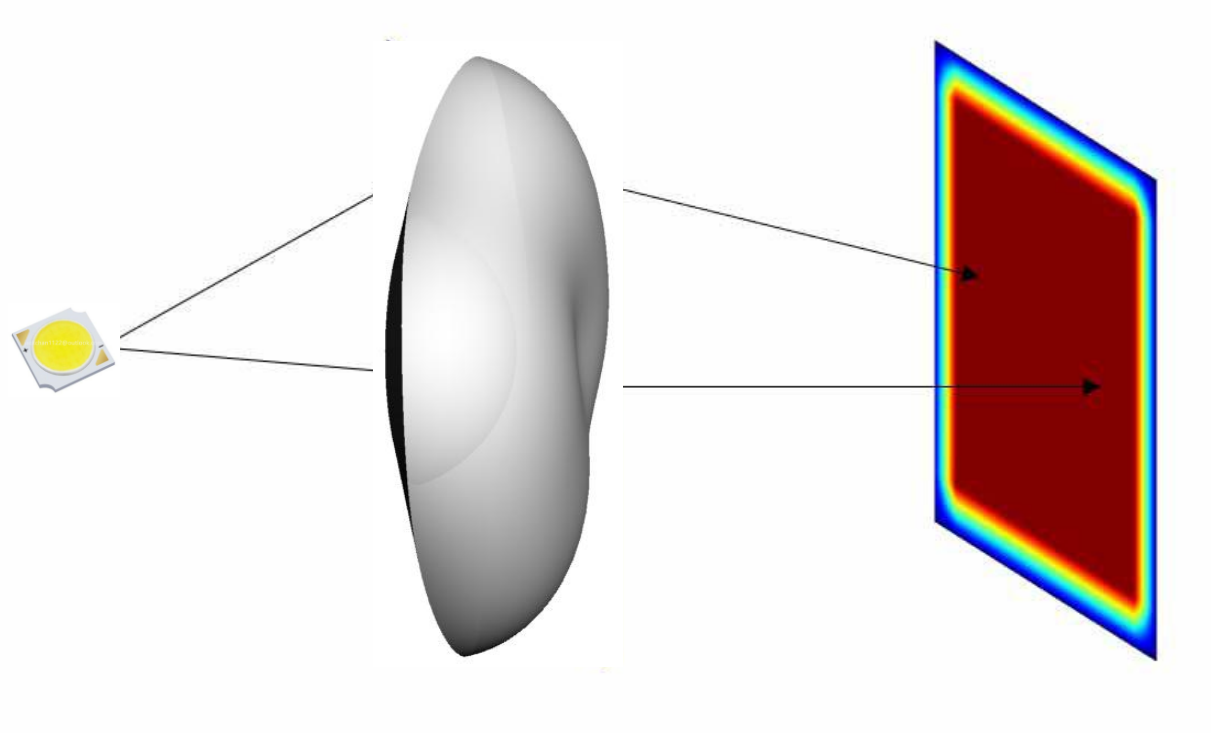
Reason 1

Optical design is far from trivial



The crucial problem to solve is: *Which ray transformation results in a continuous refractive or reflective surfaces?*

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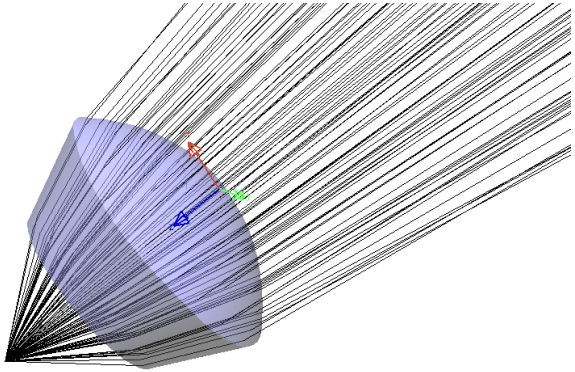
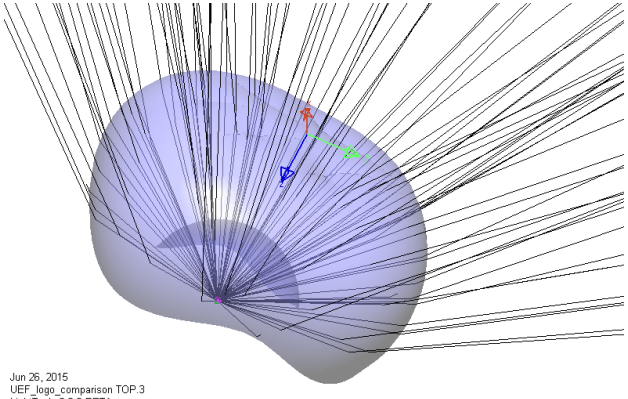
A. Bauerle et. Al. “Algorithm for irradiance tailoring,” Optics Express 2013.

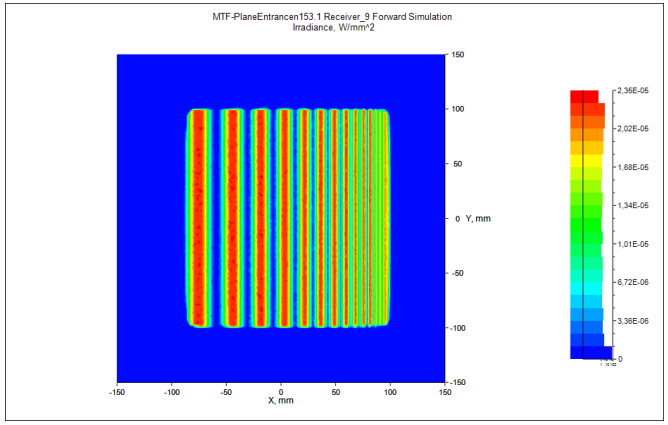
But direct freeform design methods are maturing fast

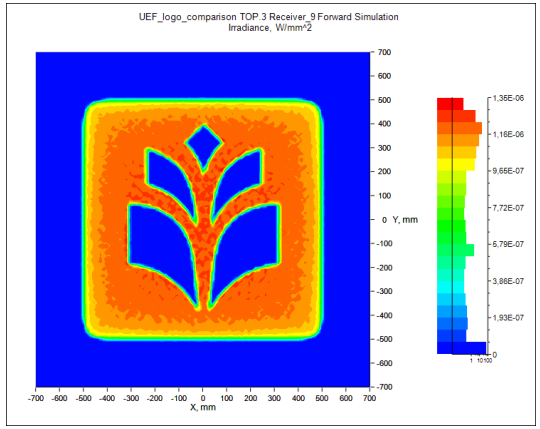


Jun 29, 2015
SmallRect-FlatEntrancen153.2
LightTools 8.3.0 BETA



Jun 26, 2015
UEF_logo_comparison TOP.3
LightTools 8.3.0 BETA





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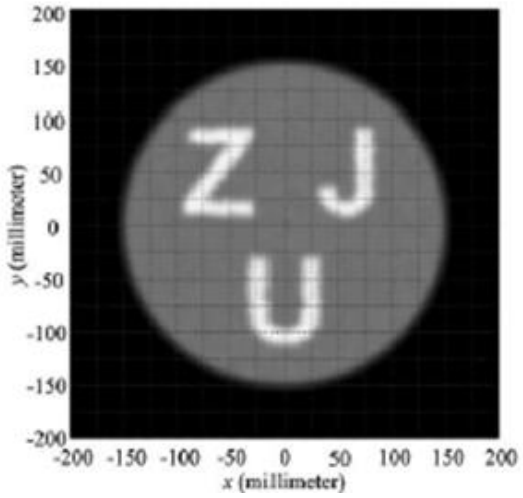
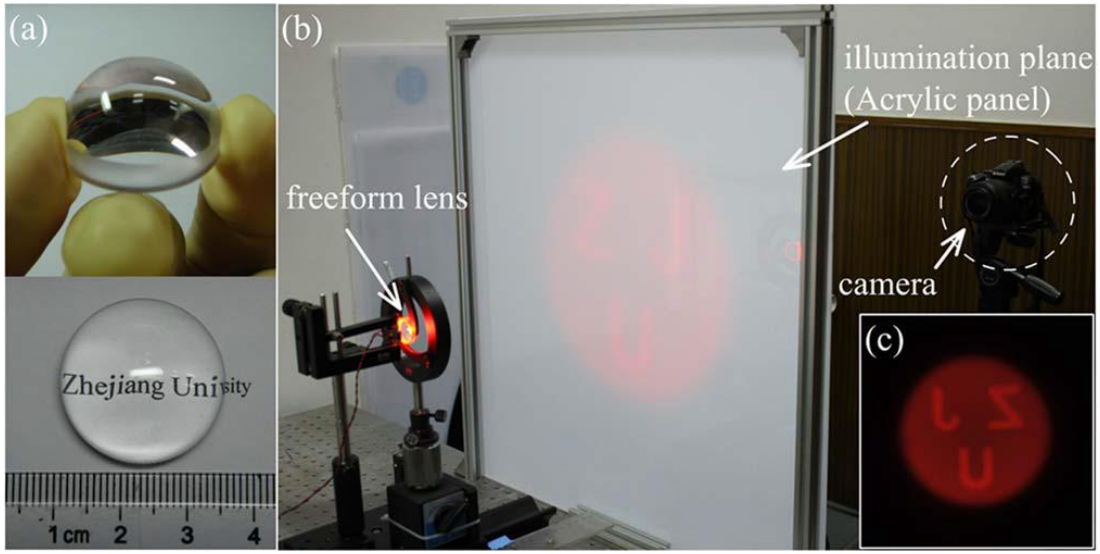
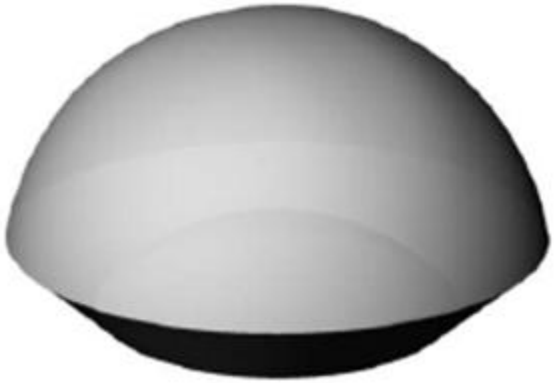
… and current fabrication technology allows to make these freeform components







R. Wu et. Al. “Freeform illumination design,” OPTICS LETTERS 38(2) 2013.

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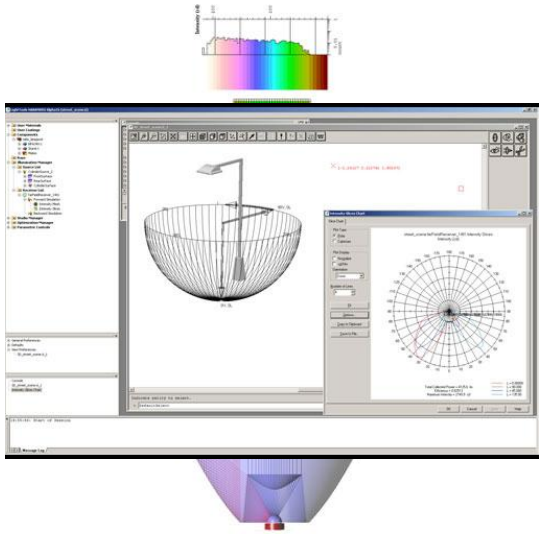
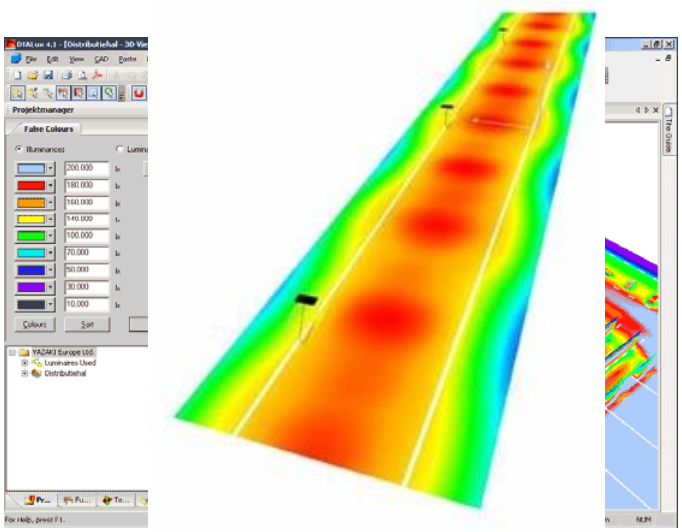
Reason 2

Freeform optics = Fully customisable components, made with a mass production technology





Optical design = Determine the shape of the optical component to realise a luminaire with a specific radiation pattern.

Lighting design = Creative use of existing luminaires for unique lighting situations.

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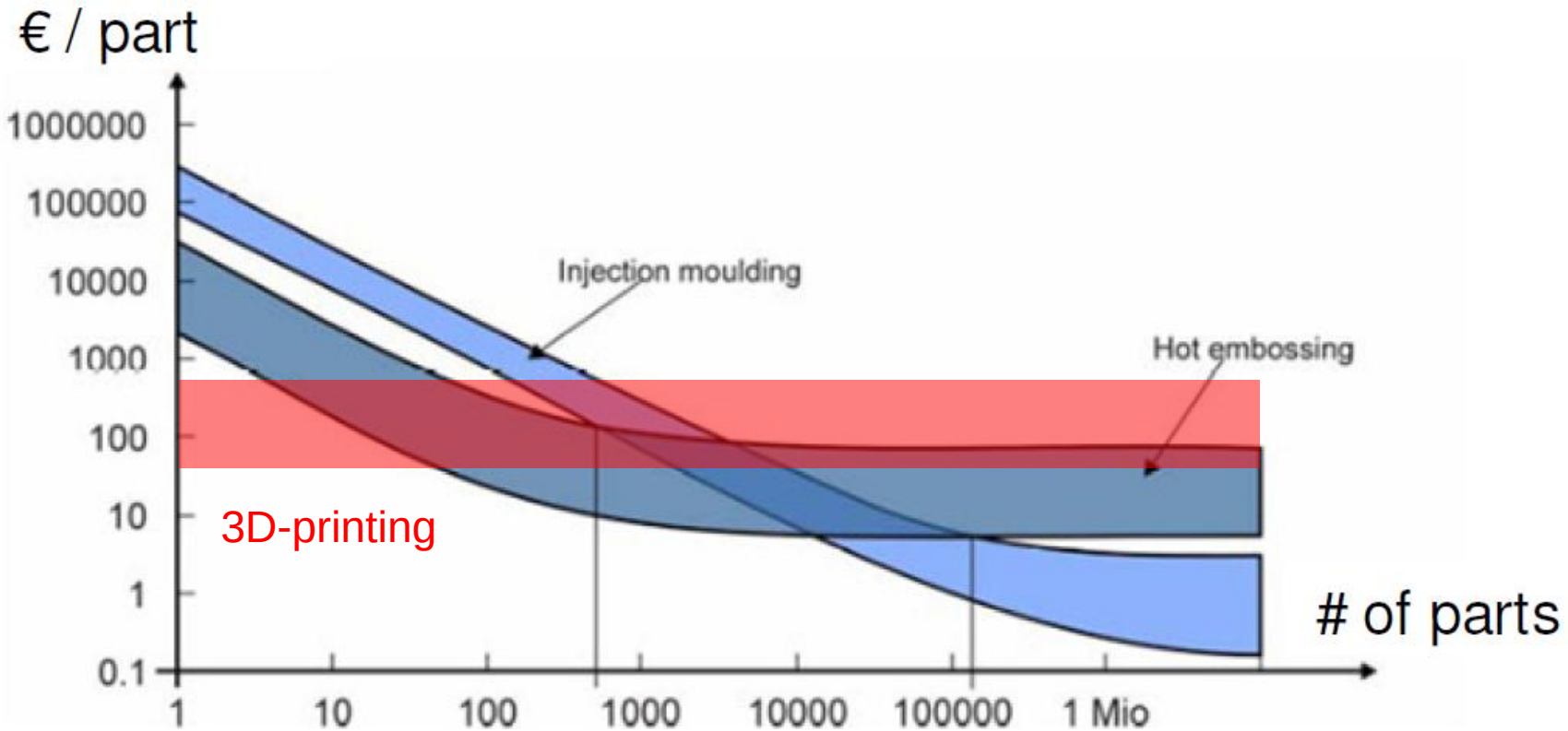
Reason 2

Freeform optics = Fully customisable components, made with a mass production technology



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3D printing of high-quality freeform optics is possible

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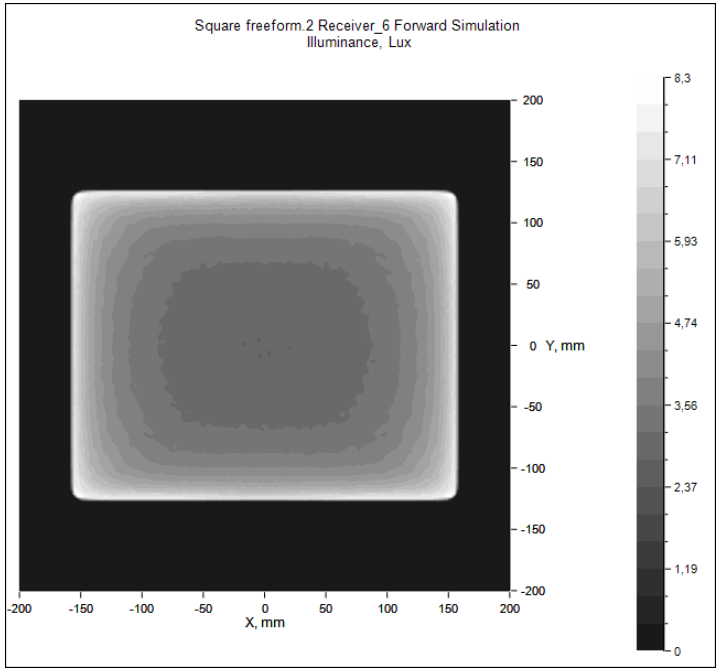
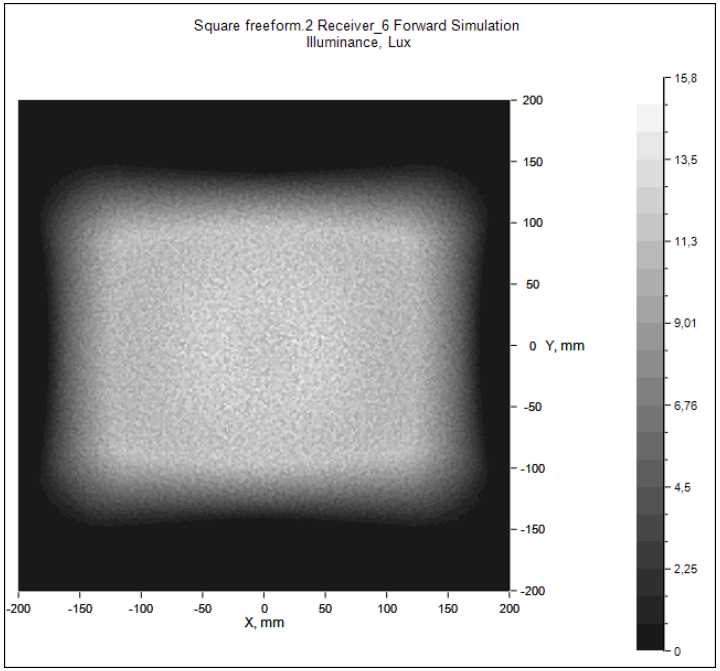
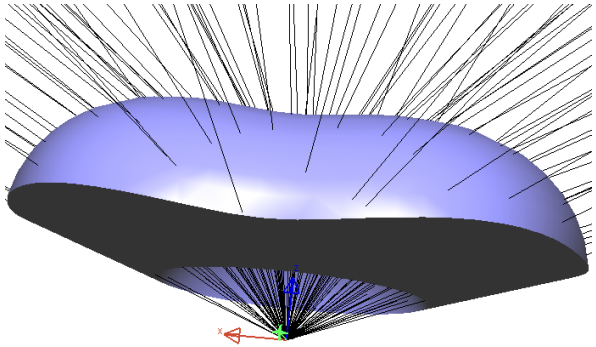
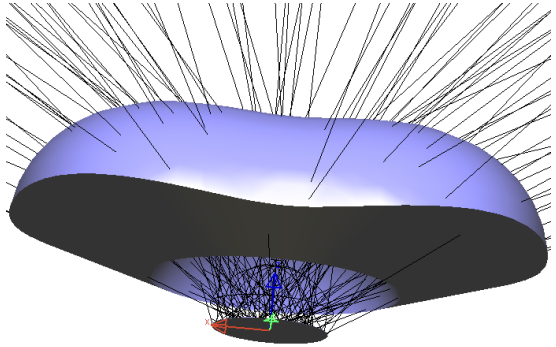
Problem 3: To realise good light tailoring we need a point source (or high-luminance source)

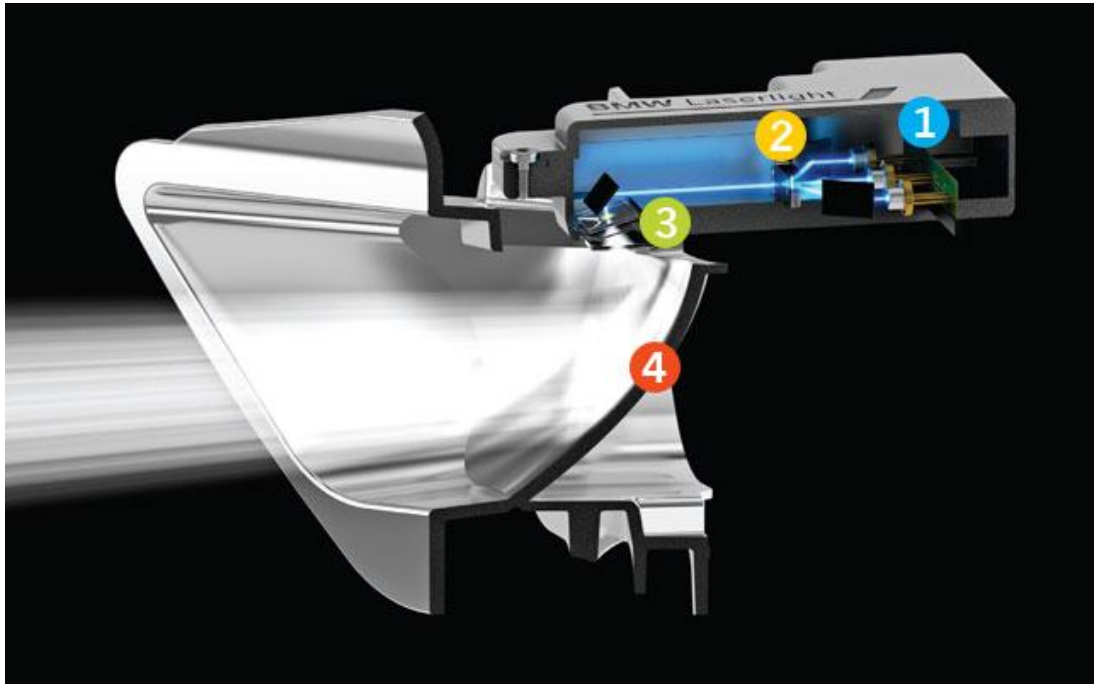








This is the reason why laser diodes are already being used in lighting applications



The headlights of the BMW i8 make use of blue laser diodes. This results in an optimal illumination pattern with a total efficiency that surpasses that of LED based headlights (source: BMW)

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Practical limitation to go towards high-luminance sources: Thermal quenching

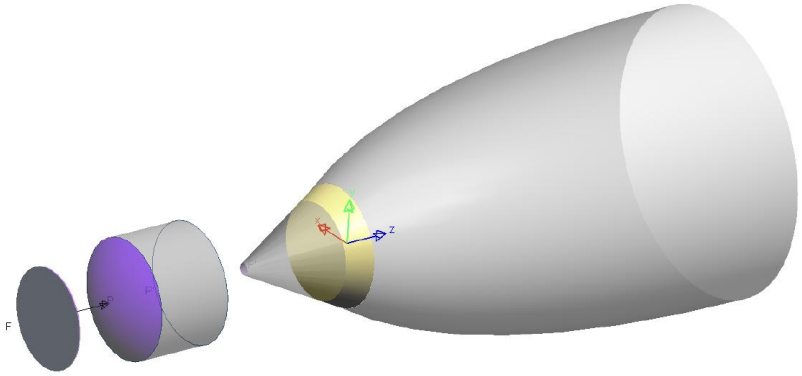
- Phosphor efficiency = Quantum efficiency
  = # converted photons / # absorbed photons

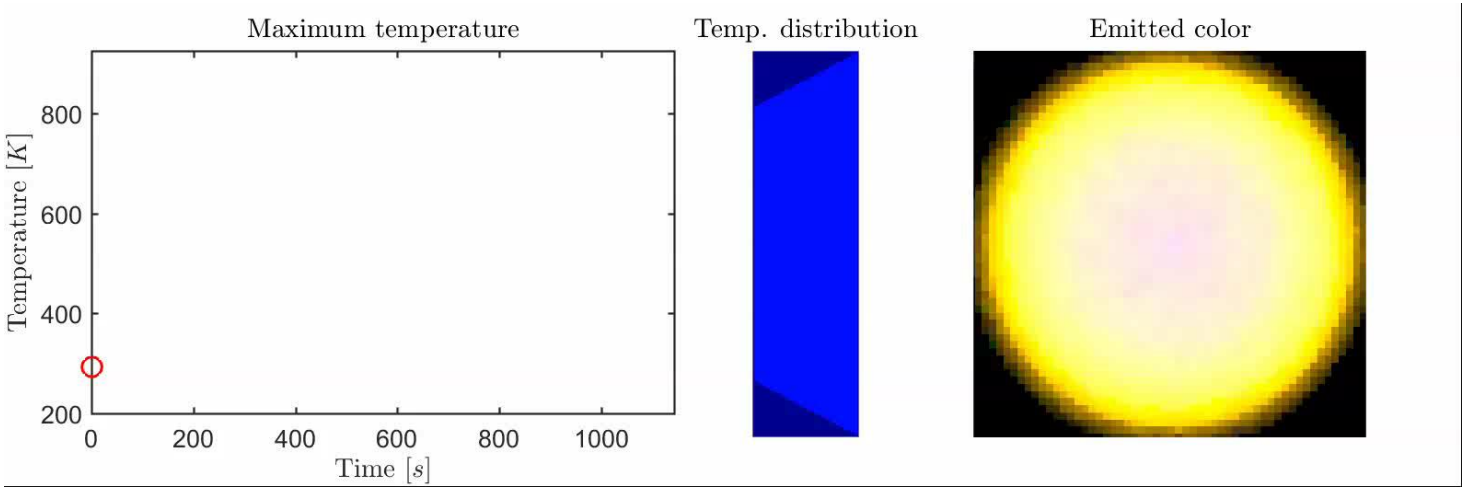
- Heat is created in the phosphor
  1. Non-radiative losses because quantum efficiency ≠ 100 %
  2. Wavelength conversion – Stokes shift losses

- Quantum yield becomes lower at higher temperatures
  = thermal quenching.

- Opto–thermal feedback
  - Higher temperature => lower quantum efficiency => even higher temperature => even lower quantum efficiency => …
  - Possible thermal runaway and system breakdown.

Simulation example





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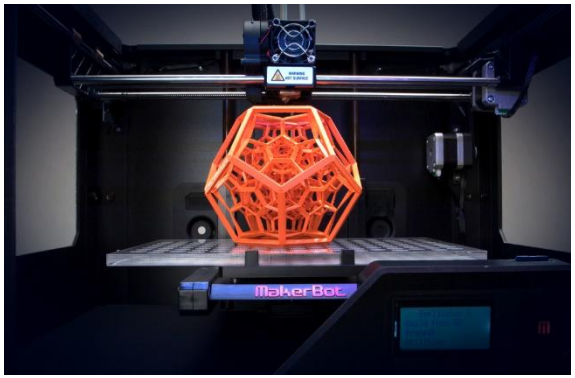
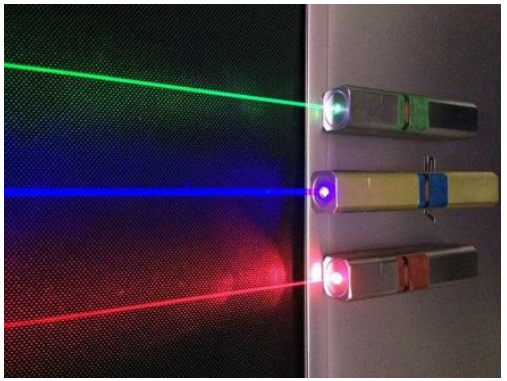
Will these technologies revolutionize the lighting industry ?

Freeform optics



3D printing



Laser diodes

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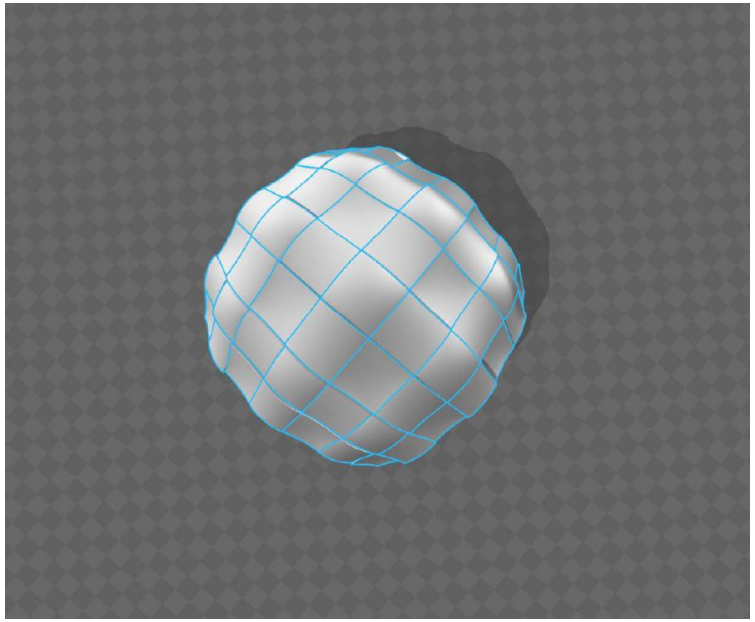
And what about glare ?



Also here, smaller sources allow better light control.