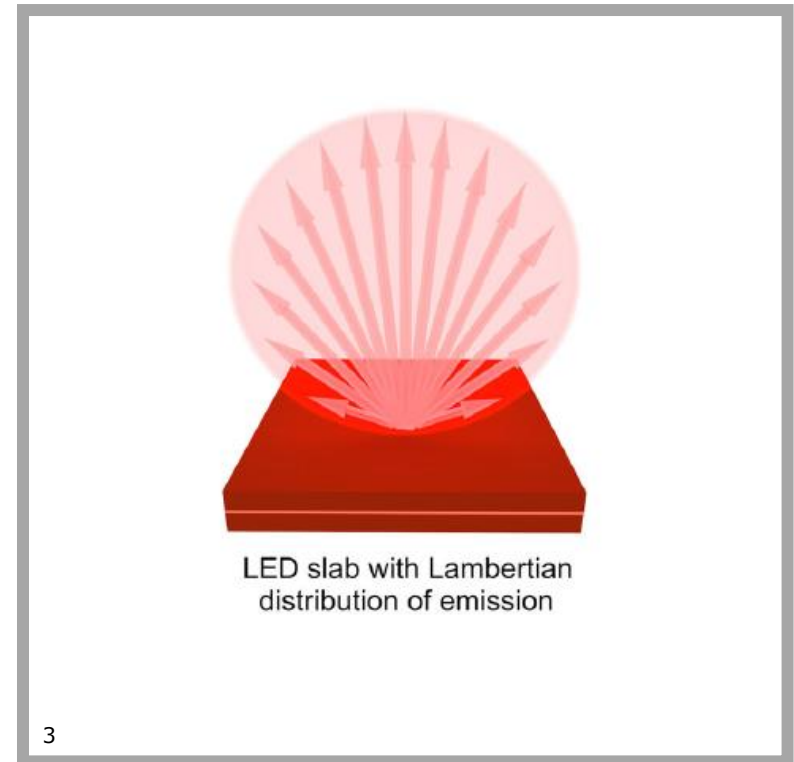
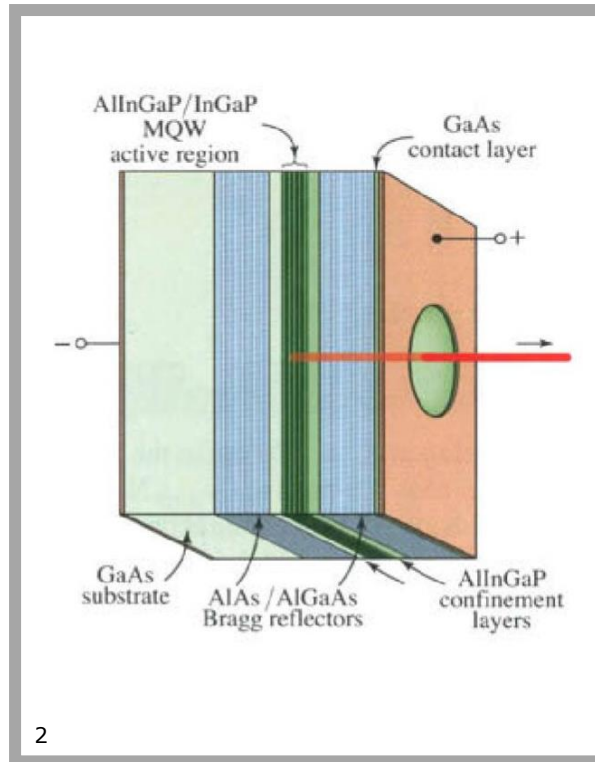
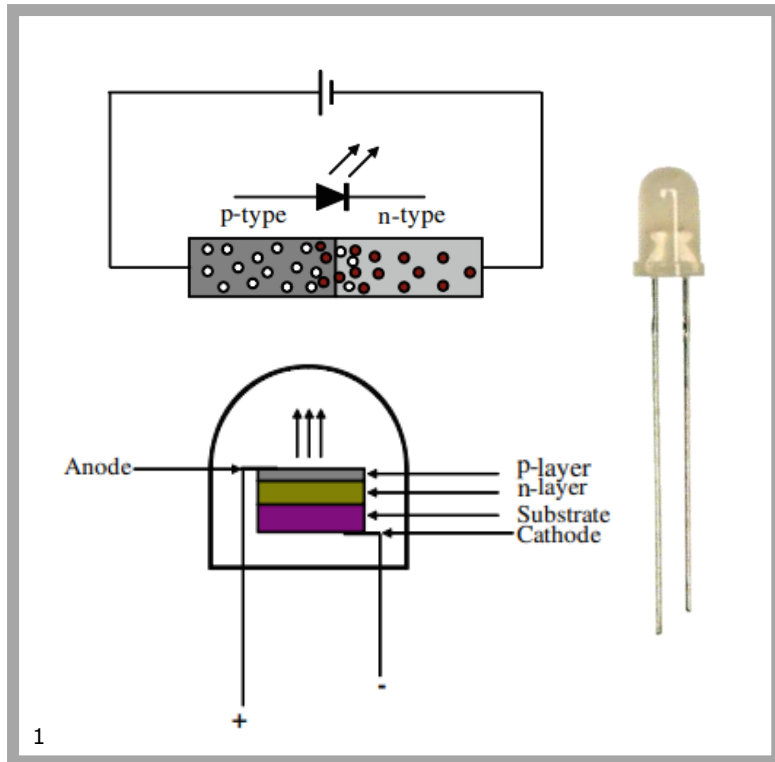


Kirstine Engell Sandager Nielsen, Ph.D. student

Optical Metasurfaces for Lighting Applications

Light Emitting Diodes (LEDs)



- 1) Ramchandra, P. et al., Light Emitting Diodes. In: Green Energy and Technology, Springer London, 61-95 (2011)
- 2) Saleh, Bahaa E. A., et al. Fundamentals of Photonics, John Wiley & Sons, Incorporated, 2013.
- 3) Khaidarov, E. et al., Control of LED emission with functional Metasurfaces. Laser Photonics Rev, 14, 1900235 (2020)

Light Emitting Diodes (LEDs)



www.vintagecalculators.com



www.avxperten.dk



www.biltema.dk



www.av-cables.dk



www.eneltec-led.com



www.audi.dk

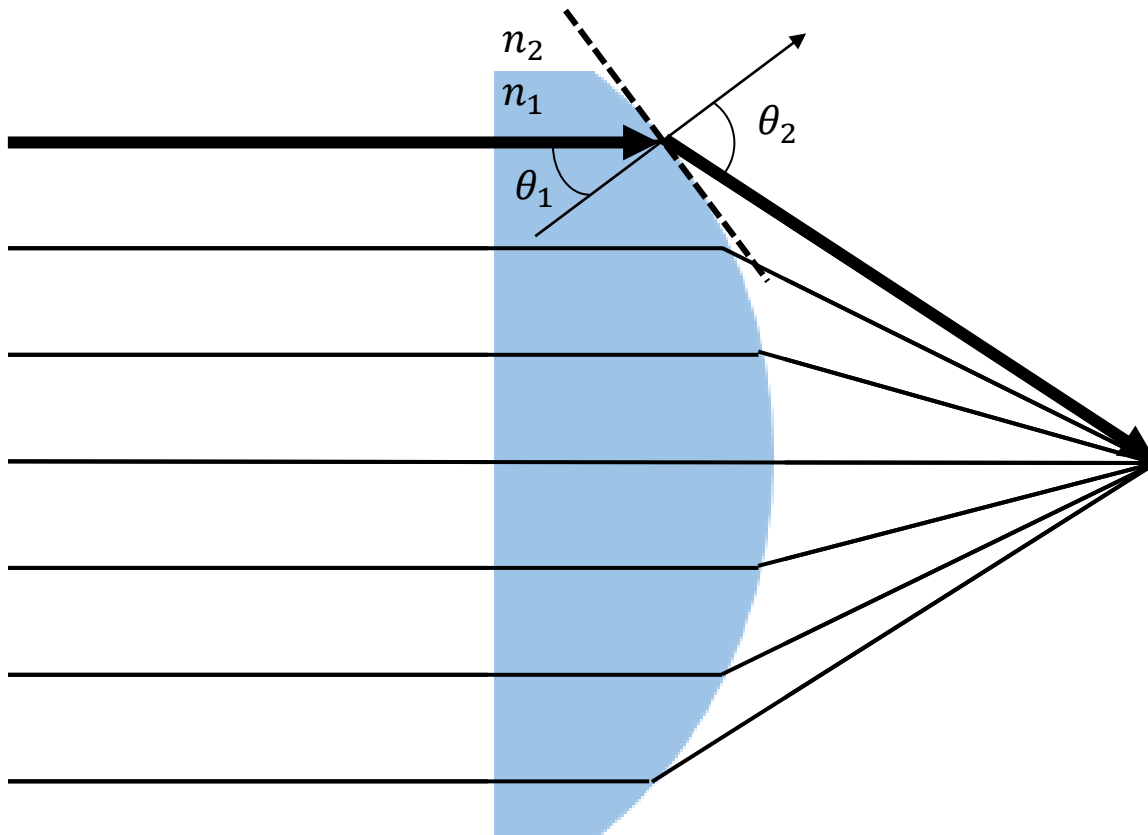


www.philips-hue.com



www.agled.com

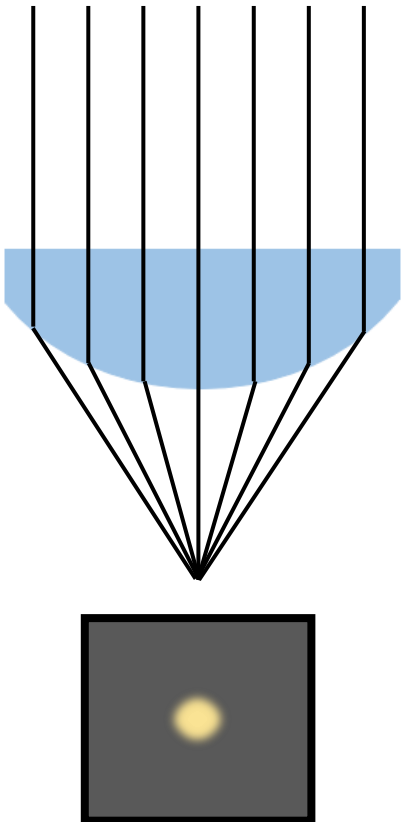
Optics



$$\sin(\theta_1) \cdot n_1 = \sin(\theta_2) \cdot n_2$$

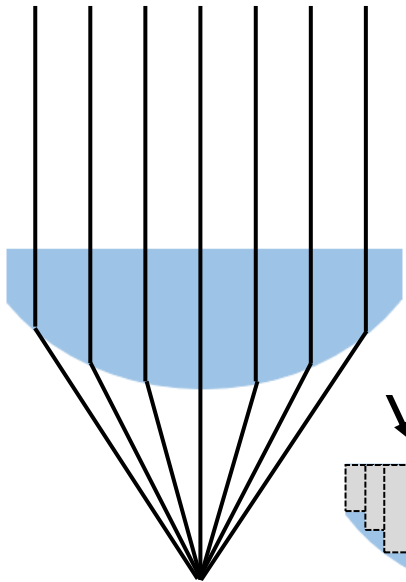
Metaoptics

Conventional Lens

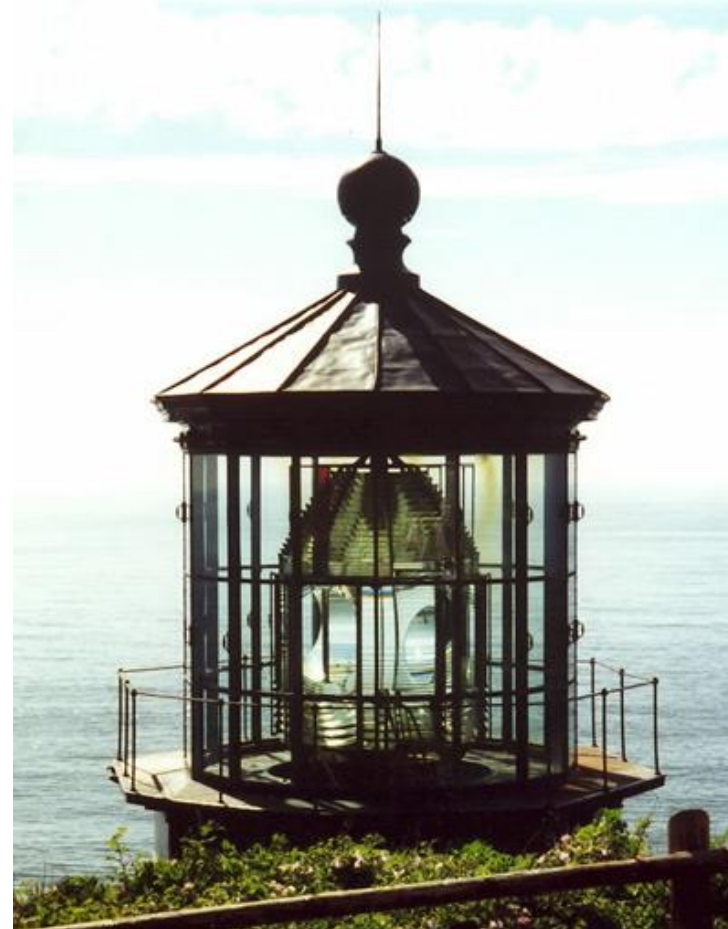
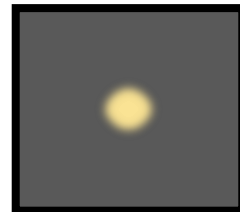
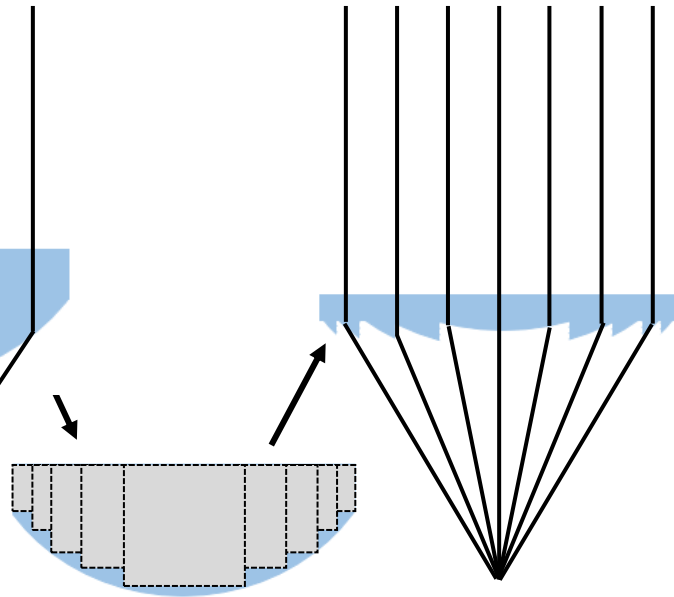


Metaoptics

Conventional Lens



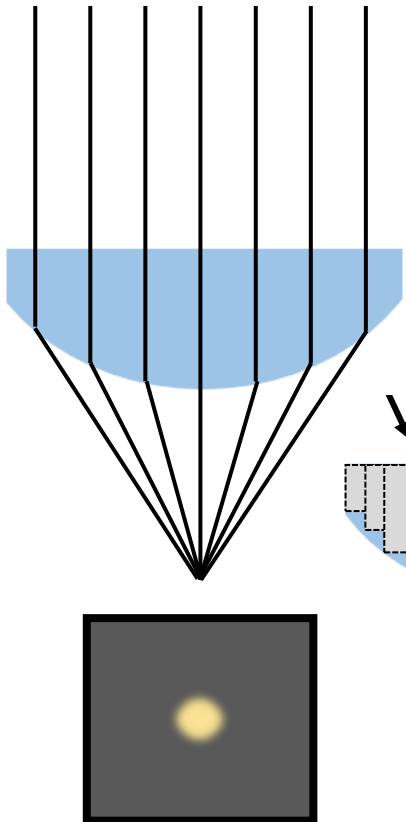
Fresnel Lens



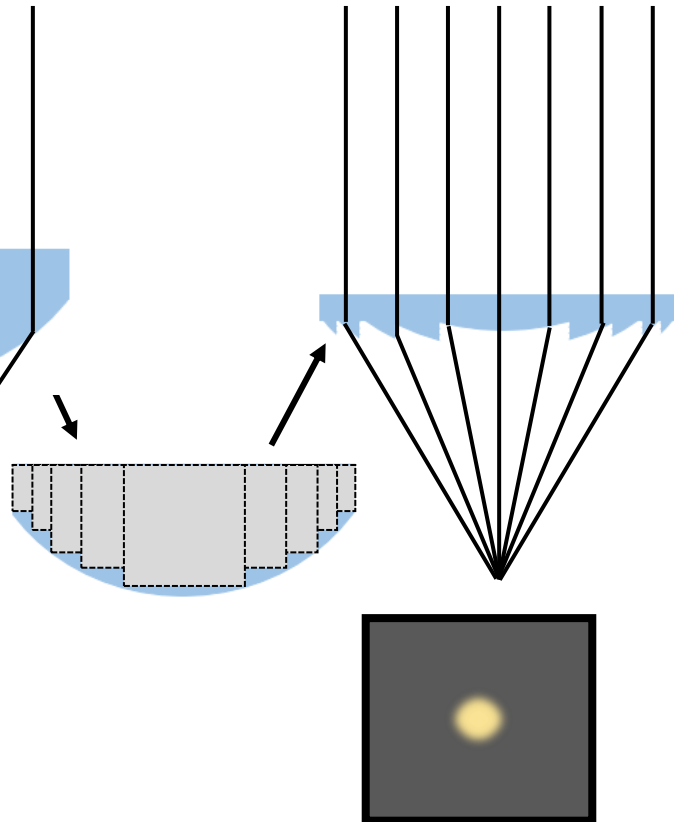
https://en.wikipedia.org/wiki/Fresnel_lens#/media/File:Cape_Meaes_Lighthouse_lens_-_Oregon.jpg

Metaoptics

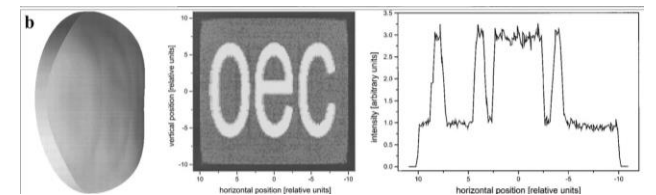
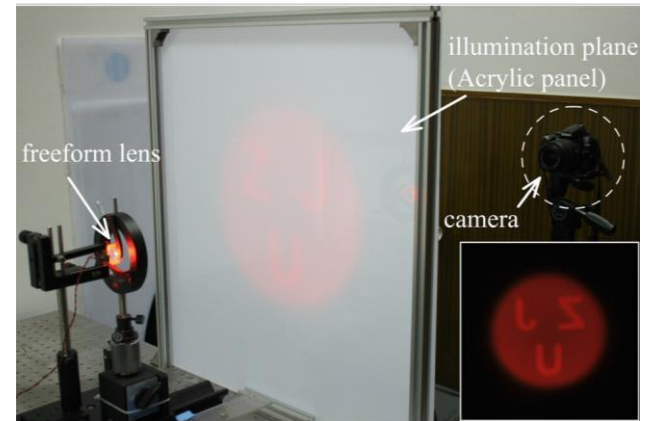
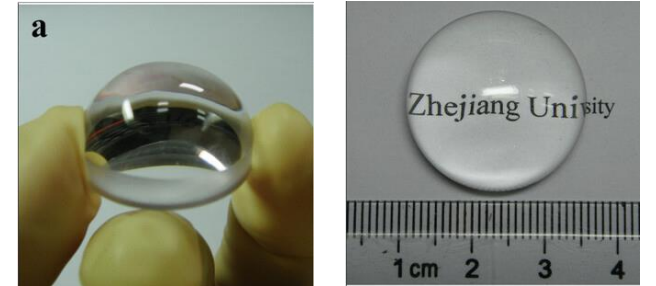
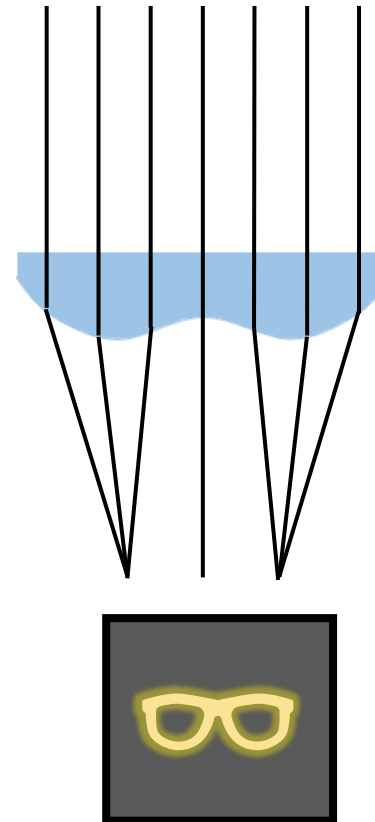
Conventional Lens



Fresnel Lens



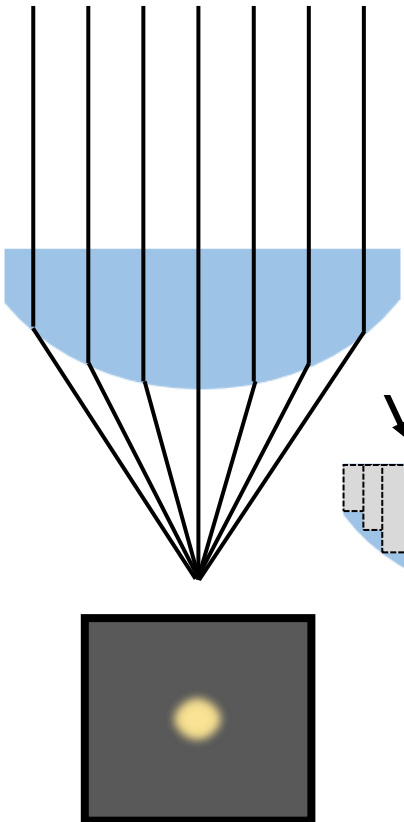
Freeform lens



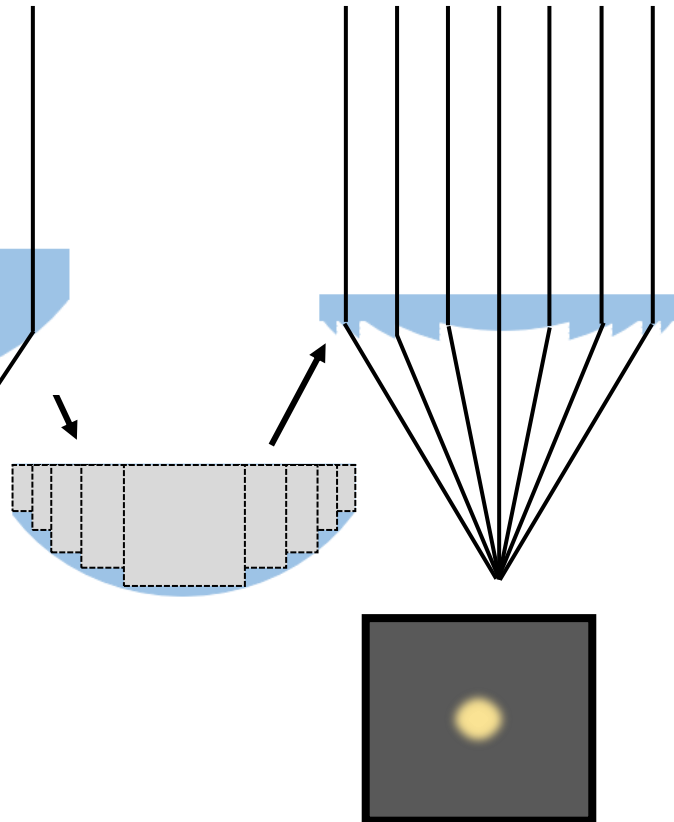
Wu, R., Feng et al., Laser & Photonics Reviews 2018, 12, 1700310.

Metaoptics

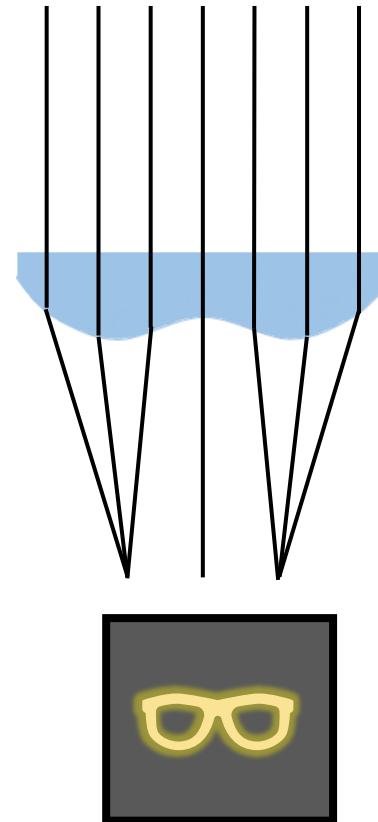
Conventional Lens



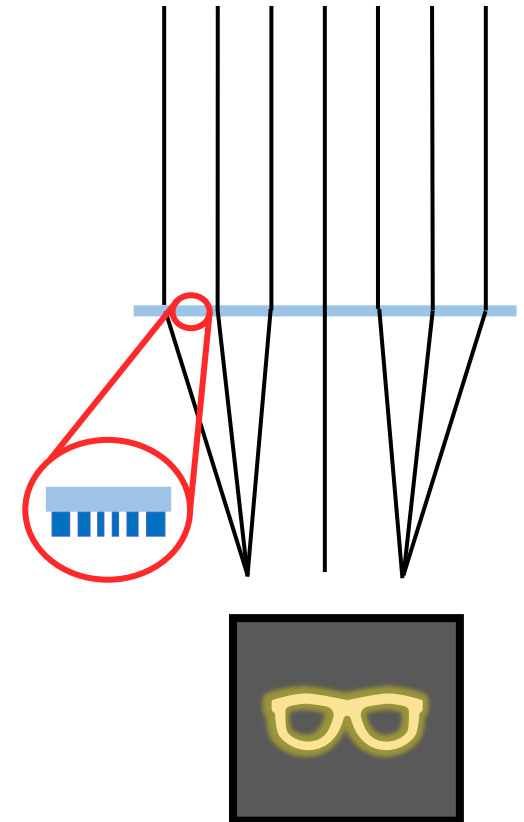
Fresnel Lens



Freeform lens

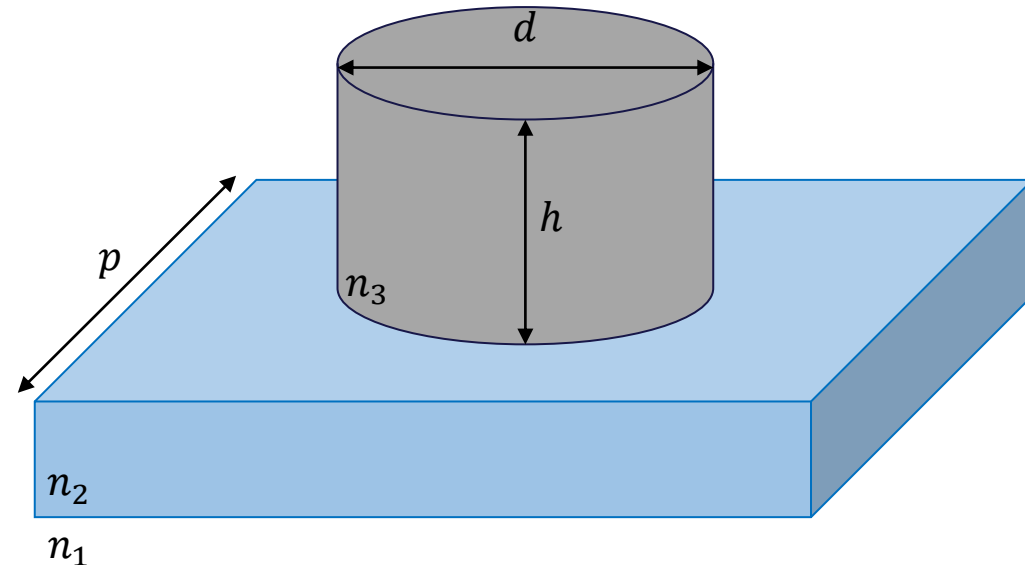
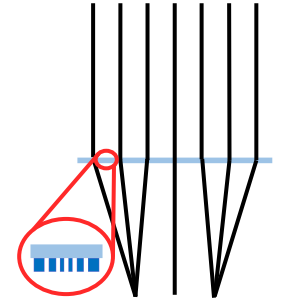


Metalens

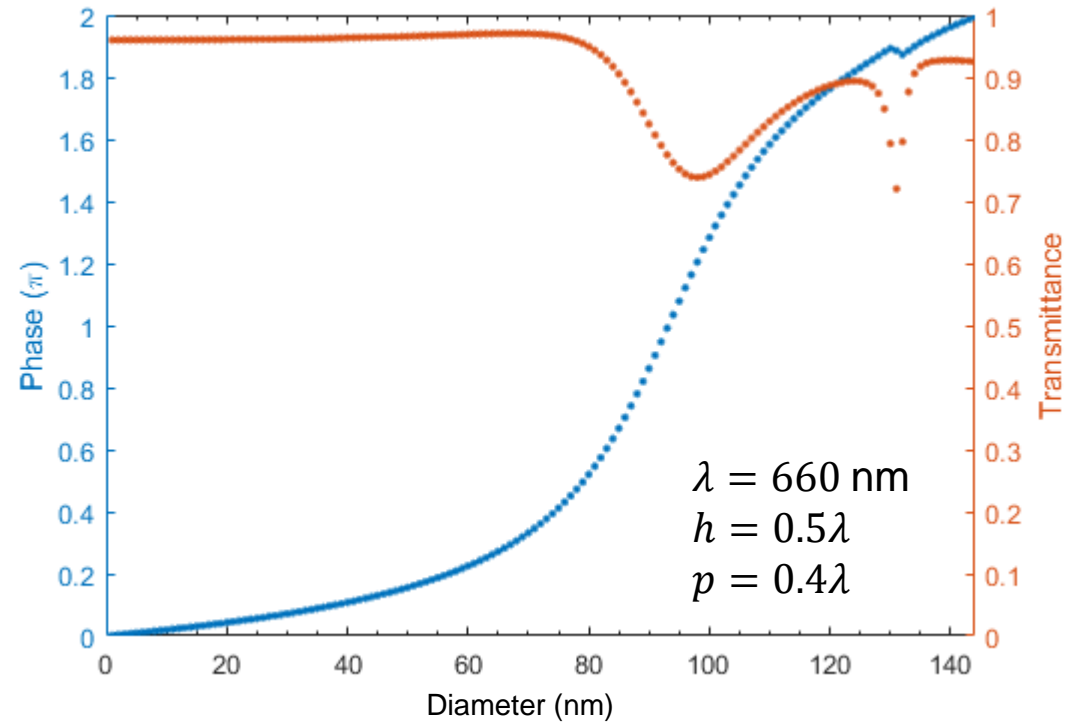
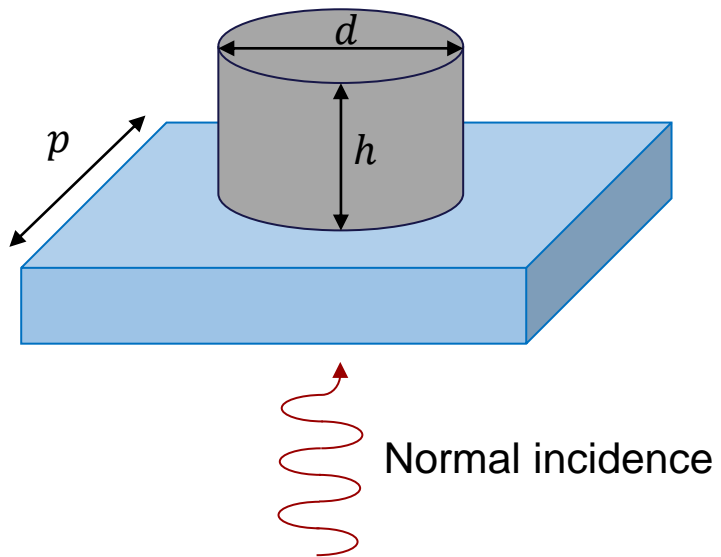
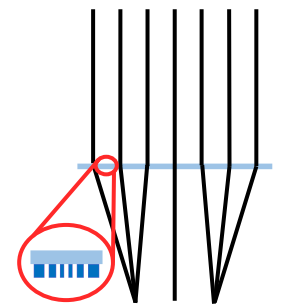


Metasurfaces

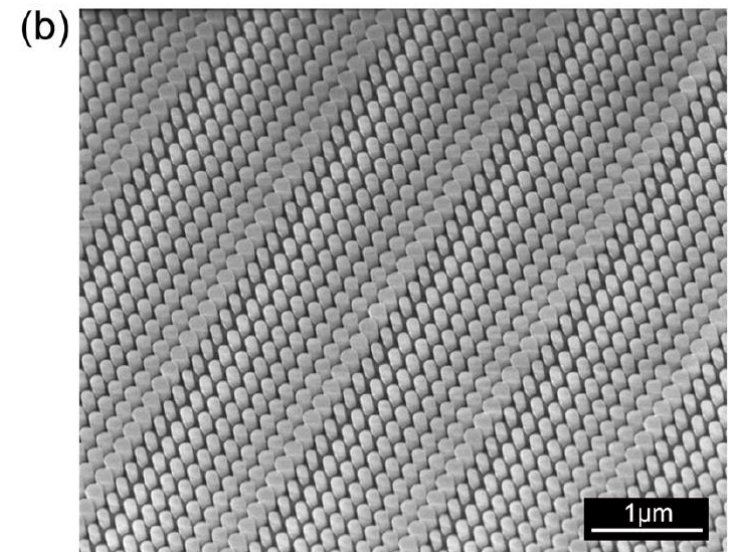
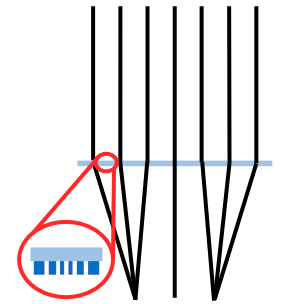
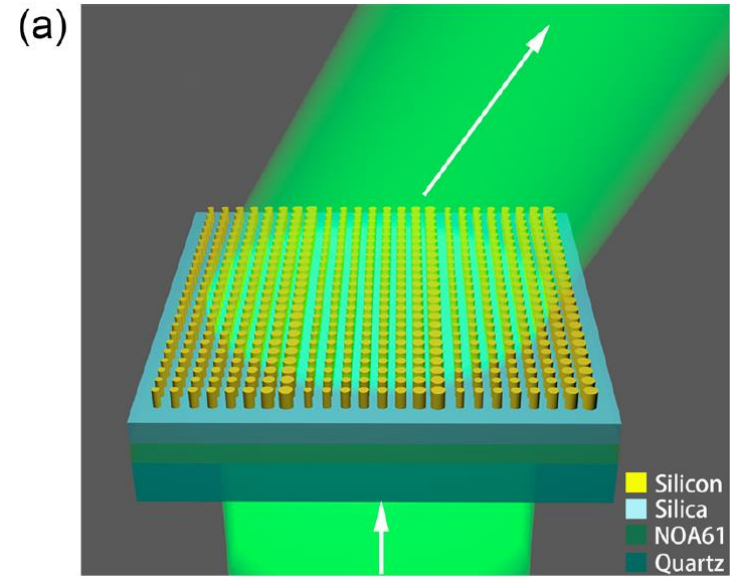
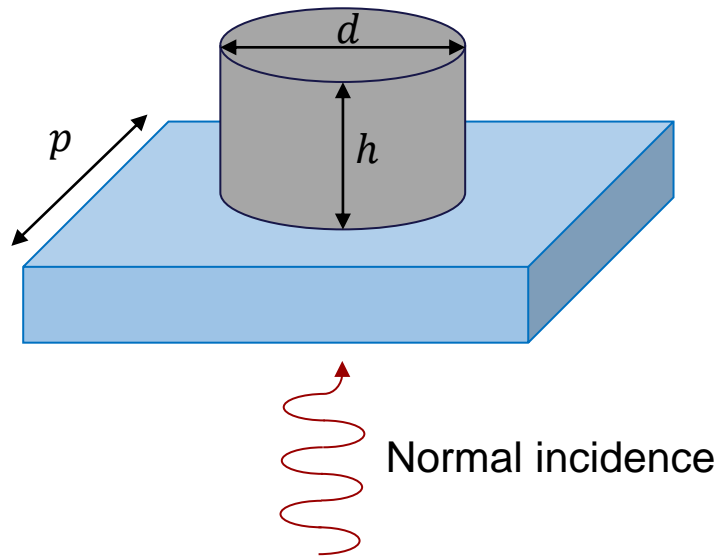
- Custom properties
- Low-loss metaatoms
 - Dielectric: Mie resonances
 - Effective refractive index
- Scale: $\sim \lambda$
- Refractive index: $n_1 \leq n_2 < n_3$
- Diffraction: $p < \lambda$



Metasurfaces

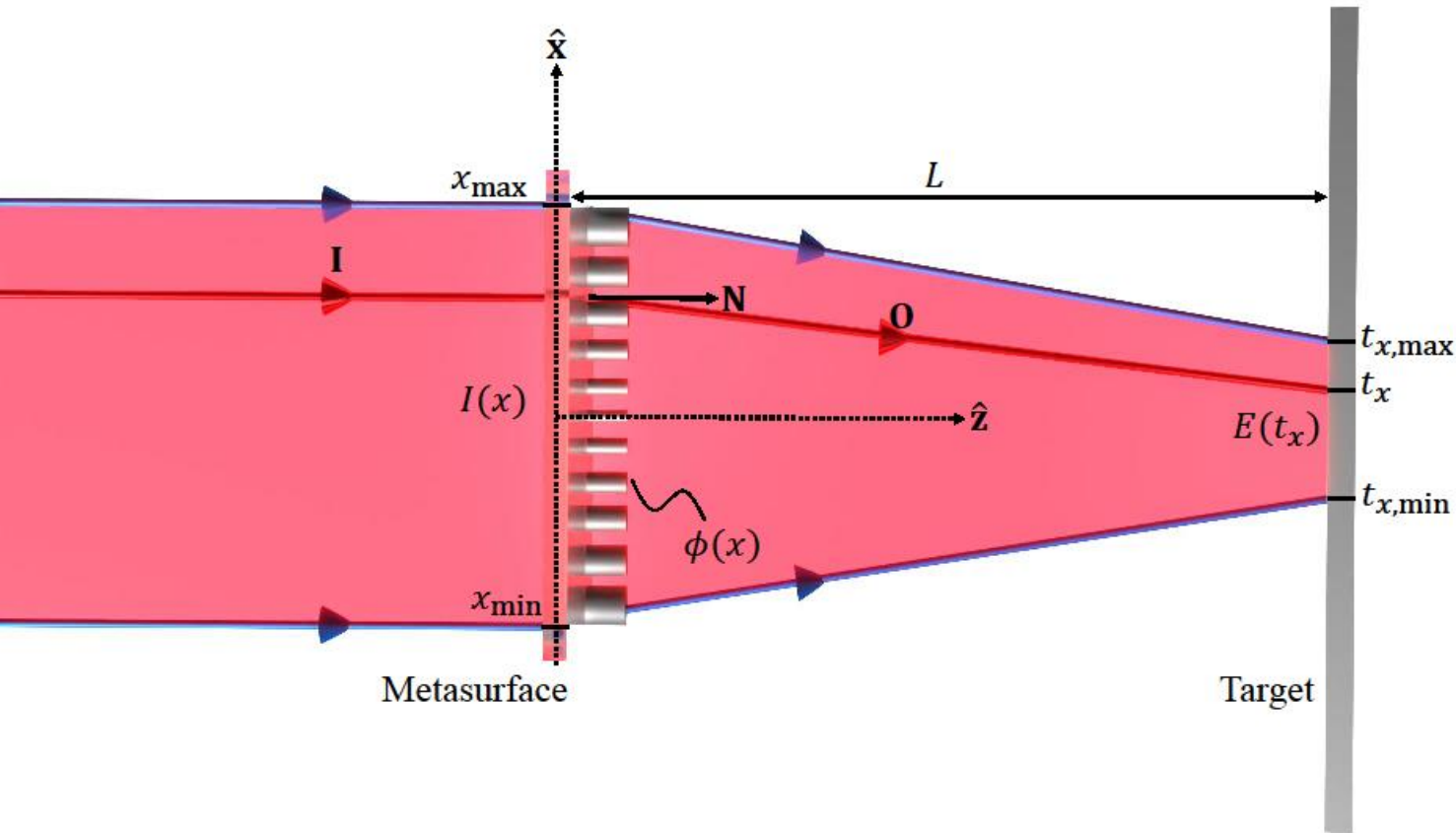


Metasurfaces



Zhou, Z. et al. (2017). Efficient Silicon Metasurfaces for Visible Light. *ACS Photonics*, 4(3), 544–551.

Freeform metaoptics



$$E(t_x) \left| \frac{\partial t_x}{\partial x} \right| = I(x)$$

Target intensity Jacobian Incident intensity

$$\mathbf{O} = (O_x, O_z) = \left(\frac{\partial \phi_x}{\partial x}, \sqrt{1 - \left(\frac{\partial \phi_x}{\partial x} \right)^2} \right)$$

$$t_x = x + L \frac{O_x}{O_z}$$

Analytical solutions

Focusing metalens

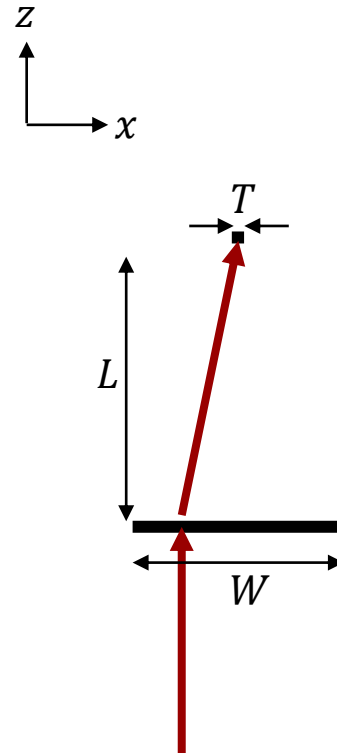
Literature

$$\phi = -\frac{2\pi}{\lambda} \left(\sqrt{(x^2 + y^2) + f^2} - f \right)^{1)}$$

Our model (1D)

For $T \ll W$

$$\phi = -\frac{2\pi}{\lambda} (\sqrt{x^2 + L^2} - L)$$



1) Mohammadreza Khorasaninejad et al., Metalenses at visible wavelengths: Diffraction-limited focusing and subwavelength resolution imaging. Science352, 1190-1194 (2016).

Analytical solutions

Focusing metalens

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Our model (1D)

For $T \ll W$

$$\phi = -\frac{2\pi}{\lambda} (\sqrt{x^2 + L^2} - L)$$

Beam deflection

Literature

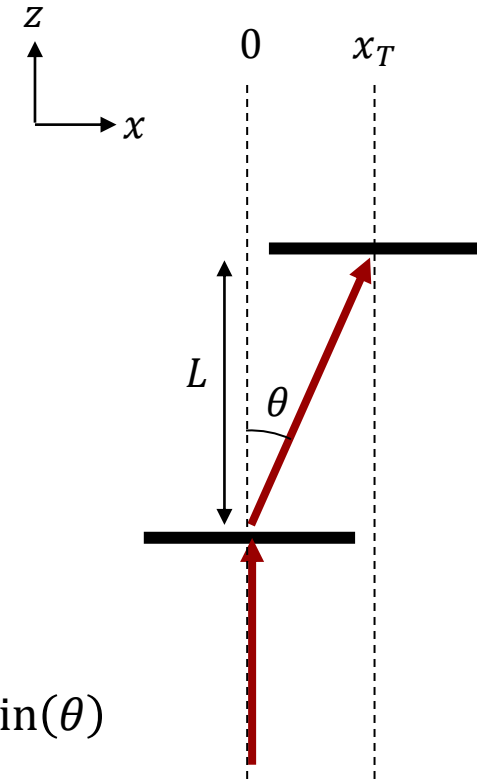
$$\frac{d\phi}{dx} = \frac{2\pi}{\lambda} n \cdot \sin(\theta)^{2)}$$

Our model (1D)

Metasurface center: $x = 0$

Target center: $x = x_T$

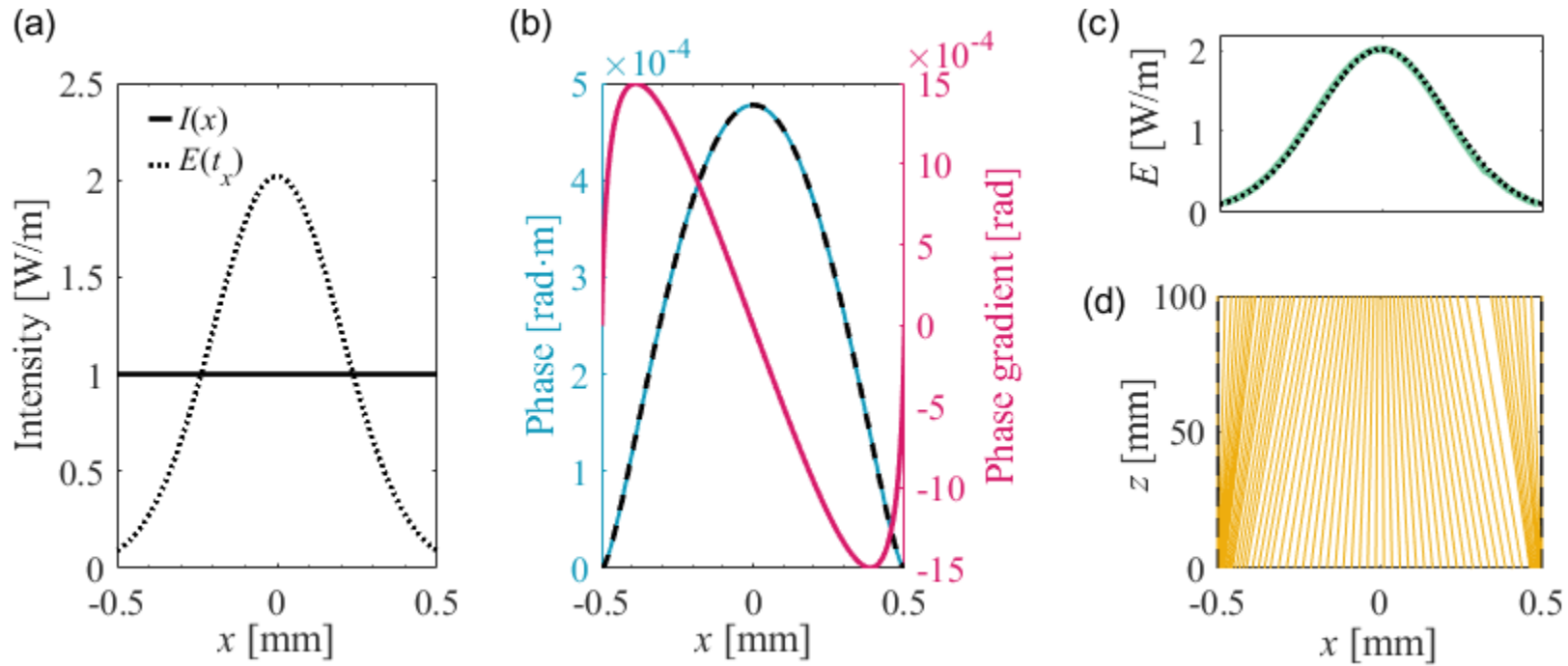
$$\frac{d\phi}{dx} = \frac{2\pi}{\lambda} n \cdot \frac{x_T}{\sqrt{L^2 + x_T^2}} = \frac{2\pi}{\lambda} n \cdot \sin(\theta)$$



1) Mohammadreza Khorasaninejad et al., Metalenses at visible wavelengths: Diffraction-limited focusing and subwavelength resolution imaging. *Science* 352, 1190-1194 (2016).

2) Zhou, Z. et al., Efficient Silicon Metasurfaces for Visible Light. *ACS Photonics*, 4(3), 544-551 (2017).

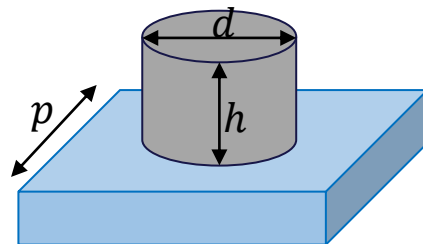
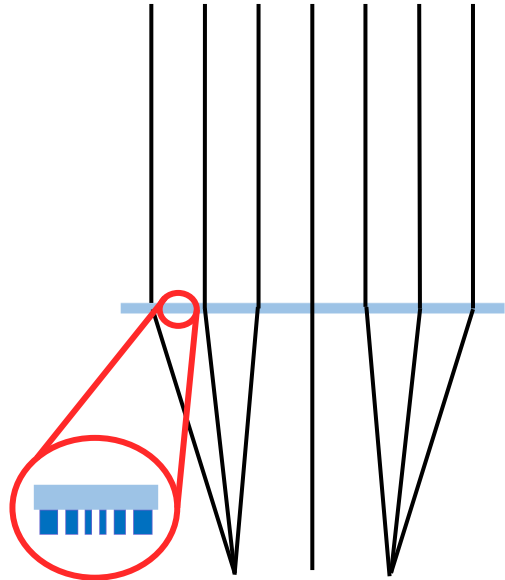
Freeform metaoptics



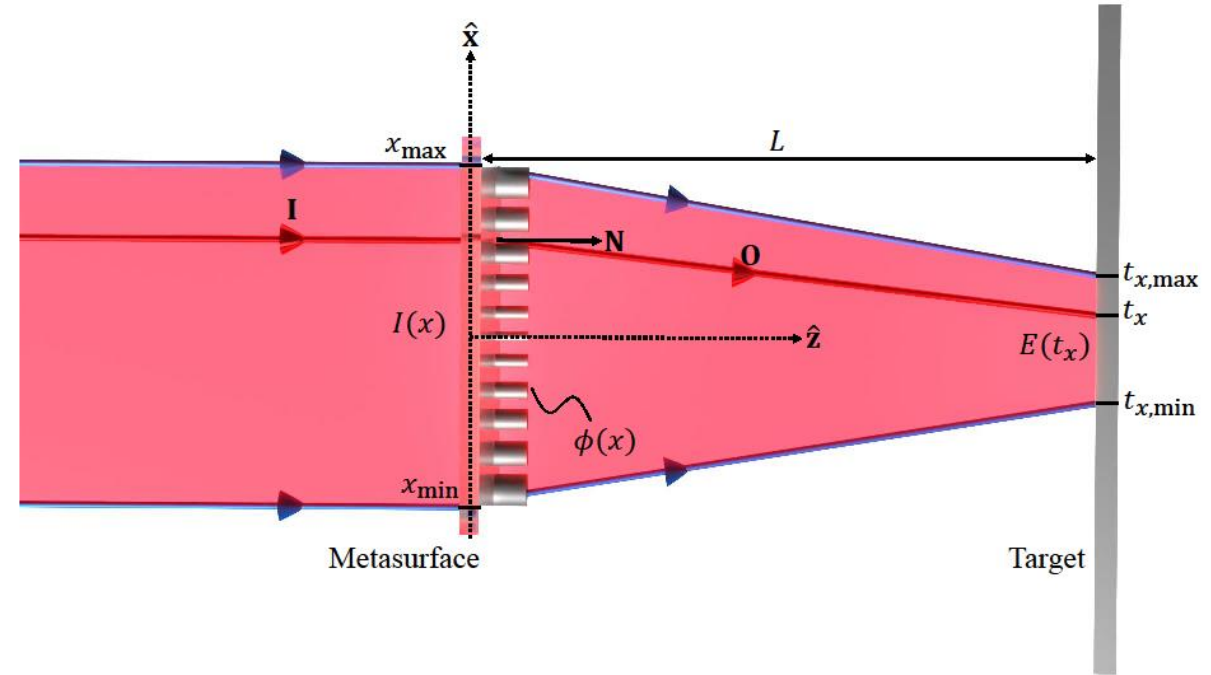
Summary



LED slab with Lambertian distribution of emission



Normal incidence



Thank you

DTU

