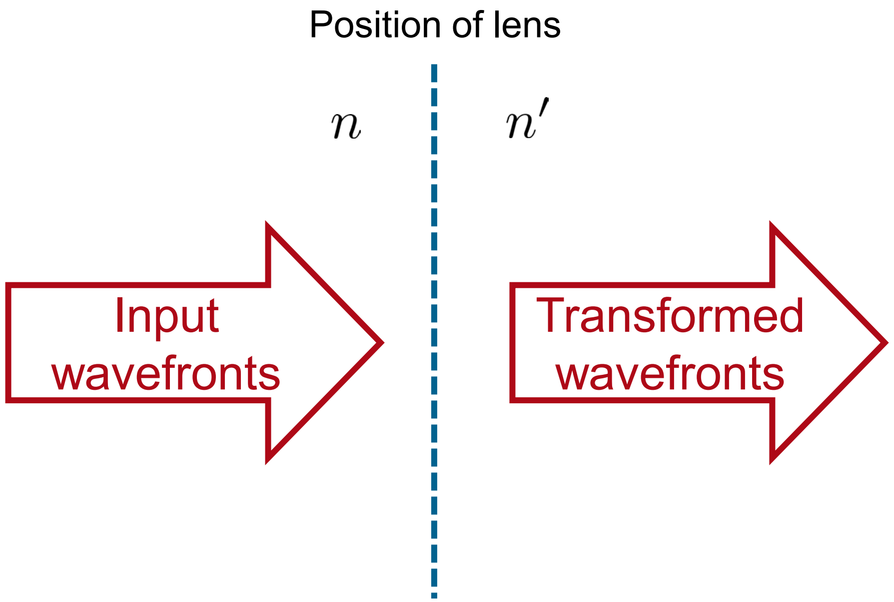
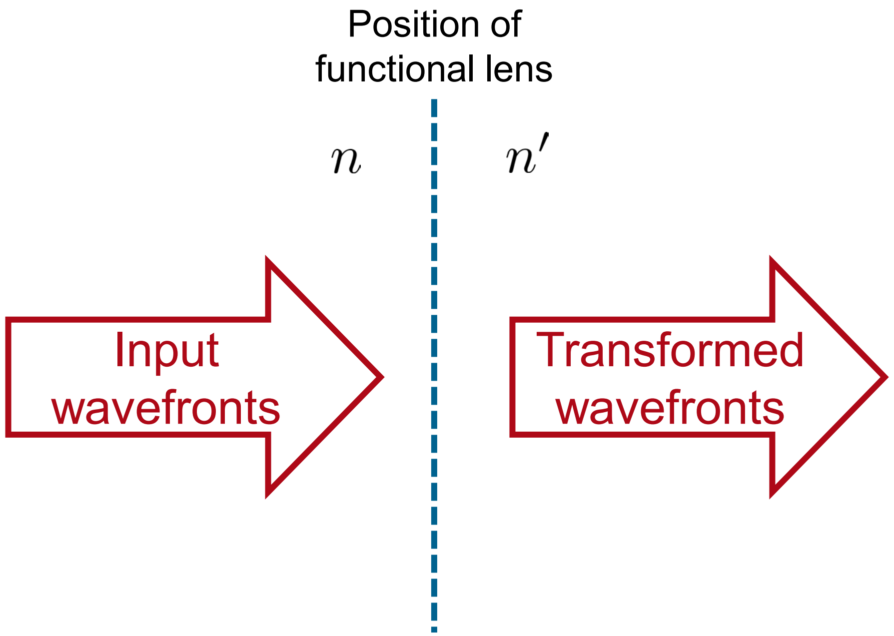
Flat Lenses: Tracing the Evolution from Smooth Surfaces to Fresnel, Diffractive, and Metalenses

Function of Lenses



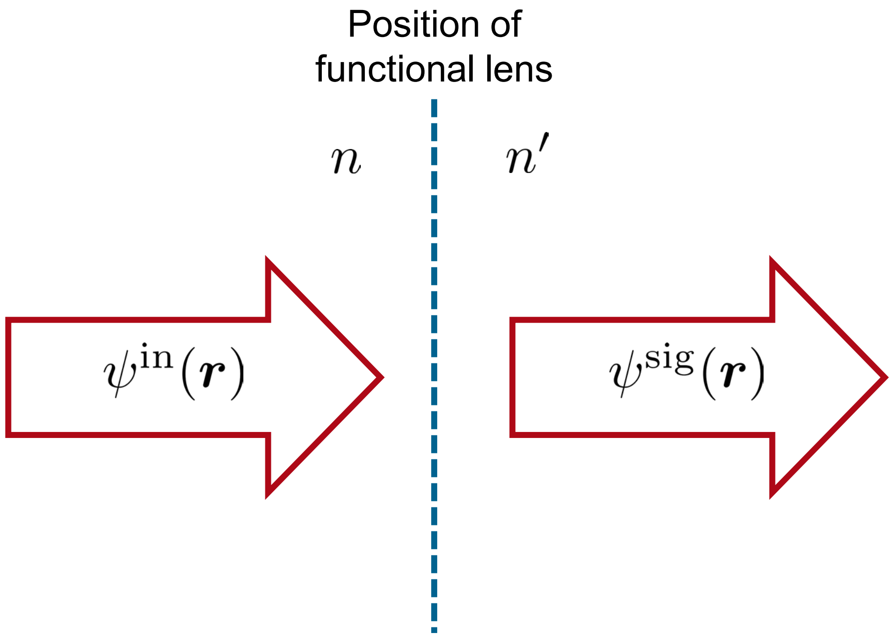
- Every lens is designed to transform one or more incoming wavefronts.
- In imaging, it is common to transform spherical and planar wavefronts.

Functional Lens



- The function of a lens is defined by the transformations it is intended to execute.
- This information is preserved and accessible for modeling and design through what is known as a functional lens.
- A functional lens provides details on all transformations through a collection of input phases and their corresponding outputs, also known as signal phases.

Functional Lens



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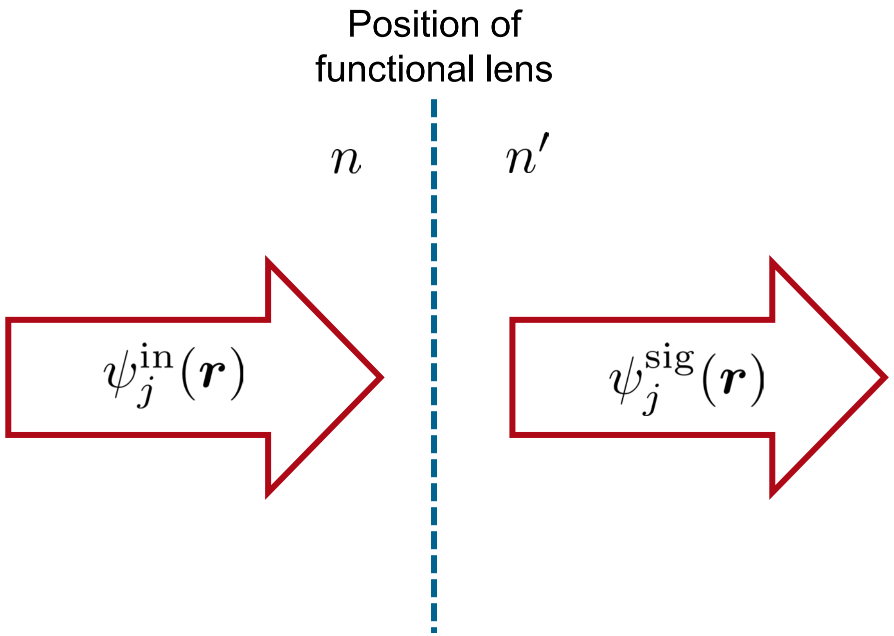
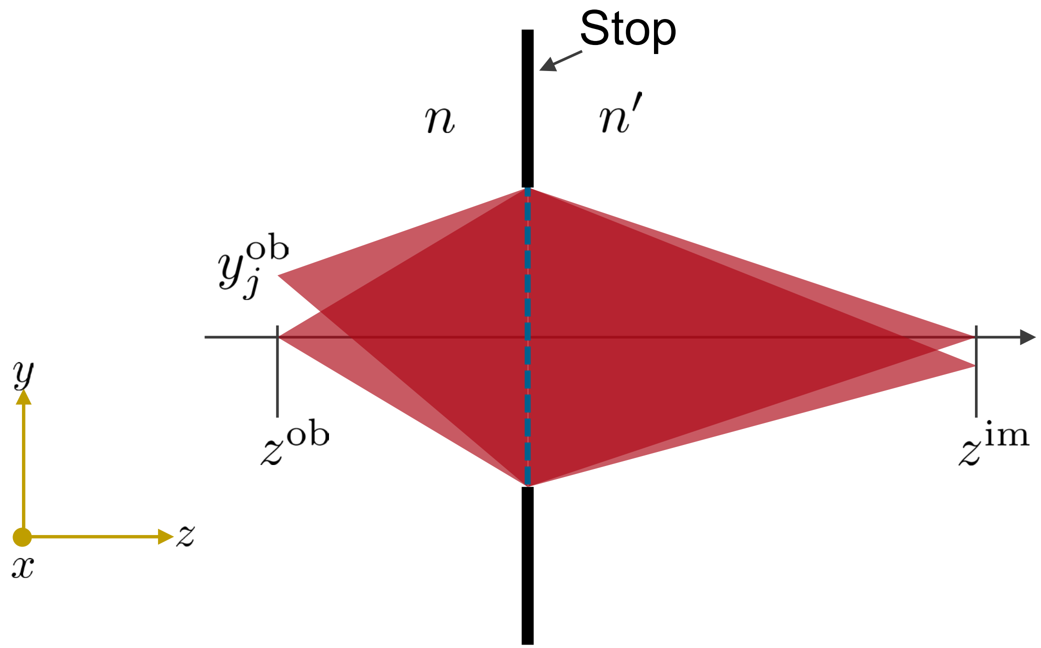
Transformations Involving Single and Multiple Fields



- A transformation that involves just one pair of wavefront phases is termed a single-field transformation.
- On the other hand, when multiple pairs of wavefront phases are involved, the process is referred to as a multifield transformation.

Basic Imaging Scenario



$$\psi_j^{\mathrm{in}}(y, z) = k_0 n \sqrt{(y - y_j^{\mathrm{ob}})^2 + (z - z^{\mathrm{ob}})^2}$$

⇩

$$\psi_j^{\mathrm{sig}}(y, z) = -k_0 n' \sqrt{(y - M y_j^{\mathrm{ob}})^2 + (z - z^{\mathrm{im}})^2}$$

with magnification M

- In a basic imaging scenario, the functional lens specifies the transformation of divergent spherical input wavefront phases into convergent spherical output wavefront phases.
- In this paper, our focus is on transformations that involve monochromatic light.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Design concepts for broadband high-efficiency DOEs

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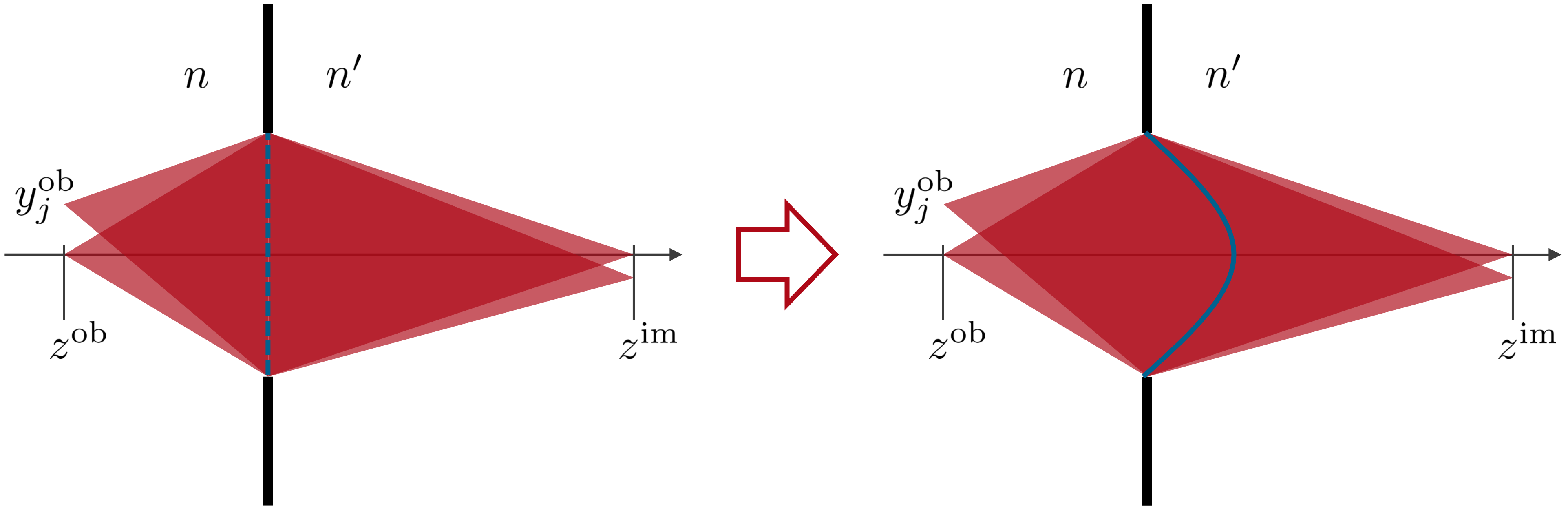
Lens Surface Design



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- The goal of lens surface design is to replace a functional lens with a physical lens that accomplishes the specified single- or multifield transformation.

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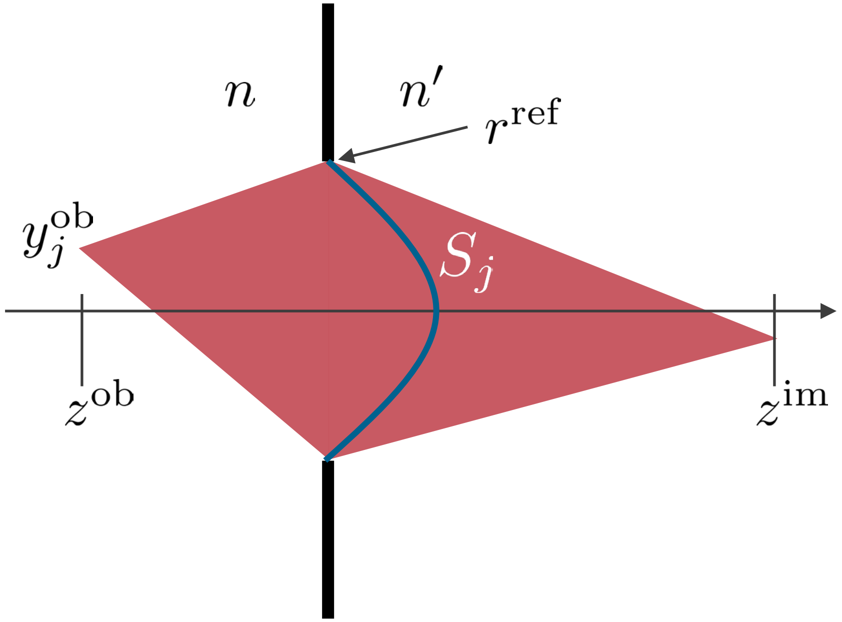


$$\psi_j^{\text{in}}(y,z) = k_0 n \sqrt{(y - y_j^{\text{ob}})^2 + (z - z^{\text{ob}})^2}$$

$$\Downarrow$$

$$\psi_j^{\text{sig}}(y,z) = -k_0 n' \sqrt{(y - M y_j^{\text{ob}})^2 + (z - z^{\text{im}})^2}$$

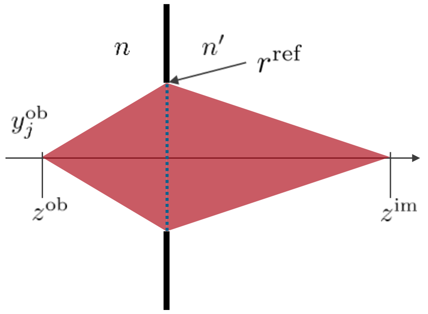
with magnification M

- The design of lens surfaces can be based on the principle of physical optics that **the phase of electromagnetic fields remains unchanged at the interface between different dielectric media**.
- This statement is an alternative expression of the law of refraction.
- We conclude the **surface design equation**:

$$\Delta\psi_j(\boldsymbol{r} \in S_j) := \psi_j^{\text{sig}}(\boldsymbol{r} \in S_j) - \psi^{\text{in}}(\boldsymbol{r} \in S_j) + \bar{\psi}_j \stackrel{!}{=} 0$$

- The constant phase $\bar{\psi}_j$ can be adjusted to guarantee that the surface S_j intersects the specified reference point $\boldsymbol{r}^{\text{ref}}$.

Lens Surface Design: Axial Field



Numerical solution of the surface design equation $\Delta\psi(\boldsymbol{r} \in S) \stackrel{!}{=} 0$ for:

- Wavelength: $532\,\mathrm{nm}$
- Refractive indexes: $n = 1.5$ and $n' = 1$
- Lens radius: $10\,\mathrm{mm}$
- Object position: $z^{\mathrm{ob}} = -50\,\mathrm{mm}$
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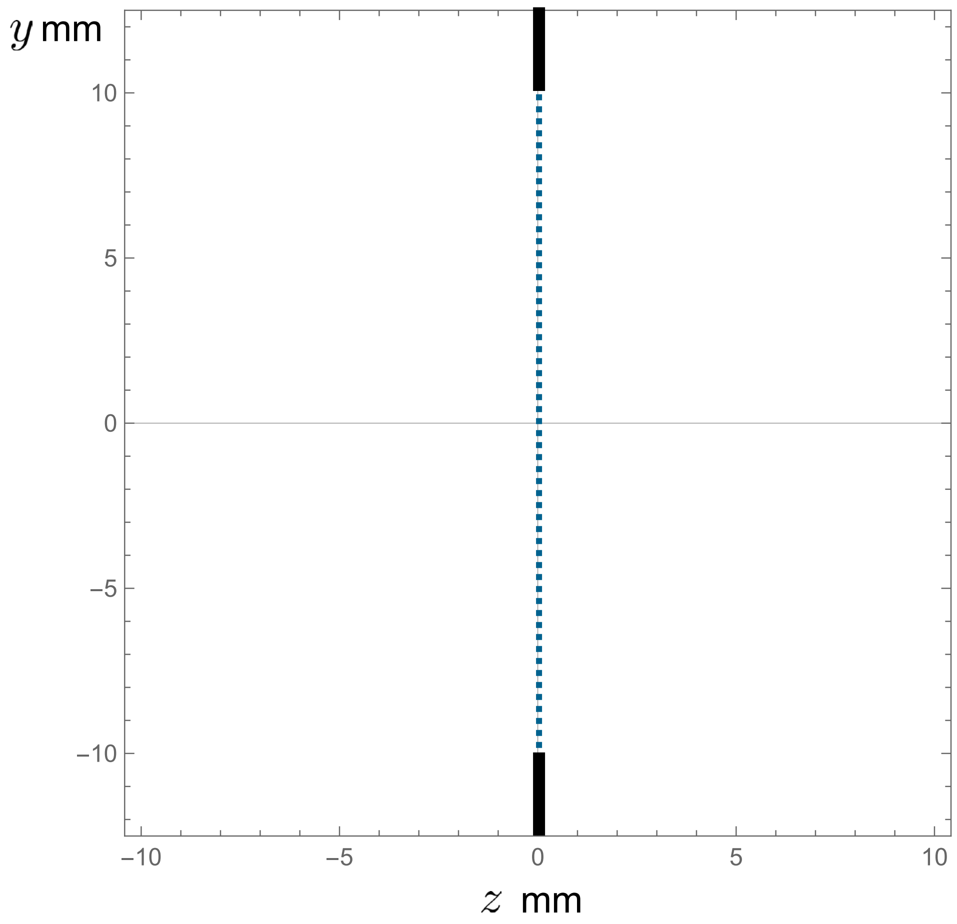

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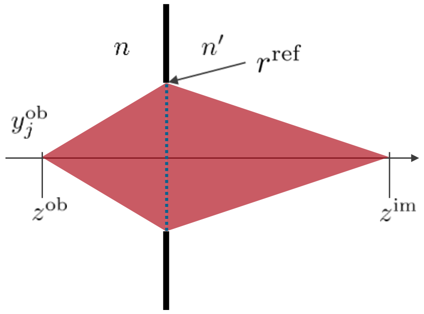

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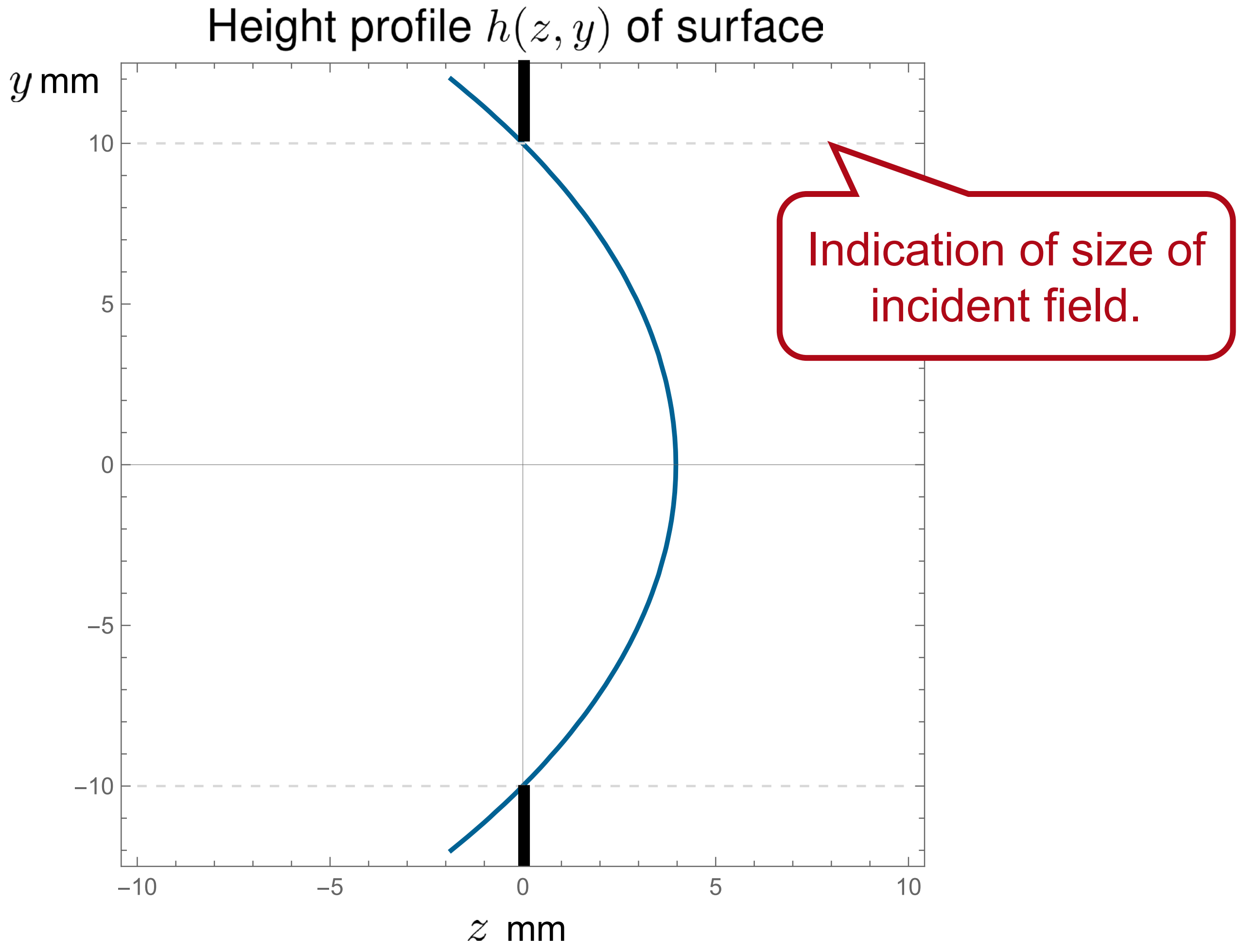

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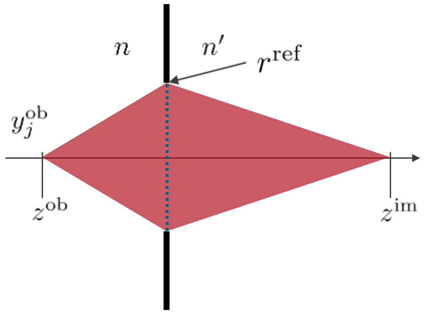

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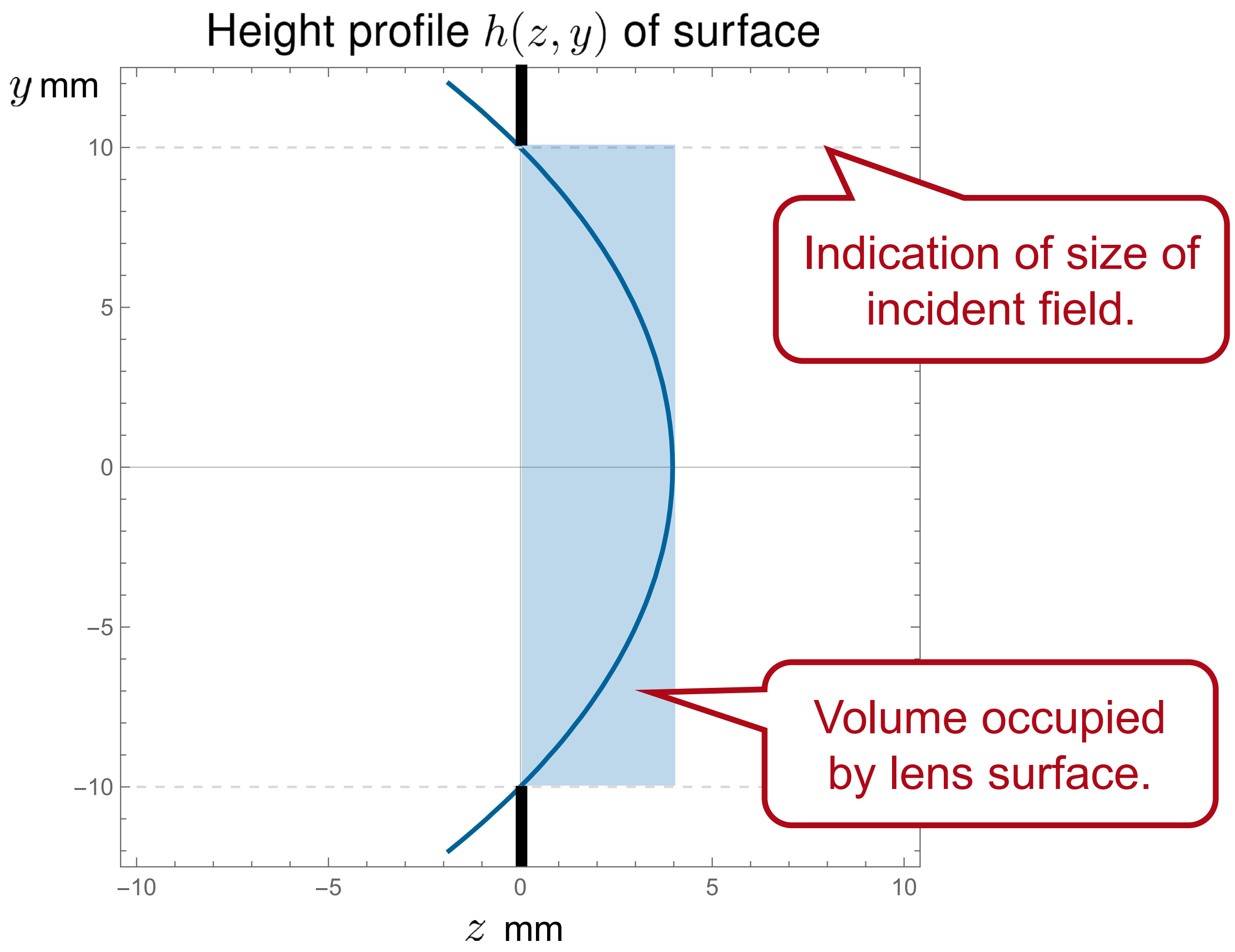

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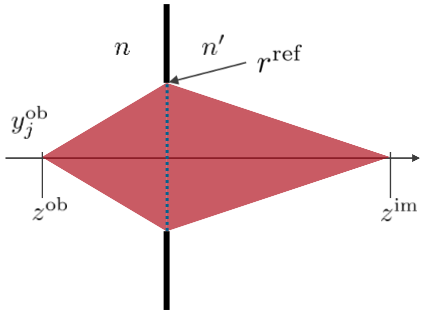

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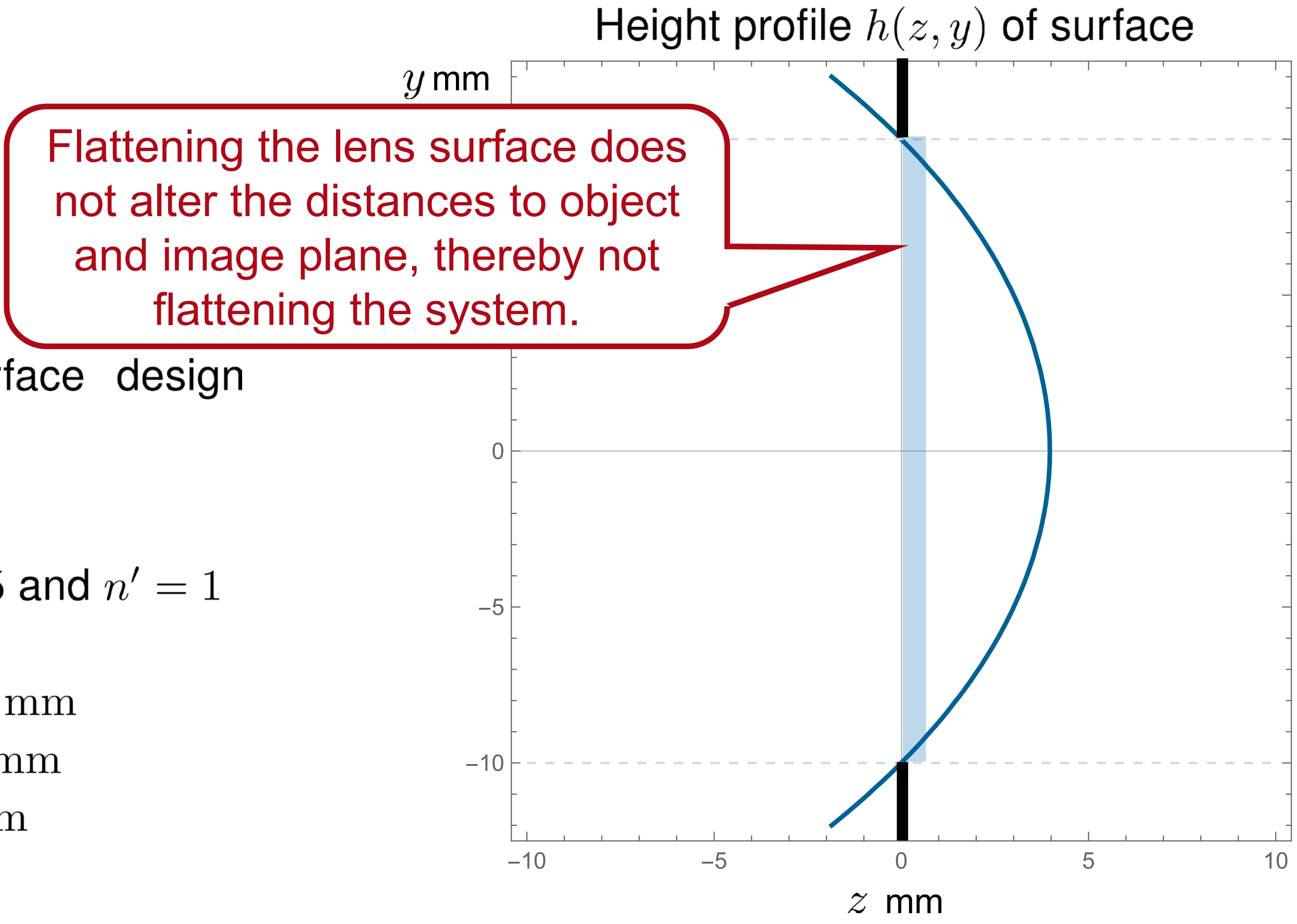

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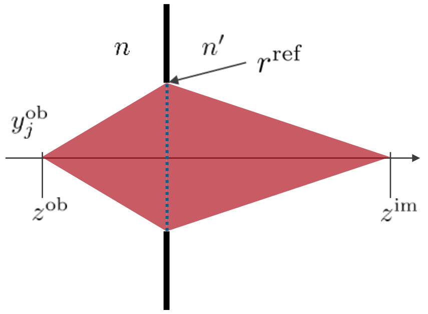

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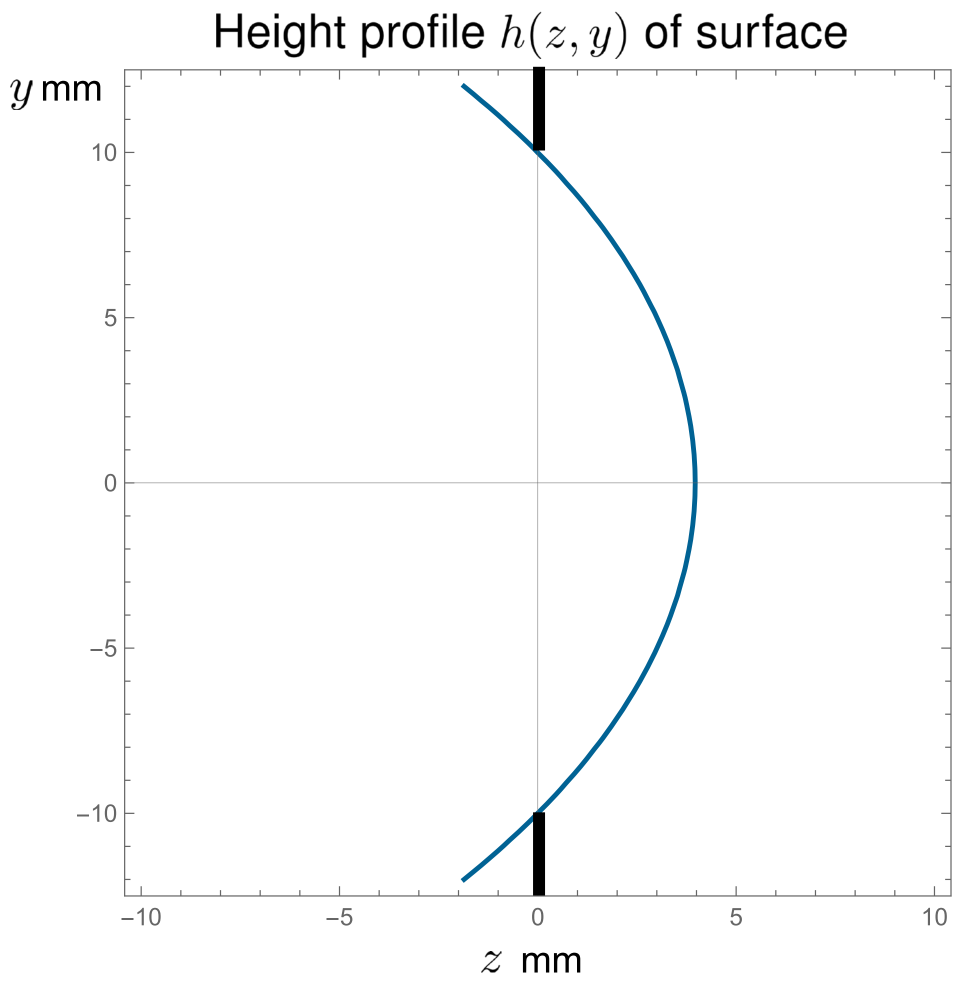
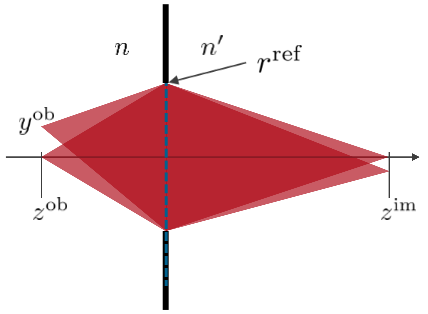


Lens Surface Design: Off-Axis Field



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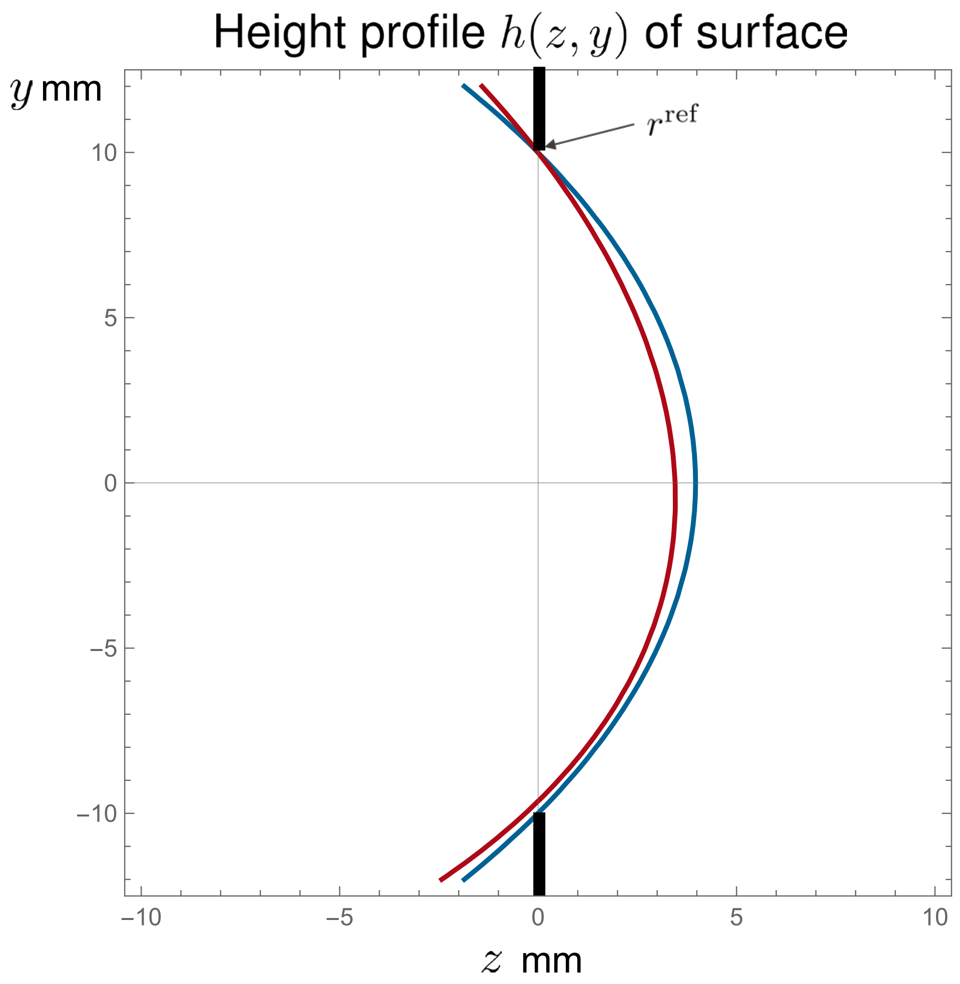

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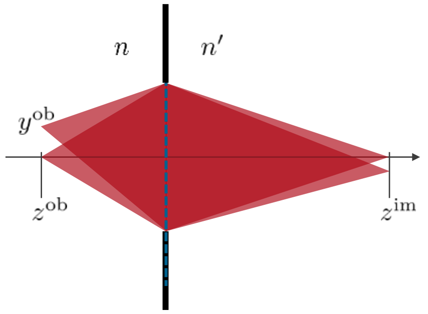

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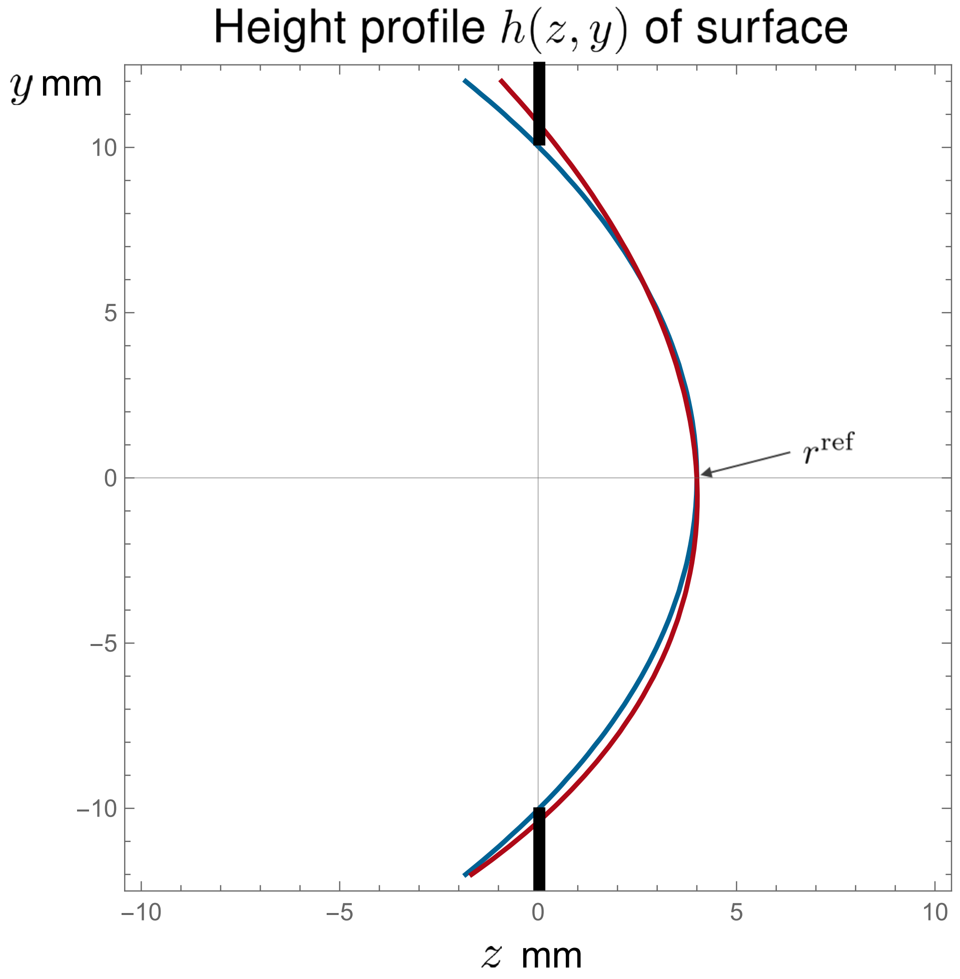

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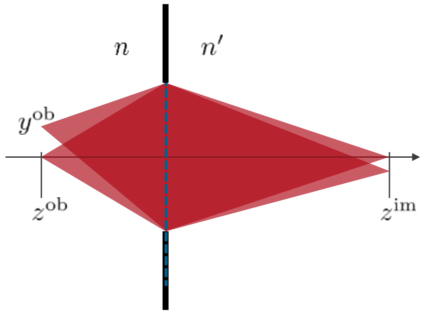
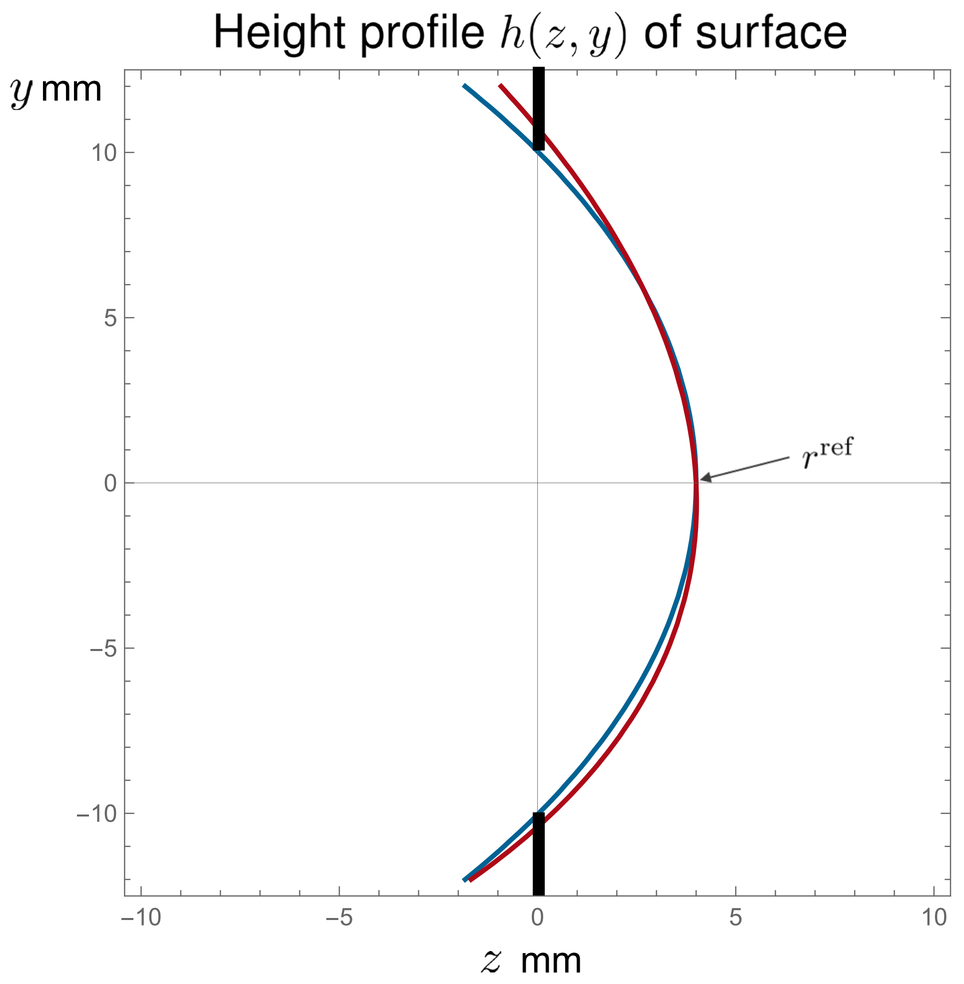
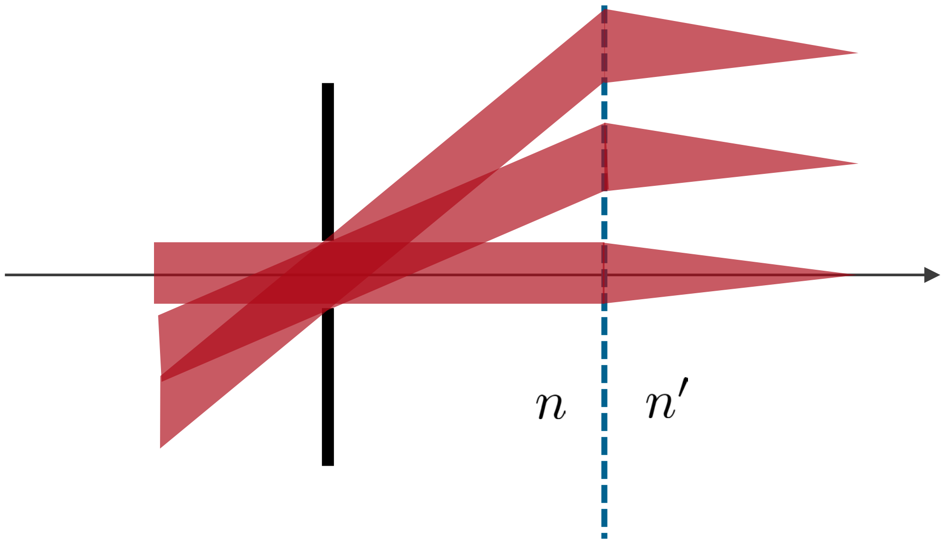


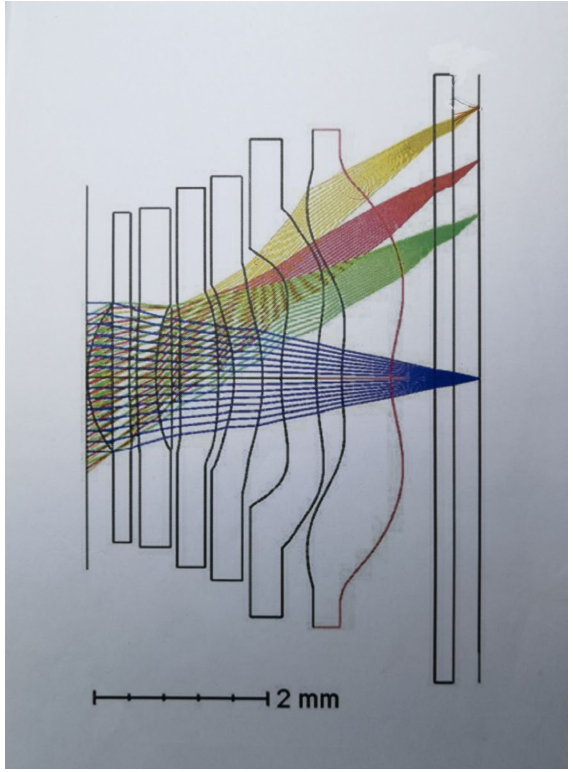
- A single surface fails to address multifield transformations and generates aberrations for any input wavefront other than the one it was designed for.
- Hence, it is essential to include extra surfaces to balance aberrations and achieve the required multi-field transformation with adequate precision.
- **There is no evidence to suggest that flat lenses eliminate this requirement.**



Imaging Example: Telecentric Image Side

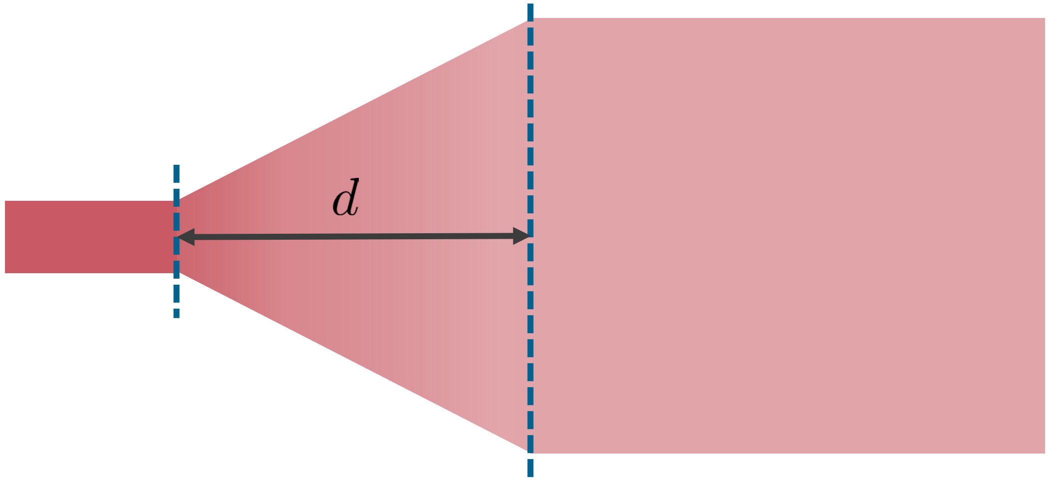


- It should be noted that there are mentions of configurations in which fields overlap yet occupy separate regions as a method to correct aberrations of flat lenses.
- Certainly, designing lens surfaces for aberration control near image planes offers benefits over lenses positioned near the stop and pupils. However, this applies equally to both flat and "thick" lens surfaces.



Example of cell phone lens system

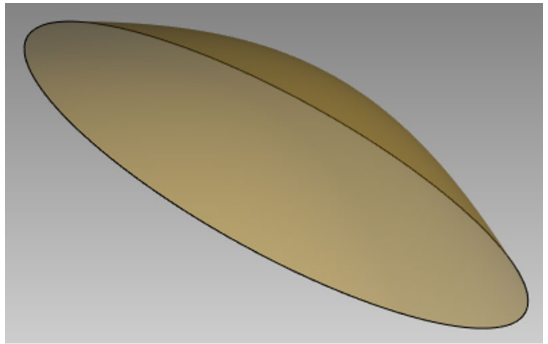
Beam Expander Scenario

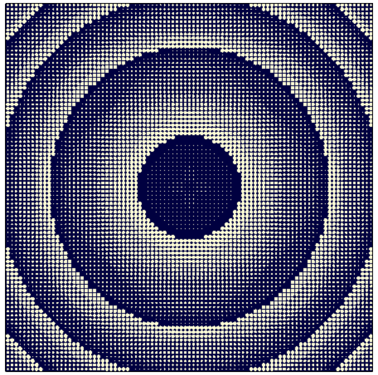


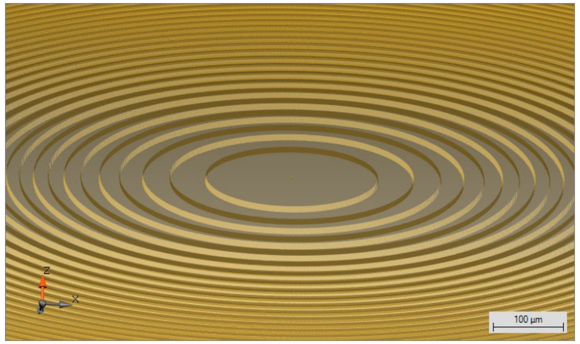
- The use of two lenses is necessary.
- The degree of beam expansion is governed by the distance d between the lenses and their numerical apertures.
- Flattening the lenses does not change that outcome.

Insights on the Capabilities of Flat Lenses

- Flat lenses reduce both the thickness and weight of the lenses.
- The slim profile of flat lenses might enable more options for decreasing the spacing between lens surfaces.
- The fabrication methods for flat lenses vary from those for traditional lenses, which may offer benefits in specific scenarios.
- Flat lenses could provide new opportunities for switchable lenses.
- Replacing thick lens surfaces with flat surfaces changes the aberration dynamics in the system, which may enhance aberration correction possibilities based on the particular scenario.







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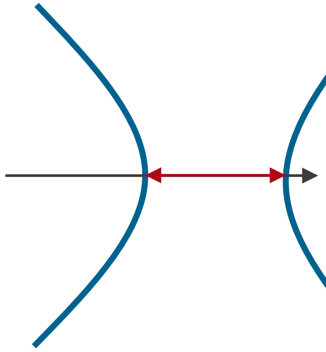

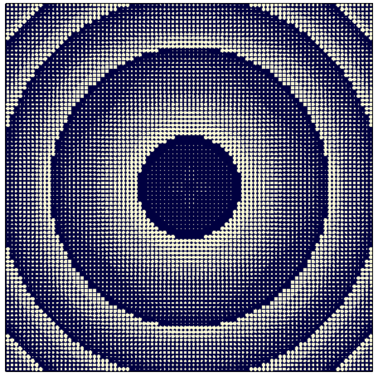

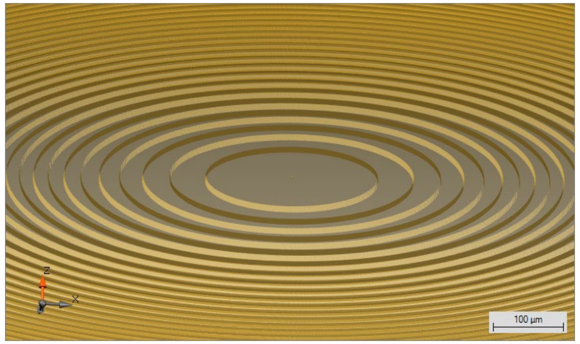

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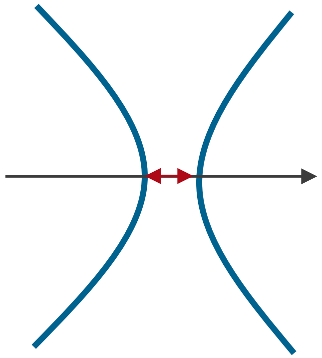

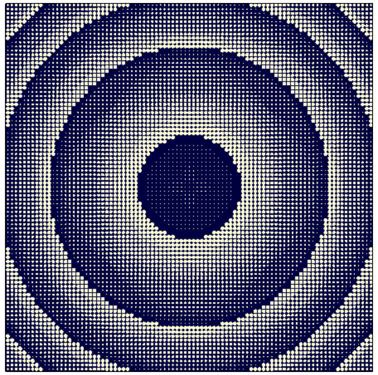

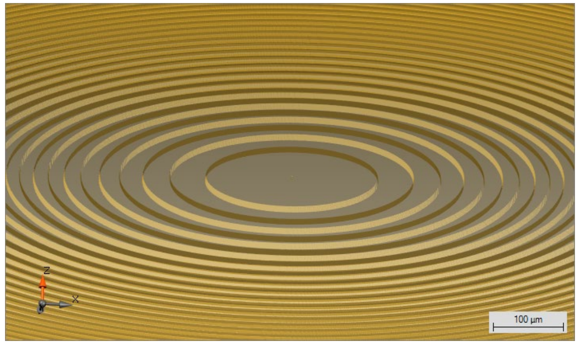

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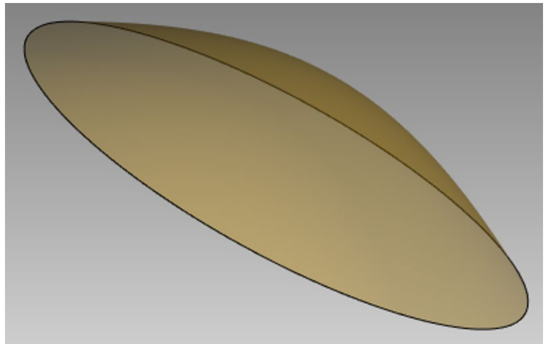

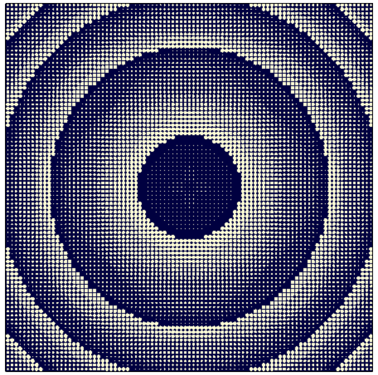

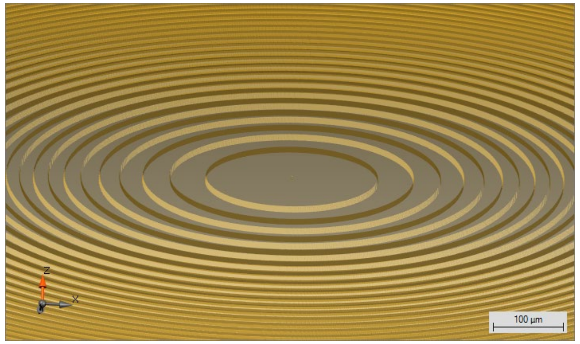

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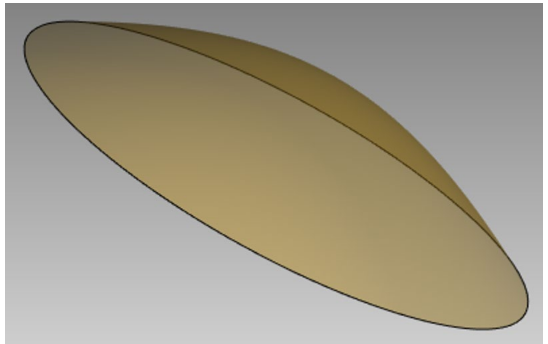

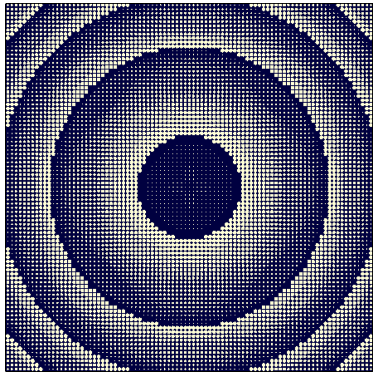

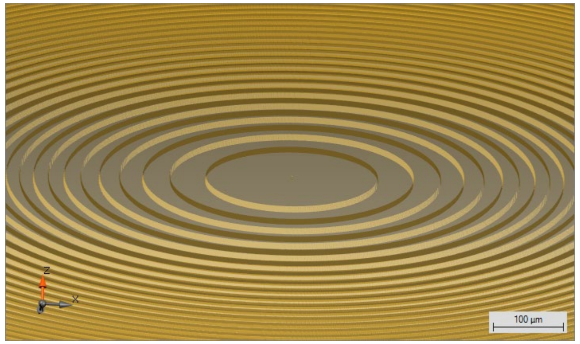

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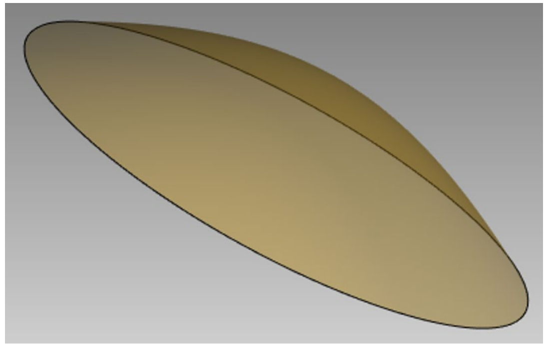

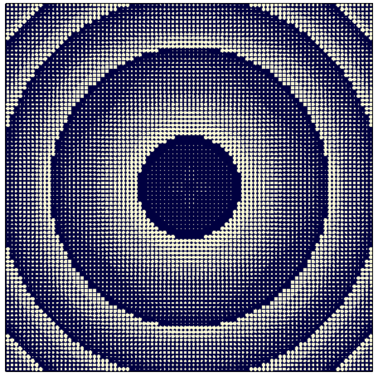

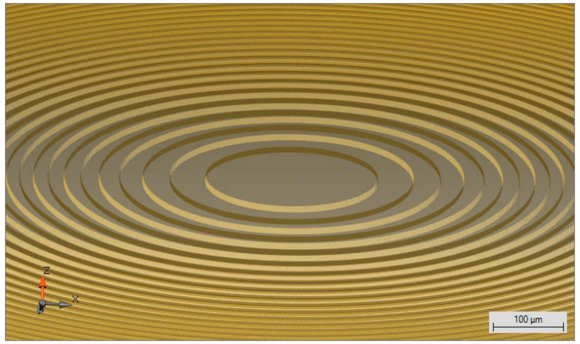

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- Replacing thick lens surfaces with flat surfaces changes the aberration dynamics in the system, which may enhance aberration correction possibilities based on the particular scenario.
- Employing diffractive lenses, which exhibit strong and opposing chromatic aberrations, to counteract the chromatic aberrations of smooth lens surfaces serves as a well-documented instance of this potential.
- Some characteristics of flat lenses, such as its polarization-sensitive function, may be considered beneficial or detrimental depending on their use.
- There is no evidence to suggest that flat lenses, including metalenses, reduce the total length of the system or the number of lens surfaces in optical systems beyond what is possible with aspherical and freeform surfaces.

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- Replacing thick lens surfaces with flat surfaces changes the aberration dynamics in the system, which may enhance aberration correction possibilities based on the particular scenario.
- Employing diffractive lenses, which exhibit strong and opposing chromatic aberrations, to counteract the chromatic aberrations of smooth lens surfaces serves as a well-documented instance of this potential.
- Some characteristics of flat lenses, such as its polarization-sensitive function, may be considered beneficial or detrimental depending on their use.
- There is no evidence to suggest that flat lenses, including metalenses, reduce the total length of the system or the number of lens surfaces in optical systems beyond what is possible with aspherical and freeform surfaces.

Insights on the Capabilities of Flat Lenses

- Flat lenses reduce both the thickness and weight of the lenses.
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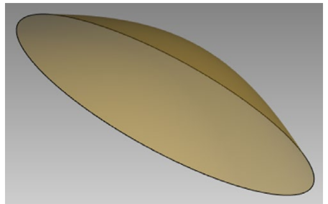
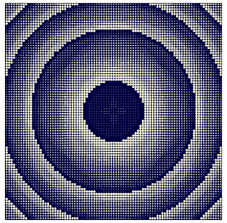
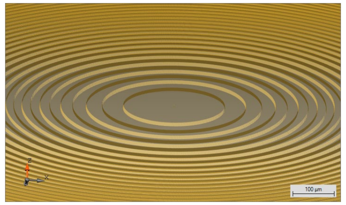
Integrating Flat Lenses into Lens Design Workflows

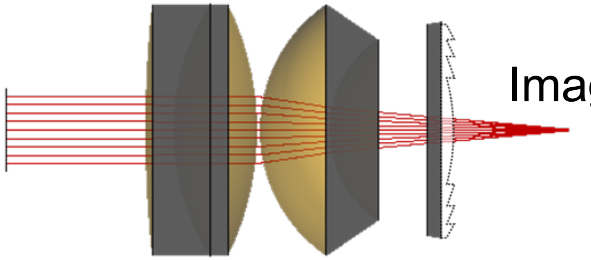
- Ultimately, flat lenses offer a notable and intriguing **addition to the array of tools for optical design**.
- The usefulness of flat lenses changes significantly based on the context of their application.

It is crucial to integrate flat lens technology into lens design workflows to fully comprehend and utilize their capabilities.



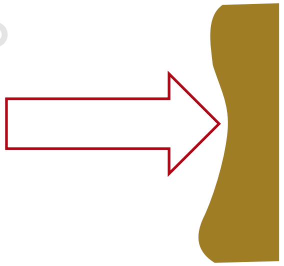




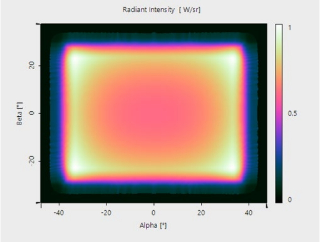


Imaging

Illumination

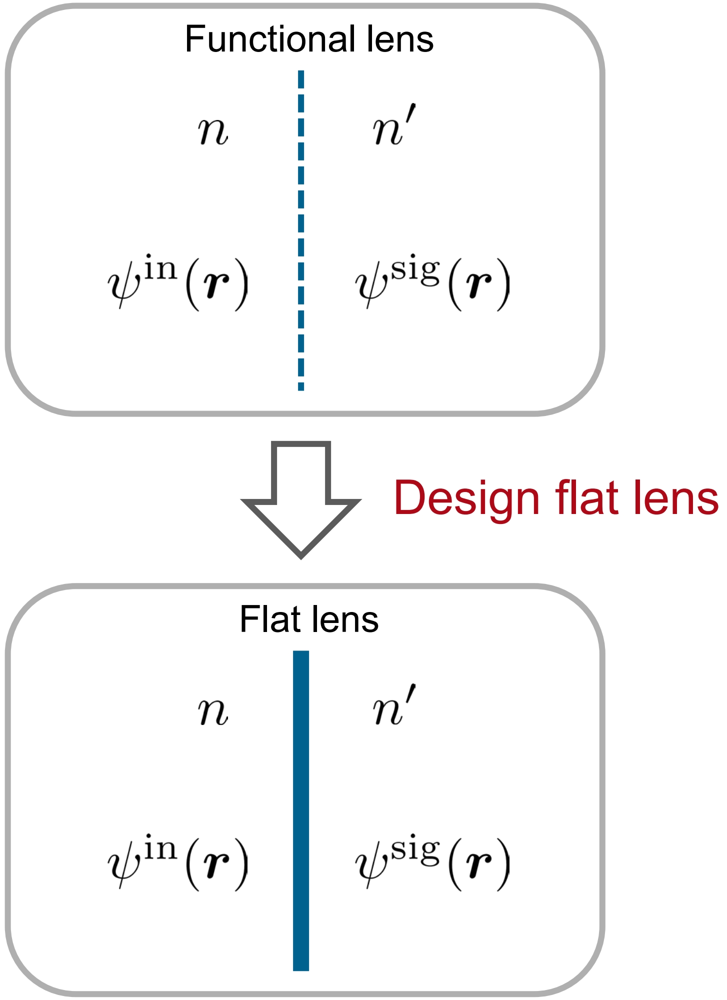


Result radiant intensity



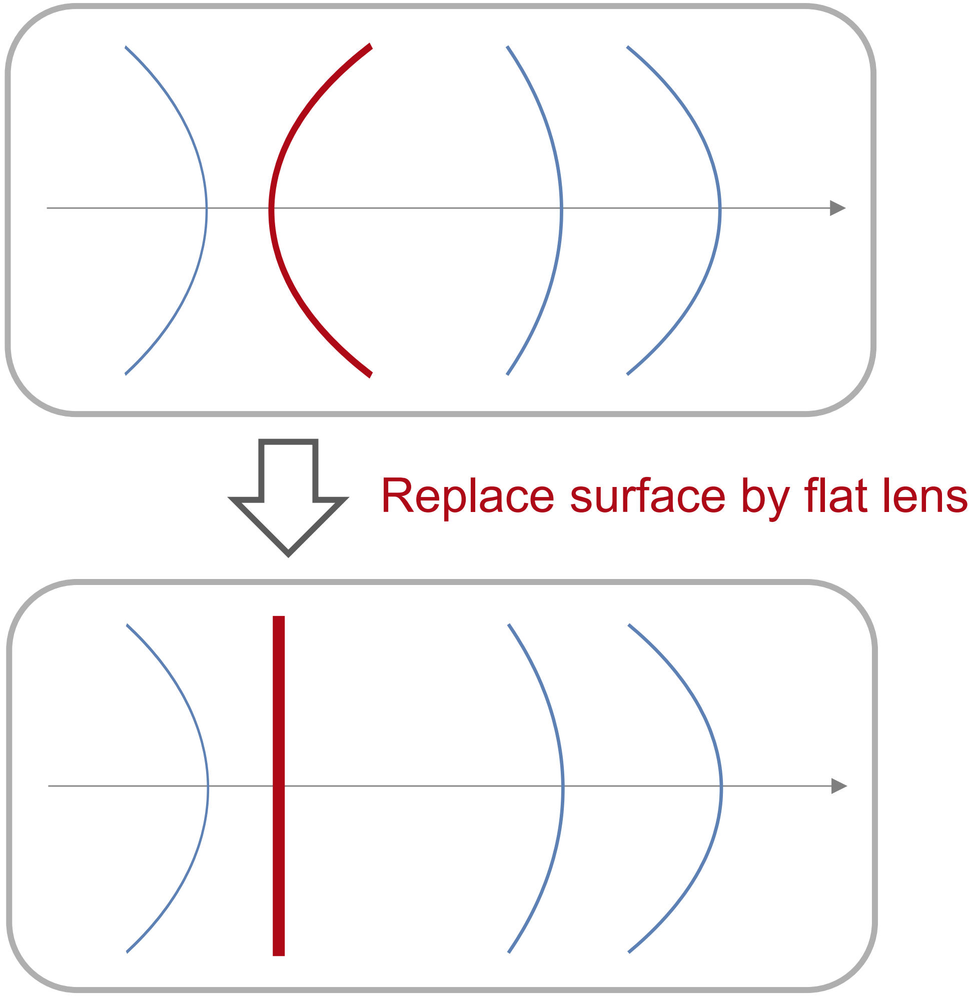
90° X 70°
Diagonal: 114°

Basic Flat Lens Design Workflow



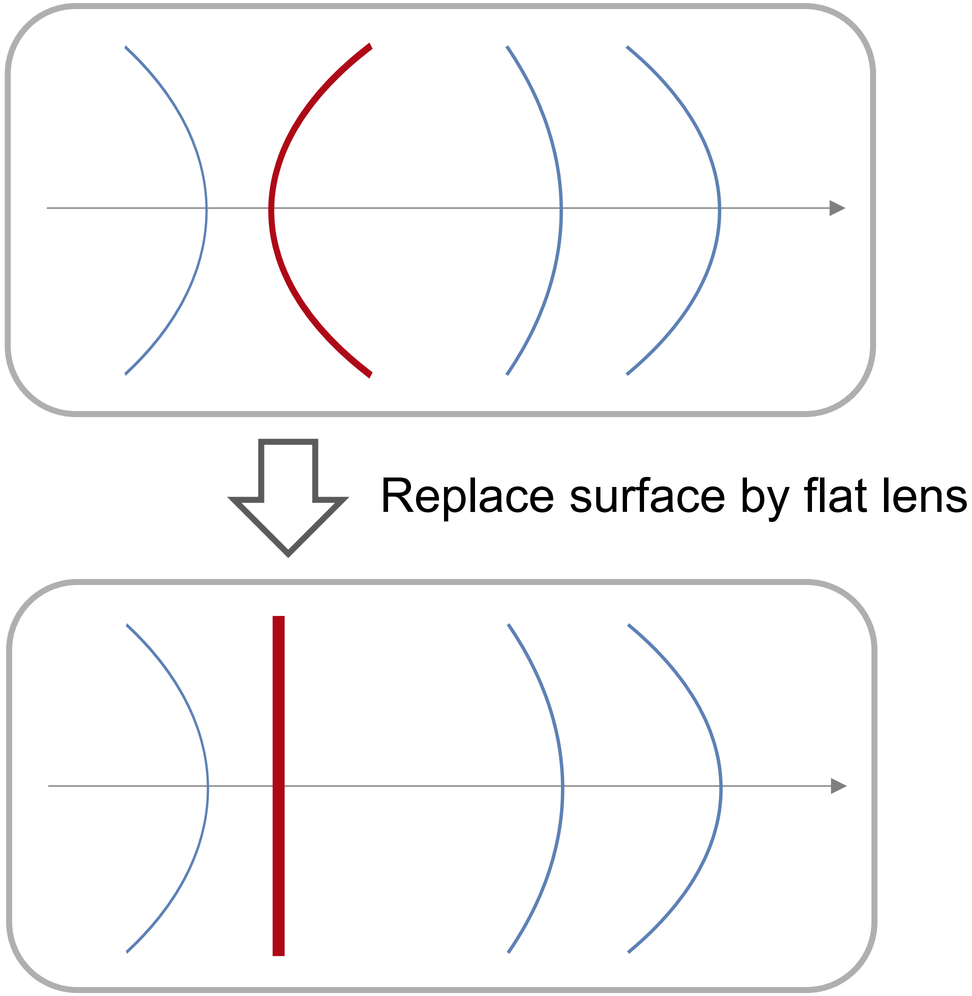
1. Carry out the structural design of a flat lens based on a specified functional lens.
2. Evaluate the performance of the flat lens.
3. Collect and export lens data for manufacturing needs.

Integrating Flat Lenses into Lens Design Workflows



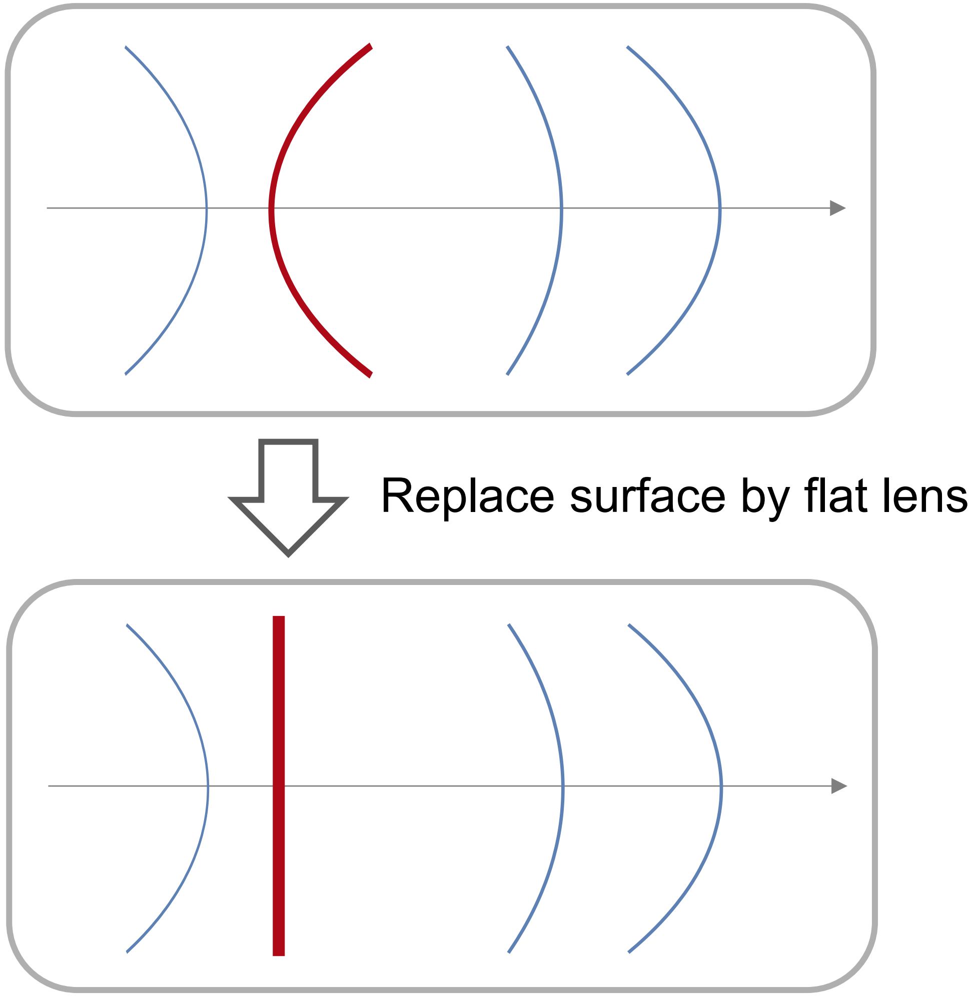
1. Substitute a 'thick' lens surface with a flat lens.
2. Assess the functioning of the system that incorporates the flat lens.
3. Facilitate system optimization.

Integrating Flat Lenses into Lens Design Workflows



- Incorporation of flat lenses into lens design workflows requires substantial advances in both theoretical underpinnings and the implementation of optics software.
- Introducing data interfaces across various software products does not offer the required solution.

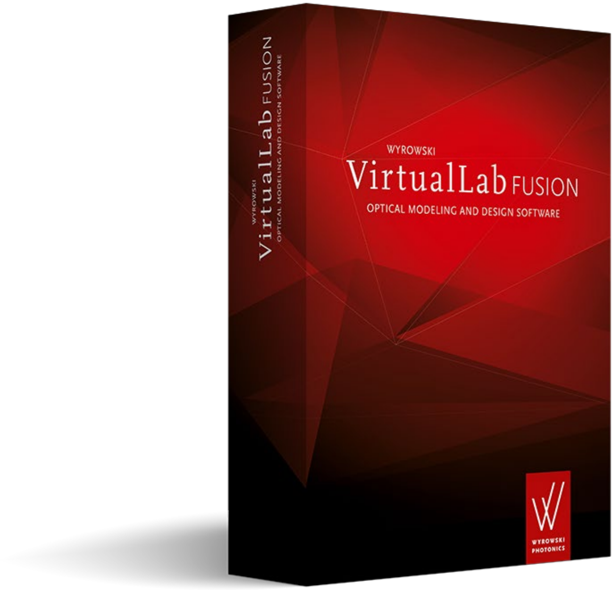
Integrating Flat Lenses into Lens Design Workflows



Three essential objectives must be achieved in the advancement of optics software:

1. Develop efficient and user-friendly design algorithms for flat lenses.
2. Enable the simulation of lens systems that incorporate flat lenses with adequate accuracy and speed.
3. Facilitate the optimization of optical systems that incorporate flat lenses.

Integrating Flat Lenses into Lens Design Workflows



At LightTrans, we are committed to enhancing the flat-lens features of our software, VirtualLab Fusion, to meet these objectives by 2025.

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See article on metalenses.

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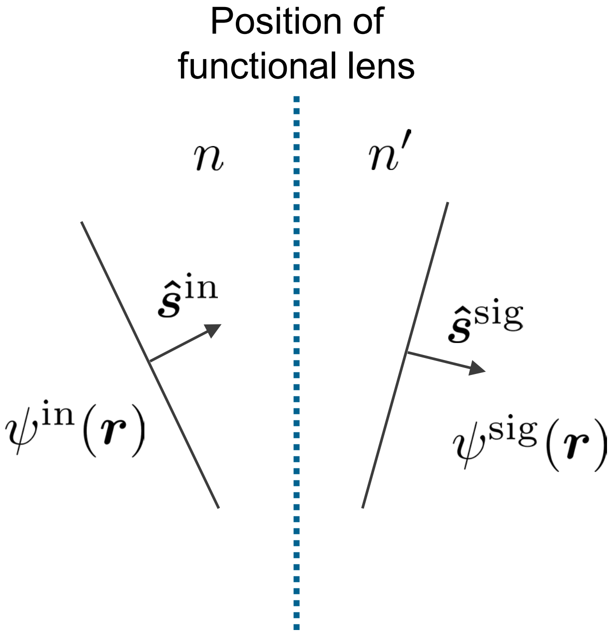
Changing the Direction of Planar Wavefronts



$$\psi^{\text{in}}(y, z) = k_0 n(s_y^{\text{in}} y + s_z^{\text{in}} z)$$

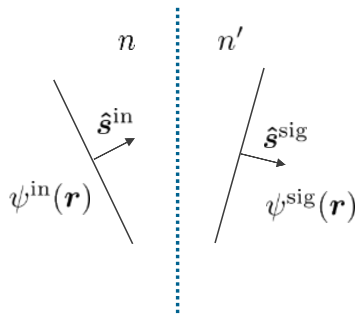
$$\Downarrow$$

$$\psi^{\text{sig}}(y, z) = k_0 n'(s_y^{\text{sig}} y + s_z^{\text{sig}} z)$$

- Our exploration of flat optics design begins by examining how a plane wave is transformed from an input direction vector $\hat{\boldsymbol{s}}^{\text{in}}$ to a signal direction vector $\hat{\boldsymbol{s}}^{\text{sig}}$.
- The appropriate surface design is determined using the surface design equation:

$$\Delta\psi(\boldsymbol{r} \in S) = \psi^{\text{sig}}(\boldsymbol{r} \in S) - \psi^{\text{in}}(\boldsymbol{r} \in S) + \bar{\psi} \stackrel{!}{=} 0$$

Surface Design for Transforming Plane Waves



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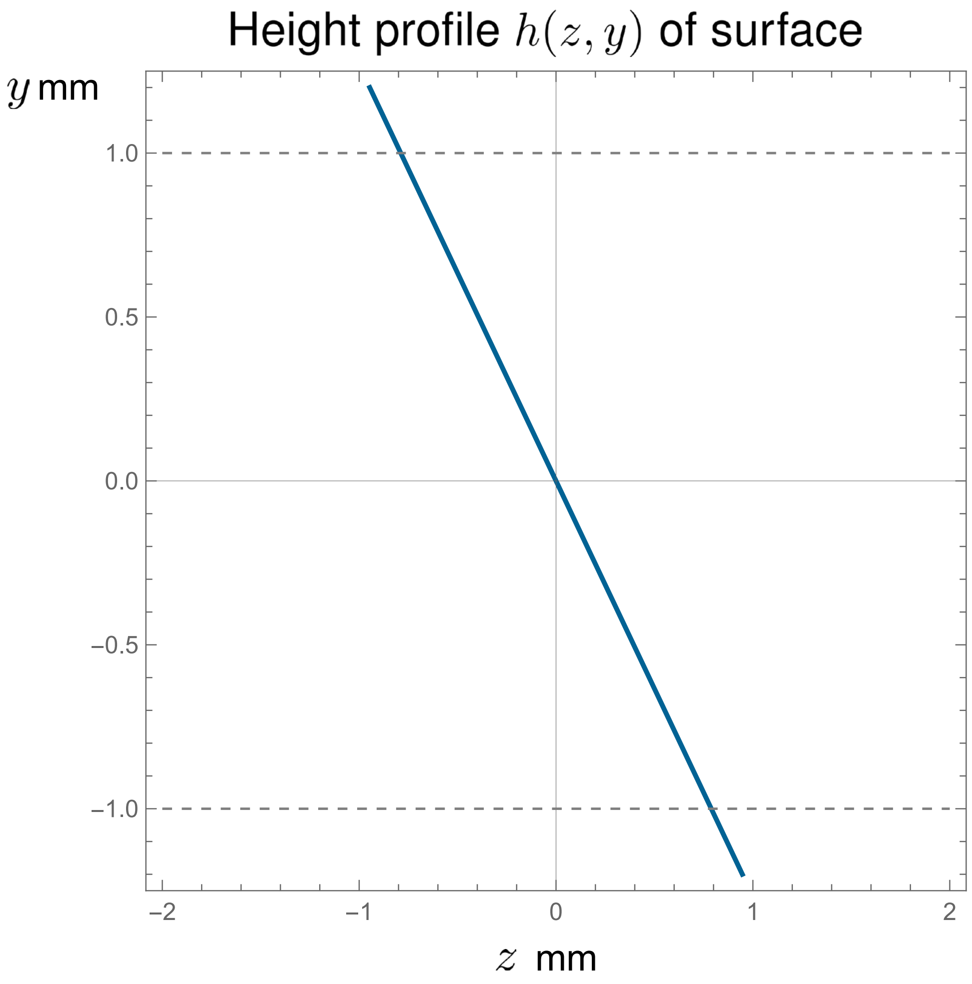
- Refractive indexes: $n = 1.5$ and $n' = 1$
- Wave diameter: $10\,\mathrm{mm}$
- Input direction: $\alpha^{in} = 0°$
- Output direction: $\alpha^{sig} = -30°$

Angles are specified in relation to the z-axis.



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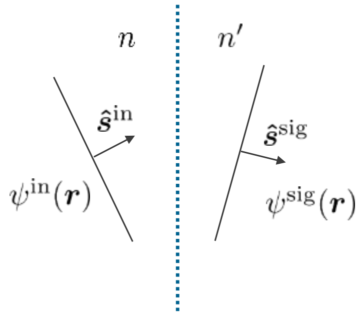

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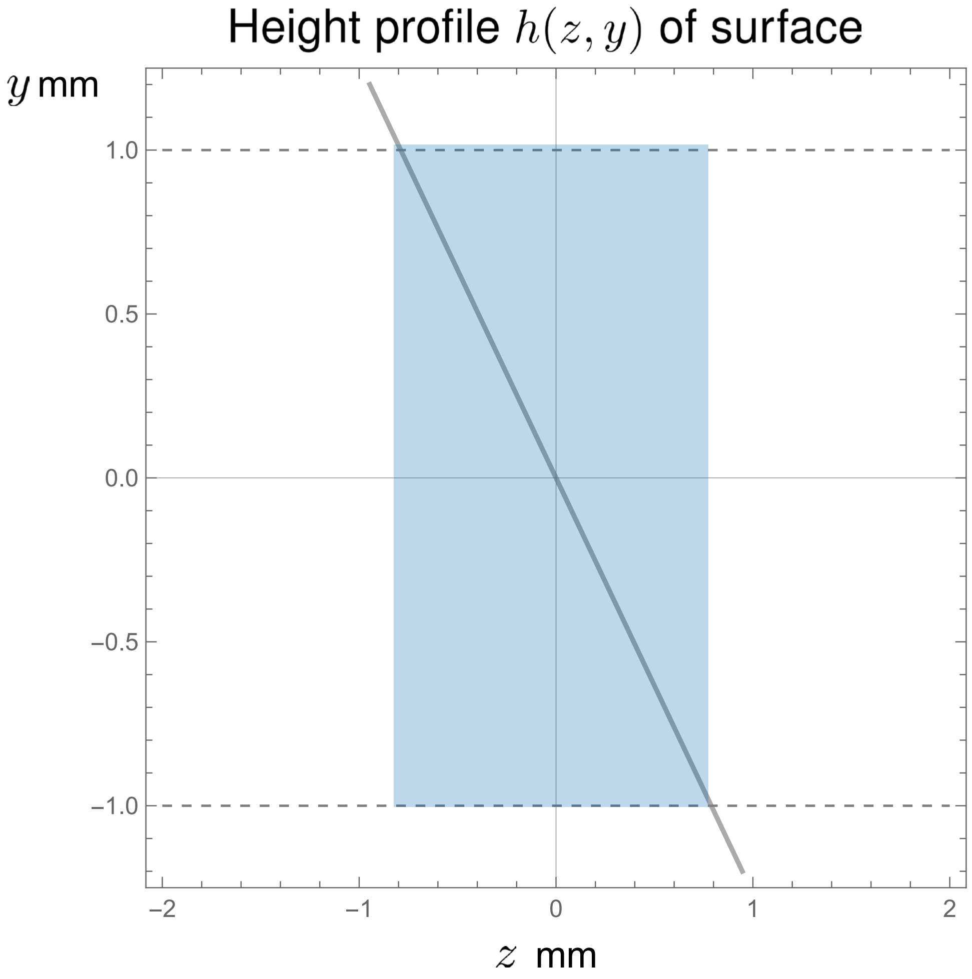

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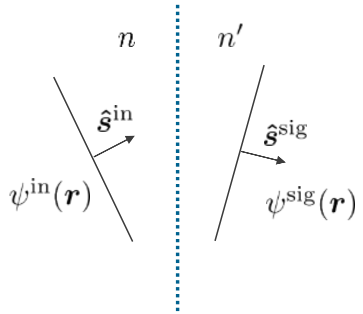

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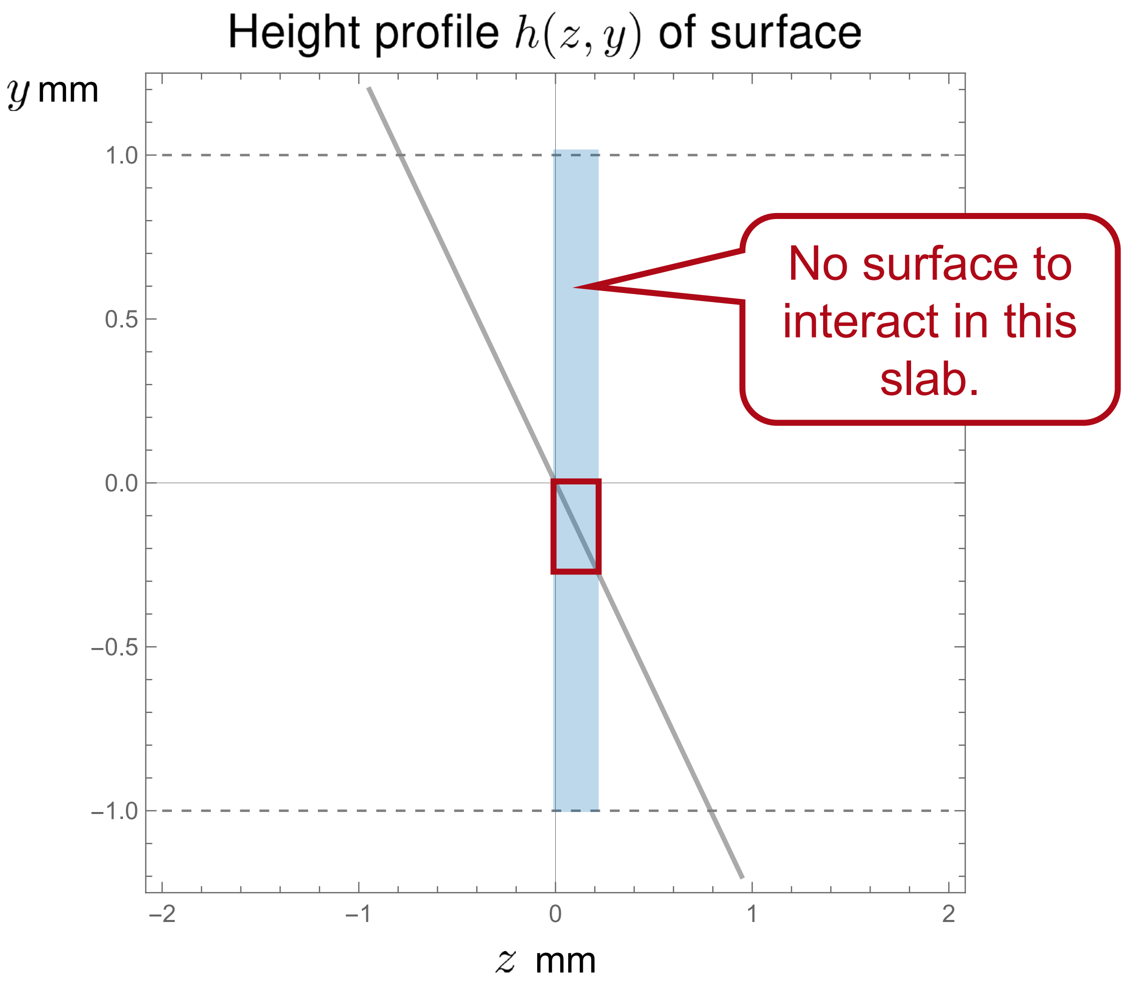


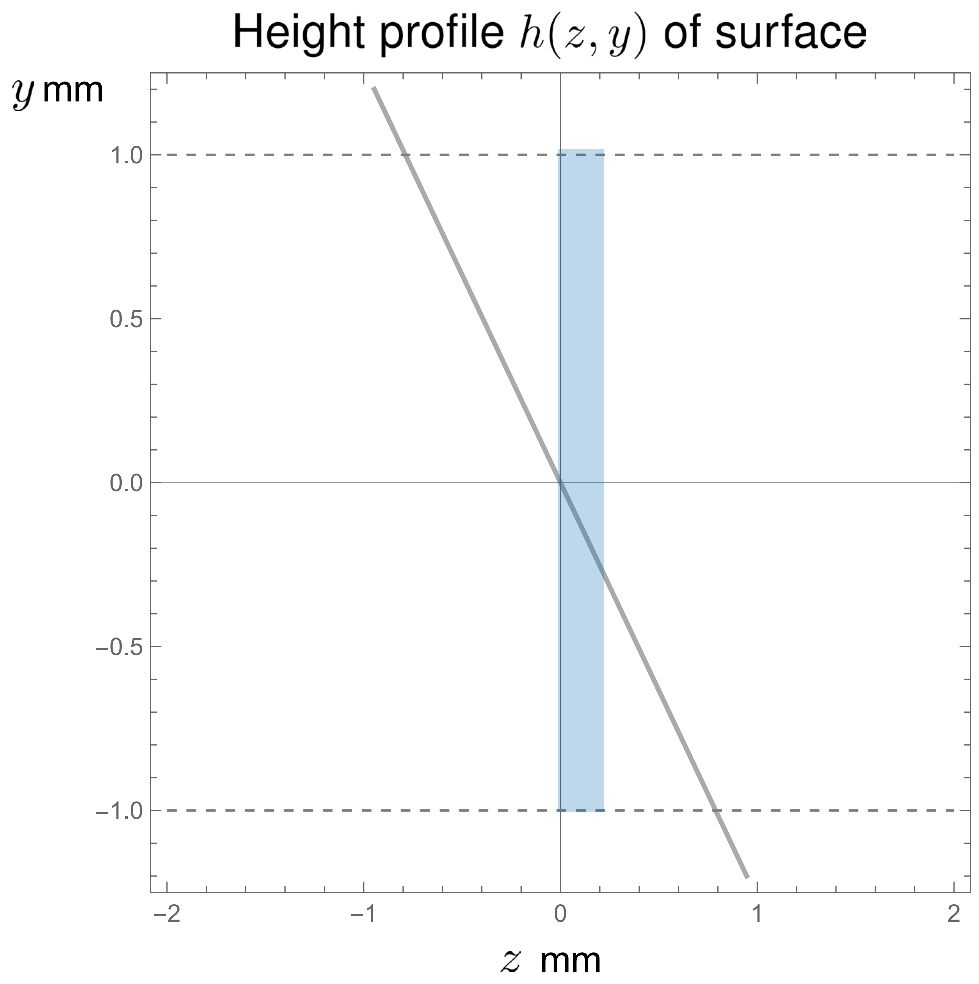
Surface Design for Transforming Plane Waves

- In addition to the solution $\Delta\psi(\boldsymbol{r} \in S) = 0$, there exist alternative solutions S_j that satisfy the design equation

$$\Delta\psi(\boldsymbol{r} \in S_j) \stackrel{!}{=} j\Delta m \cdot 2\pi,$$

  because for phase values, $j\Delta m \cdot 2\pi$ is equivalent to 0 when $m = j\Delta m$ belongs to $\mathbb{Z}$.

- The parameter Δm is used to control the spacing between these solutions, with a setting of $\Delta m = 1$ resulting in the smallest possible spacing.



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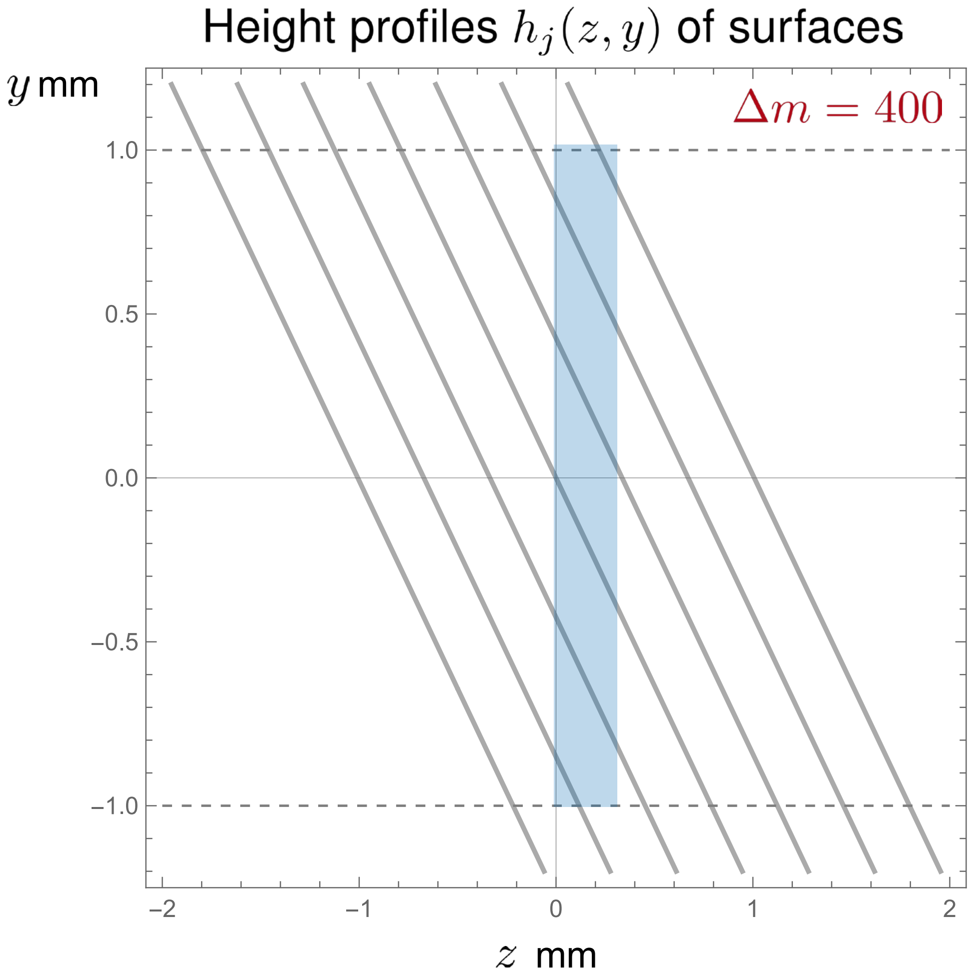

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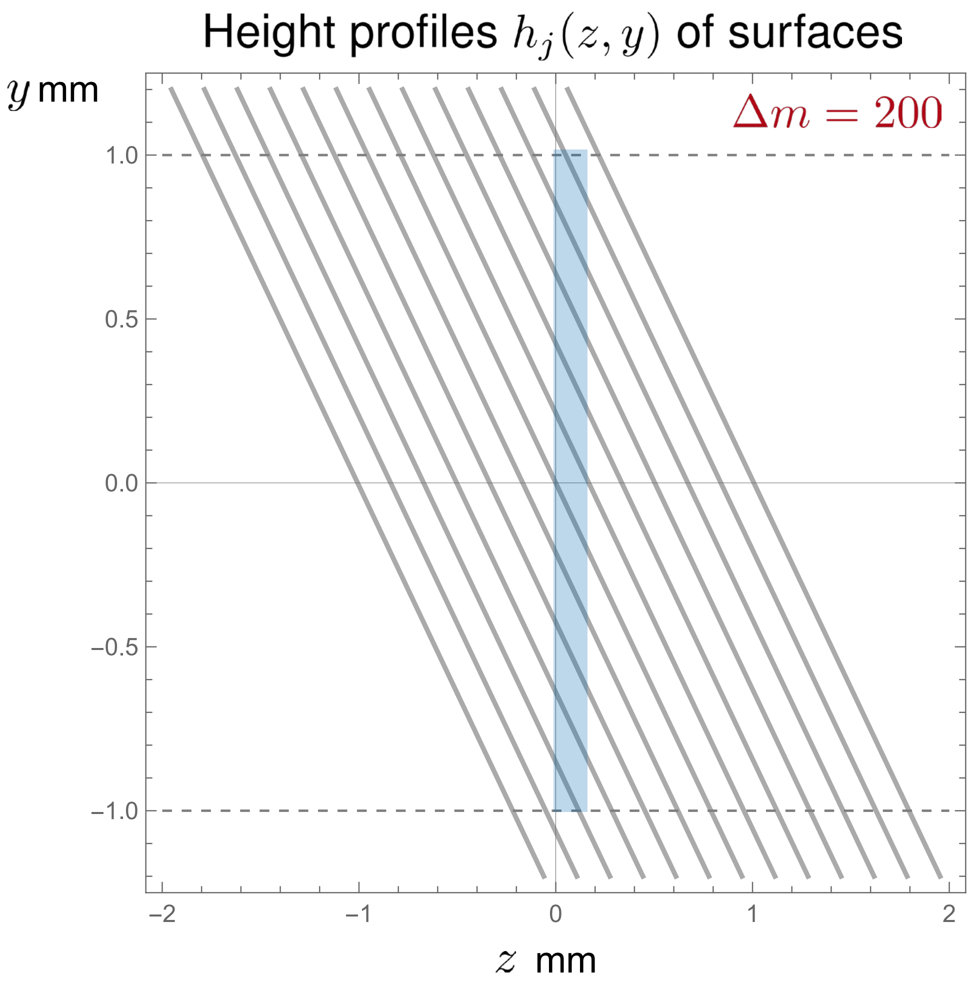

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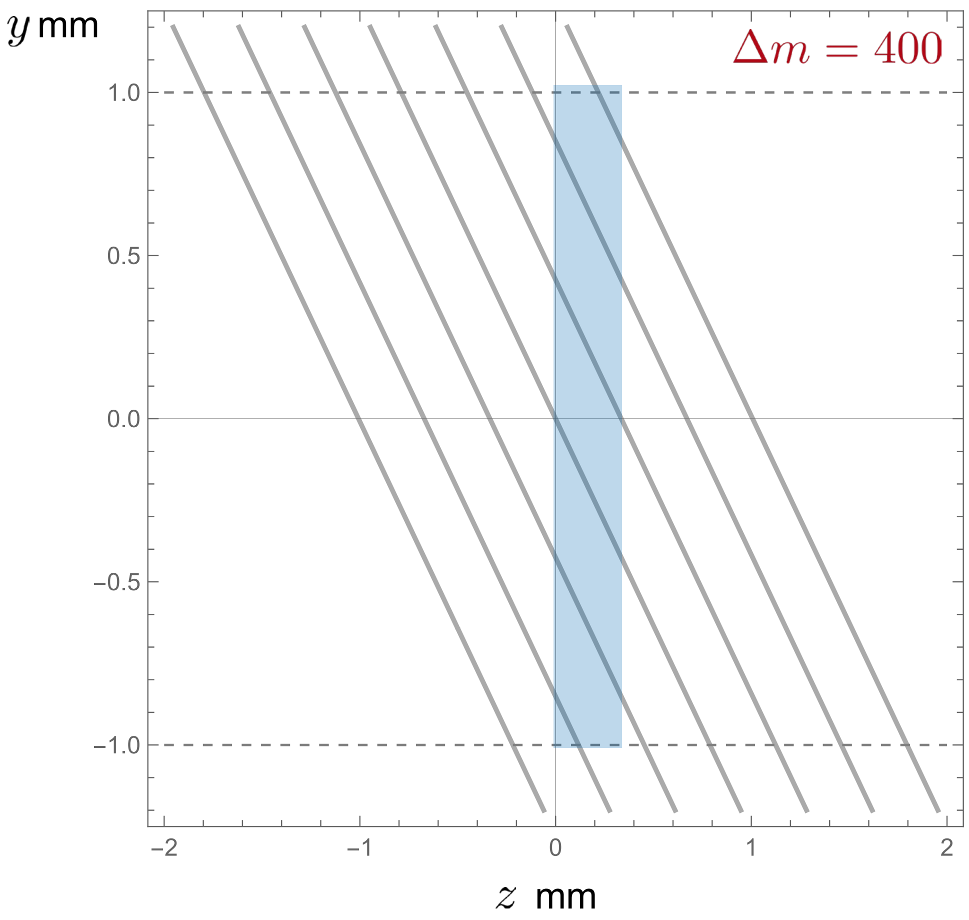
Height profiles $h_j(z, y)$ of surfaces



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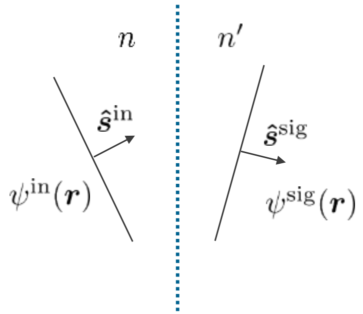

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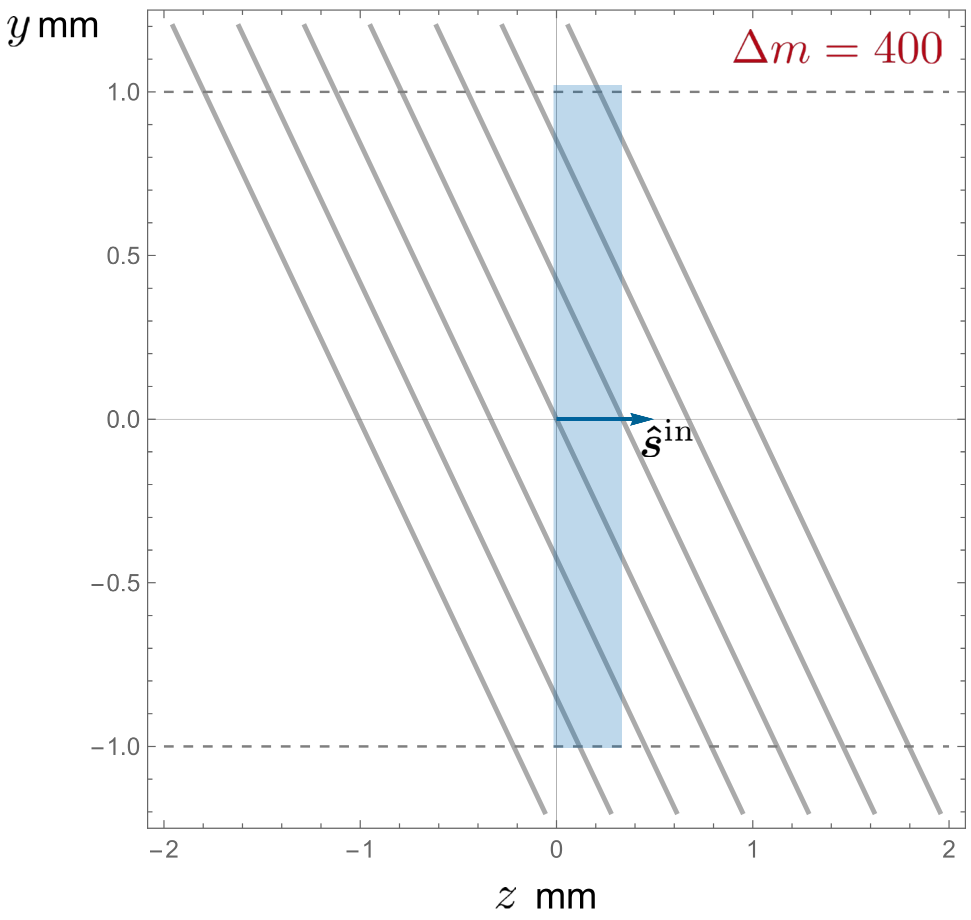

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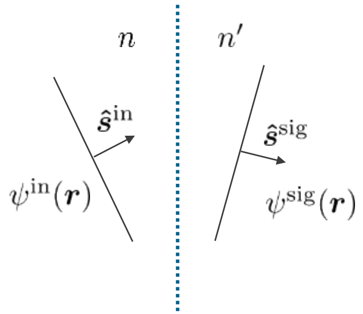

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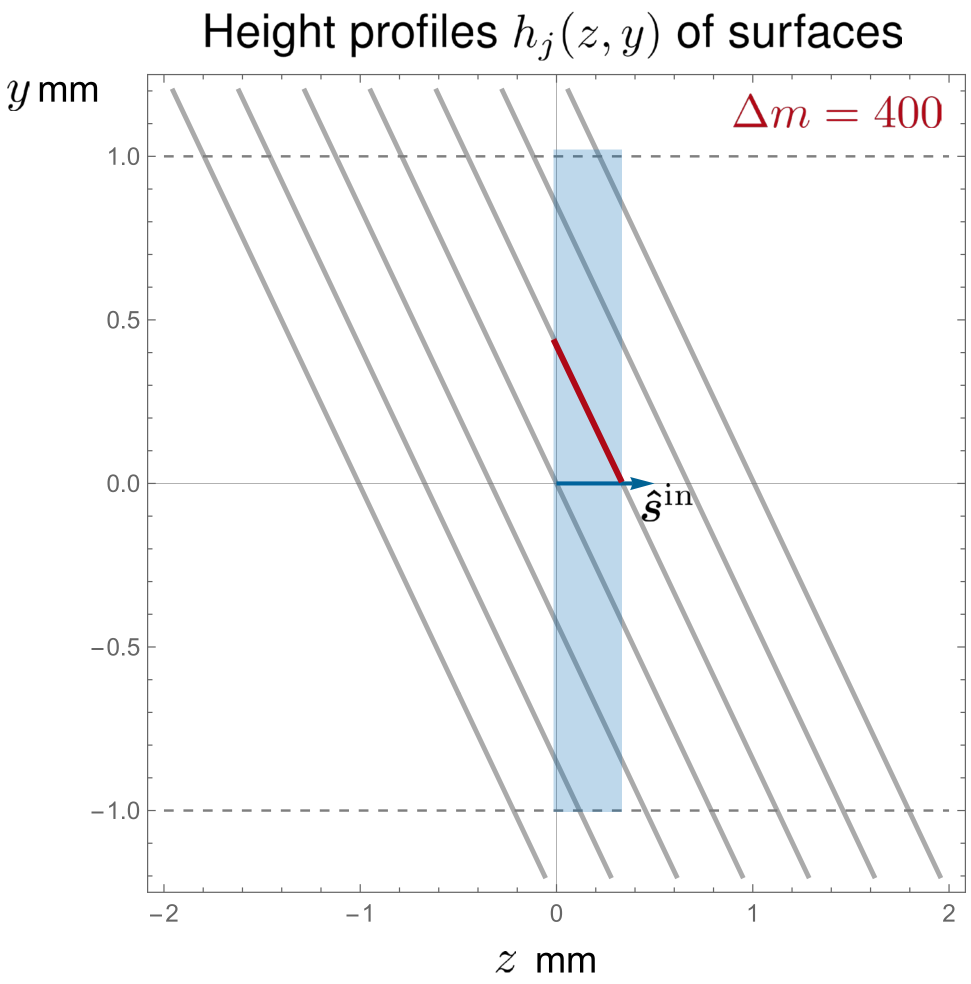

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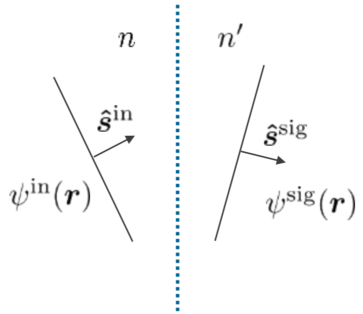

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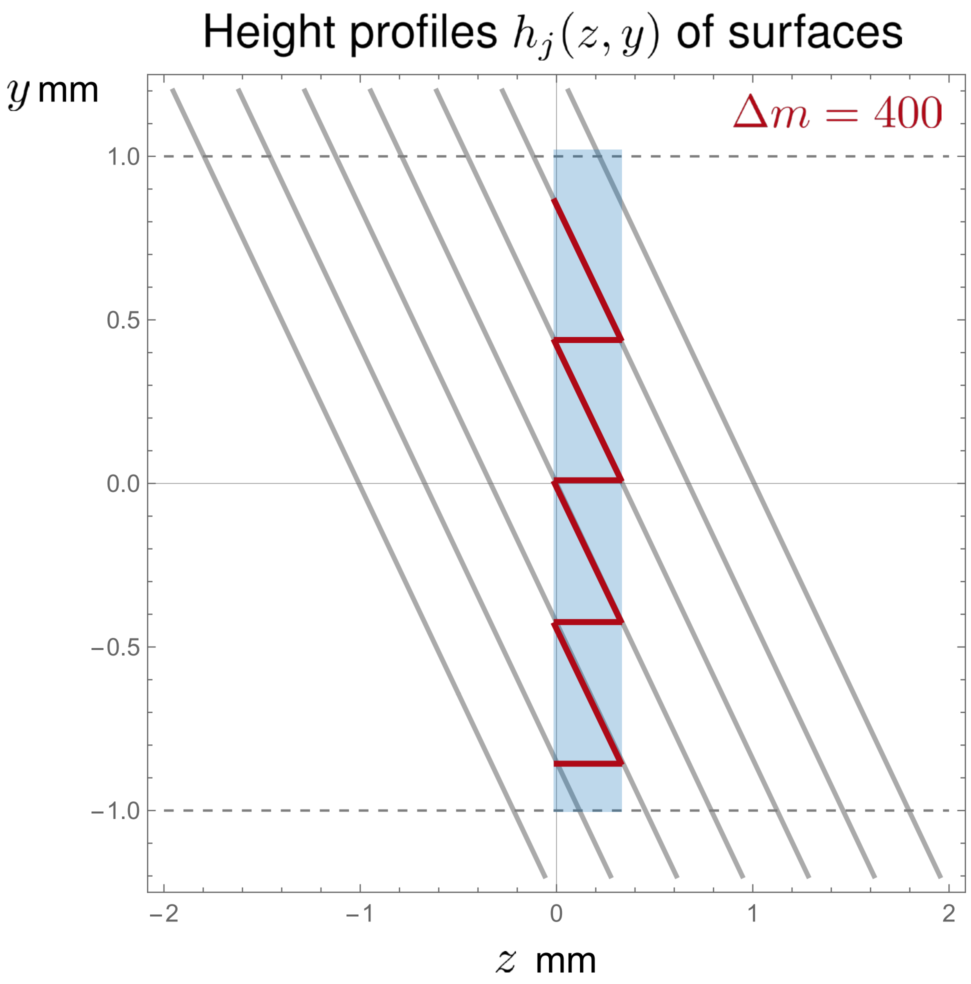

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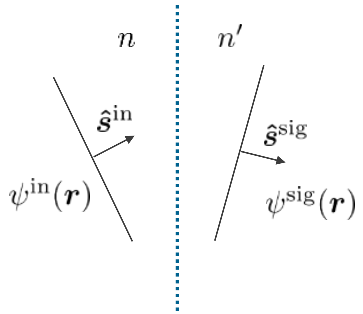

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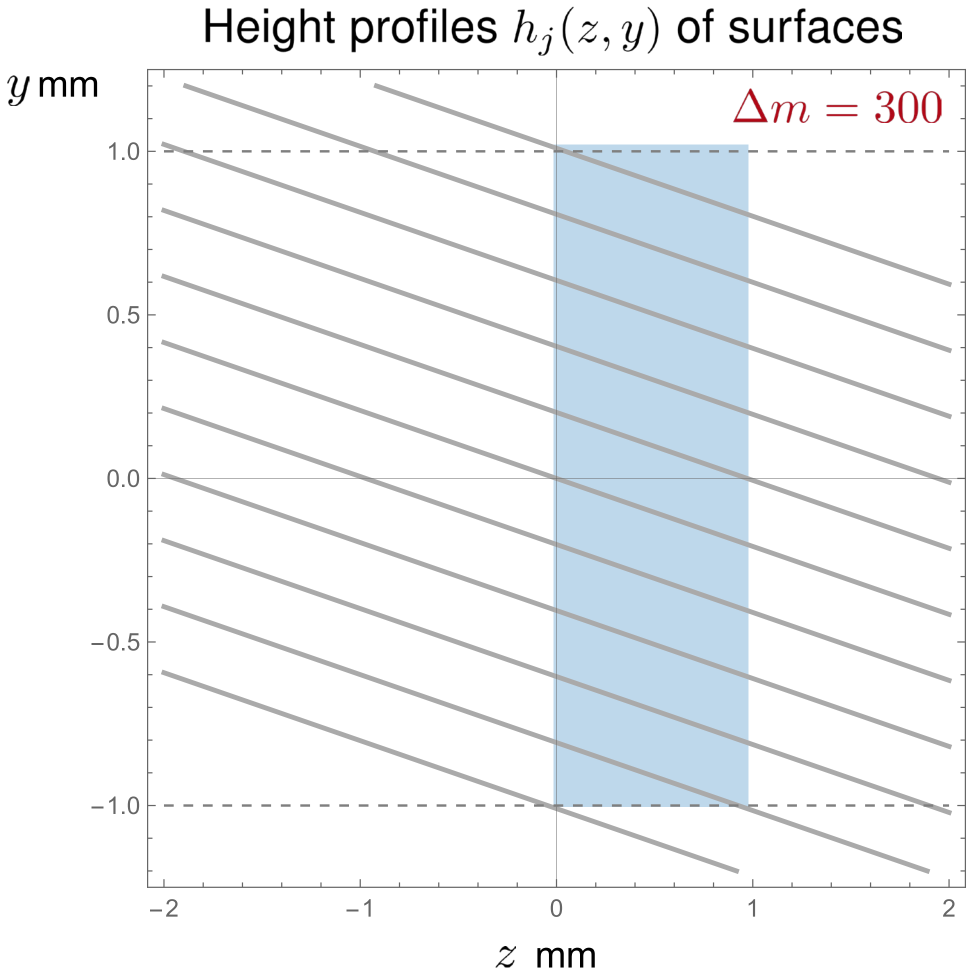

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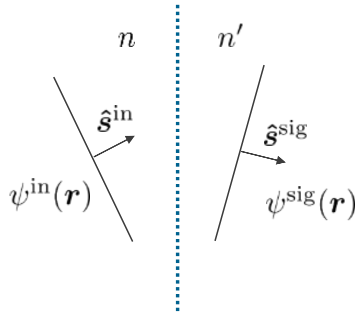

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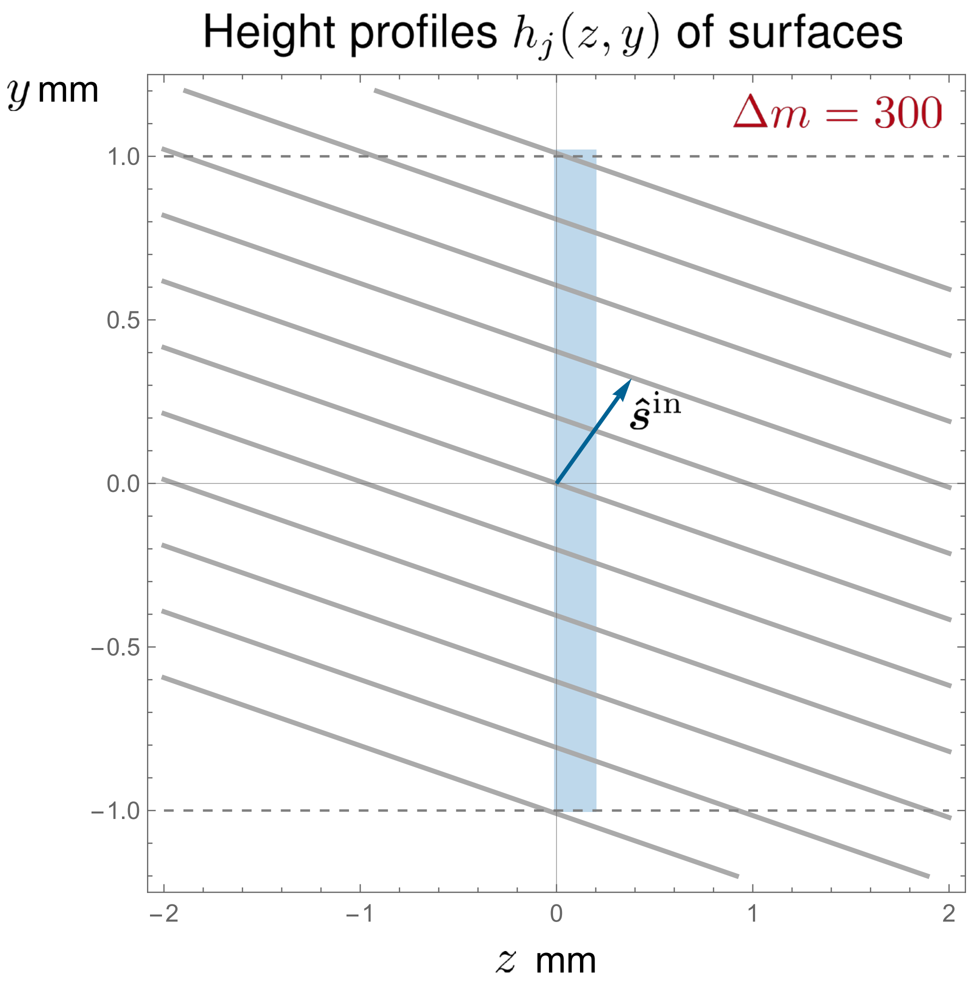

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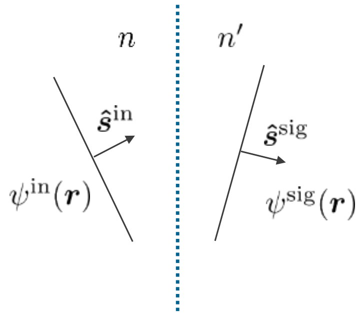

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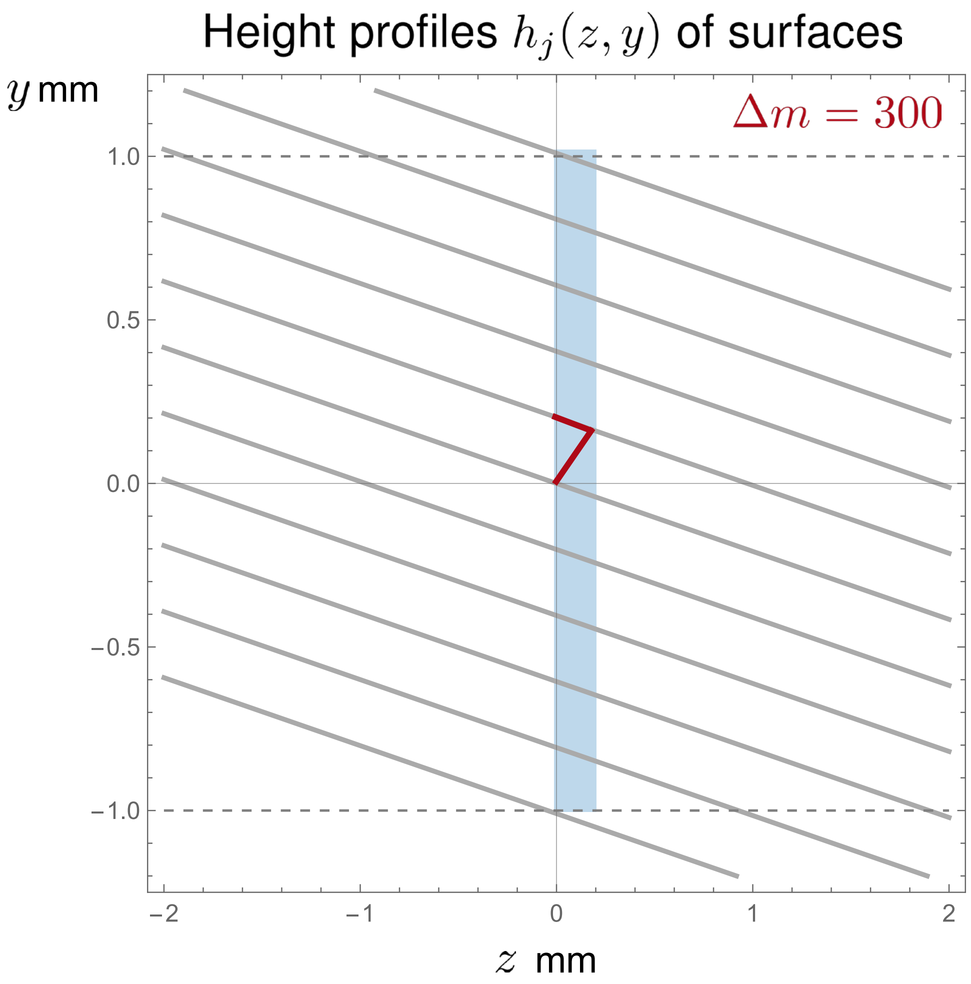

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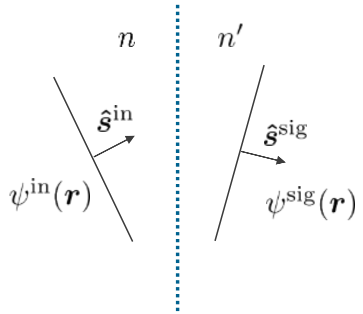

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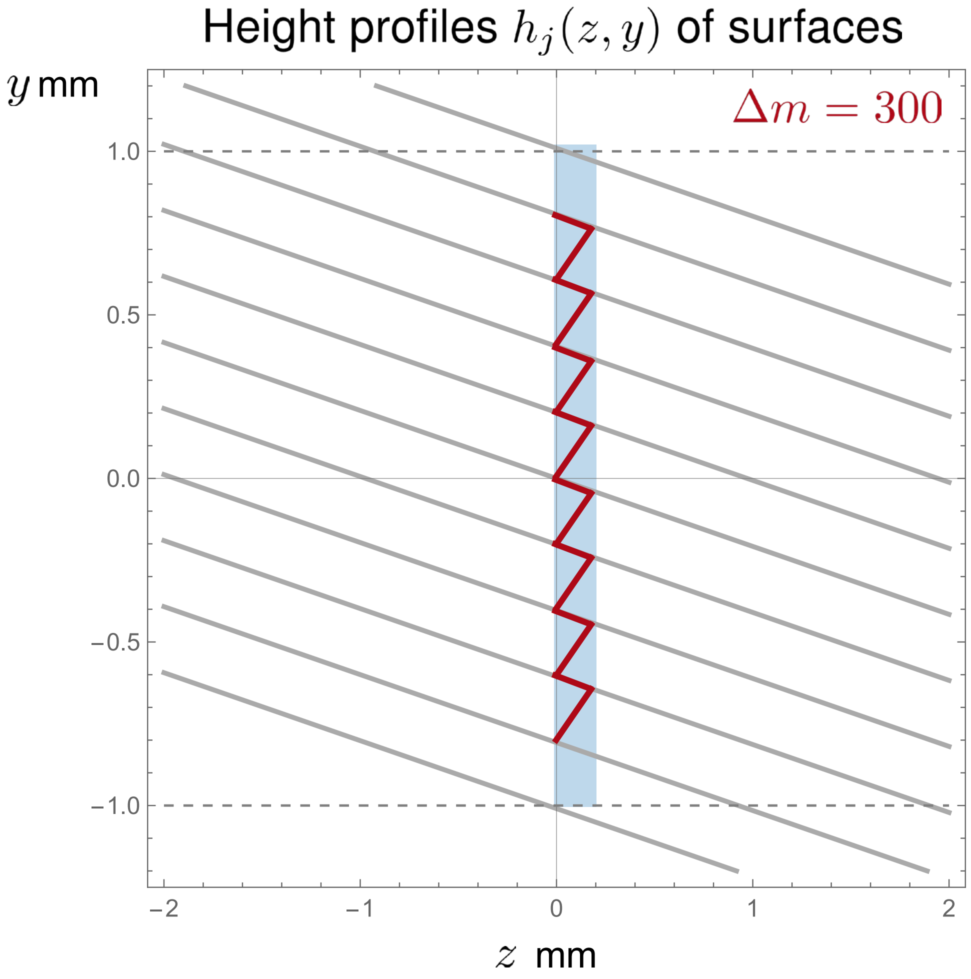
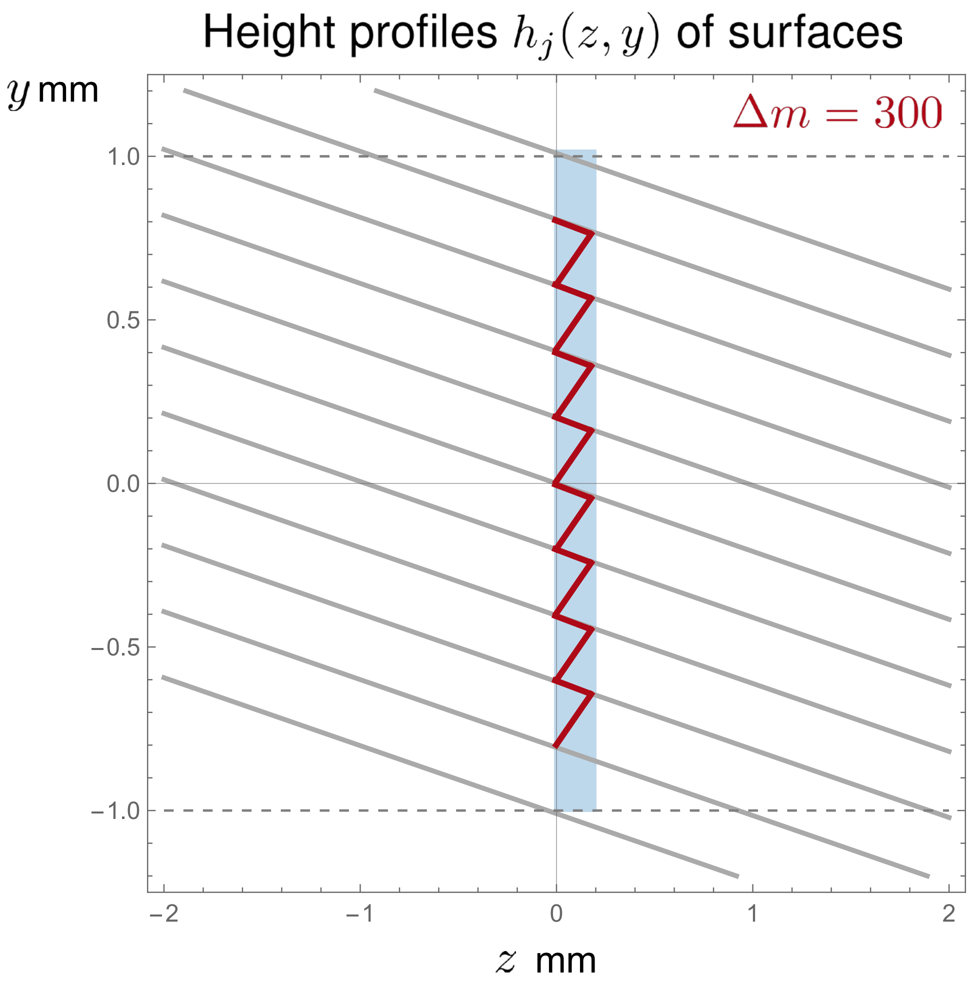


Surface Grating Design

- This approach yields analytical formulas for the grating profile tailored to any given pair of input and output directions.
- The choice of Δm determines the height and period of the grating, with $\Delta m = 1$ achieving the minimum values for both.
- The method can be applied to both the transmission and reflection scenarios.
- This grating design technique is implemented in VirtualLab Fusion.



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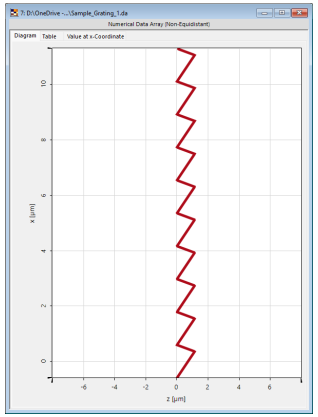
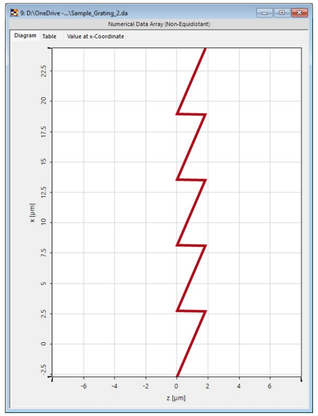
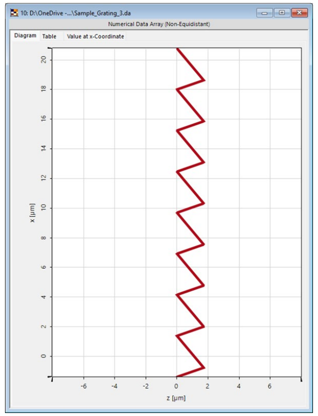
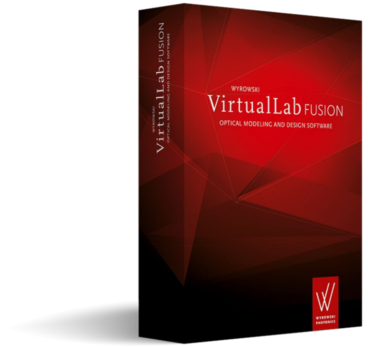
- This approach to grating design is scheduled for release in 2025 within VirtualLab Fusion.







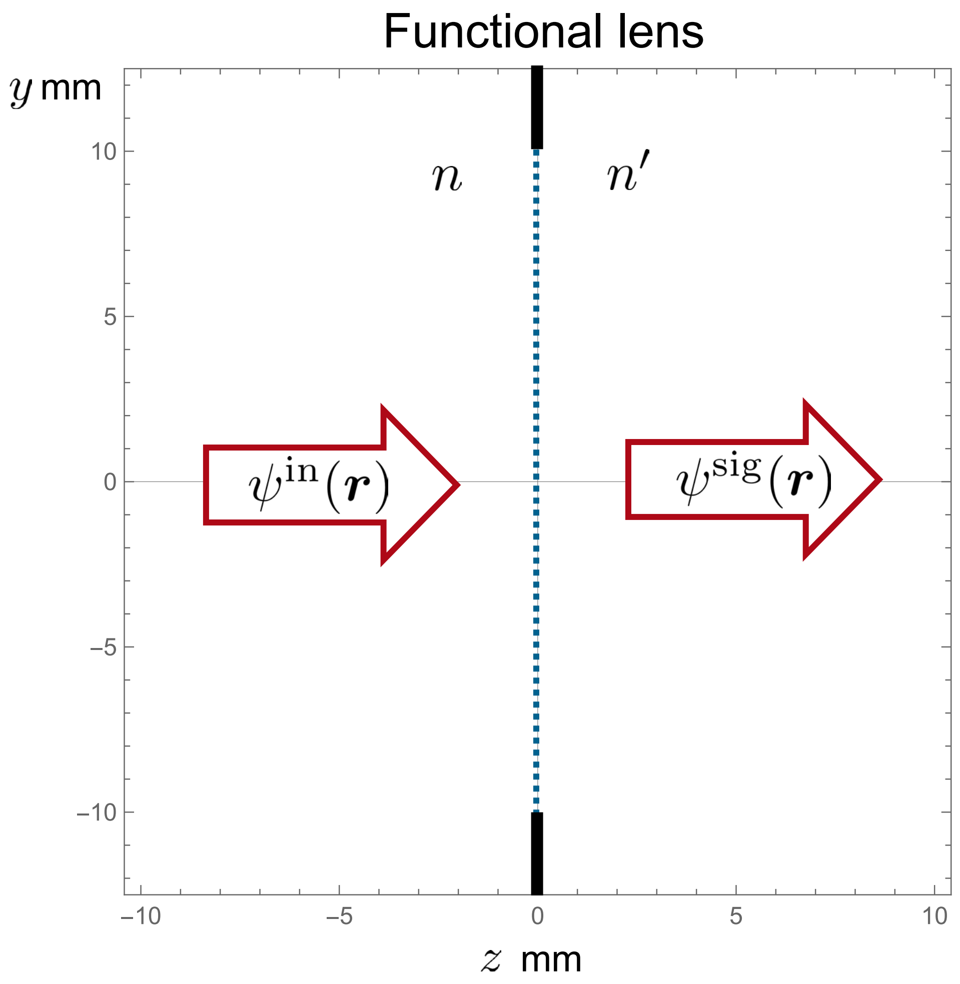


Algorithm for Designing Flat Lens Height Profiles

- By resolving the design equation

$$\Delta\psi(\boldsymbol{r} \in S) = 0,$$

a surface S is identified that converts ψ^{in} to ψ^{sig}.



Algorithm for Designing Flat Lens Height Profiles

- By resolving the design equation

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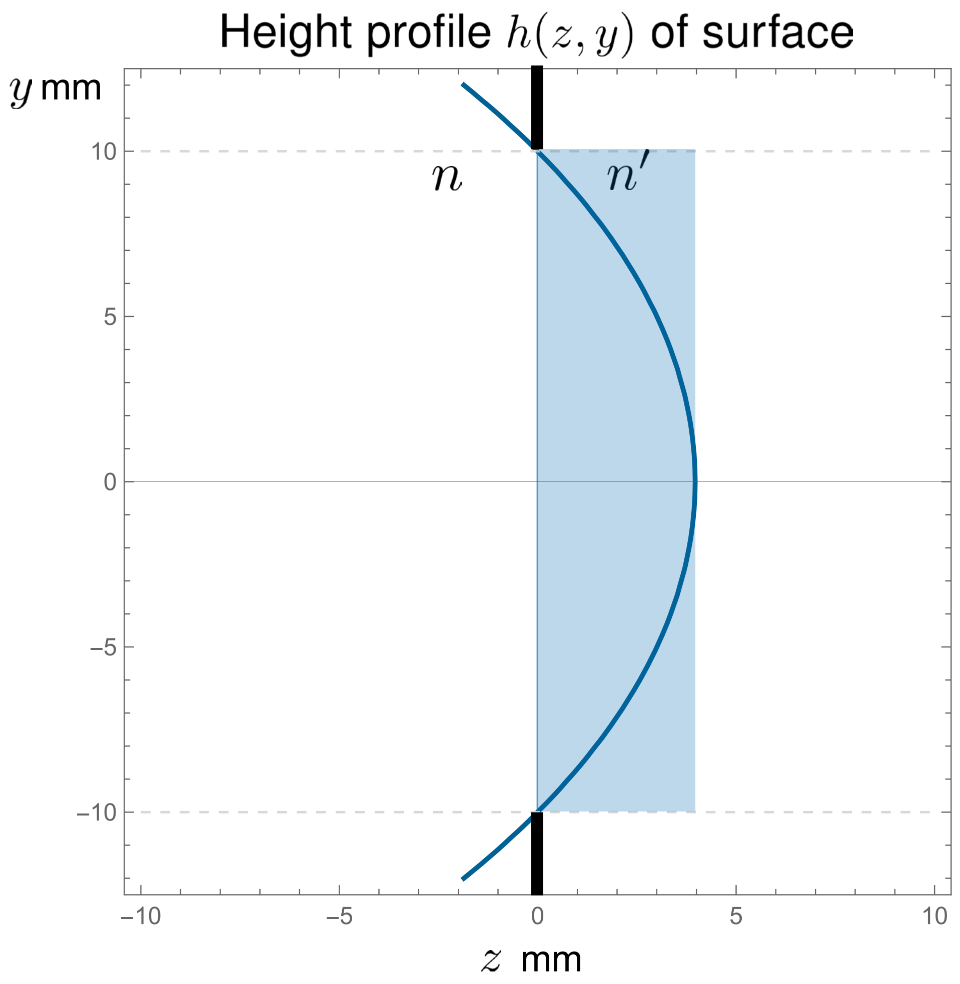

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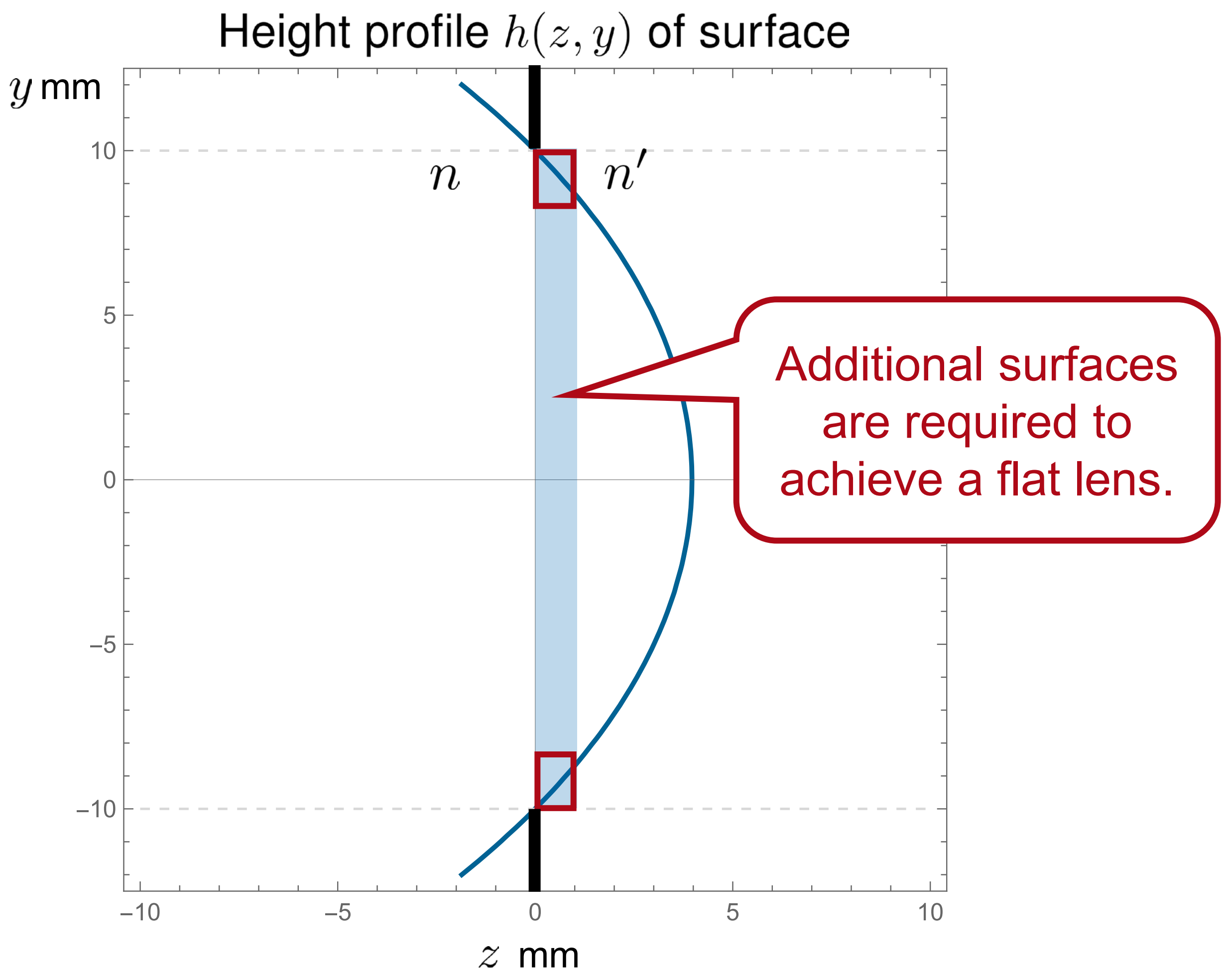

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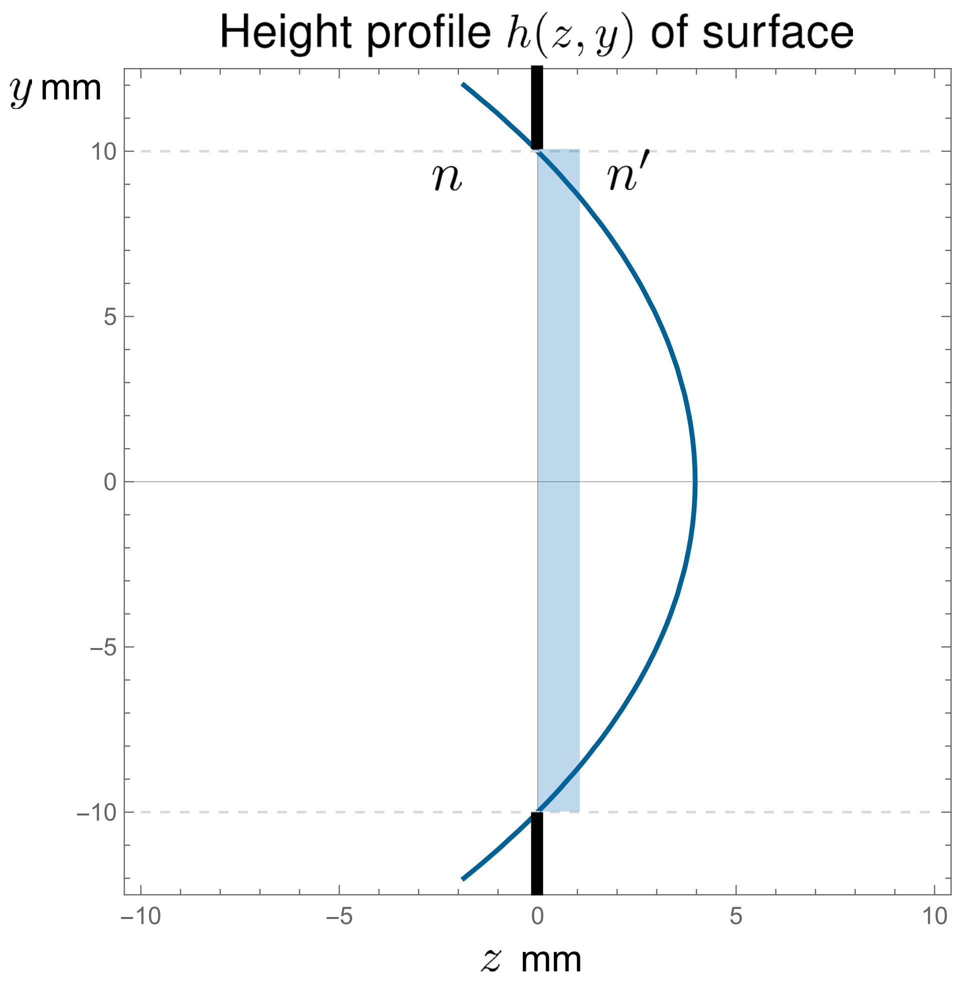
$$\Delta\psi(\boldsymbol{r} \in S_j) \stackrel{!}{=} j\Delta m \cdot 2\pi,$$

  where $m = j\Delta m$ is an integer ($\mathbb{Z}$).

- The parameter Δm is used to adjust the thickness of the flat lens, where setting $\Delta m = 1$ results in the thinnest possible configuration.



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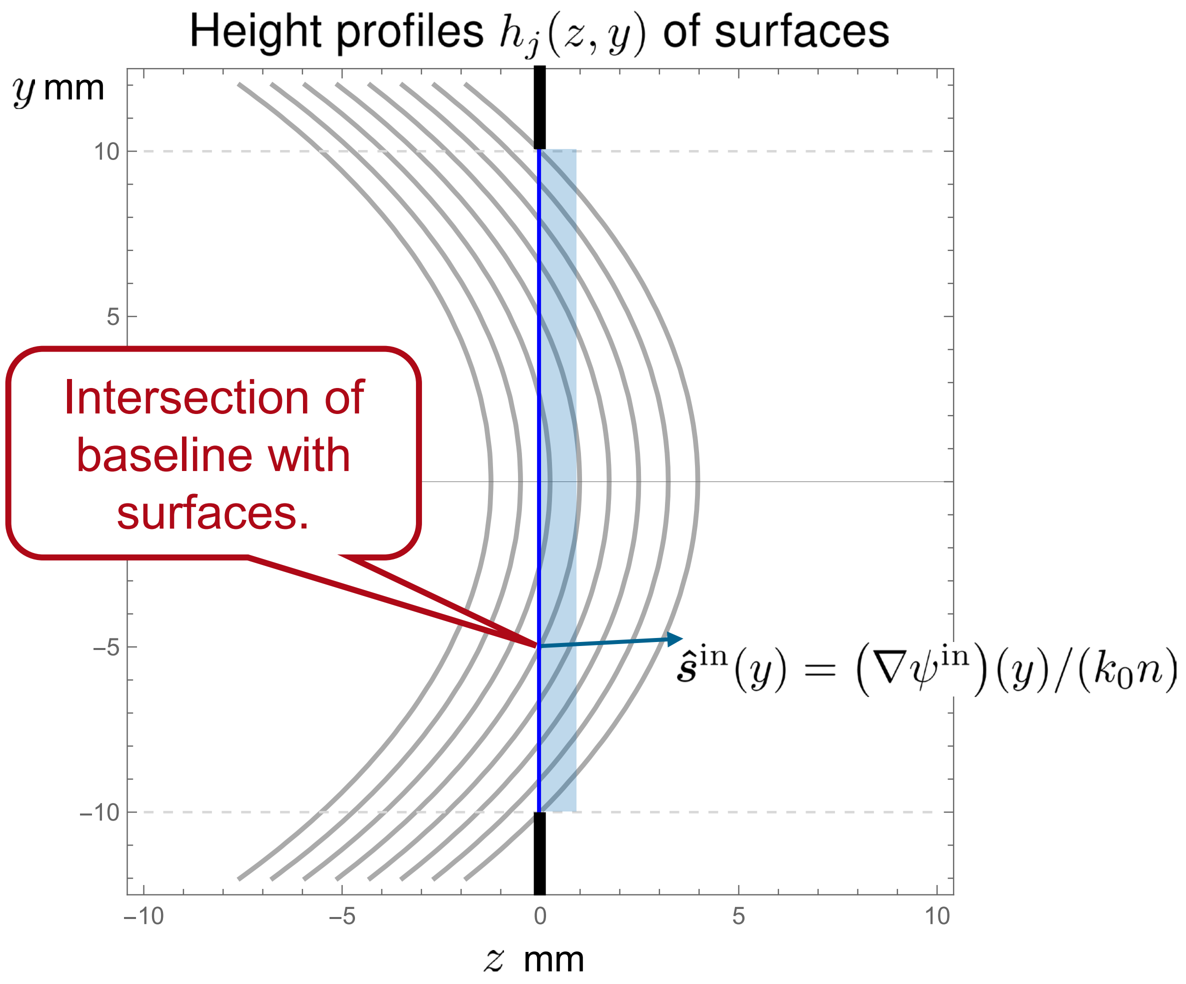

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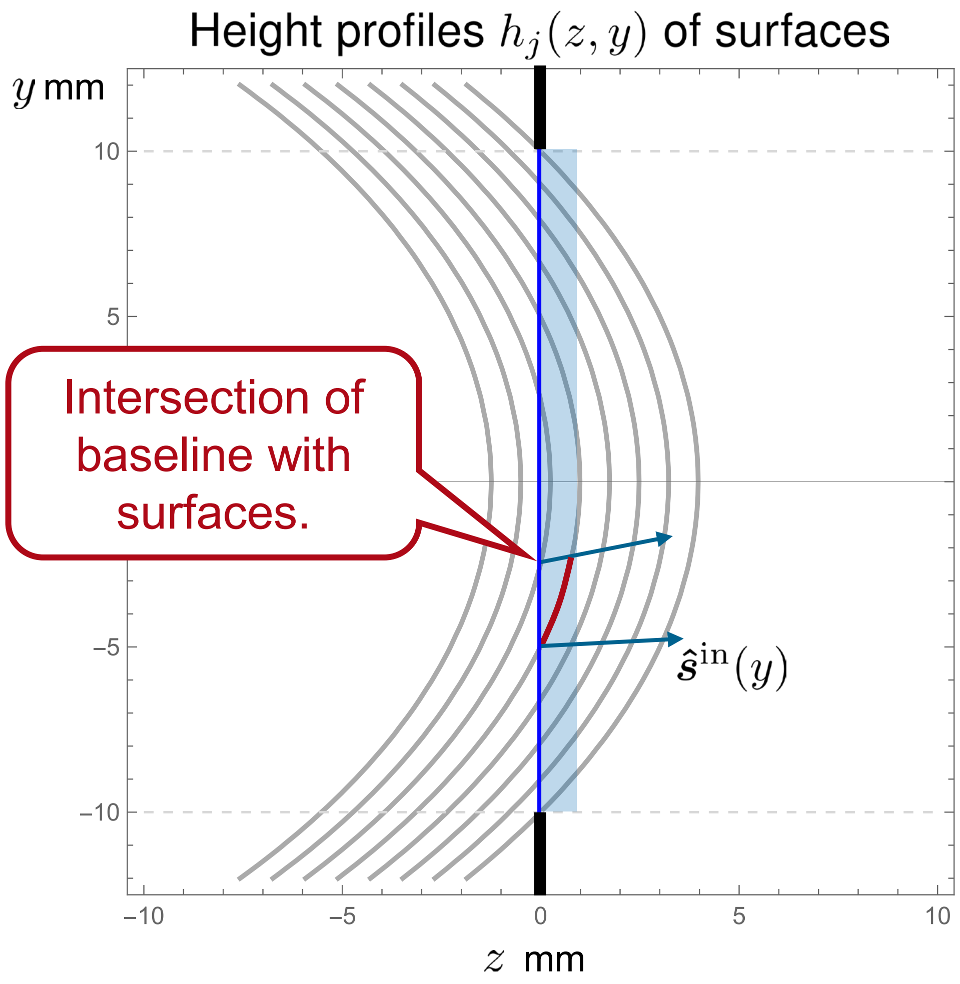

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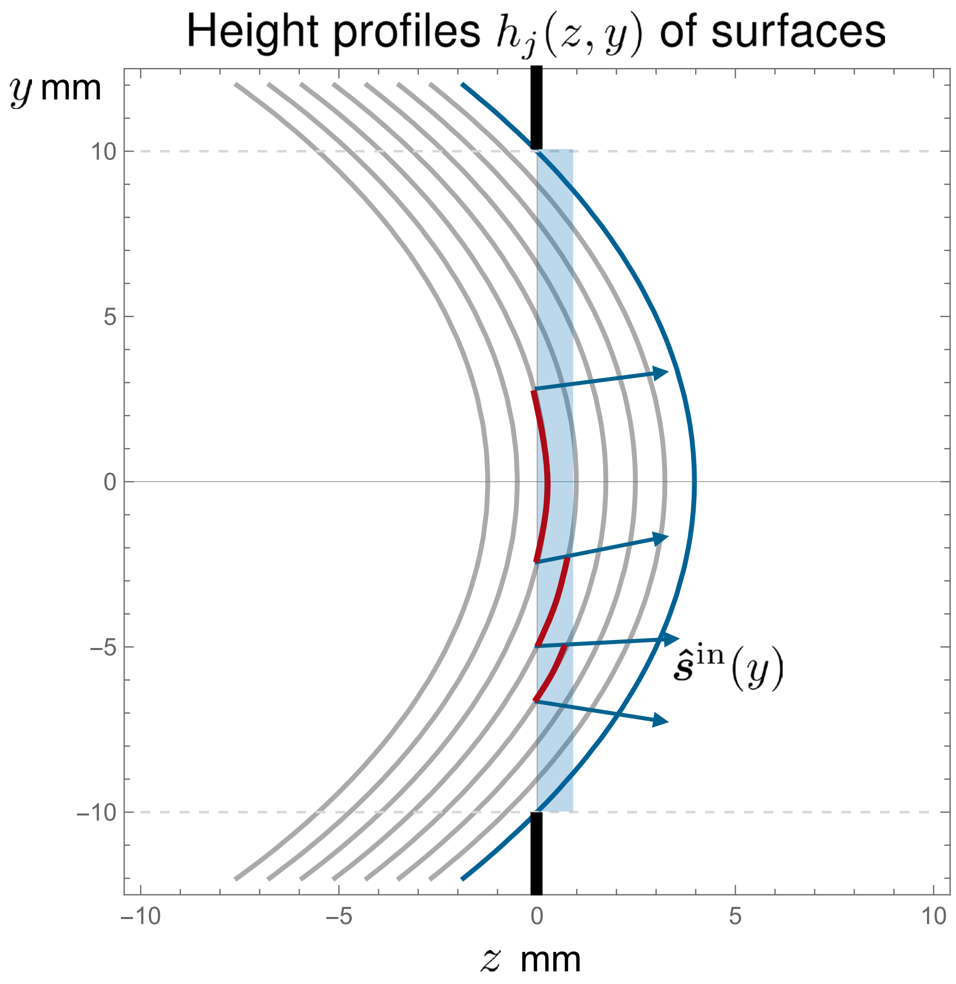
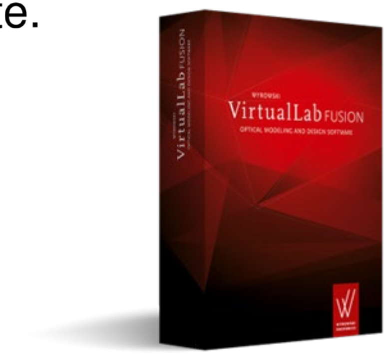
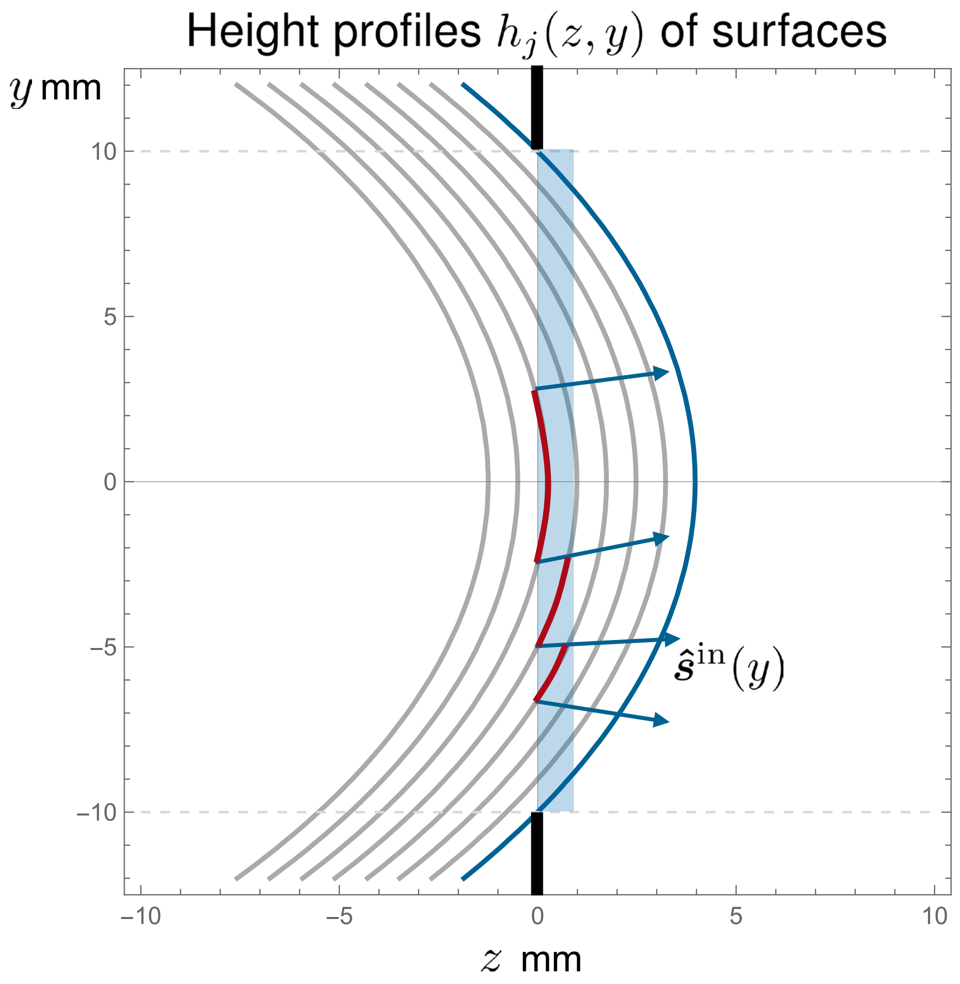


Algorithm for Designing Flat Lens Height Profiles

- This concept enables the creation of a quick and flexible algorithm for the design of flat lens surfaces.
- This method is applicable to scenarios involving both transmission and reflection and is effective regardless of whether rotational symmetry is assumed or not.
- The design algorithm is incorporated into our proprietary VirtualLab Fusion software and is scheduled to be released in an upcoming 2025 update.





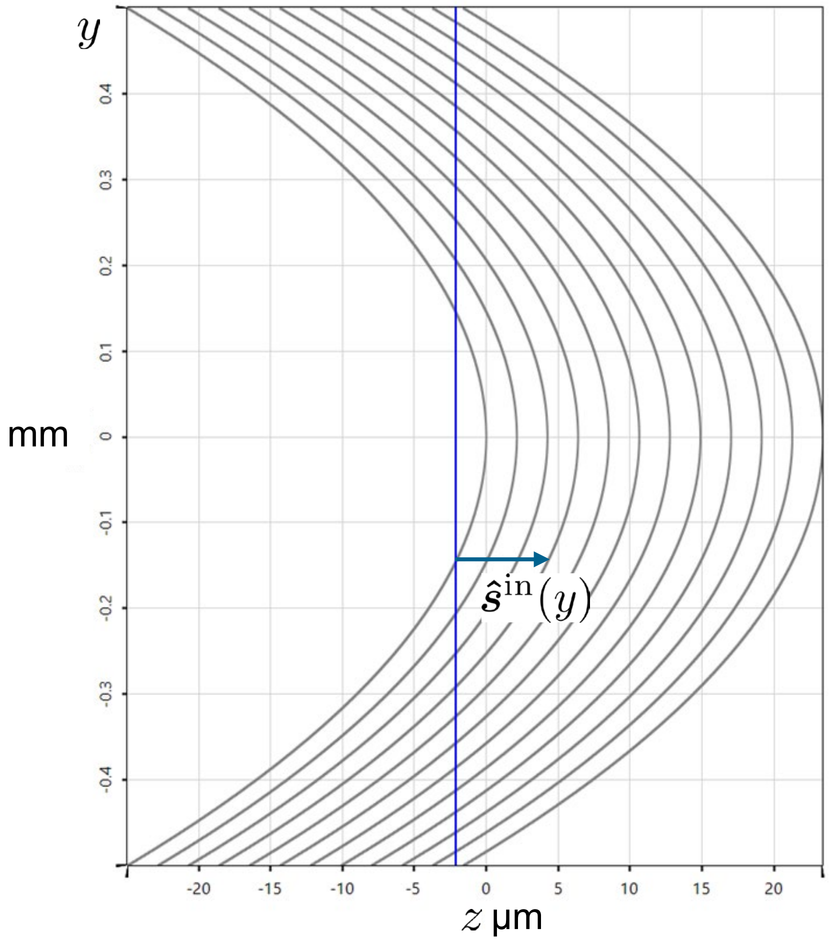
Algorithm for Designing Flat Lens Height Profiles: Examples

The examples are configured to showcase
the design algorithm for illustrative purposes.

Algorithm for Designing Flat Lens Height Profiles: Examples

- Demonstration of the algorithm using a focusing lens as an example with $\Delta m = 2$.

Height profiles $h_j(z, y)$ of surfaces



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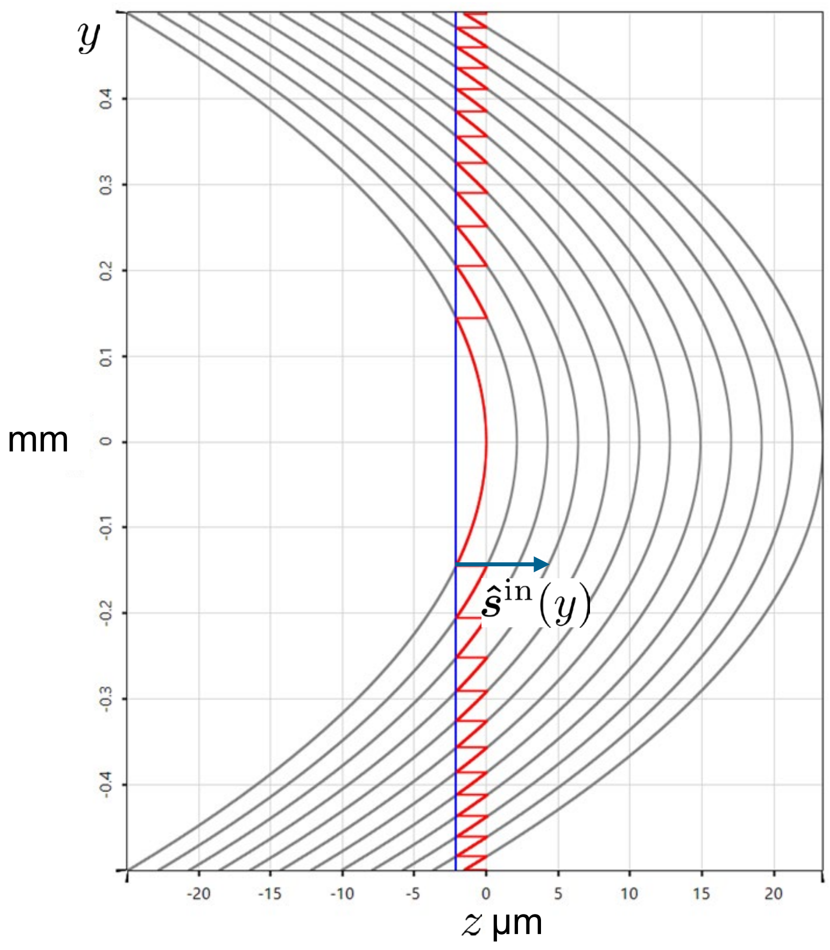

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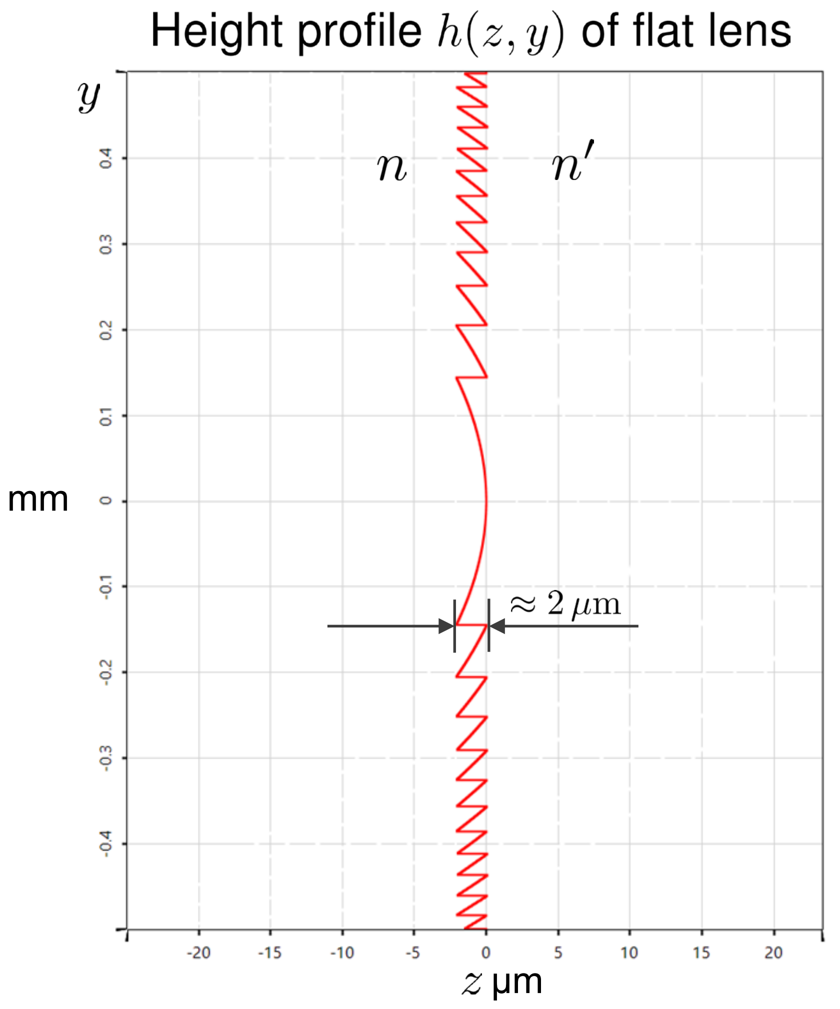

Algorithm for Designing Flat Lens Height Profiles: Examples

- Demonstration of the algorithm using a collimating lens as an example with $\Delta m = 50$.

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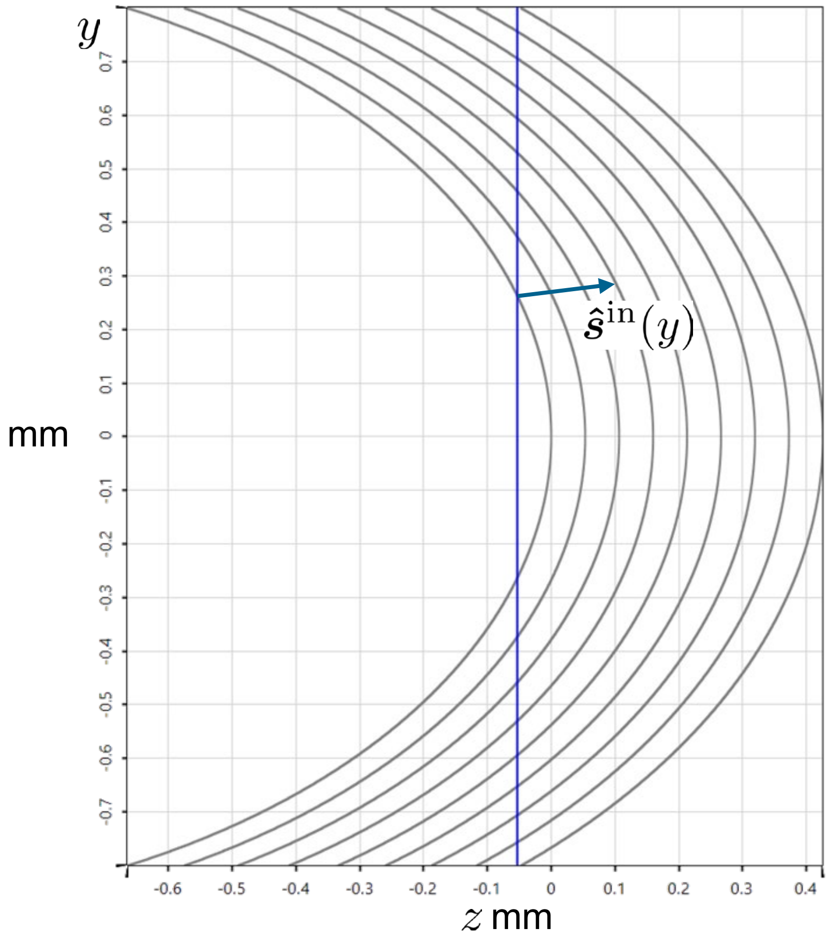

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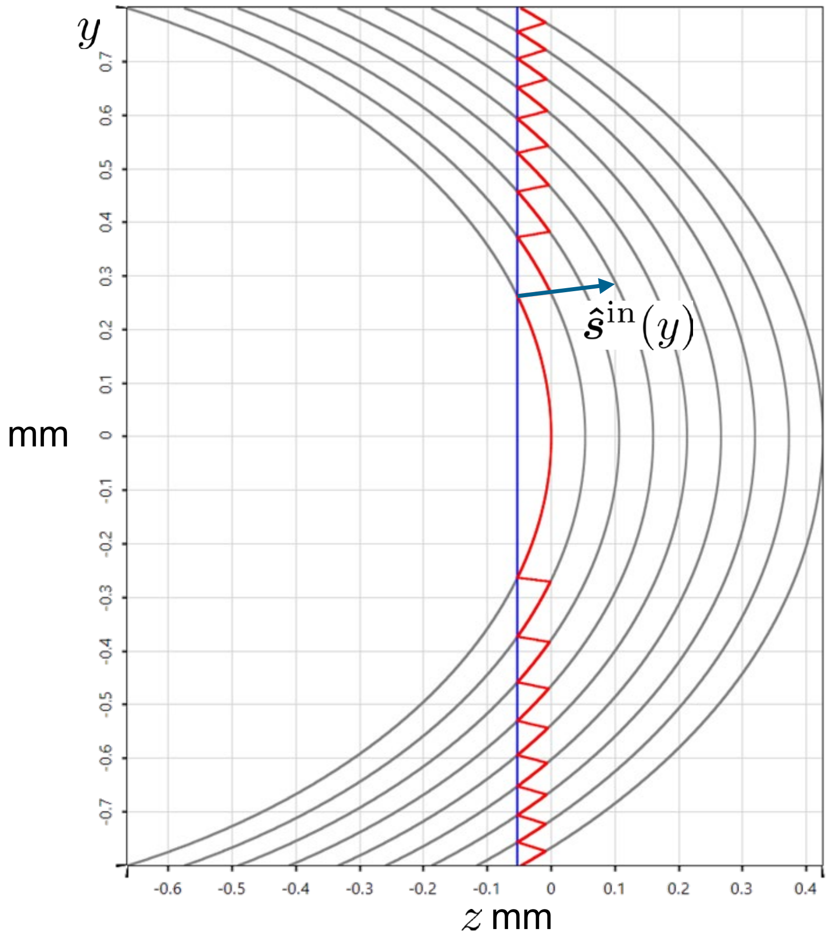

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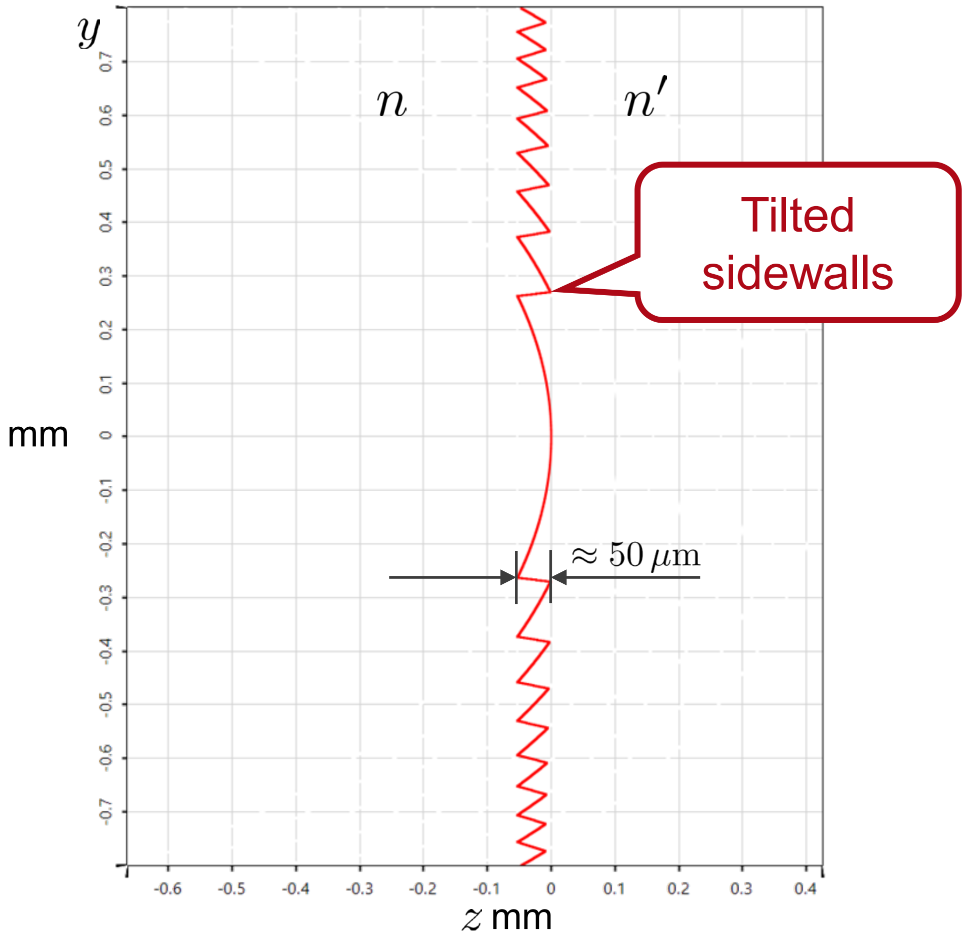
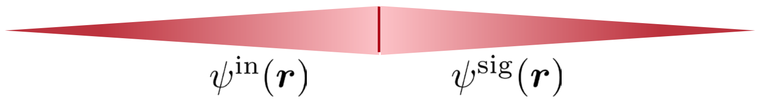
Height profile $h(z, y)$ of flat lens



Algorithm for Designing Flat Lens Height Profiles: Examples

- Demonstration of the algorithm using an imaging lens as an example with $\Delta m = 5$.



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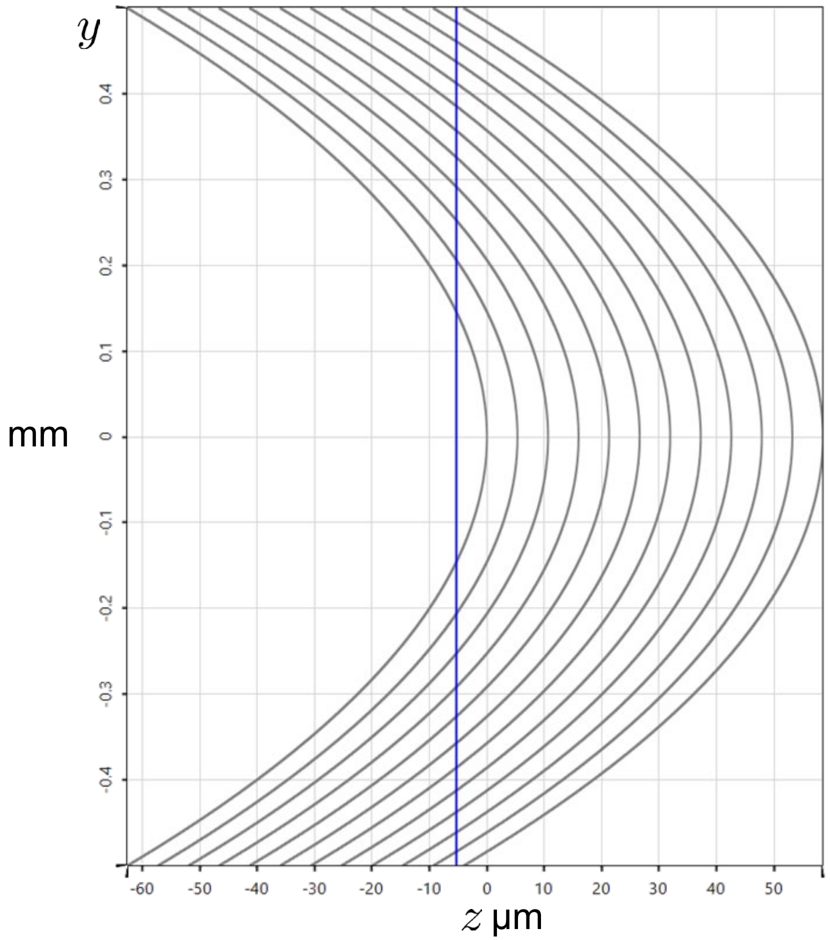

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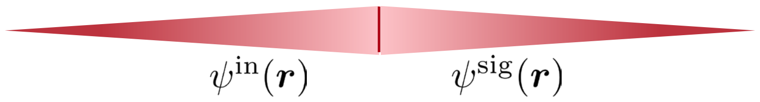

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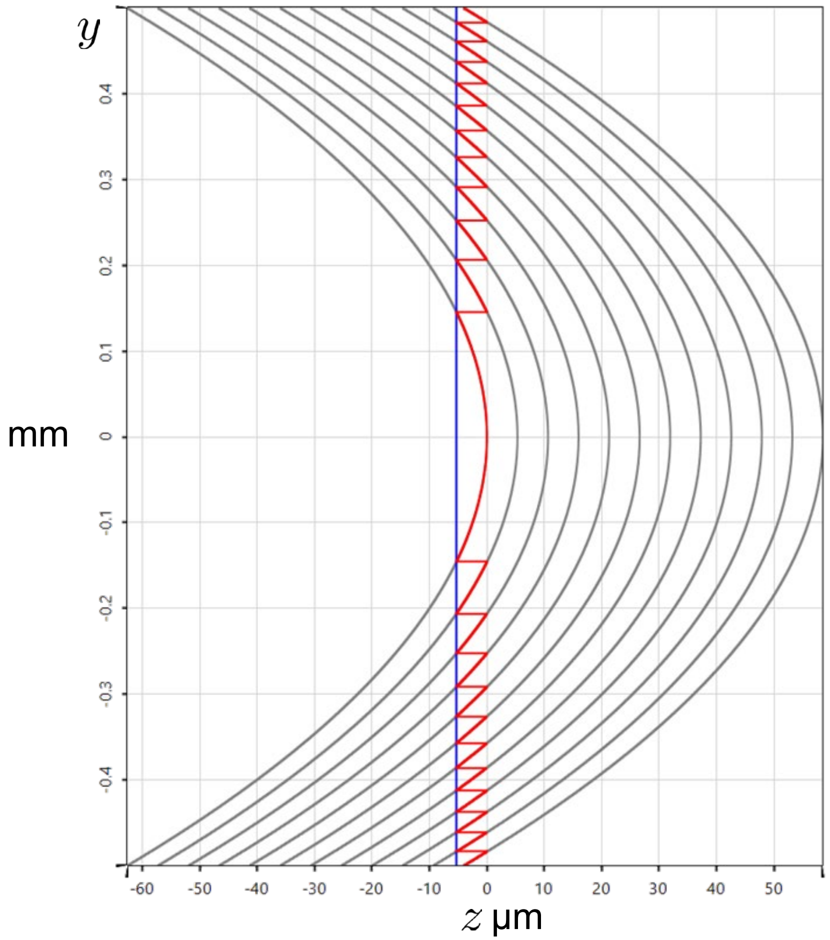

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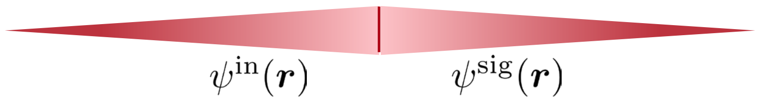

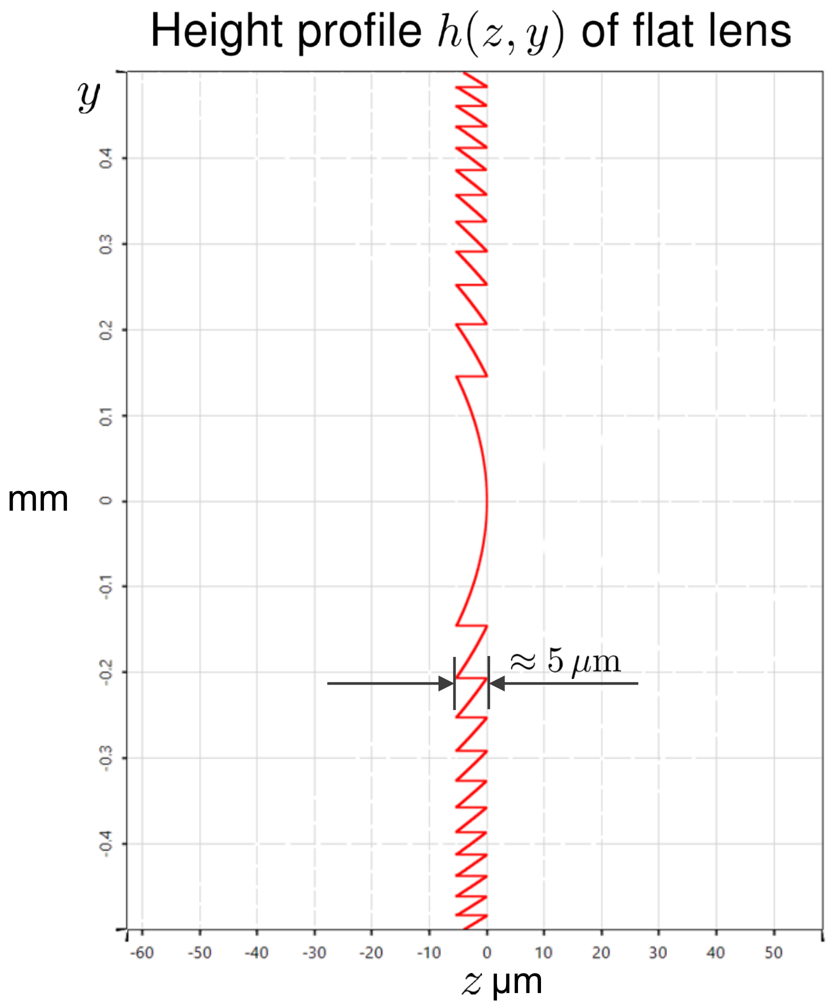

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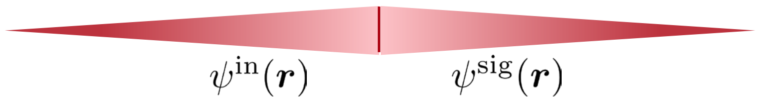

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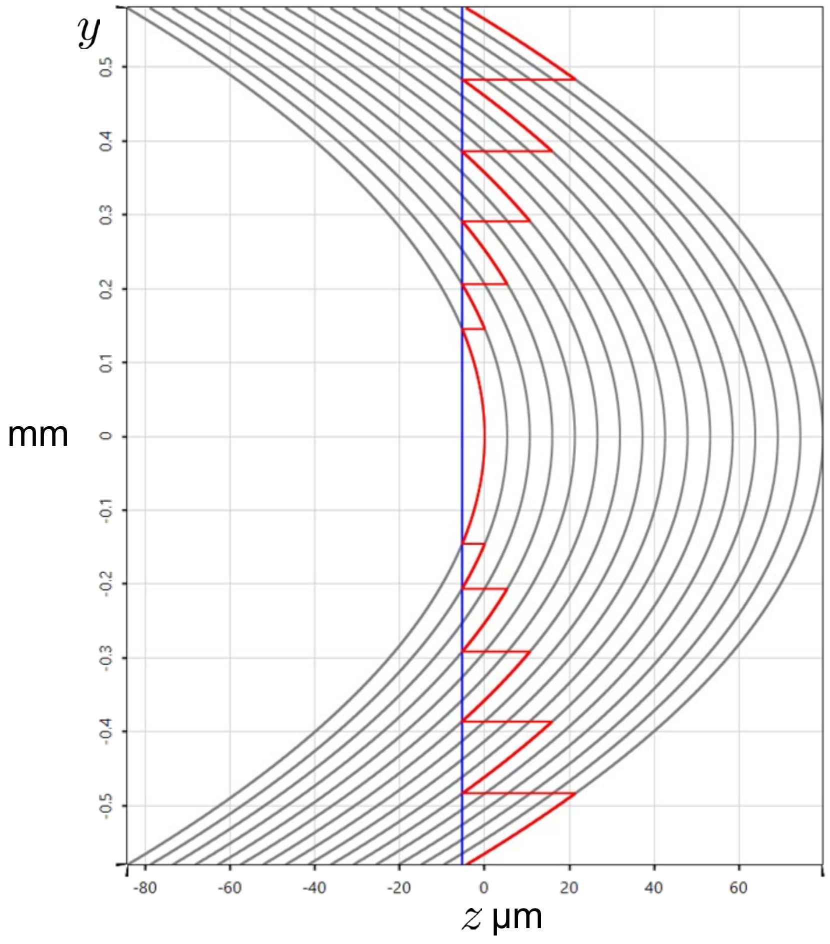
Height profiles $h_j(z, y)$ of surfaces



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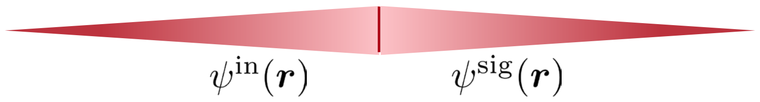

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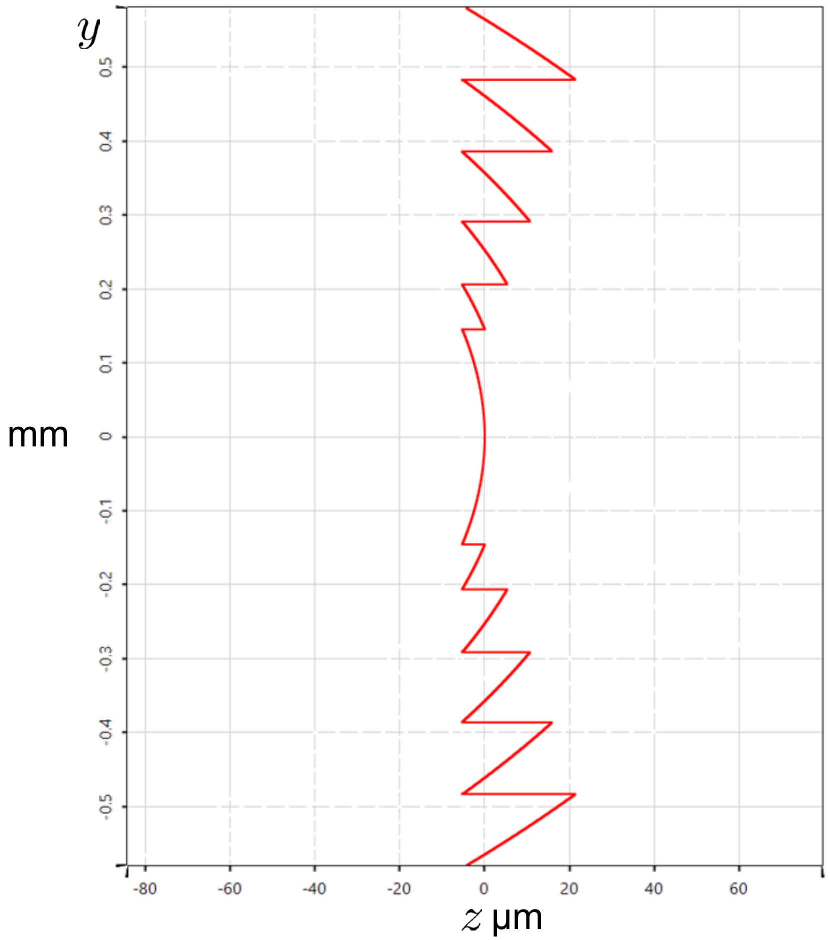
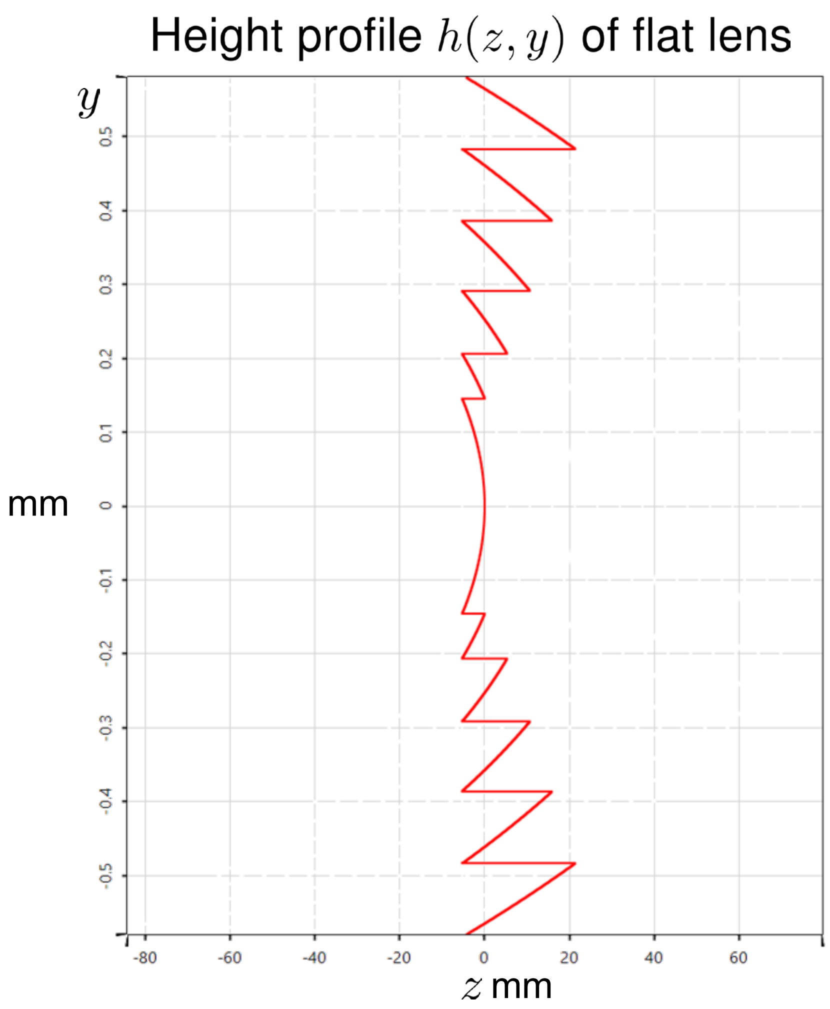


Algorithm for Designing Flat Lens Height Profiles: Examples

Meta Oculus Rift and Quest 2



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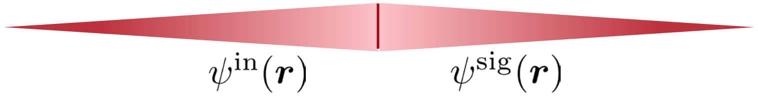

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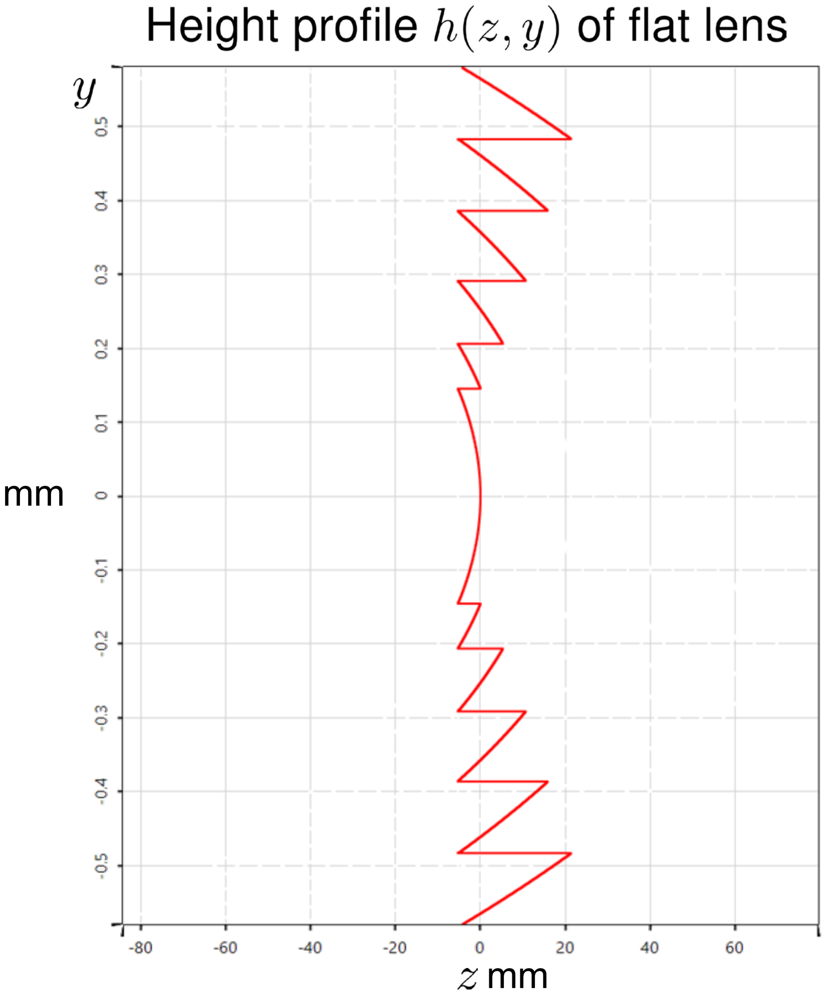

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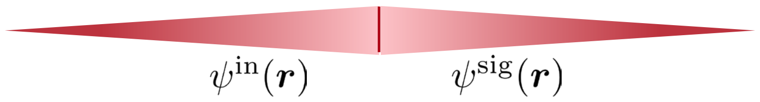

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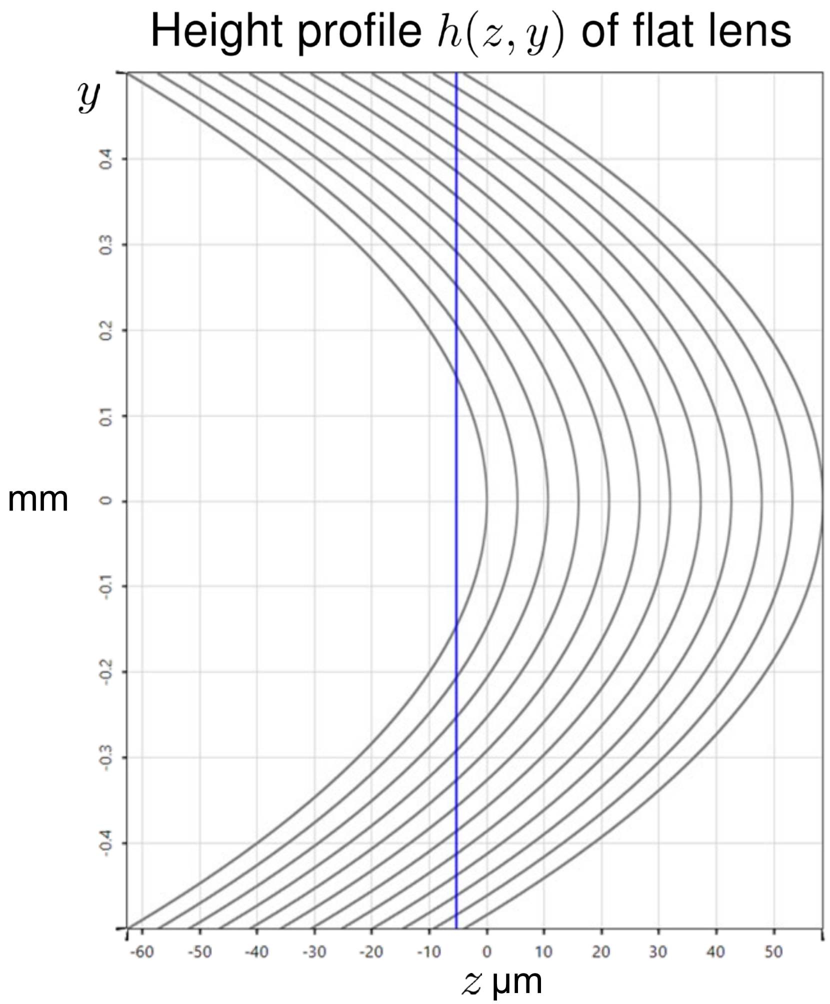
- The design algorithm allows for the distribution of lens power across both curved and flat lens surface profiles.



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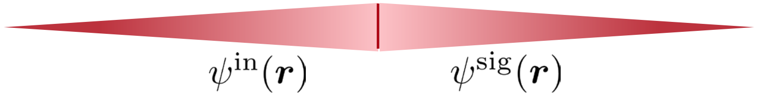

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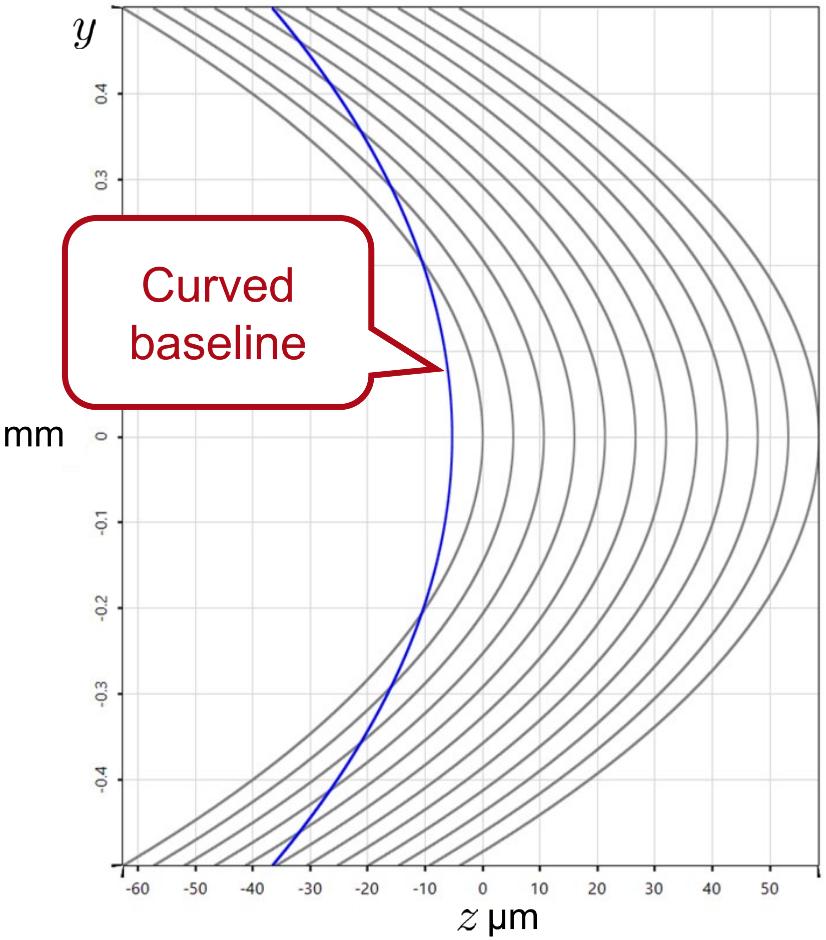
Height profile $h(z, y)$ of flat lens



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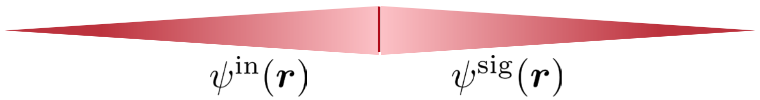

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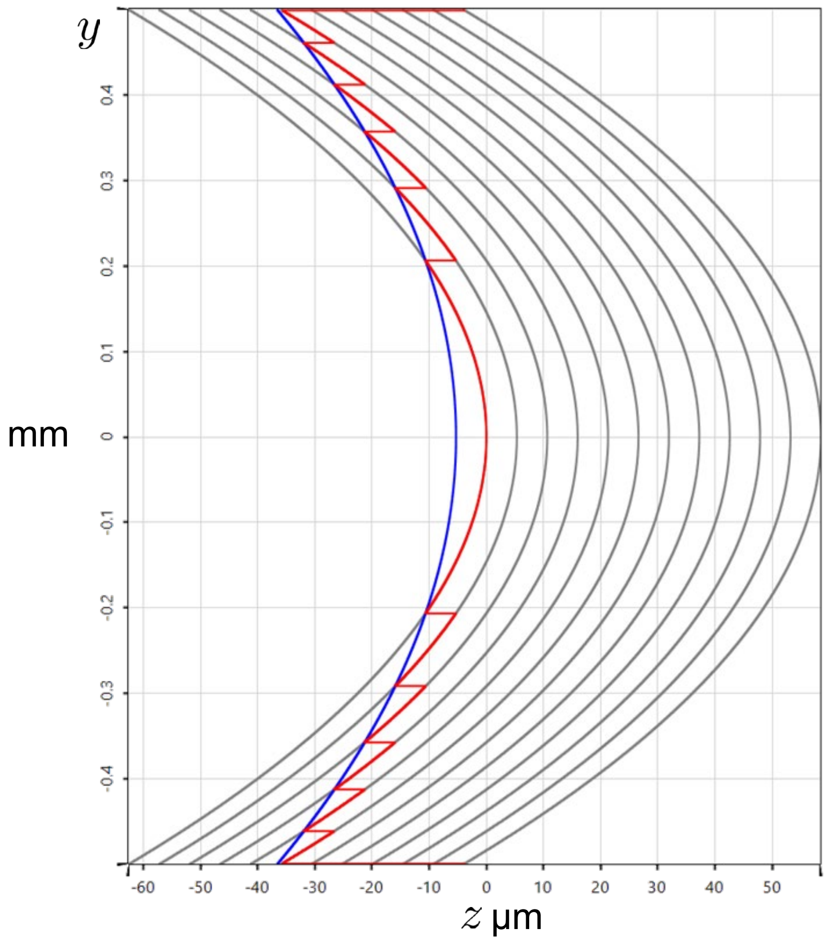

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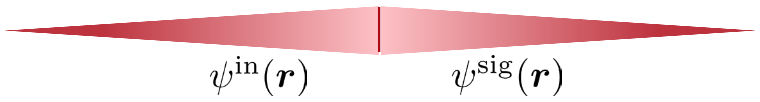

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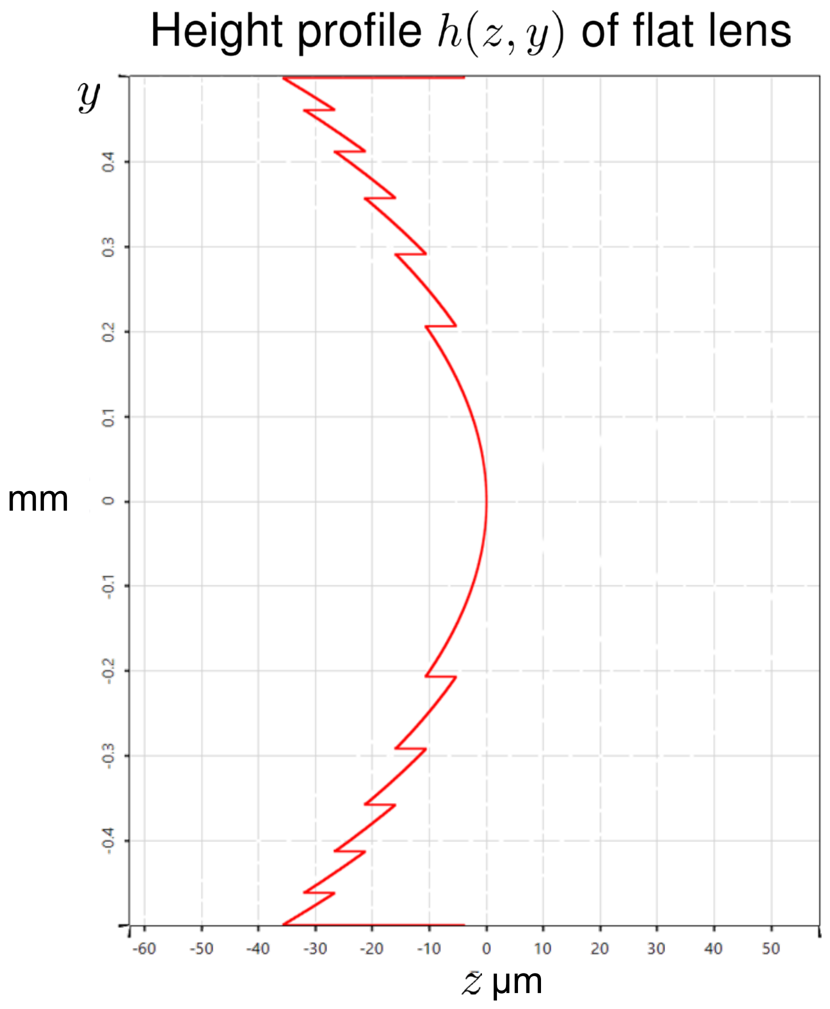
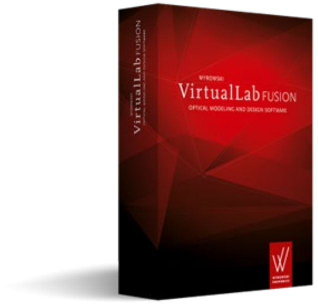
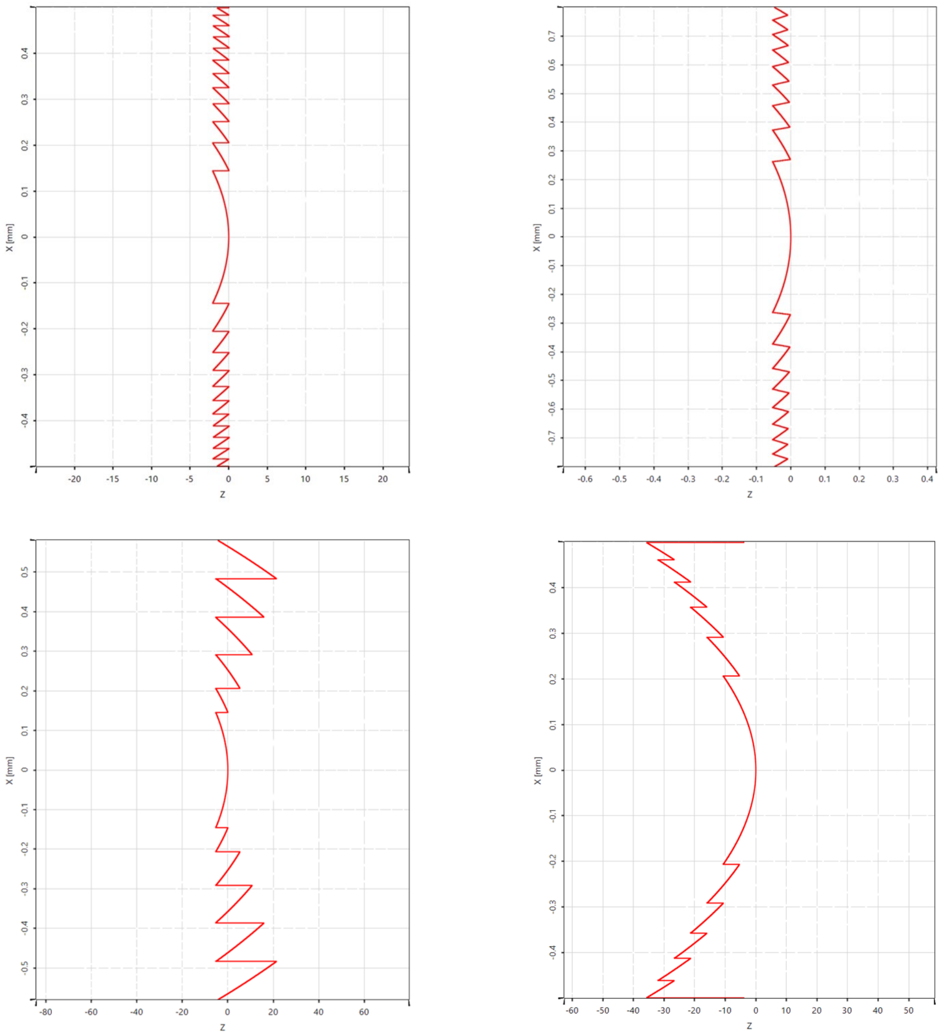


Algorithm for Designing Flat Lens Height Profiles

Three essential objectives must be achieved in the advancement of optics software:

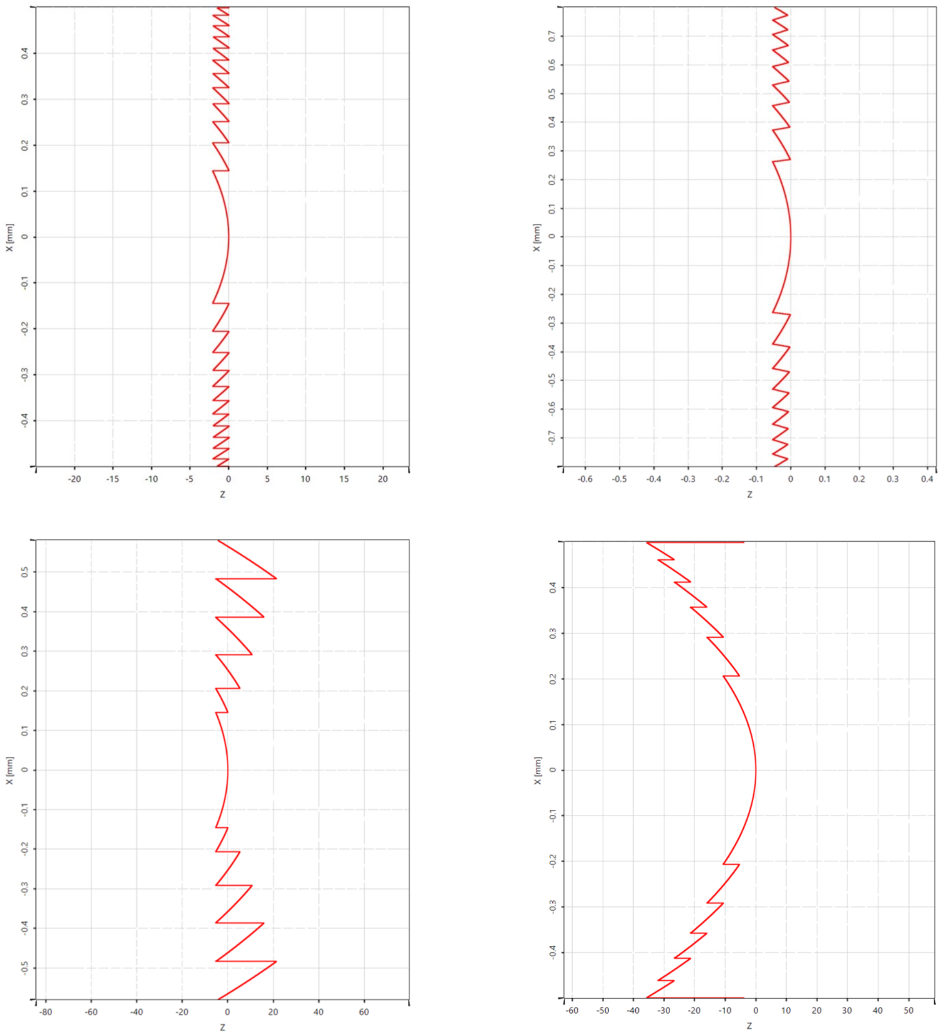
1. Develop efficient and user-friendly design algorithms for flat lenses.
2. Enable the simulation of lens systems that incorporate flat lenses with adequate accuracy and speed.
3. Facilitate the optimization of optical systems that incorporate flat lenses.





Fresnel and Diffractive Lenses

- Flat lenses, which function according to their height profiles, are commonly known as:
  - Fresnel lenses for large Δm
  - Diffractive lenses for $\Delta m = 1$
  - Superzone diffractive lenses for small $\Delta m > 1$
- For diffractive lenses, the height profile may be discretized to facilitate fabrication via binary lithography techniques.



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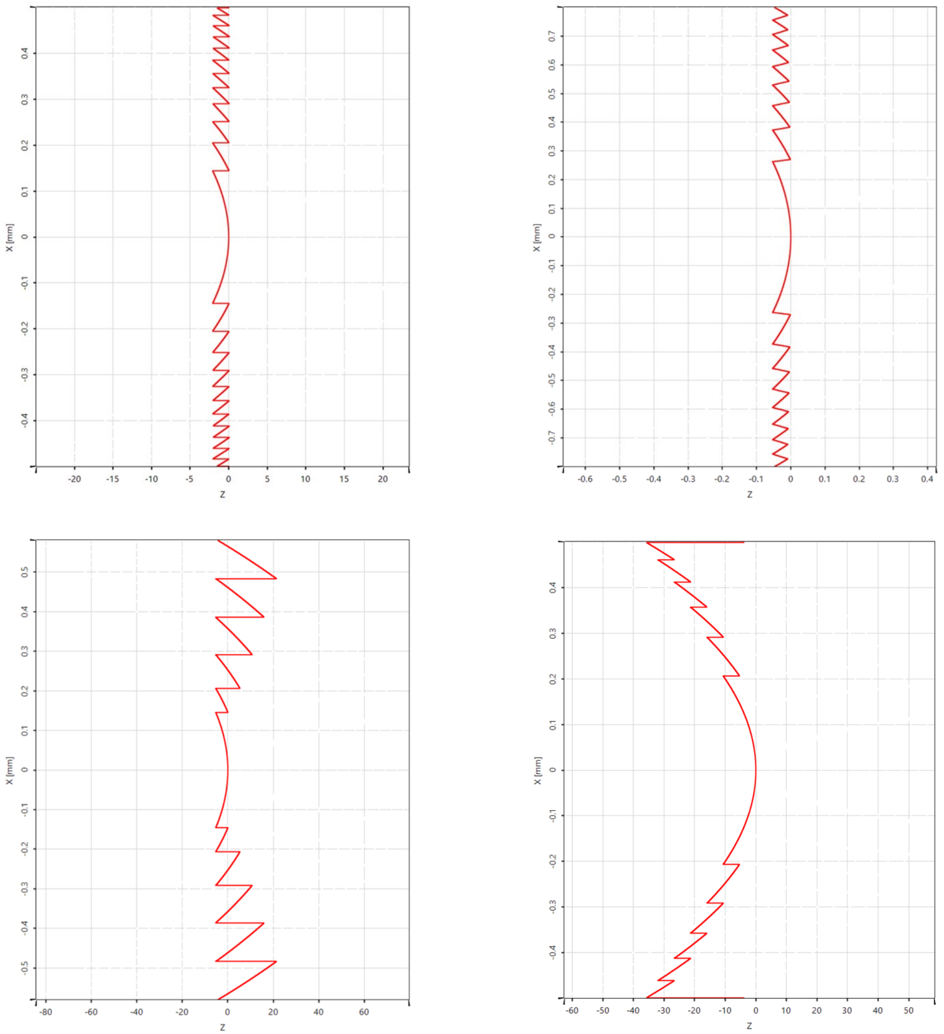

Algorithm for Designing Flat Lens Metasurfaces

Three essential objectives must be achieved in the advancement of optics software:

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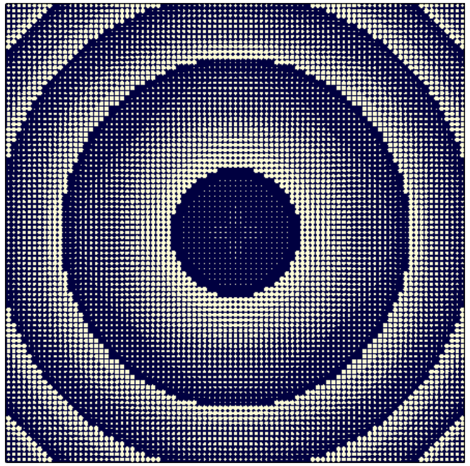
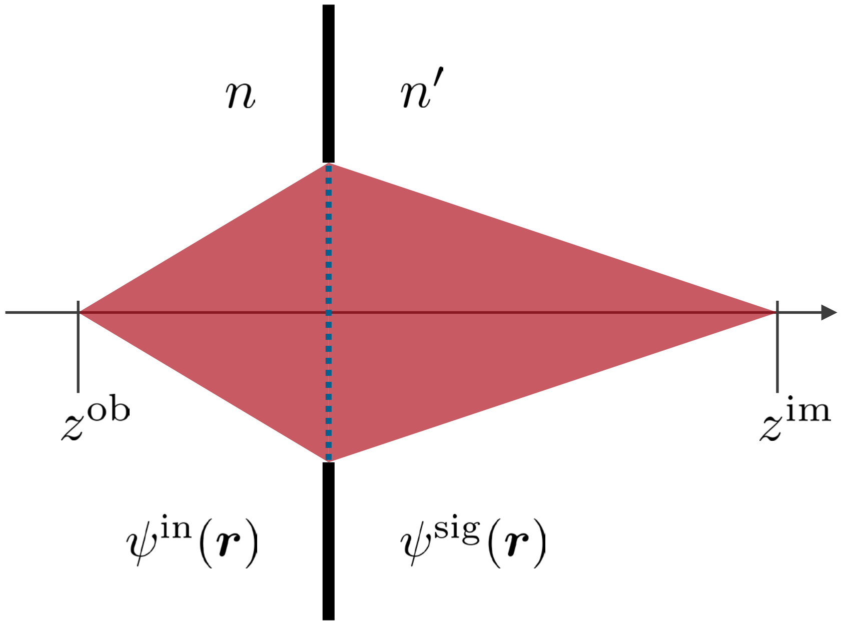
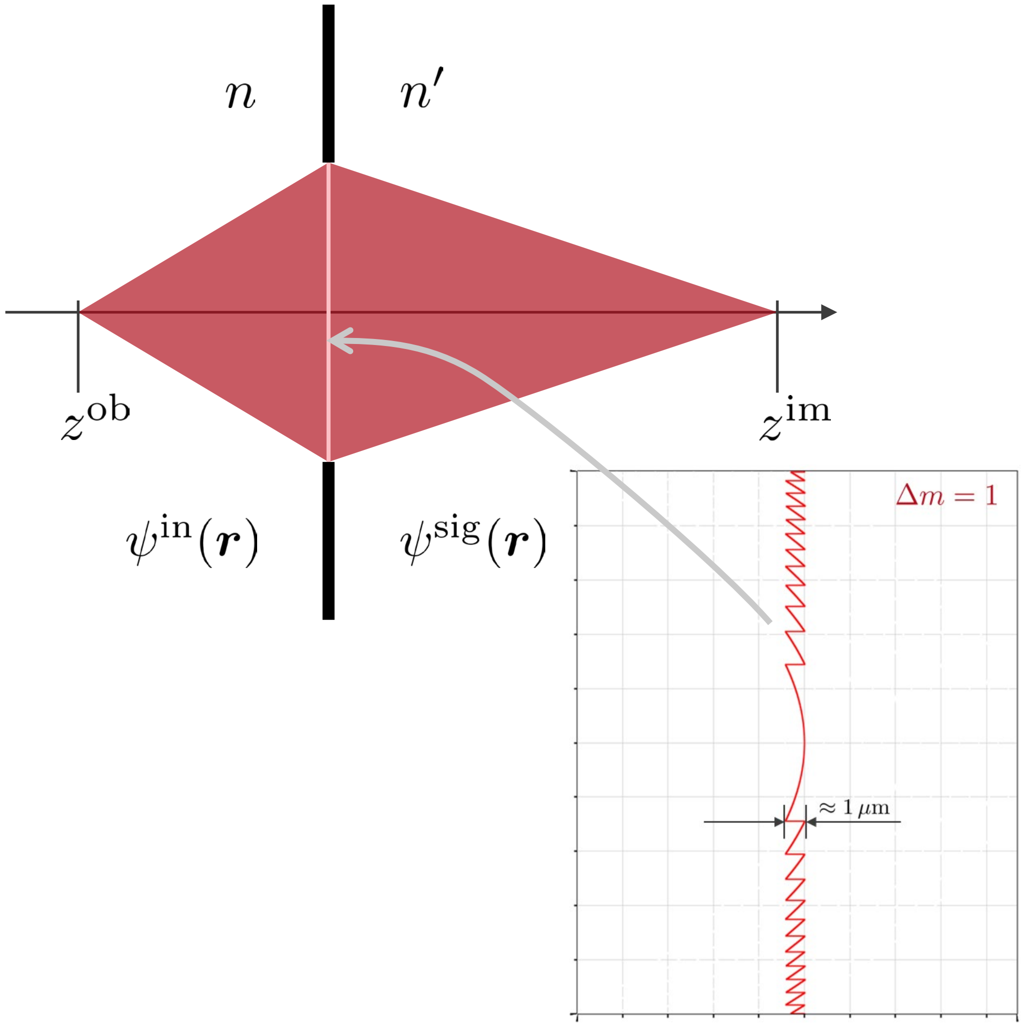


Functional Lens



- In the process of designing a diffractive lens for visible light, a layer with a thickness of approximately $1\,\mu\mathrm{m}$ is obtained.

Diffractive Lens



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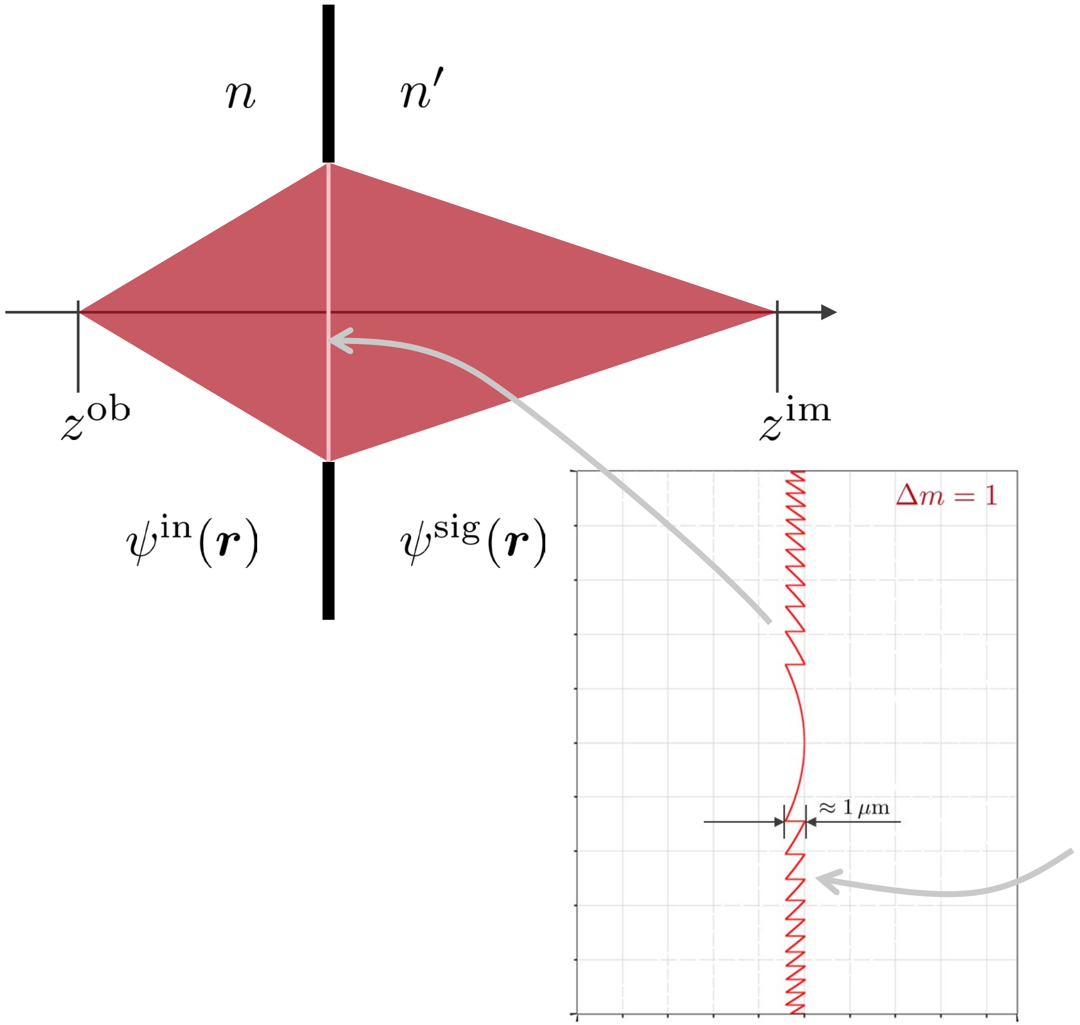


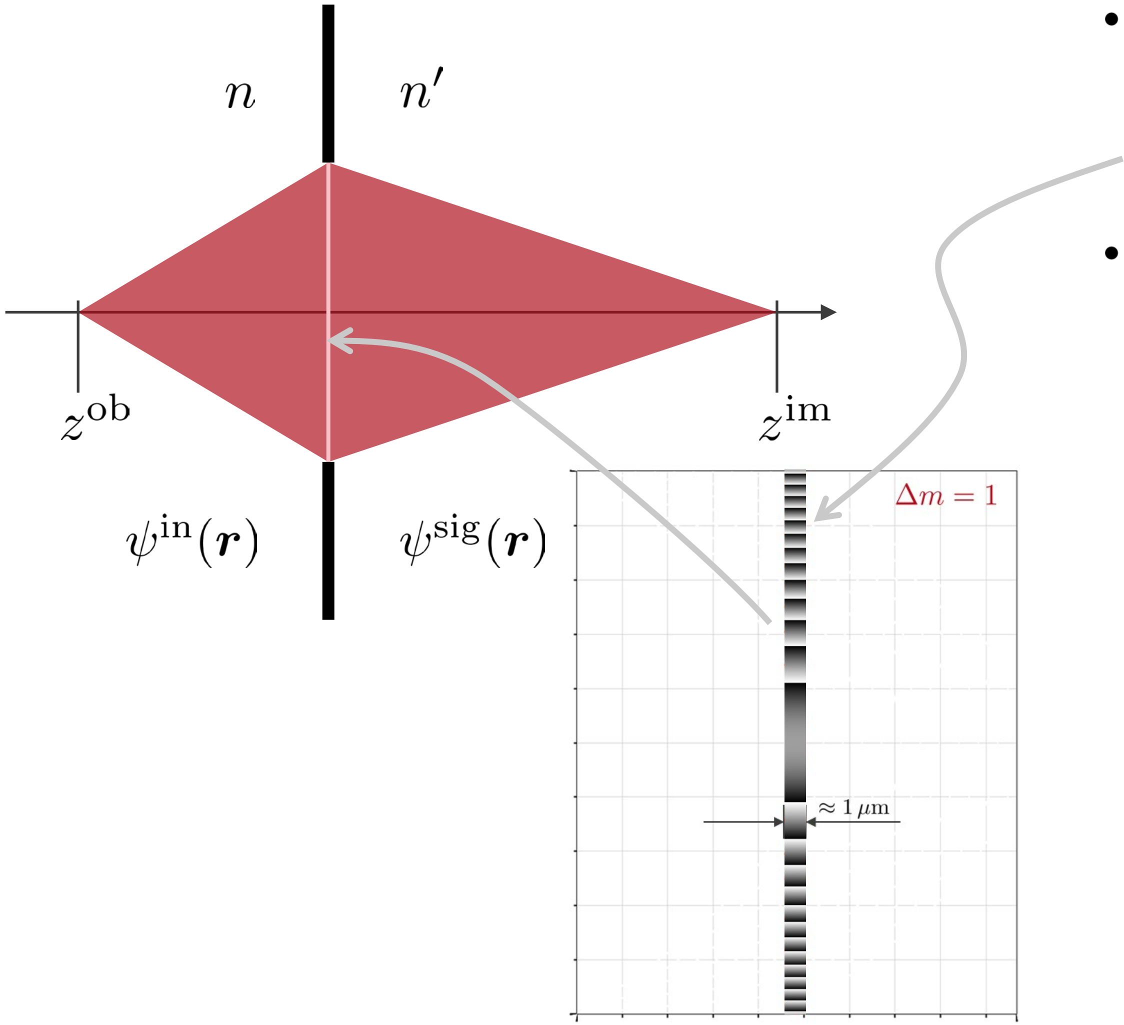
- In the process of designing a diffractive lens for visible light, a layer with a thickness of approximately $1\,\mu\mathrm{m}$ is obtained.
- From the design of the diffractive lens with $\Delta m = 1$, it is clear that this layer transforms ψ^{in} into ψ^{sig} by causing a local phase delay that matches the phase difference

$$\Delta\psi(\boldsymbol{\rho}) \bmod 2\pi$$

with $\Delta\psi(\boldsymbol{\rho}) = \psi^{\mathrm{sig}}(\boldsymbol{\rho}) - \psi^{\mathrm{in}}(\boldsymbol{\rho}) + \bar{\psi}$ and $\boldsymbol{\rho} = (x, y)$.

- The diffractive lens realizes this local phase delay by a varying height profile $h(\boldsymbol{\rho})$.

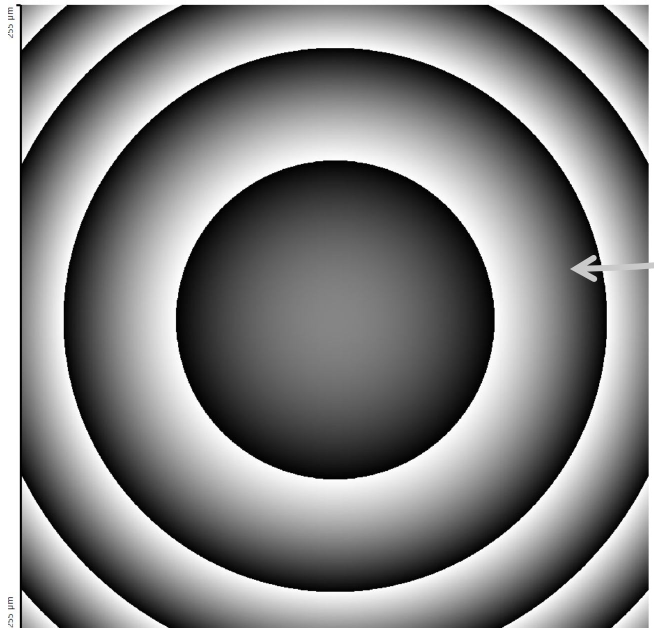
Lens Featuring a Layer with Variable Refractive Index



- Alternatively, think about a layer with a constant thickness h, but with a refractive index $n(\boldsymbol{\rho})$ that changes in lateral dimension.
- This change in refractive index is the cause of the phase difference, as can be roughly described by the equation

$$\Delta\psi(\boldsymbol{\rho}) \bmod 2\pi \approx k_0 h\, n(\boldsymbol{\rho})\,.$$

Lens Featuring a Layer with Variable Refractive Index



Variation of the refractive index $n(\boldsymbol{\rho})$ within a layer for a focusing lens.

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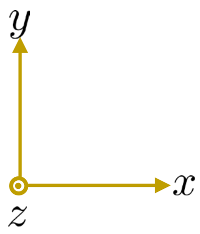

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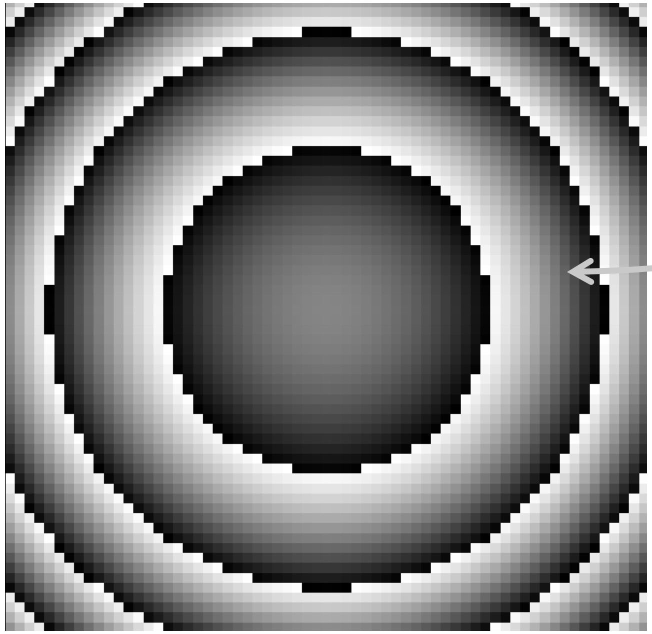
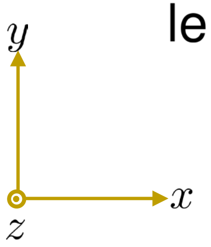


Variation of the refractive index $n(\boldsymbol{\rho}_i)$ within a layer for a focusing lens.

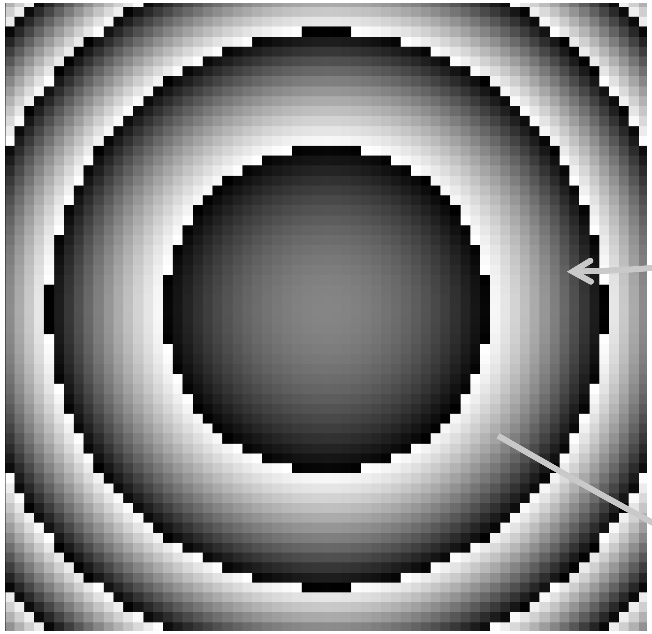
- Next, suppose that the lateral variation is implemented in a pixelated manner rather than continuously, leading to

$$\Delta\psi(\boldsymbol{\rho}_i) \bmod 2\pi \approx k_0 h\, n(\boldsymbol{\rho}_i)\,,$$

with the positions $\boldsymbol{\rho}_i$ establishing an appropriate grid, such as a Cartesian grid.

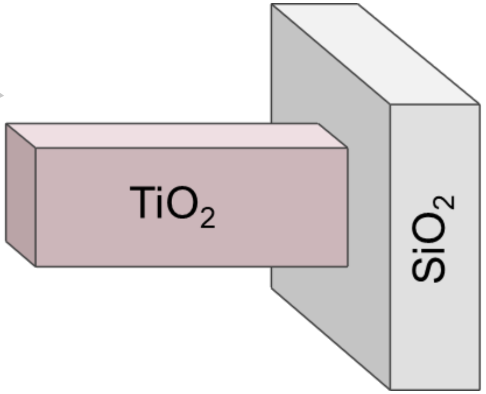


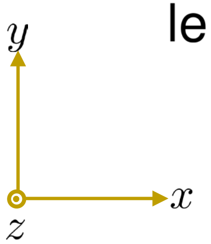
Metalenses



Variation of the refractive index $n(\boldsymbol{\rho}_i)$ within a layer for a focusing lens.

- Metasurfaces utilize a high-refractive index nanostructure for each pixel placed on a substrate with a lower refractive index to realize $n(\boldsymbol{\rho}_i)$.
- This concept requires that the distance between pixels, denoted as $\|\boldsymbol{\rho}_i - \boldsymbol{\rho}_{i+1}\|$, be less than the wavelength.





Metalenses

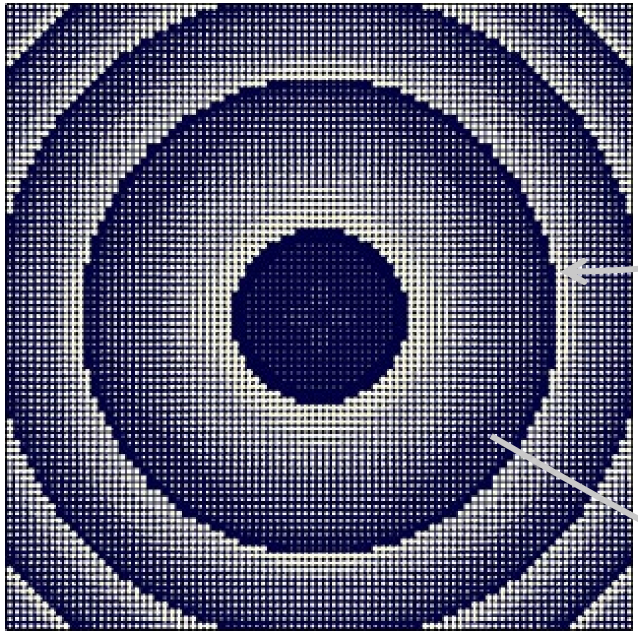


Illustration of a metalens

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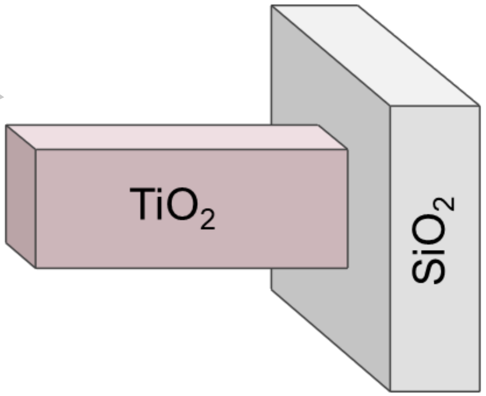
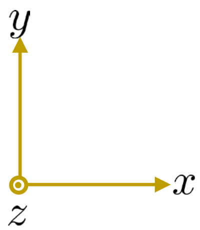
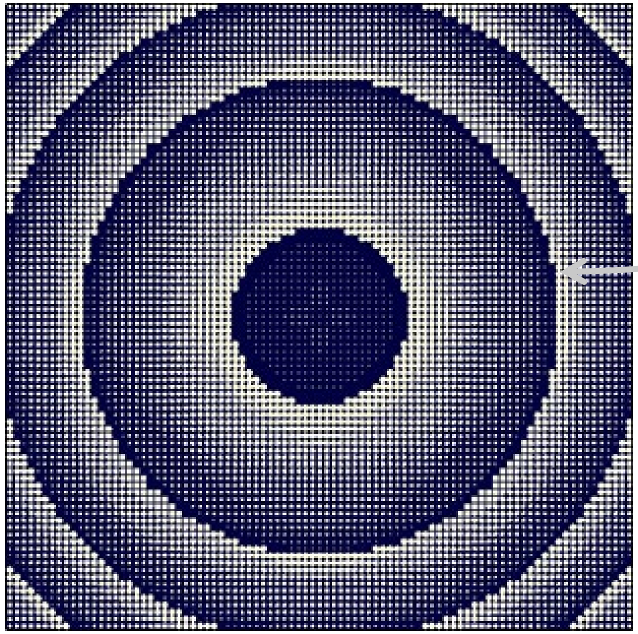




Metalenses



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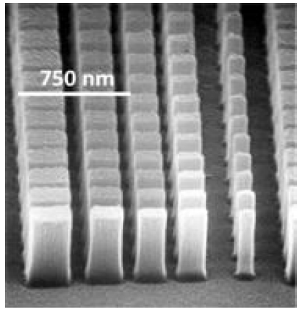
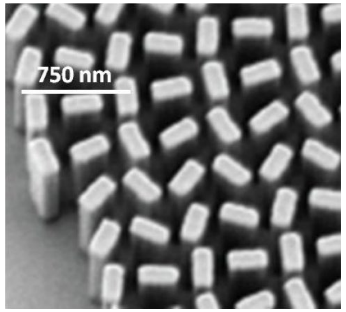
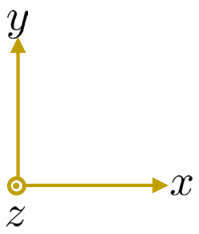
P. Lalanne *et al.*, J. Opt. Soc. Am. A **16**, 1143-1156 (1999).



M. Khorasaninejad *et al.*, Science **352**, 1190-1194 (2016).





Metalenses: Historical Background and Assessment

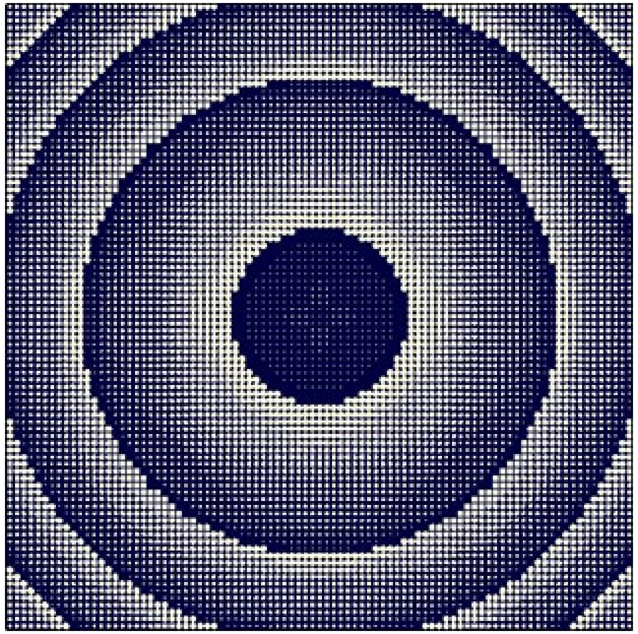


Illustration of a metalens

Recommened for an initial insightful read

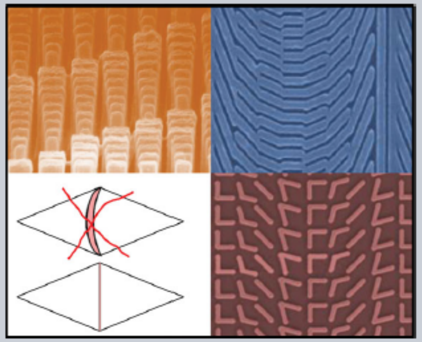
LASER & PHOTONICS REVIEWS

2017

Laser Photonics Rev. **11,** No. 3, 1600295 (2017) / **DOI** 10.1002/lpor.201600295

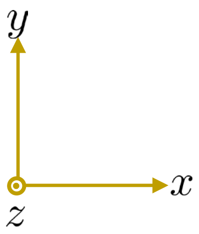
EXPERT OPINION

Abstract The so-called 'flat optics' that shape the amplitude and phase of light with high spatial resolution are presently receiving considerable attention. Numerous journal publications seemingly offer hope for great promises for ultra-flat metalenses with high efficiency, high numerical aperture, broadband operation . . . We temperate the expectation by referring to the current status of metalenses against their historical background, assessing the technical and scientific challenges recently solved and critically identifying those that still stand in the way.



Metalenses at visible wavelengths: past, present, perspectives

Philippe Lalanne[1,*] and Pierre Chavel[2,3,*]



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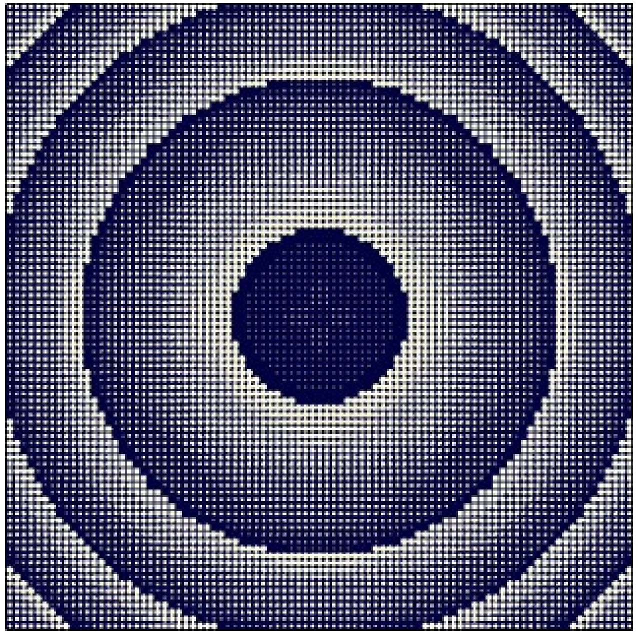

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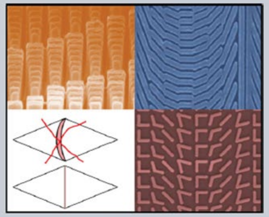


Metalenses at visible wavelengths: past, present, perspectives

Philippe Lalanne[1,*] and Pierre Chavel[2,3,*]

Tutorial

May/Jun 2023 • Vol. 5(3)

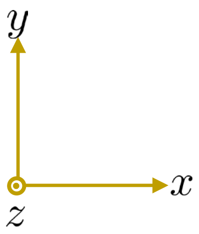
ADVANCED PHOTONICS

Wide field-of-view metalens: a tutorial

Fan Yang,[a] Mikhail Y. Shalaginov,[a] Hung-I Lin,[a] Sensong An,[a] Anu Agarwal,[a] Hualiang Zhang,[b] Clara Rivero-Baleine,[c] Tian Gu,[a,d,*] and Juejun Hu[a,d,*]

[a]Massachusetts Institute of Technology, Department of Materials Science and Engineering, Cambridge, Massachusetts, United States
[b]University of Massachusetts Lowell, Department of Electrical and Computer Engineering, Lowell, Massachusetts, United States
[c]Lockheed Martin Corporation, Orlando, Florida, United States
[d]Massachusetts Institute of Technology, Materials Research Laboratory, Cambridge, Massachusetts, United States

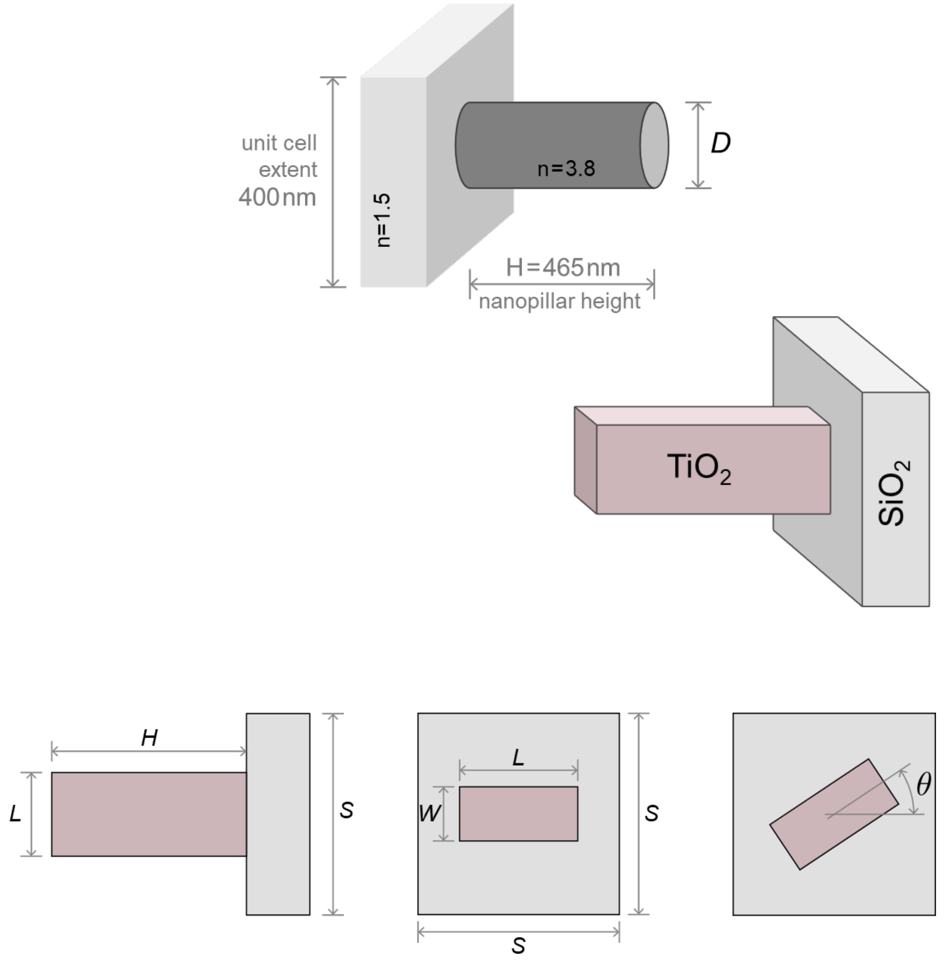
… with 220 references



Design Workflow for Metalenses

- In practical terms, the fundamental steps involved in the design of metalenses include:

  1. Choose a nanostructure, commonly known as a meta-atom or metacell, that aligns with the capabilities of your fabrication tools or collaborative partners.
  2. Analyze the phase delay of the nanostructure dependent on the structure parameters $\boldsymbol{p} = (p_1, p_2, \ldots)$, e.g. height, size, orientation, and obtain data on the phase delay $\Psi(\boldsymbol{p})$ of the metacell for the incident field $\boldsymbol{E}^{\text{in}} = \boldsymbol{U}^{\text{in}} \exp(\mathrm{i}\psi^{\text{in}})$ in $\boldsymbol{\rho}_i$.



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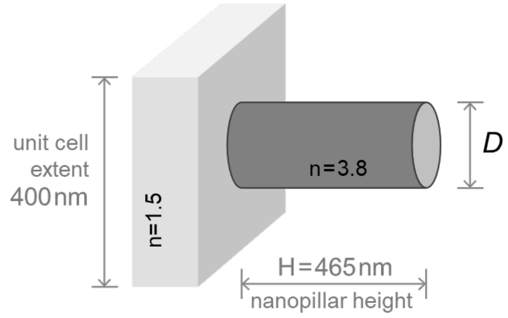
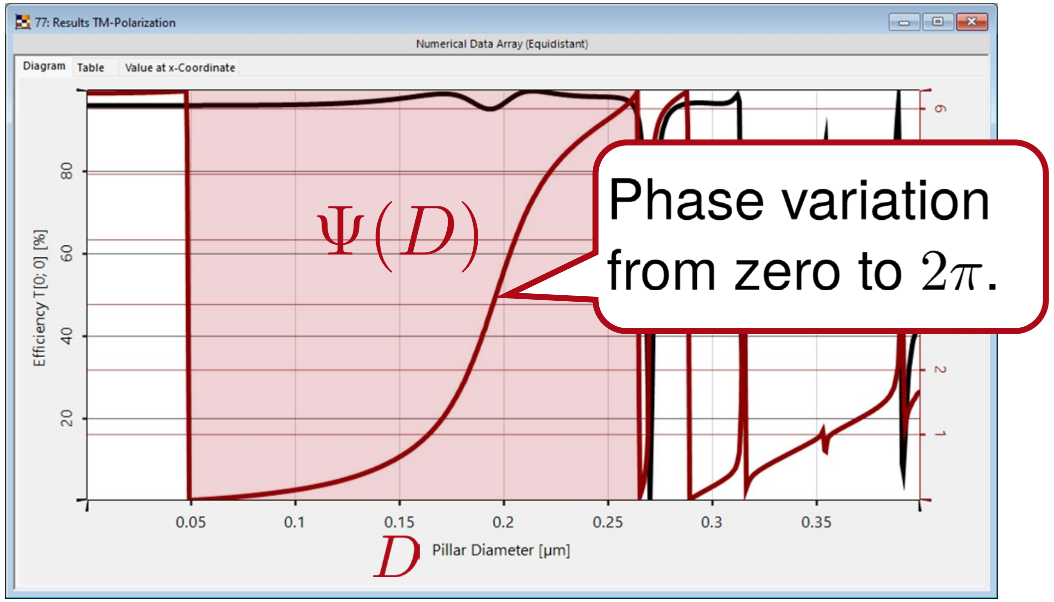




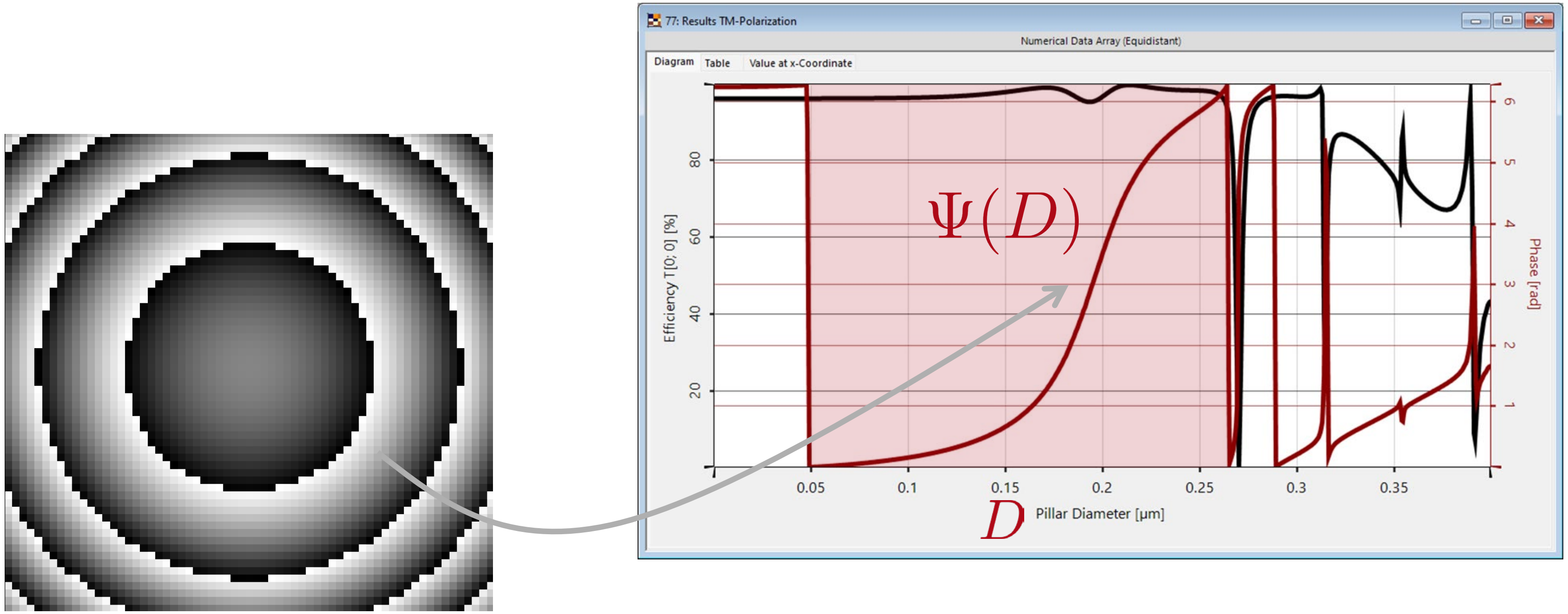
Design Workflow for Metalenses

- In practical terms, the fundamental steps involved in the design of metalenses include:

  3. Identify the parameters $\boldsymbol{p}$ such that they satisfy the following condition for each pixel $\boldsymbol{\rho}_i$:

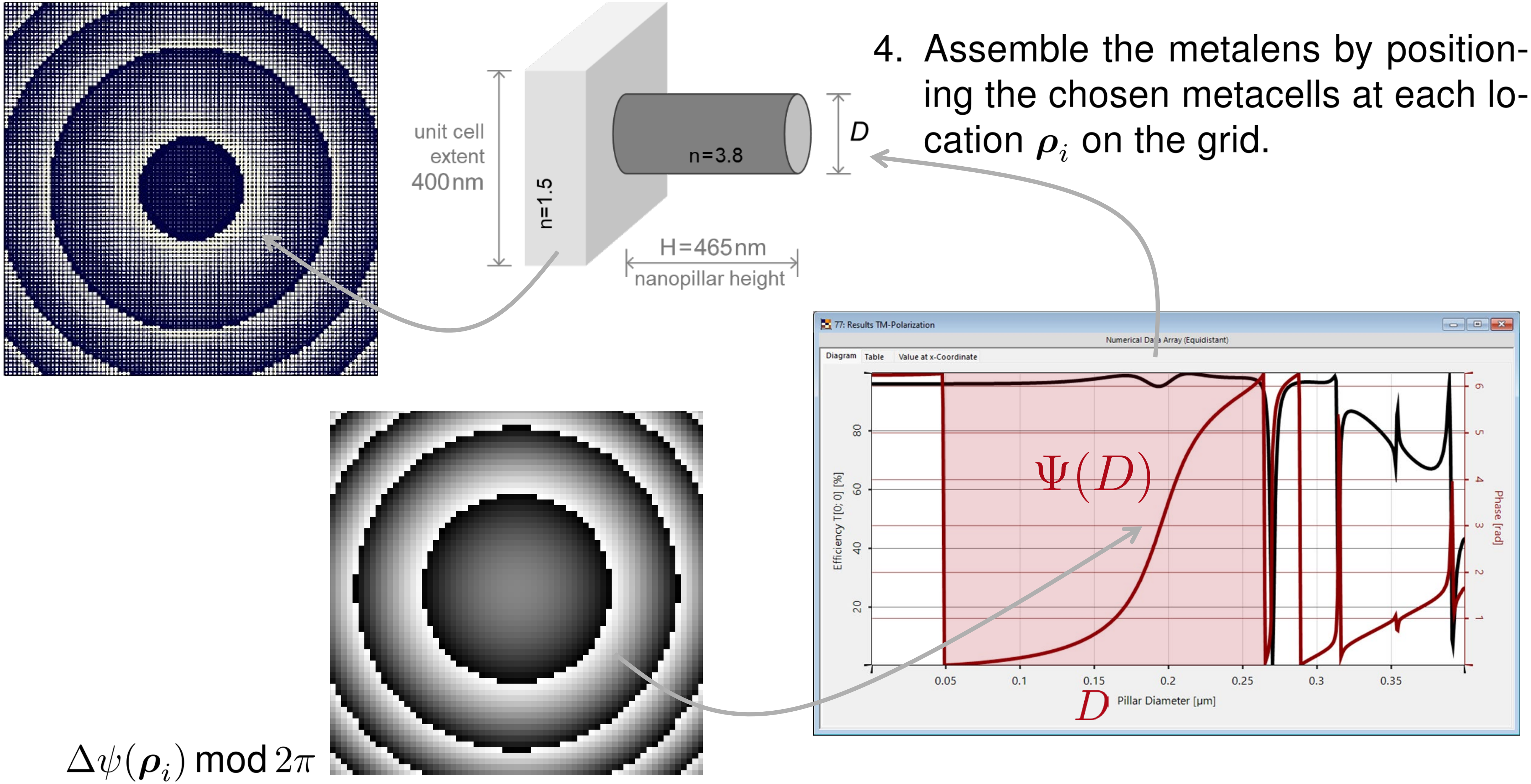
$$\Psi(\boldsymbol{p}; \boldsymbol{\rho}_i) = \Delta\psi(\boldsymbol{\rho}_i) \bmod 2\pi$$

$\Delta\psi(\boldsymbol{\rho}_i) \bmod 2\pi$



Design Workflow for Metalenses

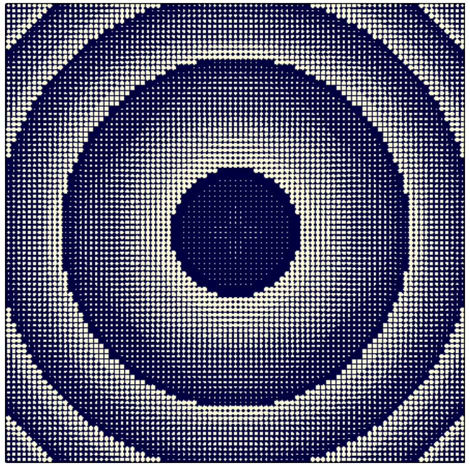
4. Assemble the metalens by positioning the chosen metacells at each location $\boldsymbol{\rho}_i$ on the grid.



Algorithm for Designing Flat Lens Metasurfaces

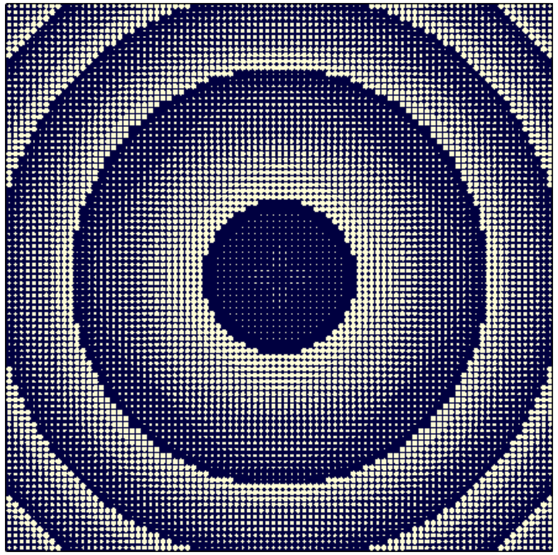
Three primary objectives are outlined that need to be achieved:

1. Design algorithms for flat lenses that are both efficient and easy to use. ✓
2. Simulation of lens systems that include flat lenses with adequate precision and speed.
3. Methods for optimizing optical systems that incorporate flat lenses.



- The described design method for meta-surfaces is available through VirtualLab Fusion software.
- The development is ongoing and new features are planned for future updates in 2025.

Design and Analysis of a Metalens: Focusing Example



Input field

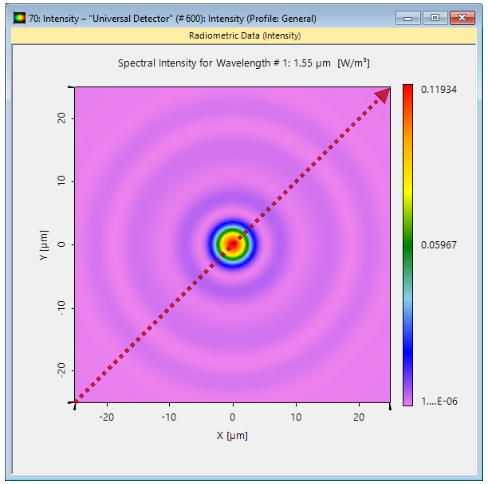
- wavelength: 1550 nm
- polarization: along x
- diameter: 70 µm × 70 µm

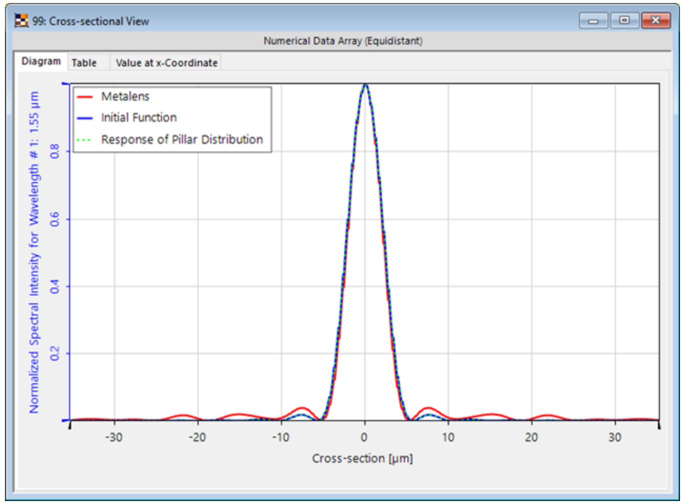
Lens

- size of unit cell: 790.5 nm × 790.5 nm
- substrate glass: 1.5
- refractive index of pillars: 2.4 (TiO_2)
- shape of pillars: cylindrical
- focal length: 200 µm (NA 0.175)

Parameters from: Bayata, Elyas; Design and Characterization of Optical Metasurface Systems, University of Washington, 2022. (https://labs.ece.uw.edu/amlab/Thesis/UWPhDThesis_Elyas_Bayati_Final.pdf)

Analysis of Focal Spot



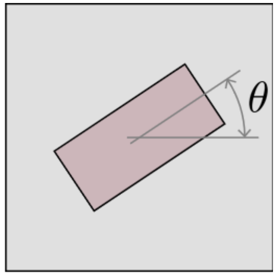


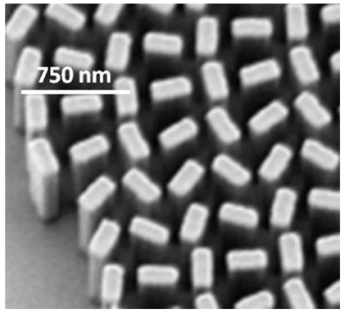
Metalens System Modeling

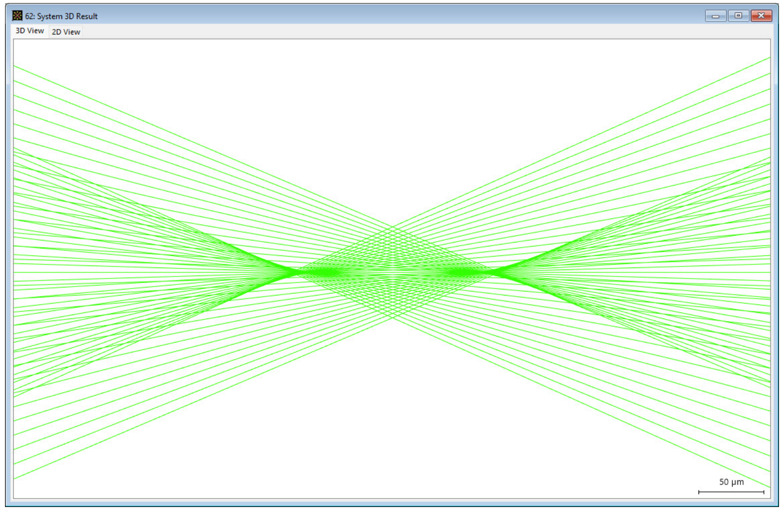
Three primary objectives are outlined that need to be achieved:

1. Design algorithms for flat lenses that are both efficient and easy to use.
2. Simulation of lens systems that include flat lenses with adequate precision and speed.
3. Methods for optimizing optical systems that incorporate flat lenses.

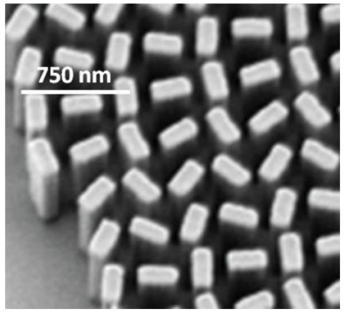
Meta-atom







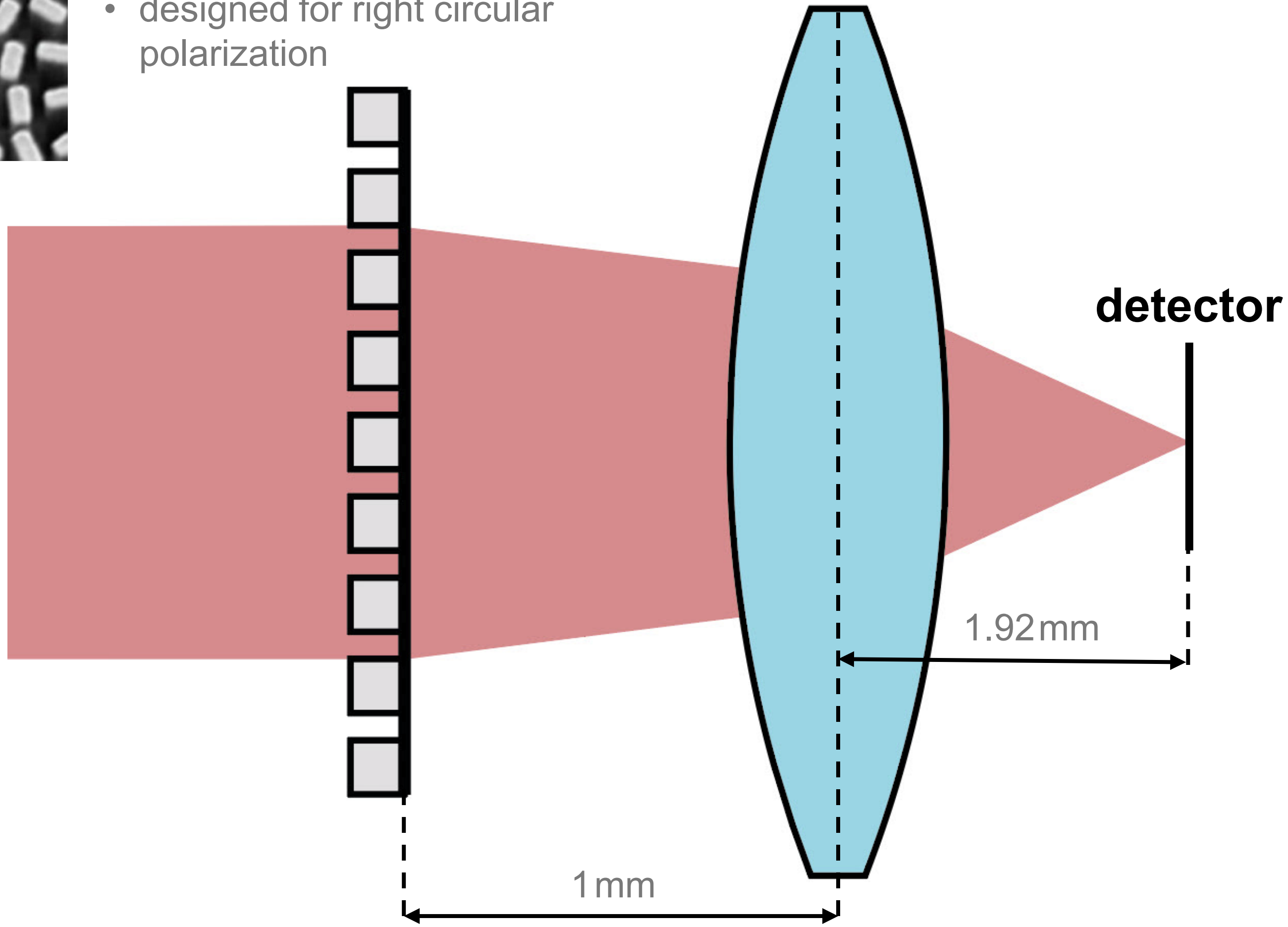
Polarization-Controlled Bifocal System



focusing meta lens
- focal length: 60 mm
- diameter: 2 mm
- designed for right circular polarization

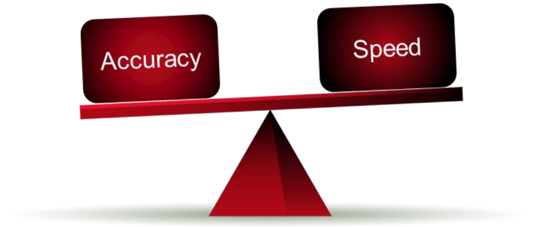
focusing lens
- focal length: 2 mm

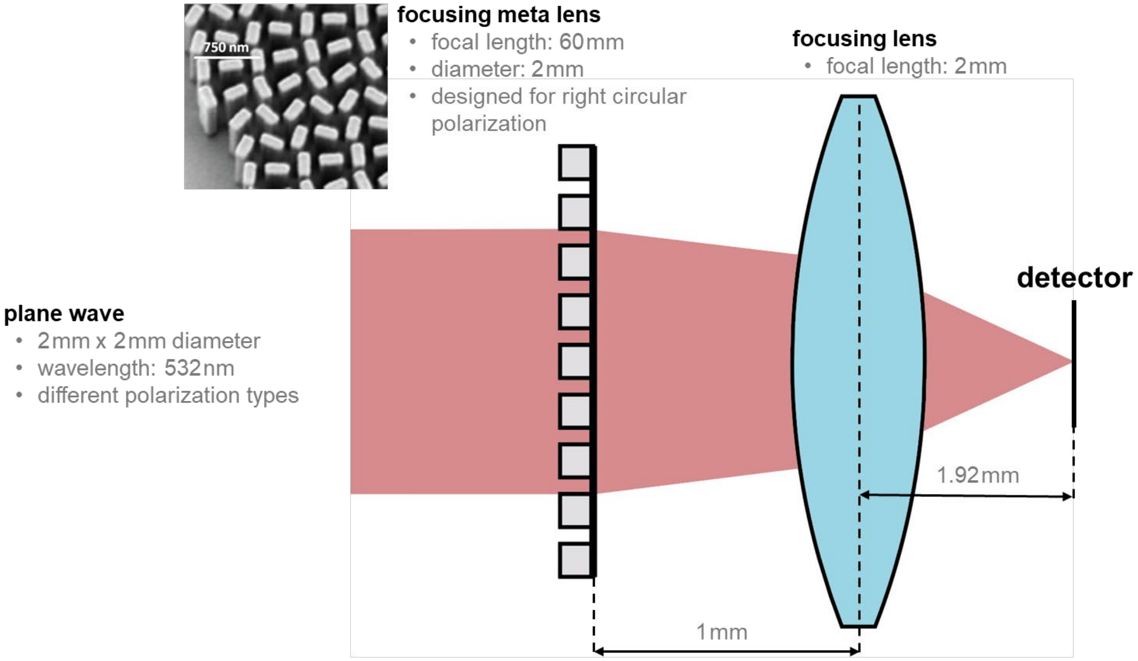
plane wave
- 2 mm x 2 mm diameter
- wavelength: 532 nm
- different polarization types



Polarization-Controlled Bifocal System

- The metalens is simulated through a quick and approximated model, demonstrating the polarization-sensitive focal length of the meta-lens while overlooking some effects of stray light.
- The modeling approach is compatible with the advanced fast lens system modeling technology used in VirtualLab Fusion.
- The selected **balance between modeling accuracy and speed** allows the simulation of the system in seconds.





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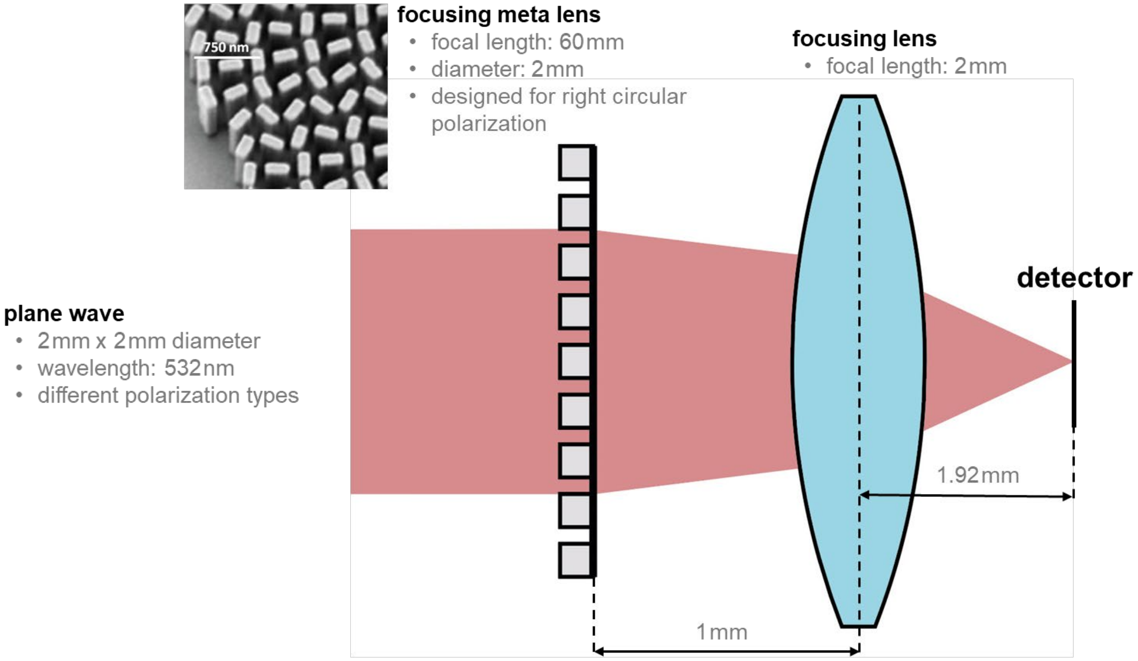
- The selected **balance between modeling accuracy and speed** allows the simulation of the system in seconds.

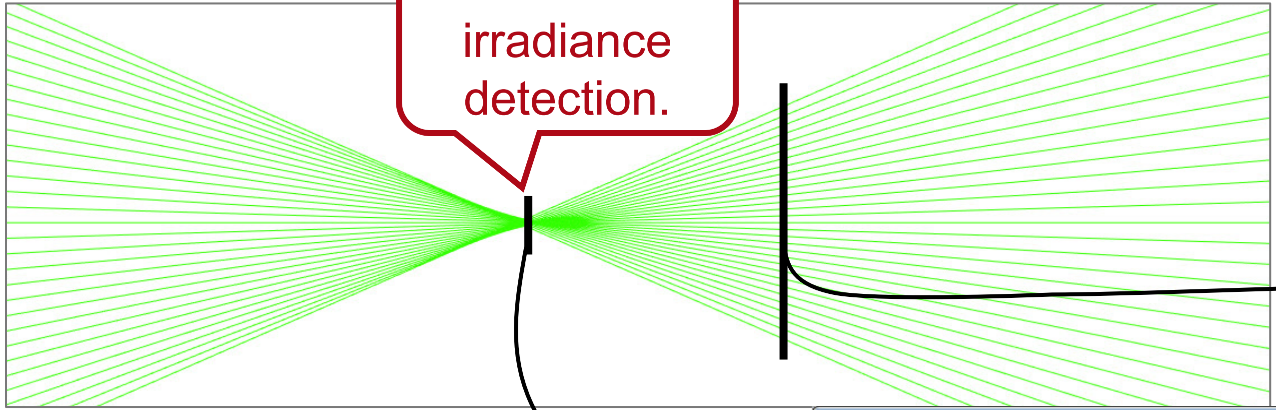
Simulation time a few seconds

computer type	local notebook
available cores	8
processor	11th Gen Intel® Core ™ i9
RAM	32 GB
graphics cards	NVDIA RTX A3000 Laptop GPU

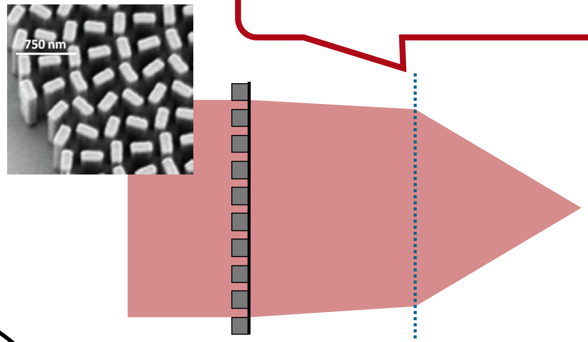


Modeling Results: Functional Lens

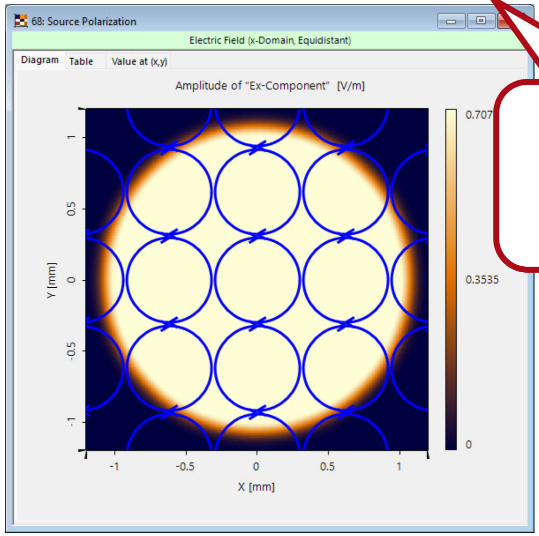
Planes for irradiance detection.



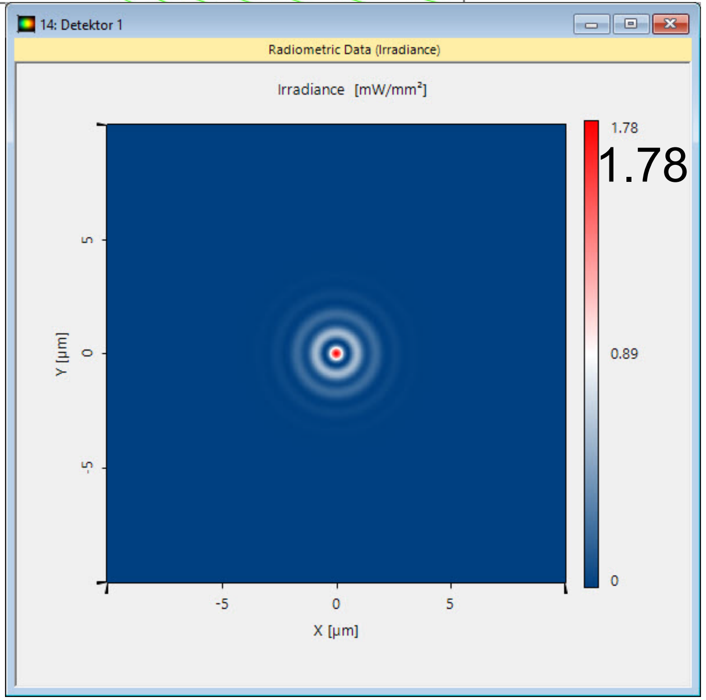
Functional

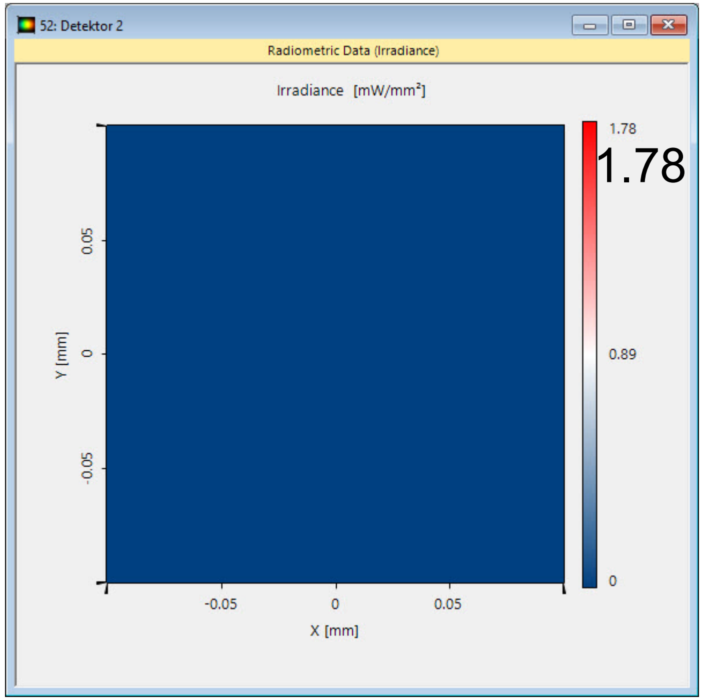


Right Circular Polarization



Polarization of incoming light





1.78

1.78

Modeling Results: Functional Lens

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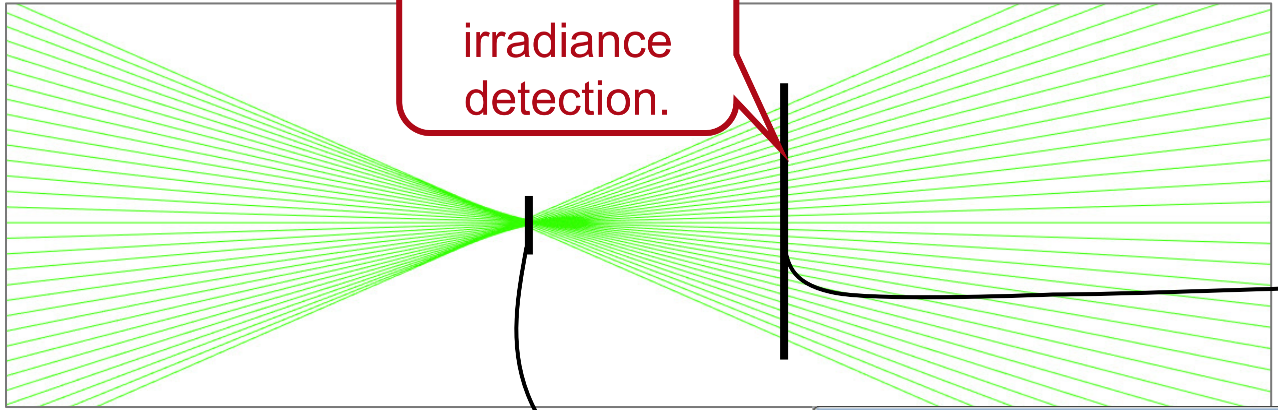

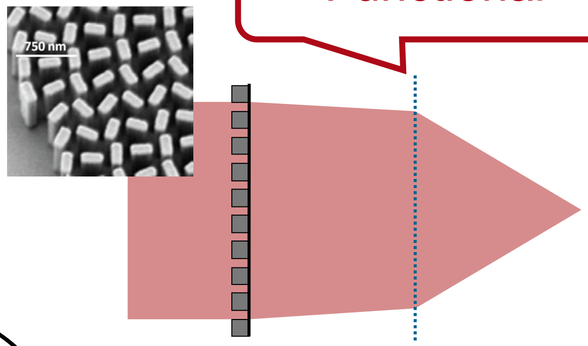

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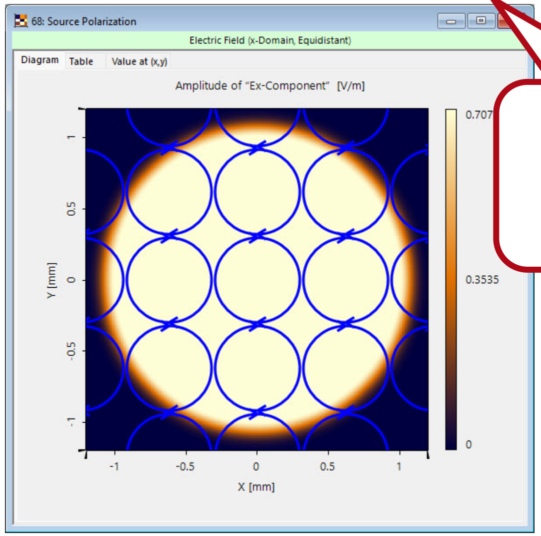

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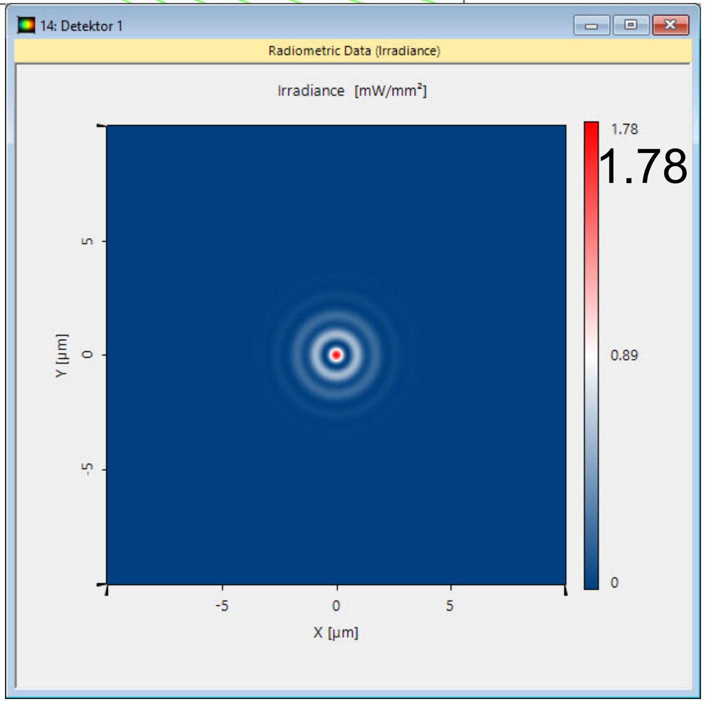

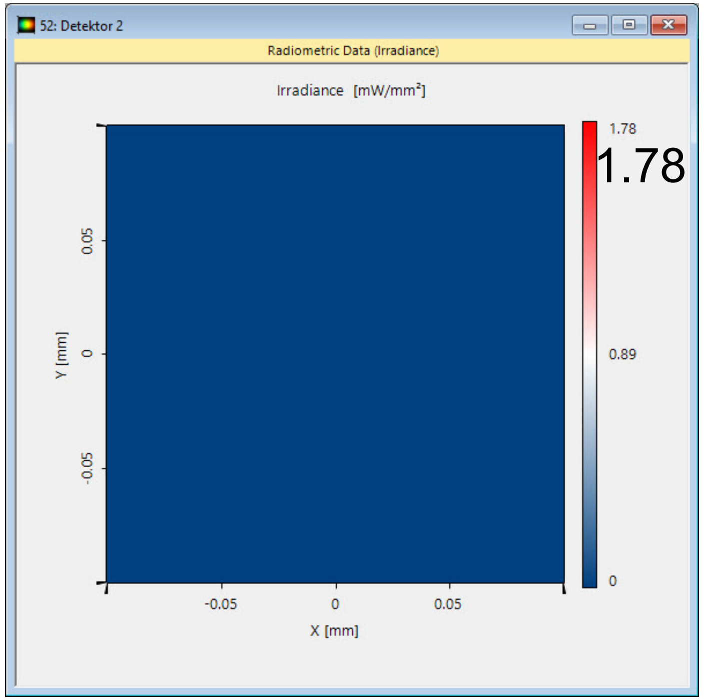

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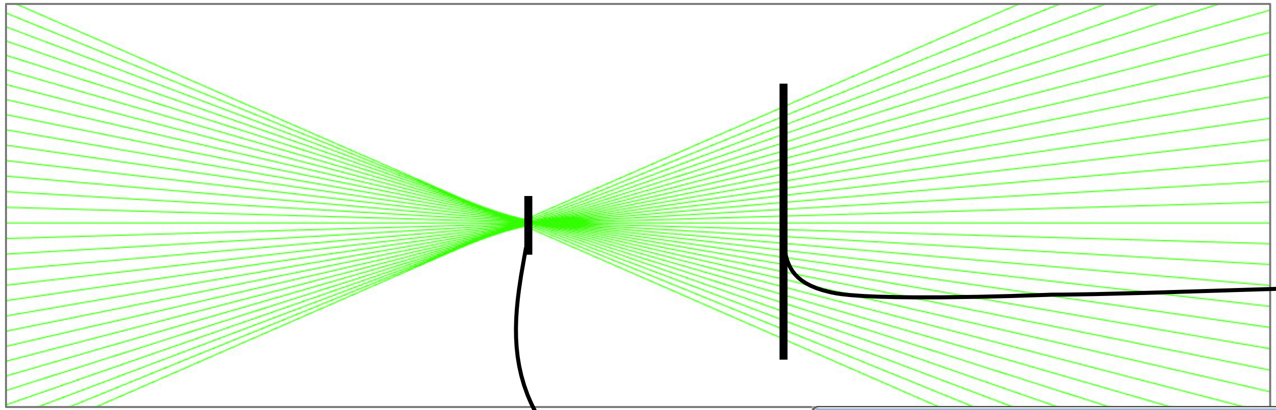

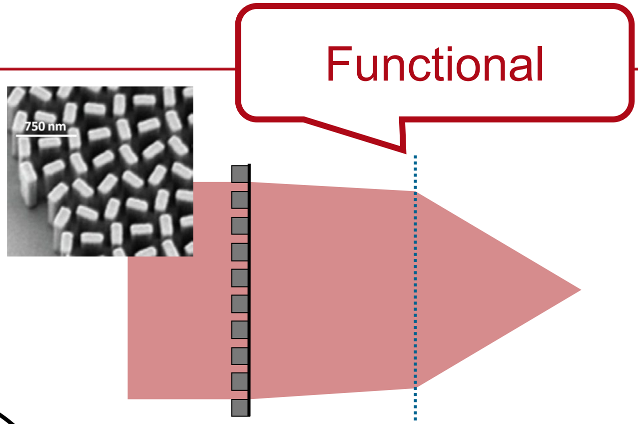

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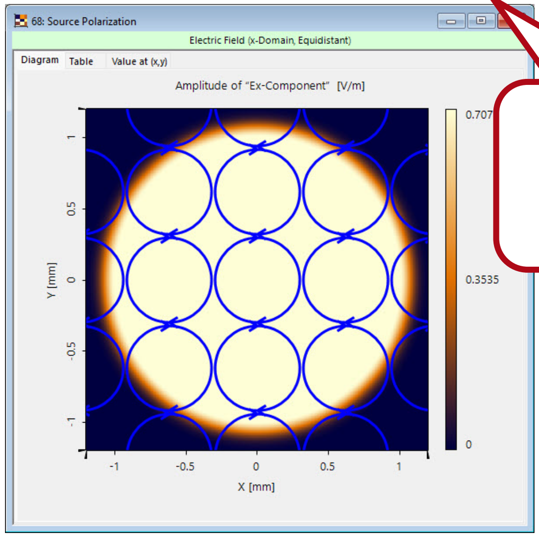

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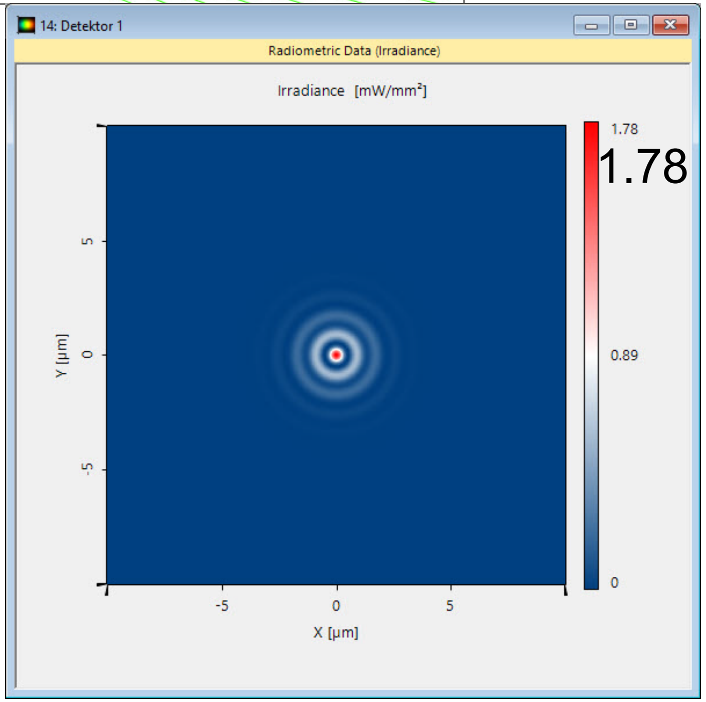

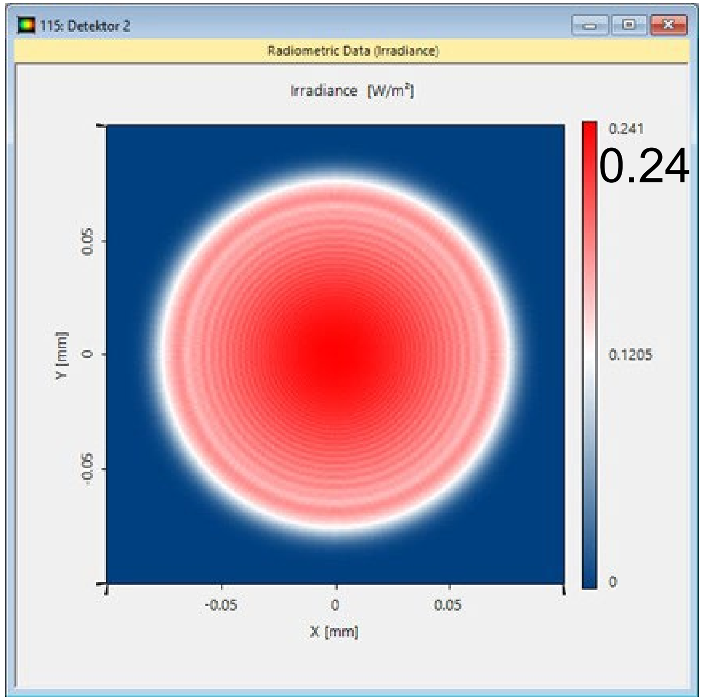

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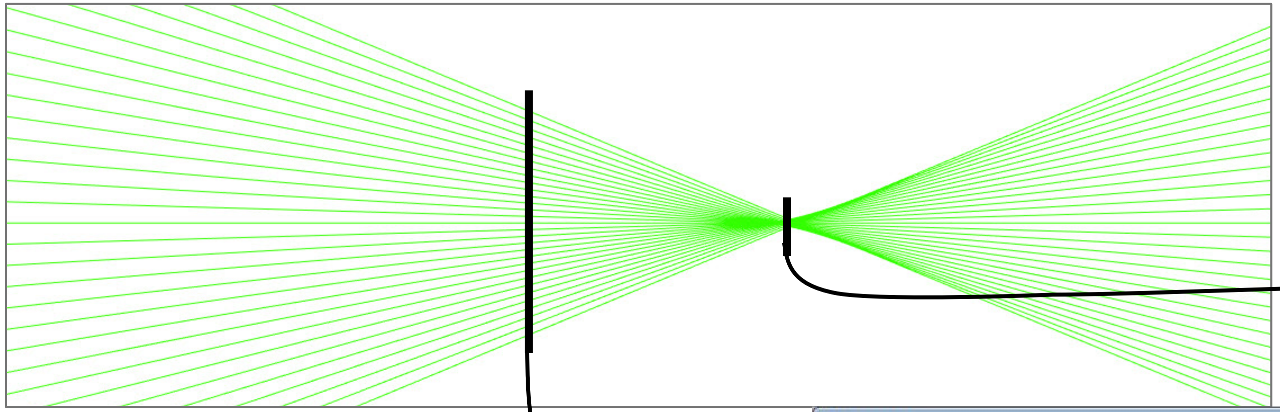
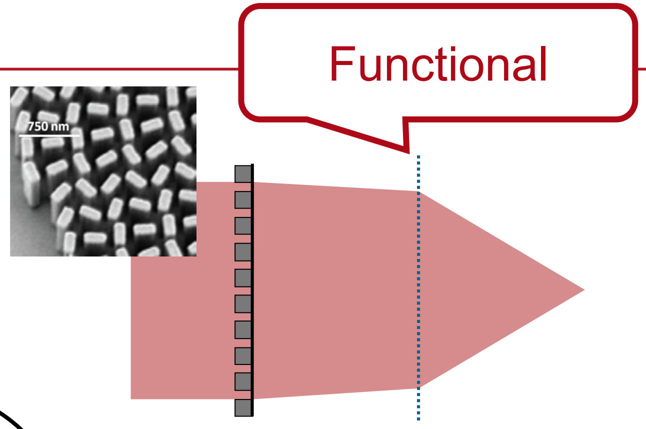
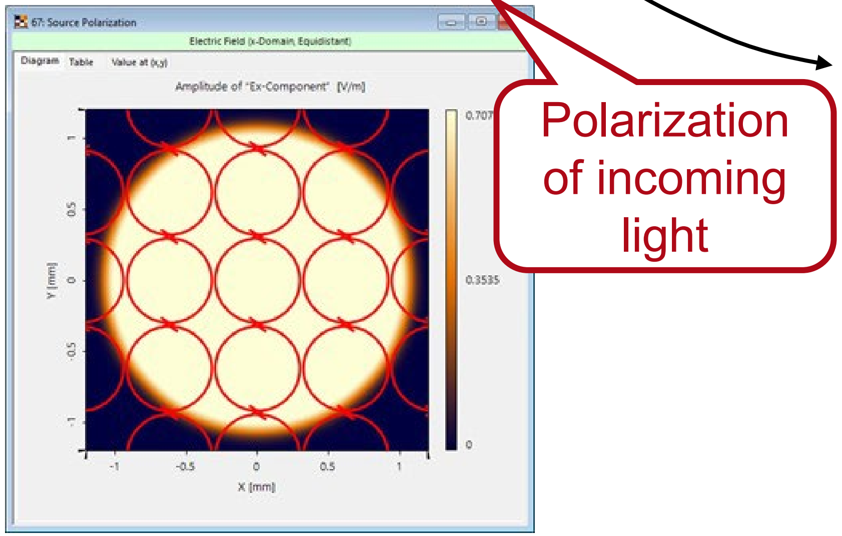
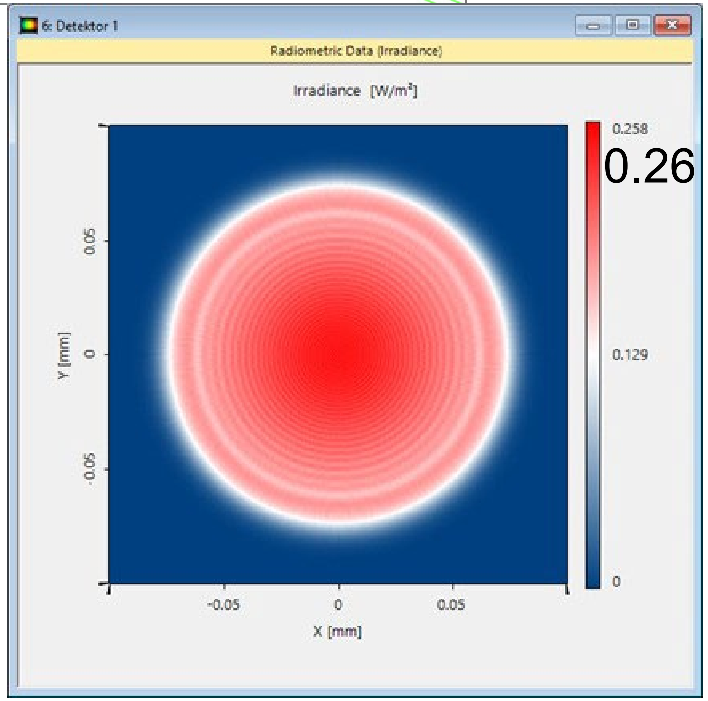
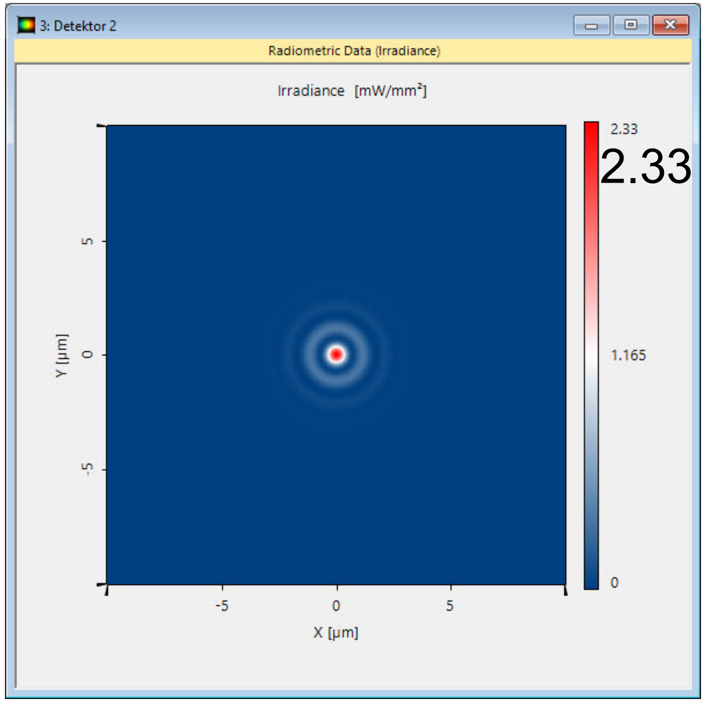




Left Circular Polarization







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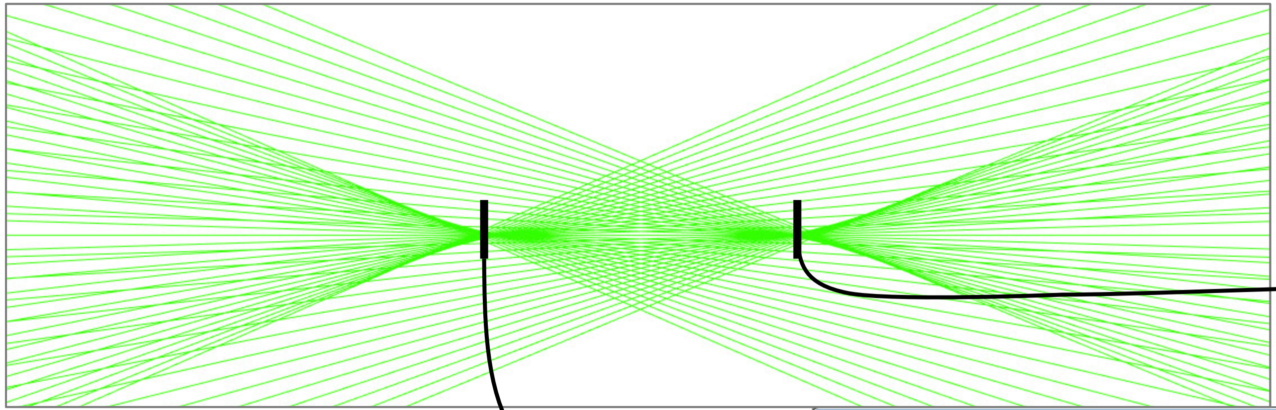
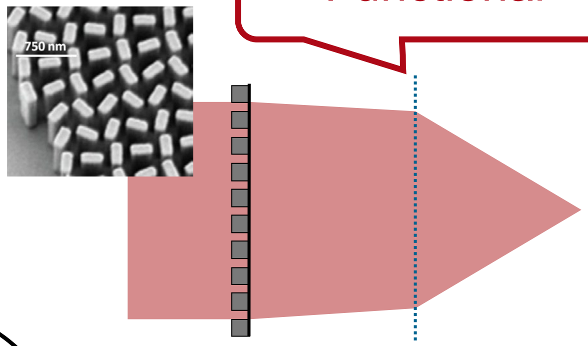
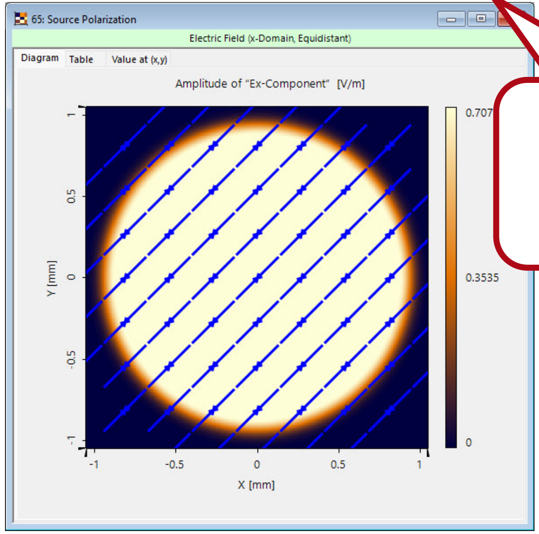


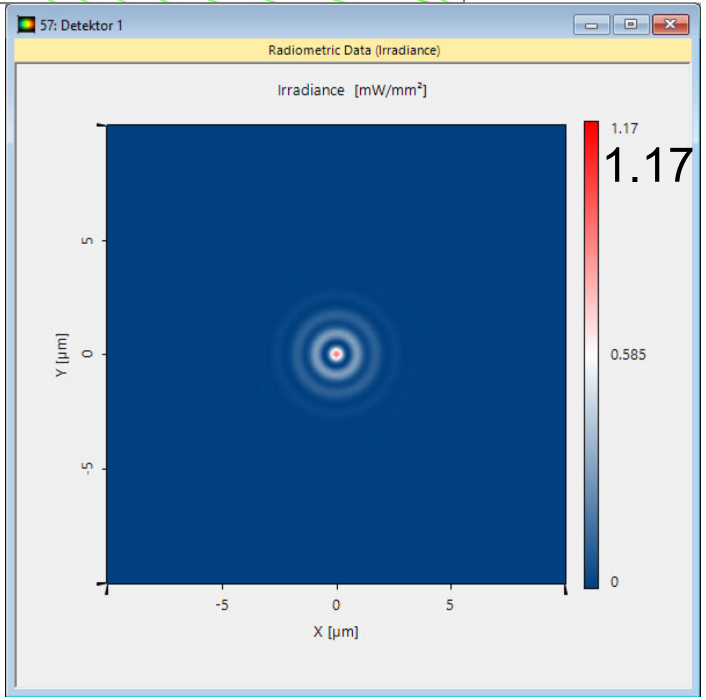
Functional

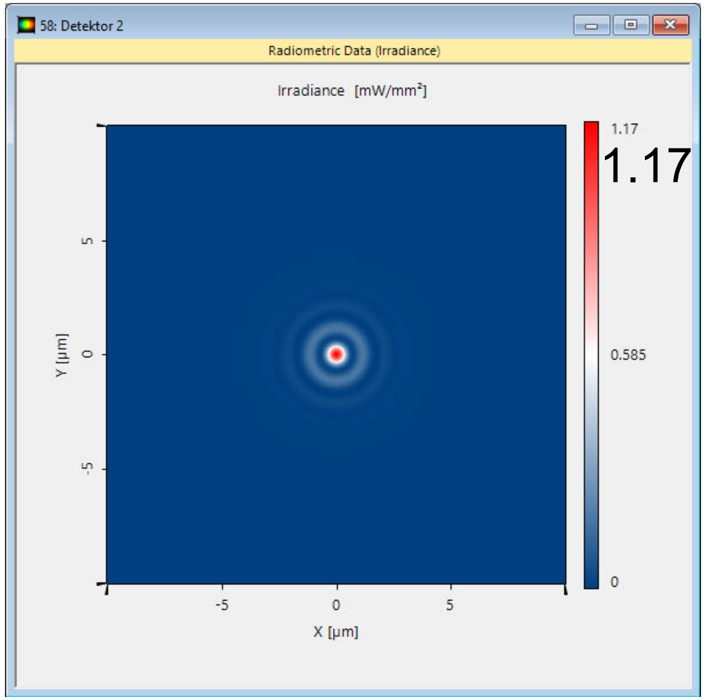


45° Linear Polarization

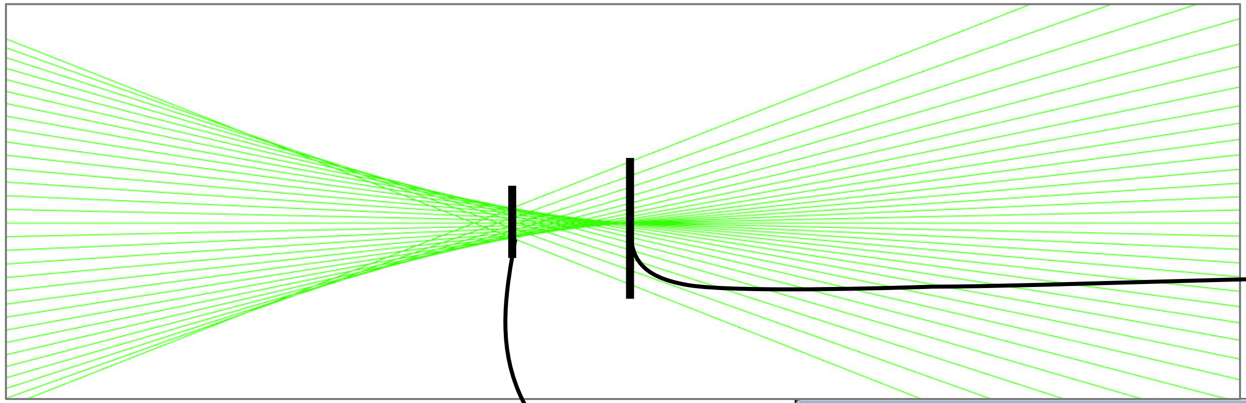


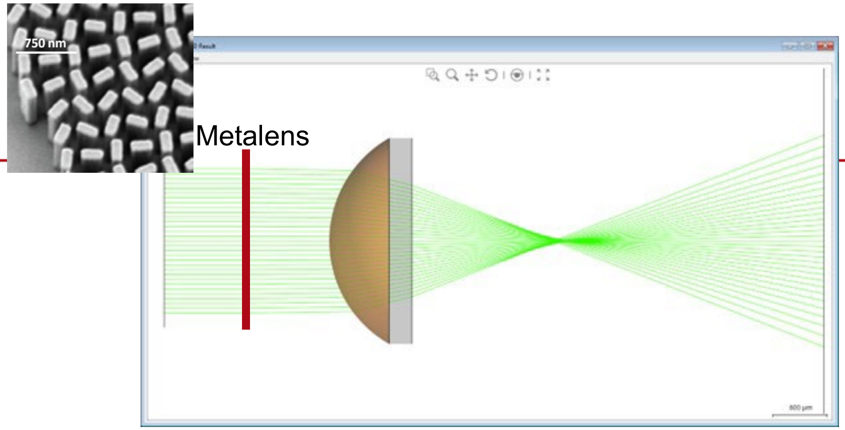
Polarization of incoming light



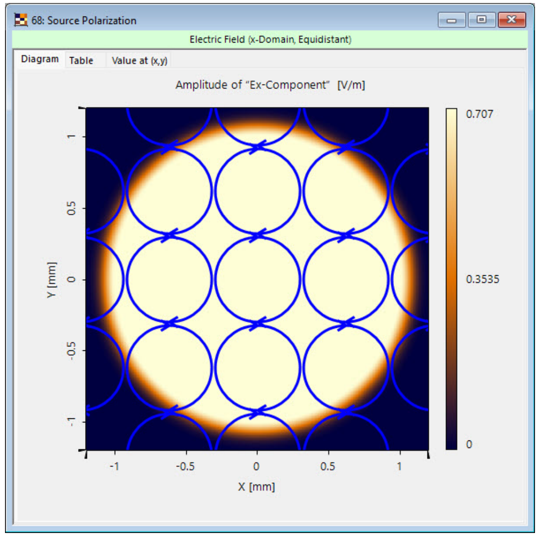


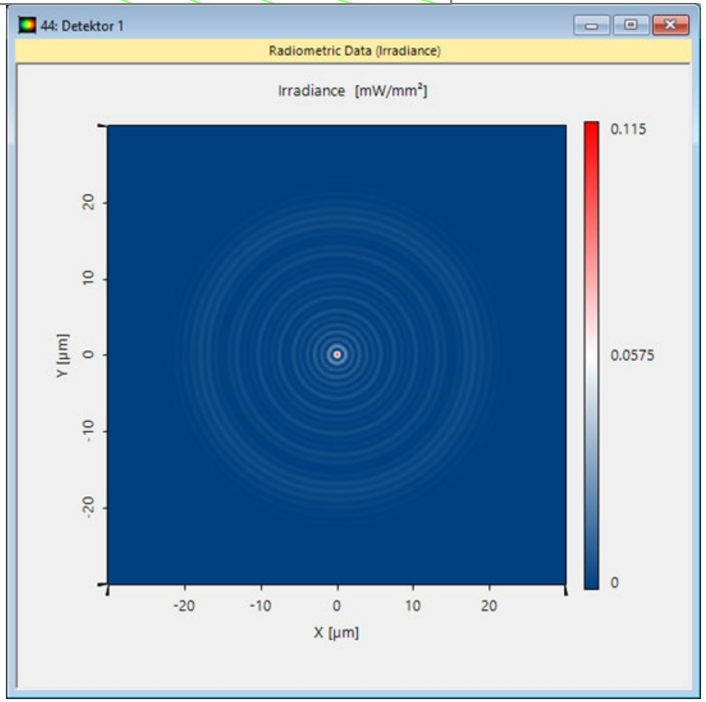
Modeling Results: Spherical Lens

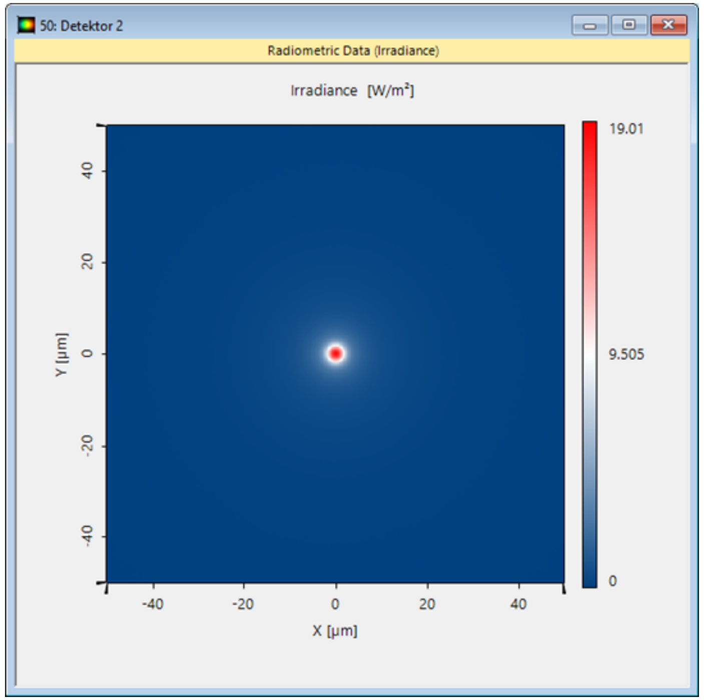




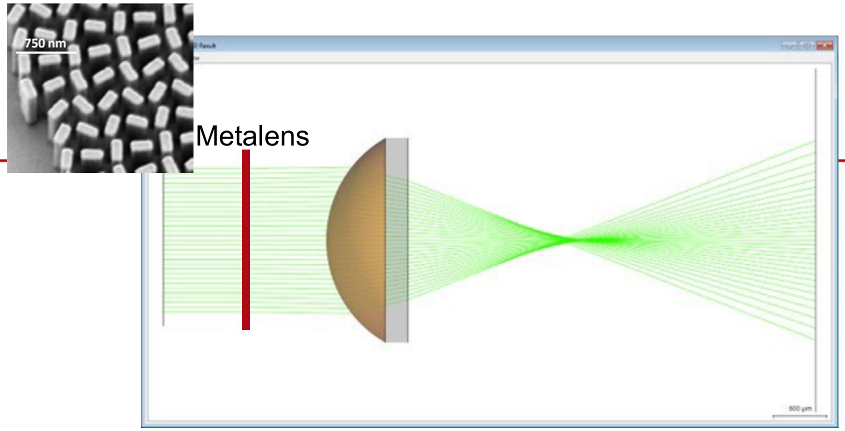
Right Circular Polarization

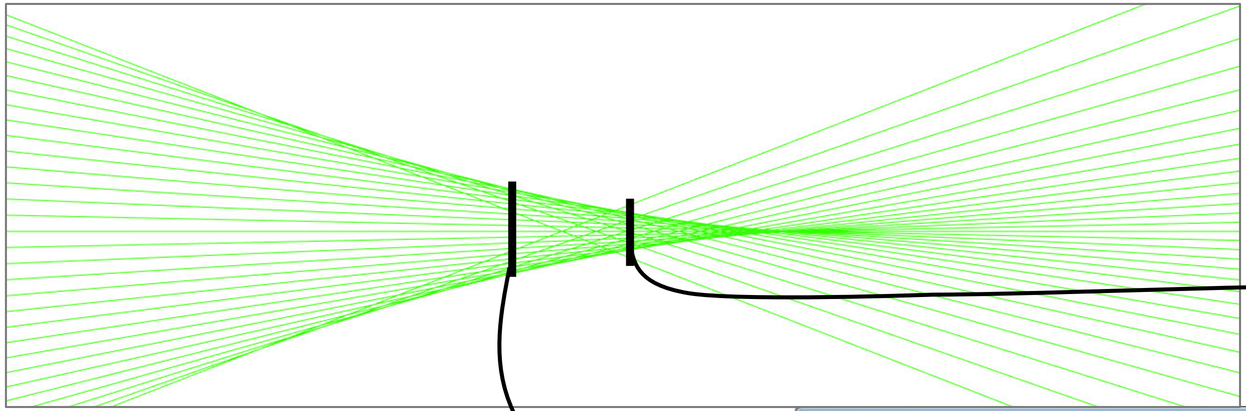




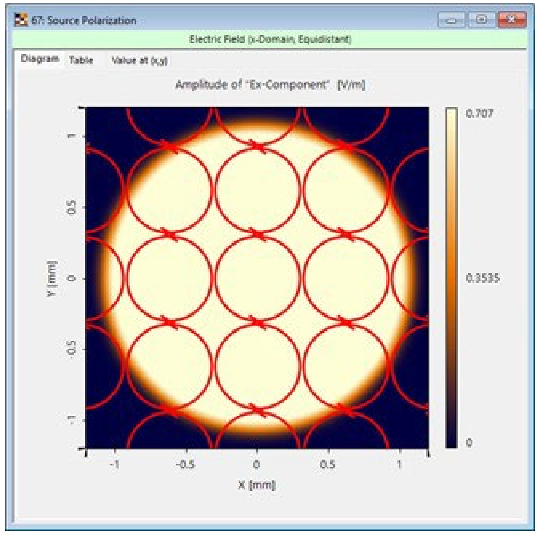


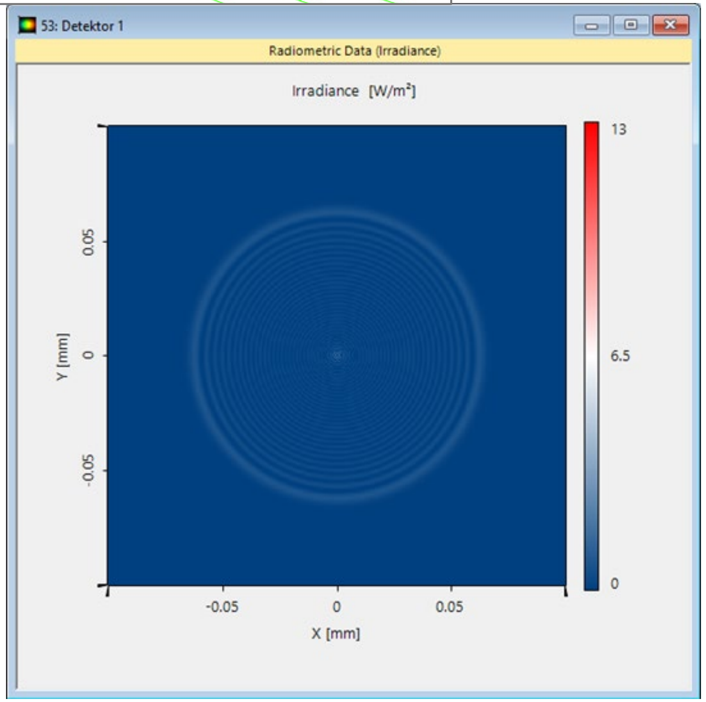
Modeling Results: Spherical Lens

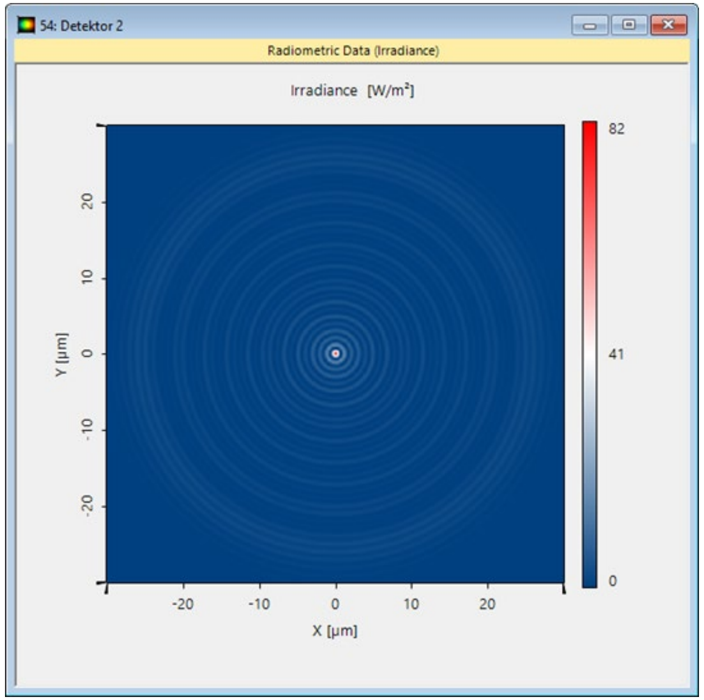




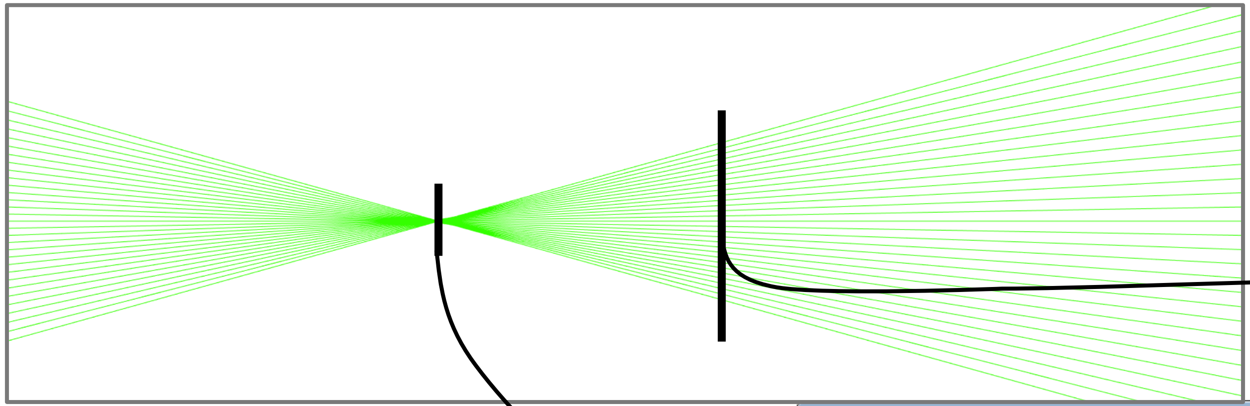
Left Circular Polarization

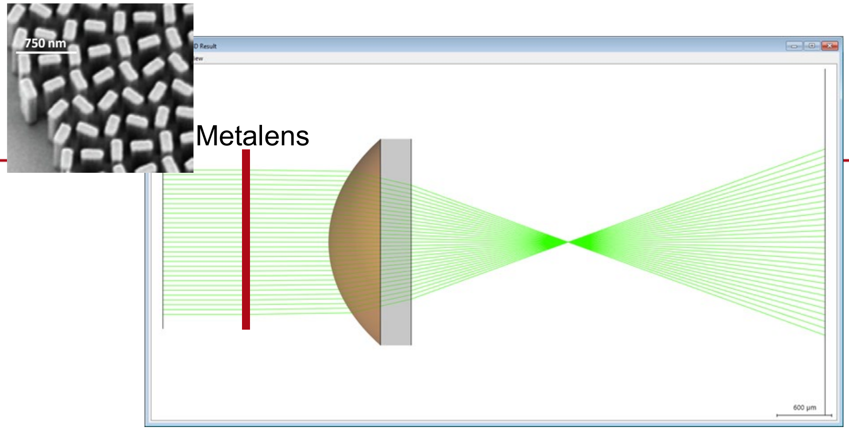




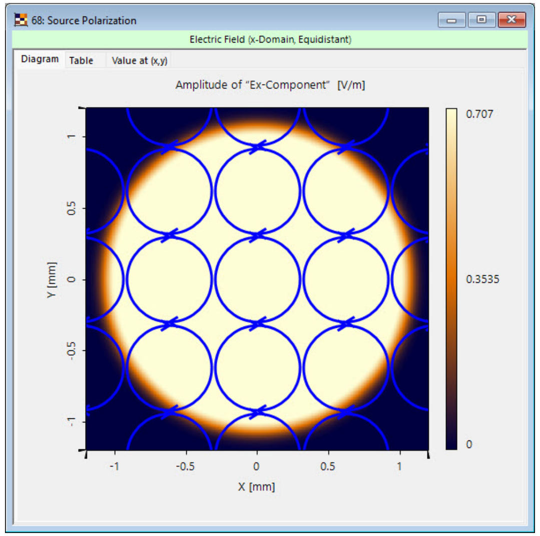


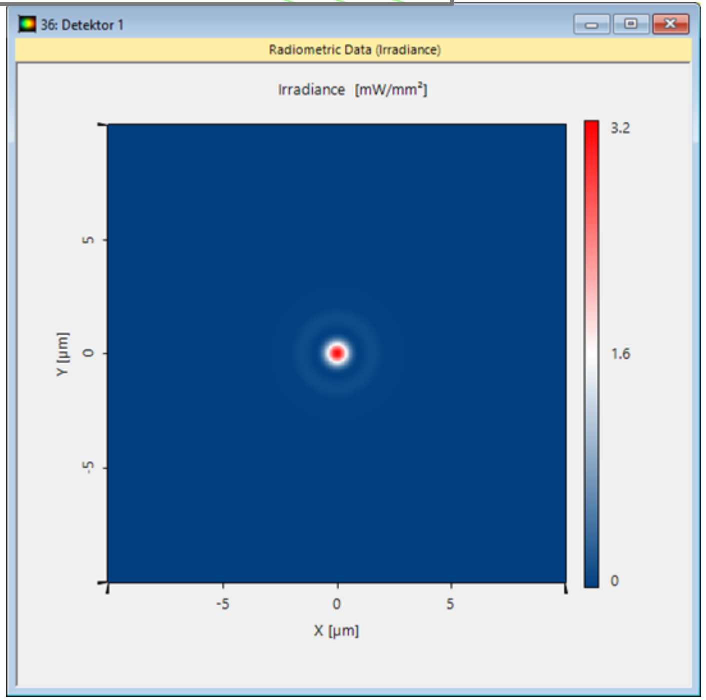
Modeling Results: Aspherical Lens

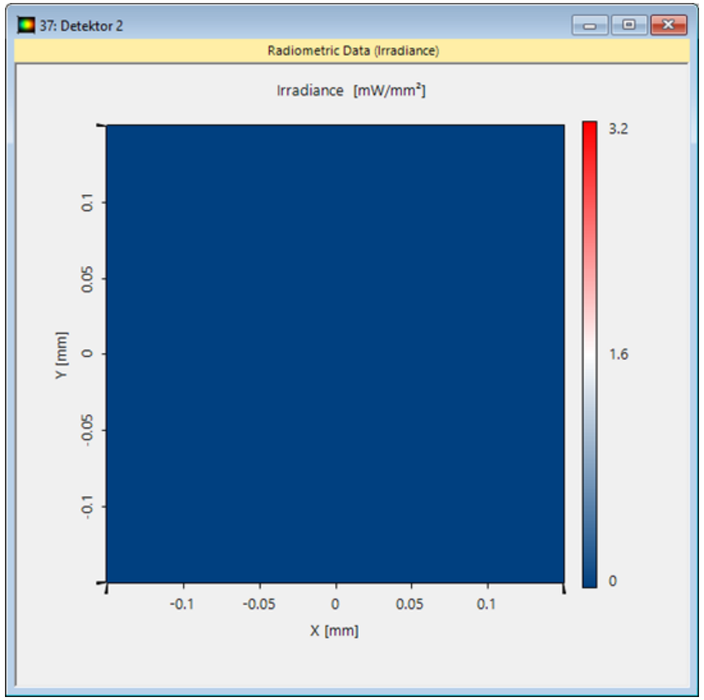




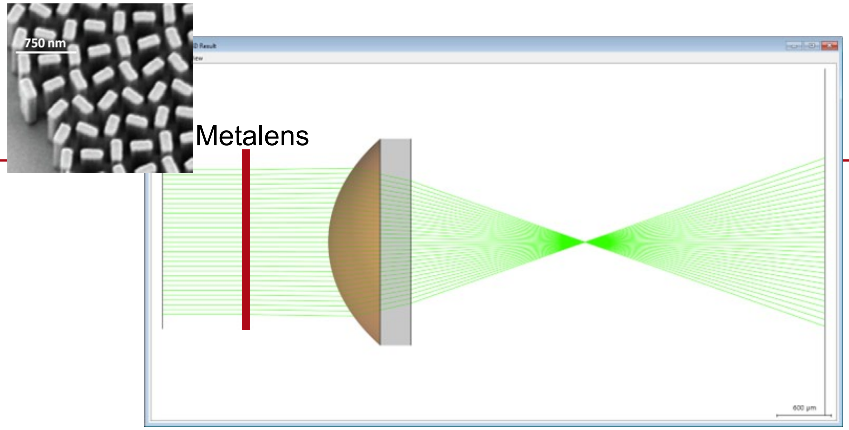
Right Circular Polarization

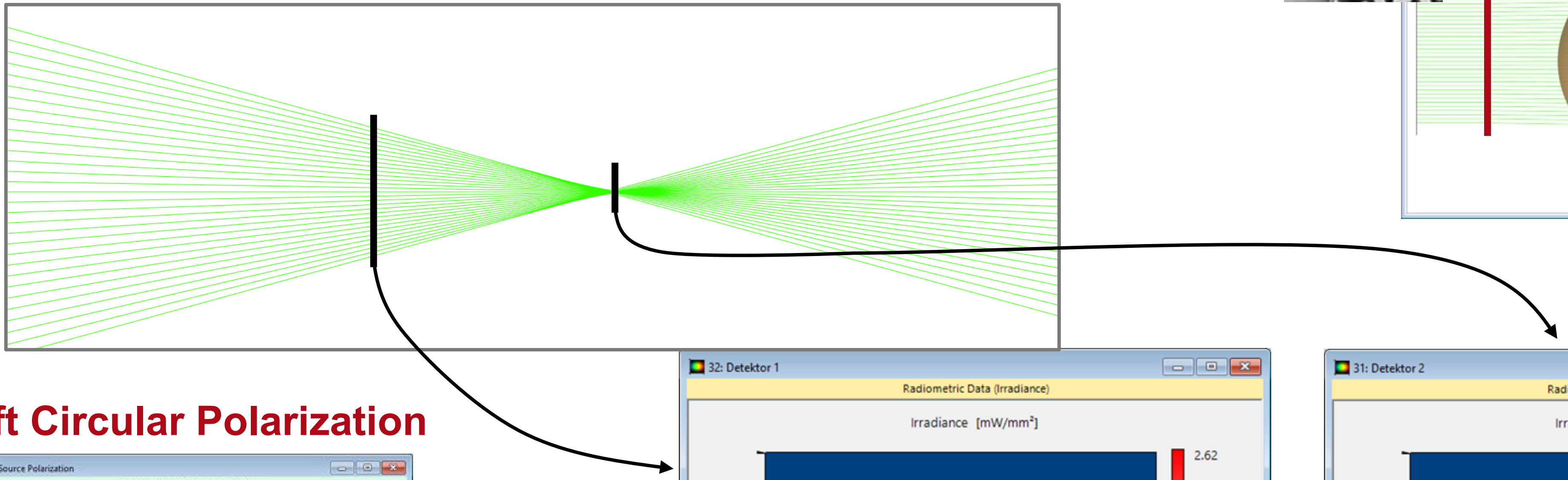




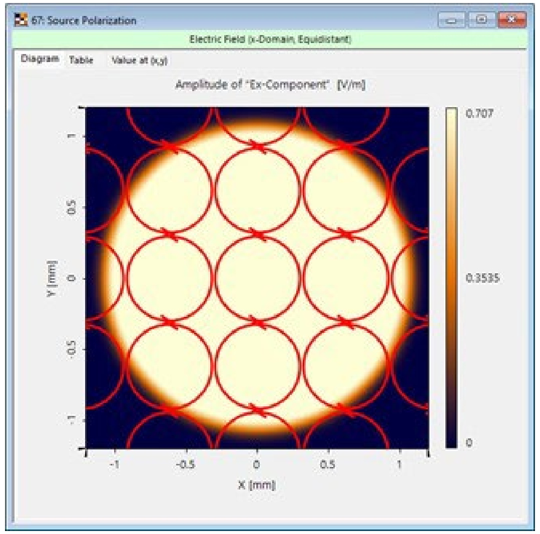


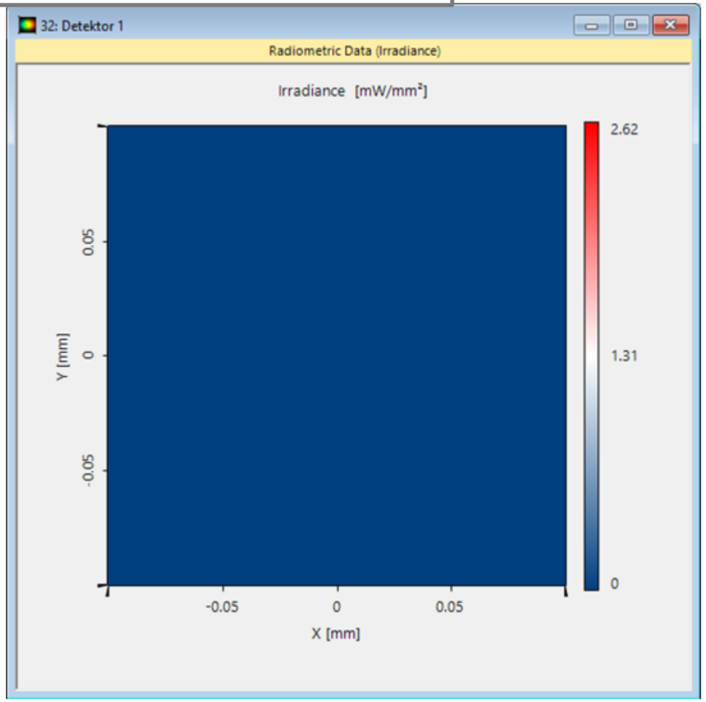
Modeling Results: Aspherical Lens

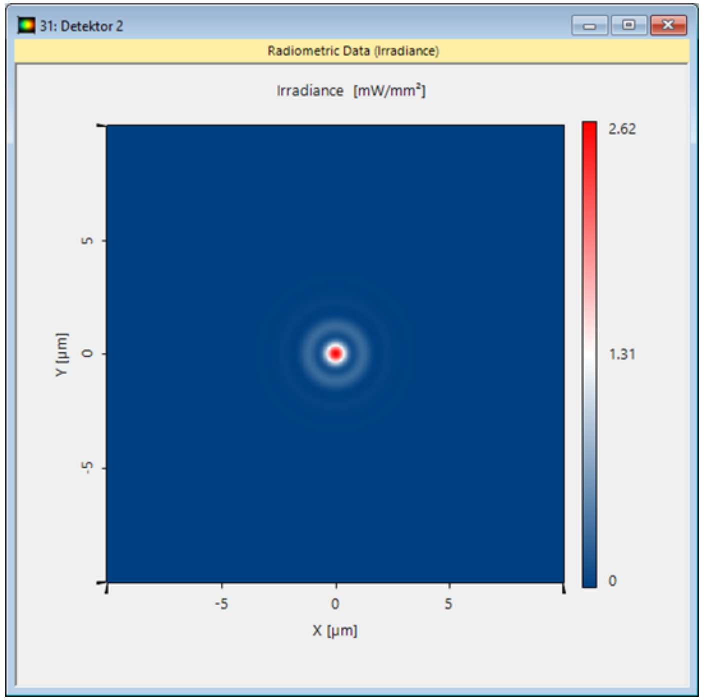




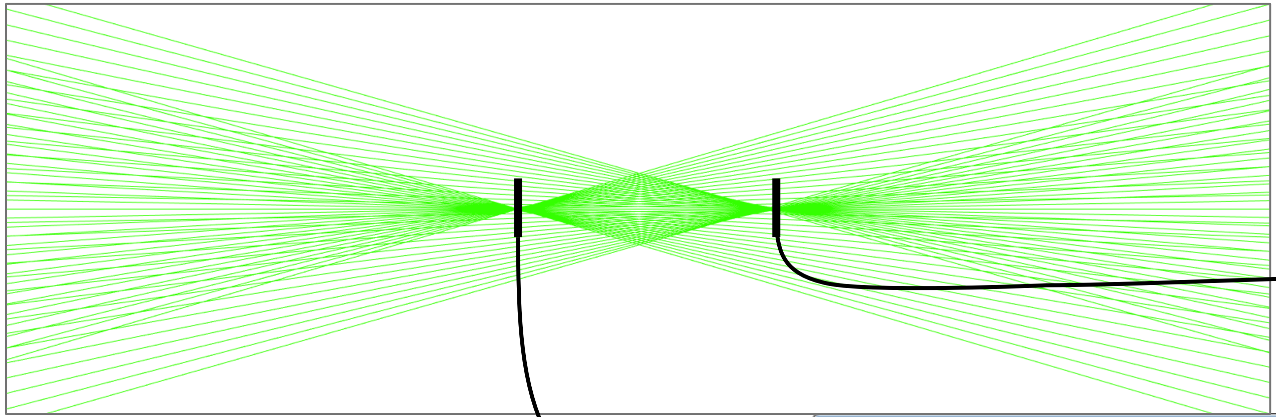
Left Circular Polarization

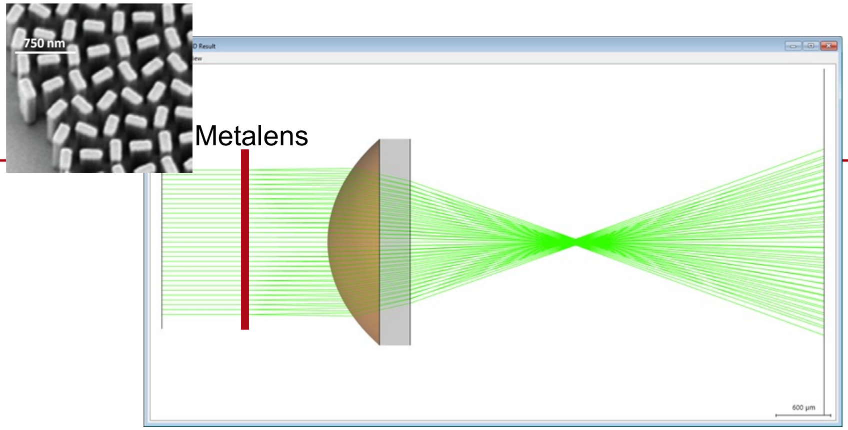




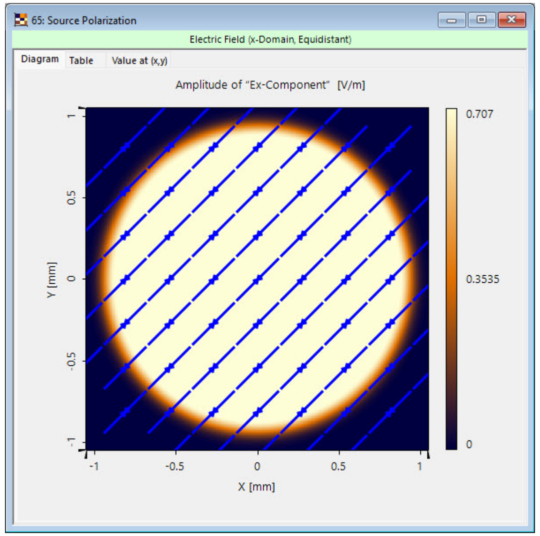


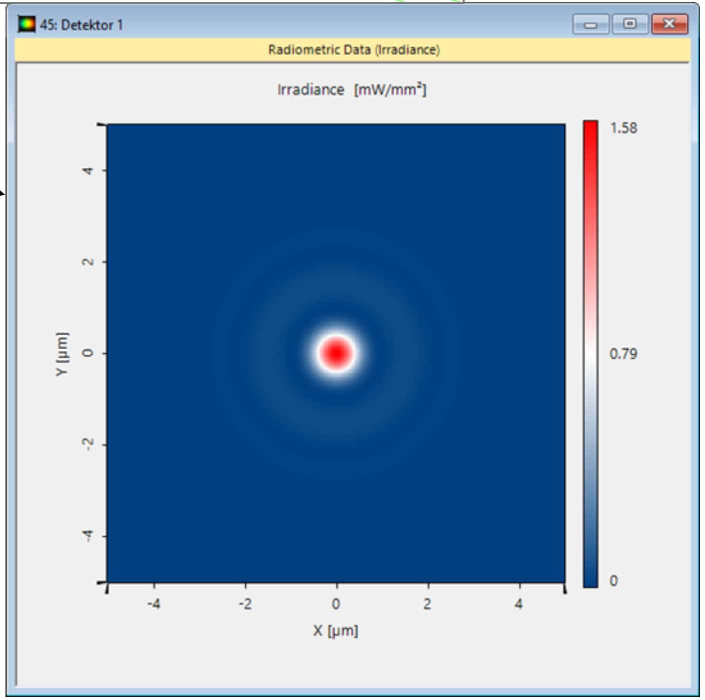
Modeling Results: Aspherical Lens

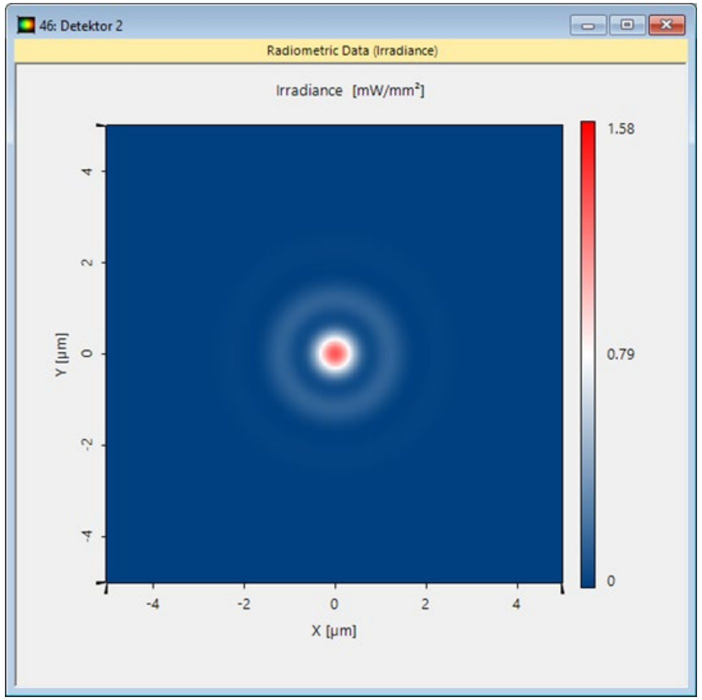




45° Linear Polarization







Metalens System Modeling

Three primary objectives are outlined that need to be achieved:

1. Design algorithms for flat lenses that are both efficient and easy to use.
2. Simulation of lens systems that include flat lenses with adequate precision and speed.
3. Methods for optimizing optical systems that incorporate flat lenses.

For more information see article on metalenses.

Summary

- Flat lenses represent a significant and fascinating enhancement to the toolkit available for optical design, particularly in the fields of imaging and illumination.
- The effectiveness and utility of flat lenses are highly dependent upon the context in which they are applied.
- **Ultimately, it is essential to incorporate flat lens technology into lens design workflows to fully grasp and take advantage of their potential.**
- At LightTrans, we are committed to significant advancements in realizing this important objective through our software VirtualLab Fusion in 2024.
- Stay tuned for more updates!