Adjoint Optimisation of Multi-Angle Achromatic Metalenses

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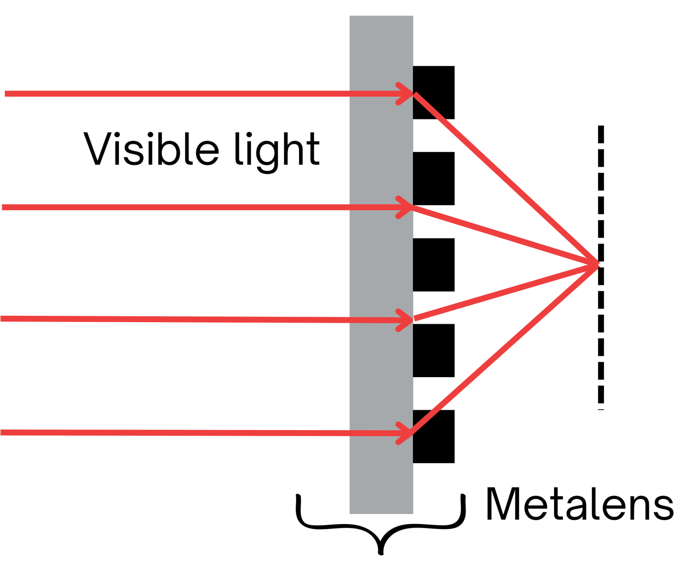
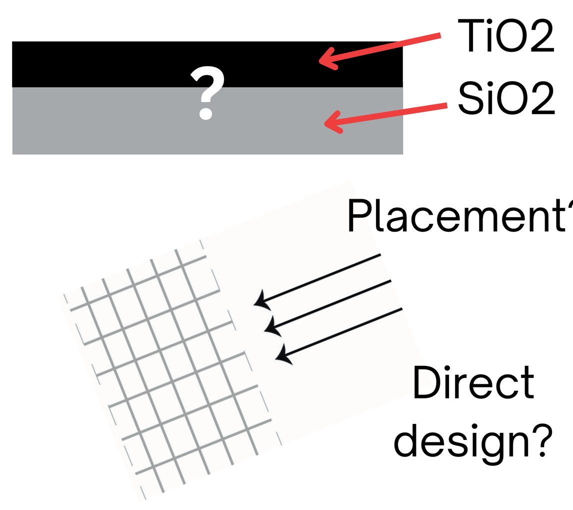
Introduction



Metalenses have **vast applications** (e.g. biomedical imaging, virtual reality)...[1]



...but main issue arises in design: high degrees of freedom **complicates traditional optimisation**.

Low cost-effectiveness, as days needed to generate potentially sub-optimal designs.[2]

Aims

Rapid developments into inverse design has advanced state-of-the-art in flat optics.

a. Develop valid & **inexpensive optimisation process** for efficient achromatic metalens design.
b. Obtain optimised & fabricable designs that maintain wide-spectrum **high-quality focusing**.

Methodology

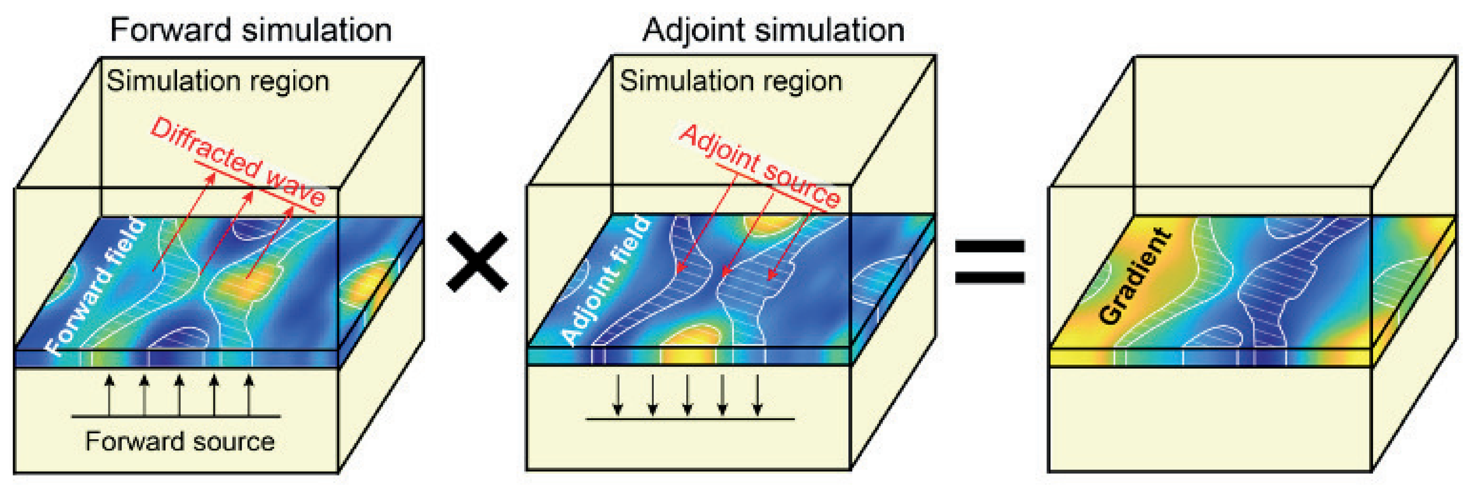
Inverse Design

Given a desired response, what is the optimal structure?

- Maximise $f = |E_z(\mathbf{r}_0)|^2$ subject to Maxwell's equations

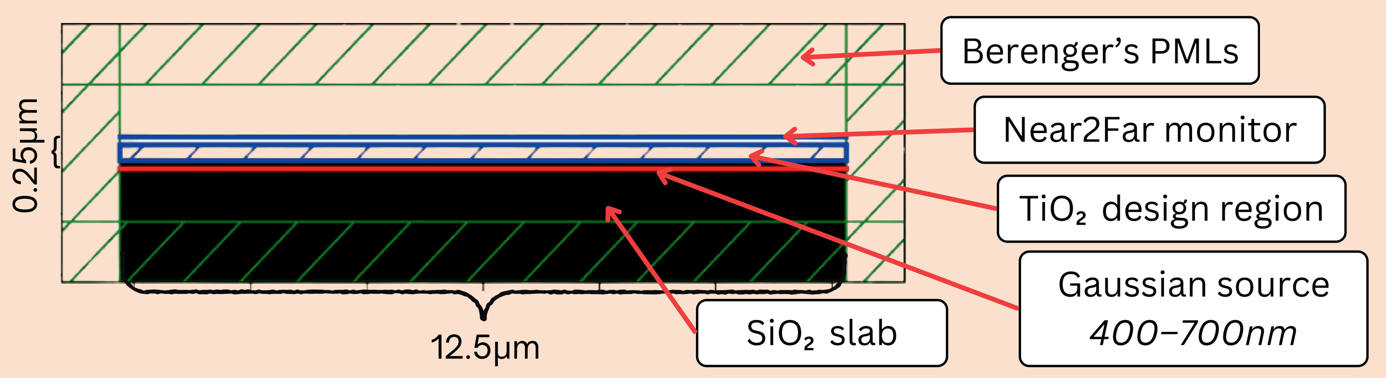
$$\nabla \cdot \epsilon \mathbf{E} = \rho, \nabla \cdot \mu \mathbf{H} = 0,$$
$$\nabla \times \mathbf{E} = -j\omega\mu\mathbf{H}, \nabla \times \mathbf{H} = \mathbf{J}_f + j\omega\epsilon\mathbf{E}$$

- Computational speedup **via Lorentz's reciprocity**; use adjoint electromagnetic field auxiliary to the direct field; backpropagate the intended field response to obtain structural updates



Optimisation Process

Setting up Electromagnetic Simulation
using open-source Python library MEEP w/ adjoint solver.[3]



Minimum feature size set as 25nm.

Gradient Calculations
with forward runs to evaluate f, then adjoint runs from focal point.

- **Forward**: electromagnetic FDTD method using Yee lattice discretization
- **Adjoint**: backpropagation of desired response through the metastructure

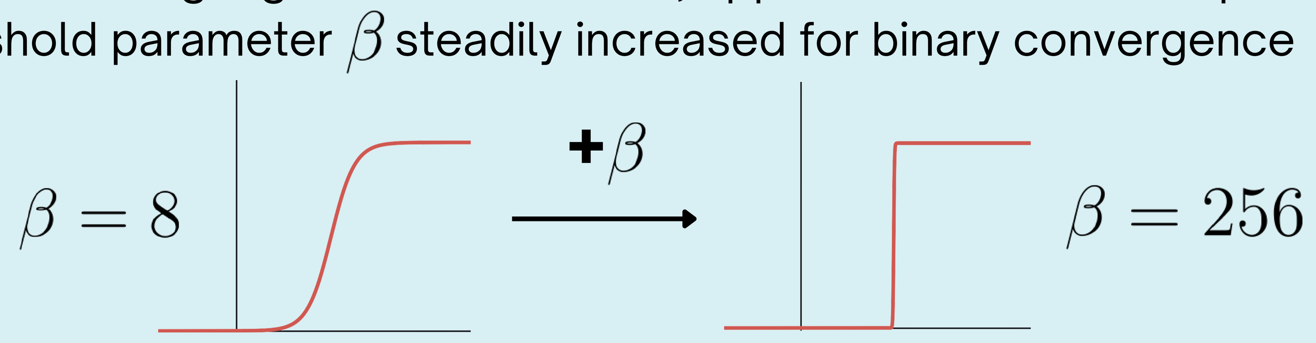
Optimisation algorithm: the **method of moving asymptotes**.[4]

- Recast in epigraph form to ensure differentiability in maximin problem

$$\max f(x) = \max \min \{f_1(\mathbf{E}), f_2(\mathbf{E}), \cdots, f_n(\mathbf{E})\}$$
$$\hookrightarrow \max t, \ \text{s.t.}\ f_k(\mathbf{E}) - t \geq 0$$

Filtering & Projection
to enforce binary-constrained single-layered metagratings.

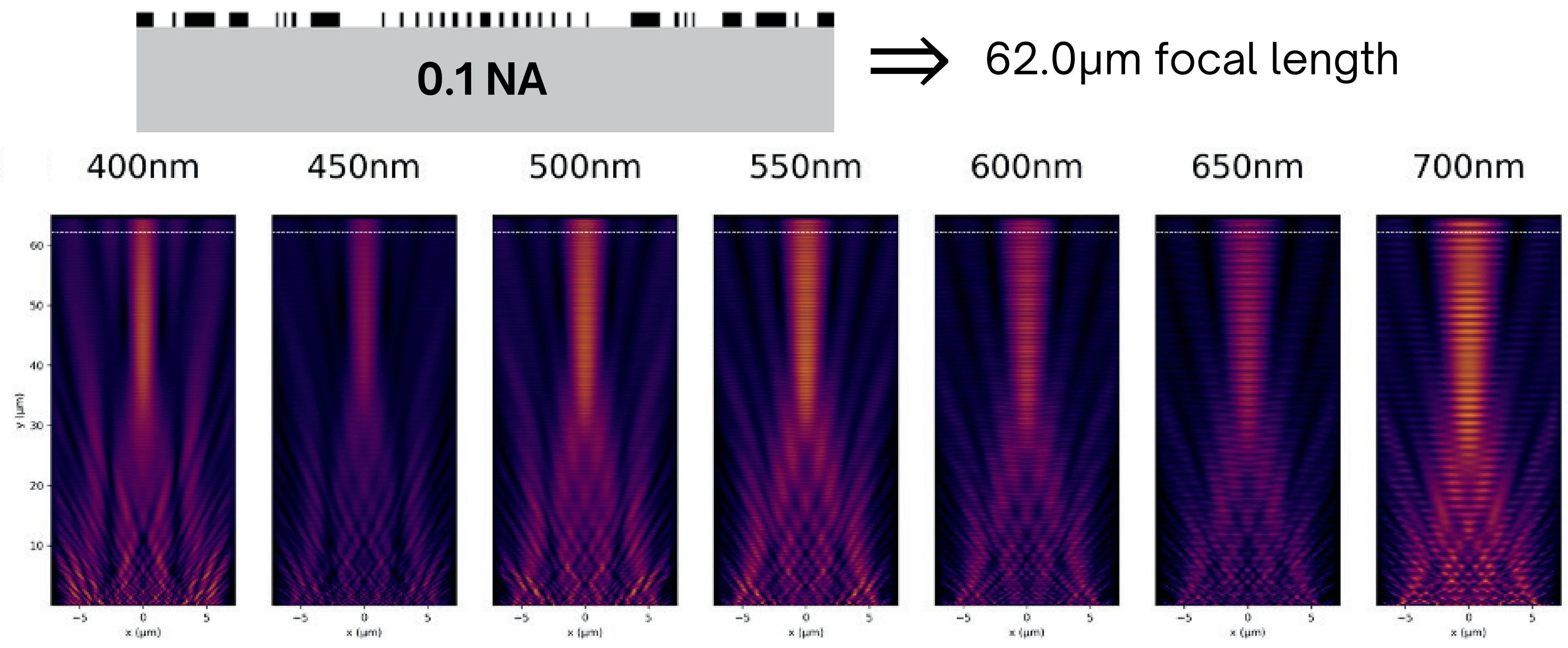
- Achieved using Sigmund's "hat filter"; approx. to Heaviside step function[5]
- Threshold parameter β steadily increased for binary convergence



Results & Discussion

Achromatic Metalenses

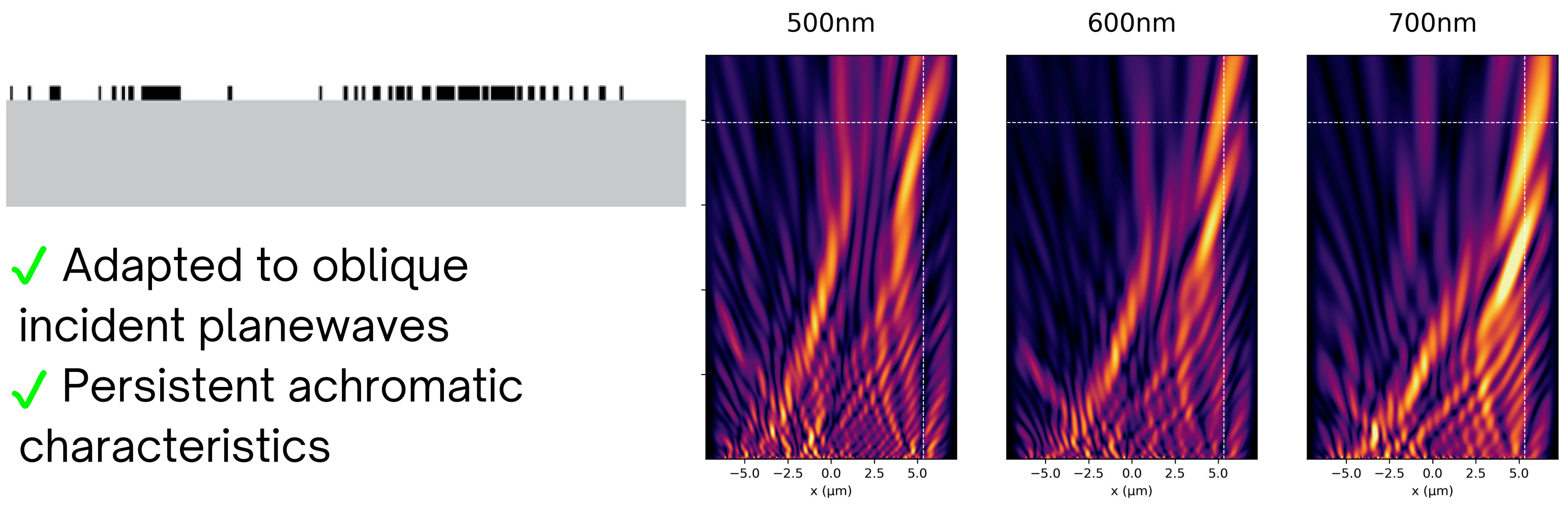
Tested parameters: 0.1 – 0.5 NA, for visible spectrum of 400-700nm



✓ Distinct focusing of broadband light
✓ Customisable numerical aperture
✓ Adaptable optimisation process + fast processing times (~4.36h)

Achromatic + Wide Fields of View (WFOV)

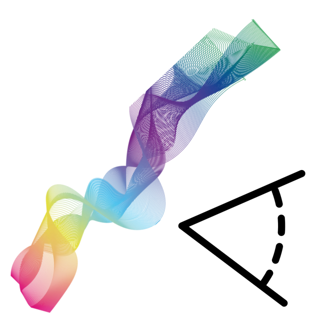
Tested parameters: 0.3 NA, wavelengths 500–700nm, 15° incidence
Achieved by incorporating k-point wavevector w/ varying amplitude.



✓ Adapted to oblique incident planewaves
✓ Persistent achromatic characteristics

Conclusion

Computationally-inexpensive and **cost-effective** approach



Simultaneous realisation of **achromatic functionality** with **wide fields-of-view**

Future Work:

- Multi-layered metalenses (e.g. 2.5D metastructure schematics)
- Expansions on high-NA and WFOV capabilities

References:

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