Surrogate Model Training for Nanopillars

Reusable Meta-Atom Library

Part of the Meta Optics Solution Guide

Surrogate Model Document

Document ID:	UC-META-SURROGATE
Version:	1.0
Date:	May 4, 2026
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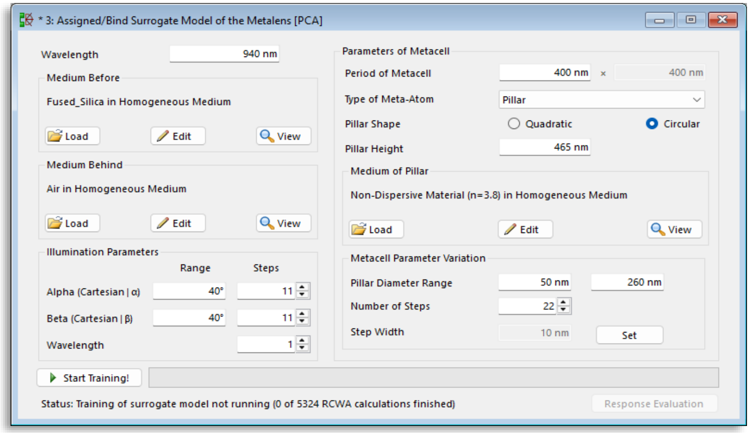


Executive Summary

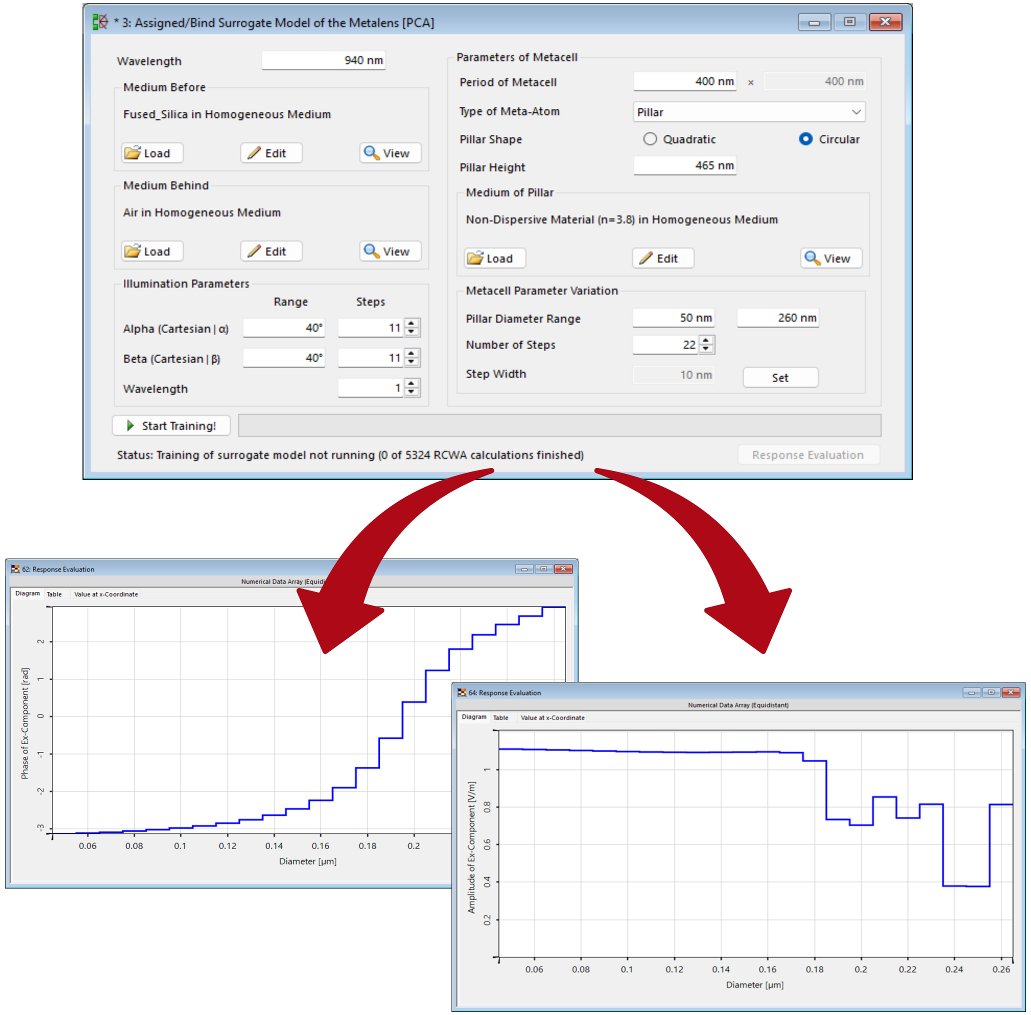
What Has Been Done A surrogate model for nanopillar-based meta-atoms has been trained to replaces on-the-fly RCWA computations with precomputed responses.

Training Configuration

- Diameter step size: 10 nm (fabrication-constrained quantization)
- Angular sampling: 11 × 11 = 121 distinct incidence angles
- Total RCWA simulations: 5324

Hardware & Performance Training time: 48 minutes, System: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM

Train once. Use everywhere.



Application Scenario

The Challenge RCWA simulations of meta-atoms are computationally expensive. Running them on-the-fly during metalens design is impractical.

The Solution A surrogate model precomputes the electromagnetic response once. During design and simulation, responses are looked up instantly.

Scope of This Document We train a surrogate model for nanopillars and analyze its phase and amplitude response as a function of incidence angle.

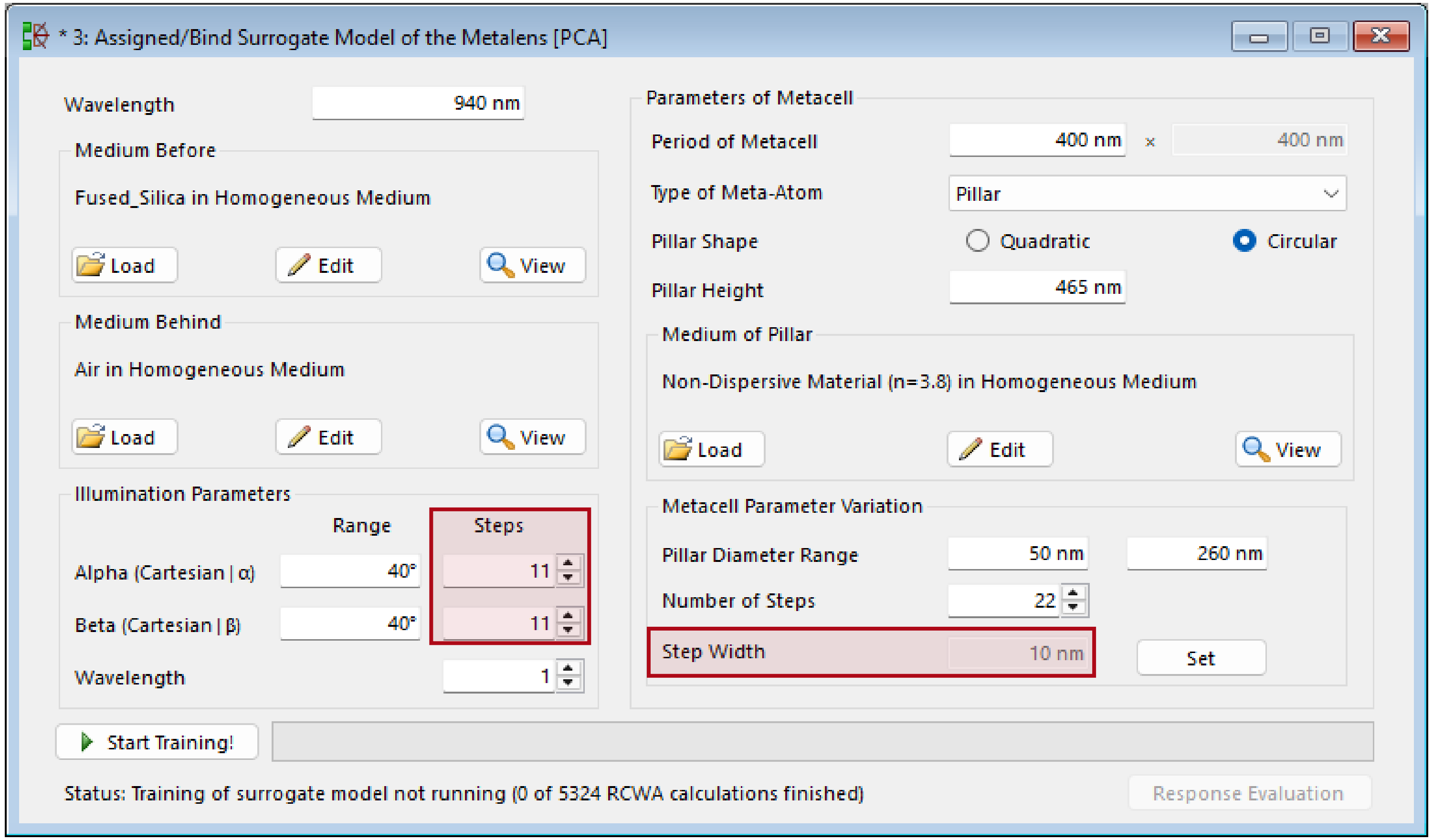
Surrogate Model Specifications

Parameter	Value
Design wavelength	940 nm
Period	400 nm × 400 nm
Pillar height	465 nm
Pillar diameter range	50 nm – 260 nm
Diameter step size	10 nm (quantized)
Medium before	Fused silica
Medium after	Air
Incidence angle range (α)	-20° – 20°
Incidence angle range (β)	-20° – 20°
Angular sampling	11 × 11 steps

Surrogate Model – Sampling Parameters

Key Parameters

- Diameter increments are fixed by fabrication constraints.
- Angular sampling is a free parameter.
- Higher angular sampling might increase accuracy, but training time would also increase.
- We choose 11 × 11 points as good compromise for this example.

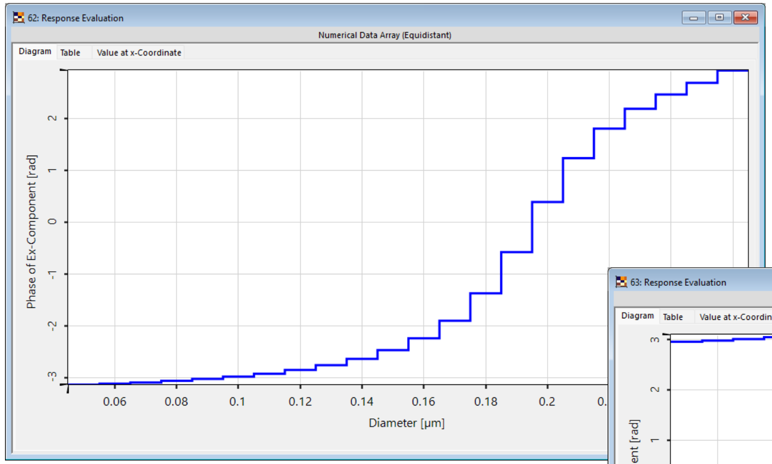


Result – Phase Response over Pillar Diameter

Angle	Maximal Phase Increment
(0°,0°)	0.966
(10°,10°)	1.096
(20°,20°)	1.268

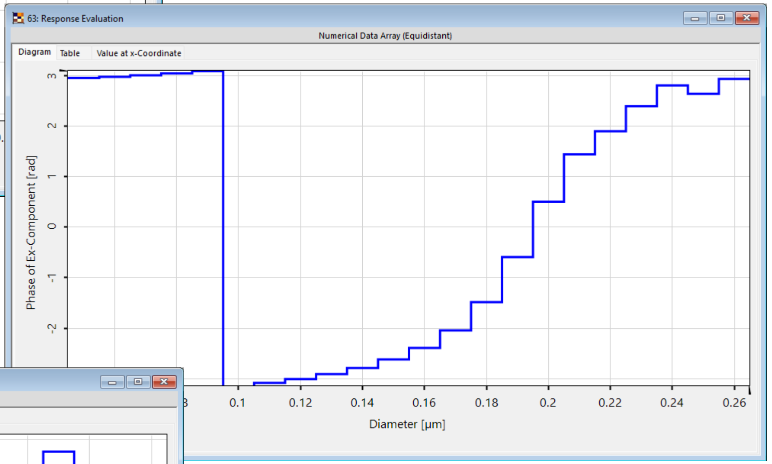
Key Observations

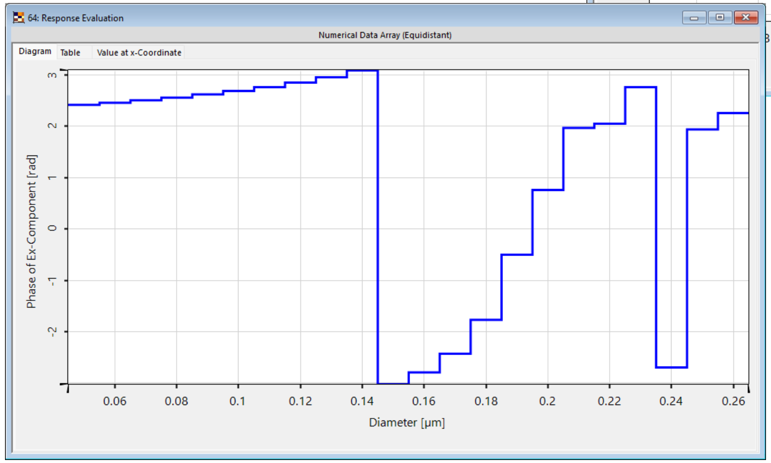
- The quantify the expected phase error of the element we calculate the phase difference between two subsequent pillar diameters.
- For higher illumination the area in which phase coverage is still achieved becomes narrower, hence the maximum phase difference - and therefore the expected phase error - increases.



(0°, 0°) - Inclination

(10°, 10°) - Inclination



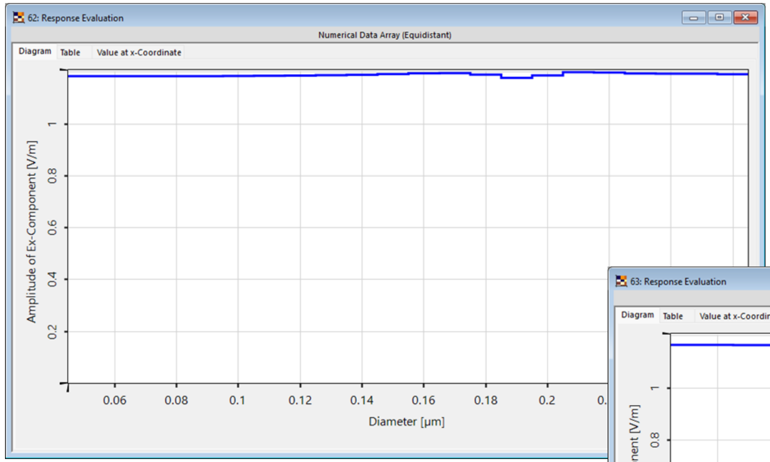


(20°, 20°) - Inclination

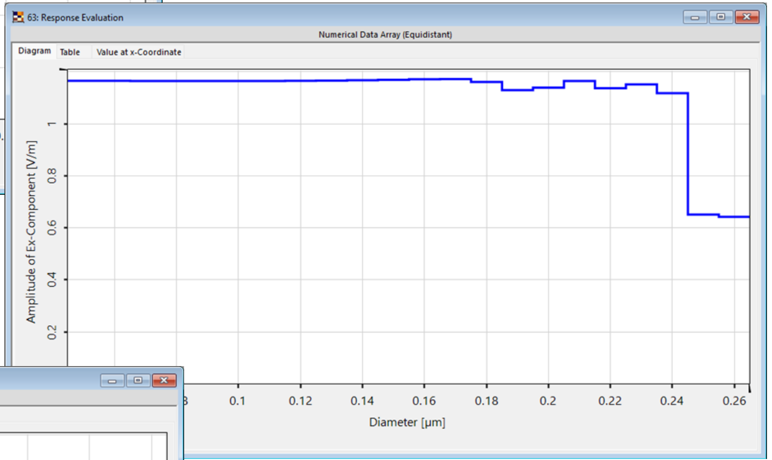
Result – Amplitude Response over Pillar Diameter

Key Observations

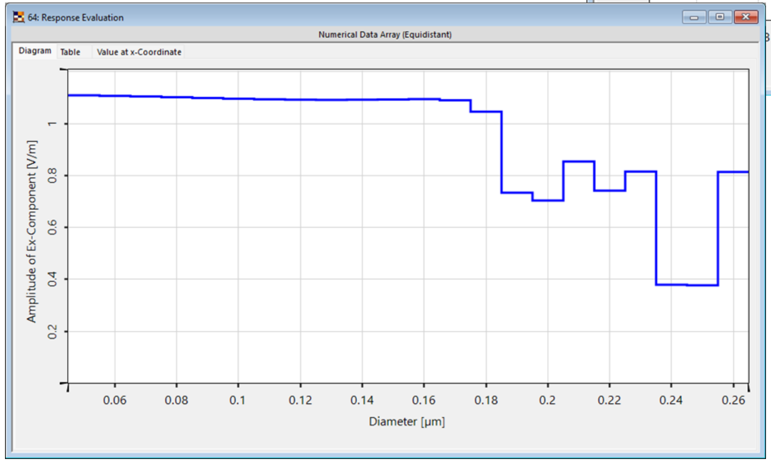
- On-axis illumination shows a negligible effect on the amplitude.
- For higher illumination angle the amplitude variation increases signifincantly, especially for larger pillar diameter.



(0°, 0°) - Inclination



(10°, 10°) - Inclination

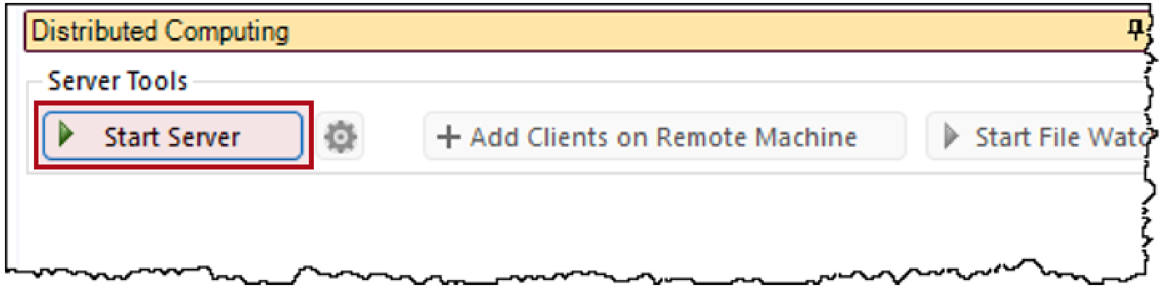


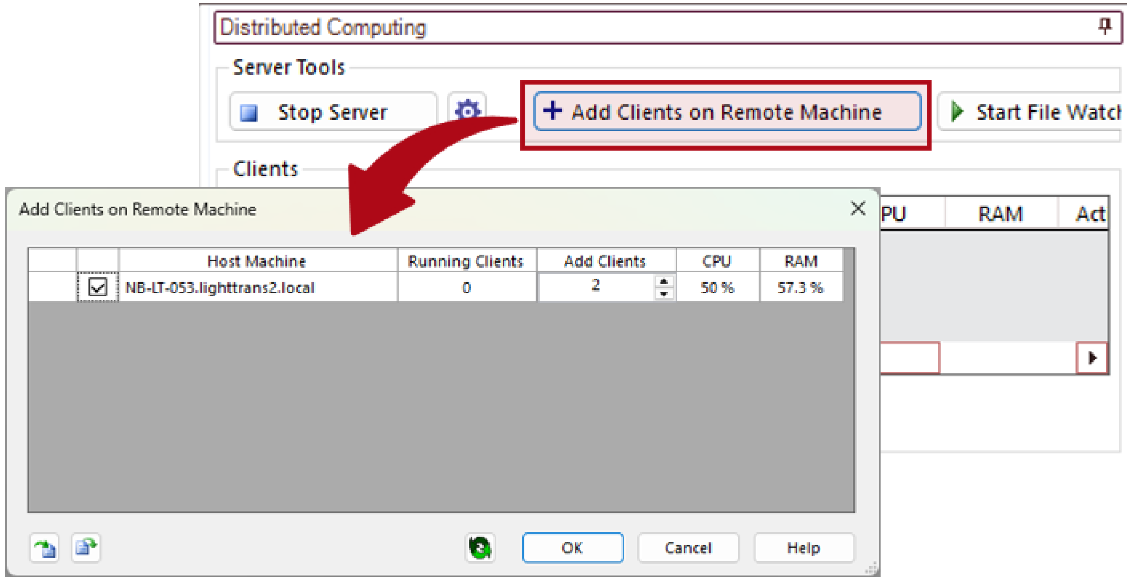
(20°, 20°) - Inclination

Use Distributed Computing to Fasten Training Time

Technical Insight

- During training, we compute a large number of RCWAs (>5000).
- The computations are independent of each other and can therefore be paralleled.
- Using our distributed computing technology, the training can be distributed across different machines, drastically reducing the training time.





Demonstrated Workflow

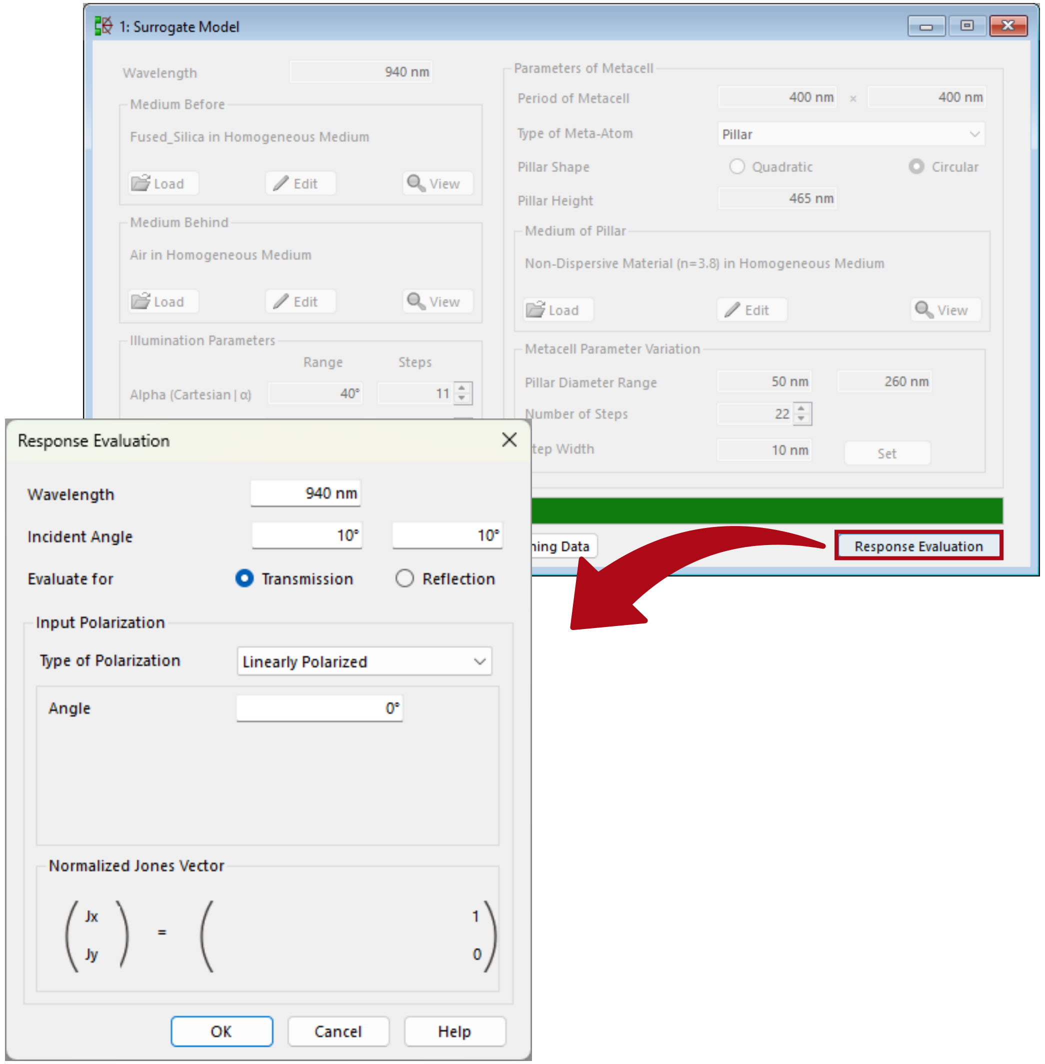
Step-by-Step Workflow

1. **Set fabrication parameters:** Initialize new surrogate model. Set meta-atom, period, height and diameter range according to your fabrication constraints.

2. **Set optical parameter:** Set media, wavelength and angle range to match your intended use cases. Higher steps will lead to more accurate results but also increase the number of calculated RCWAs.

3. **Start training:** Run training (takes in our example approximately 50 minutes on specified machine).

4. **Check response:** Click *Response Evaluation*. Choose parameters you like to investigate. Check for your region of interest if amplitude and phase behave as expected.



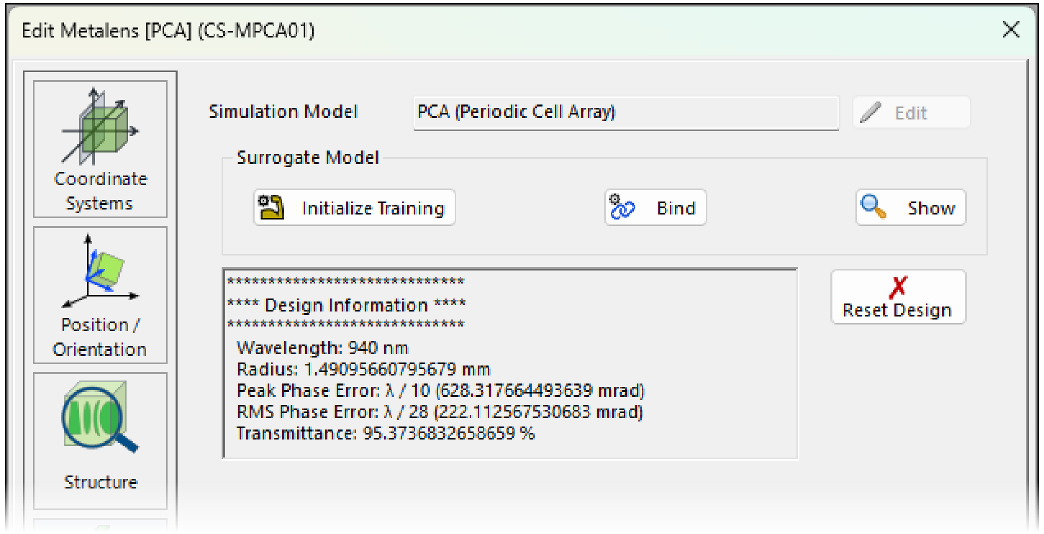
Conclusion

Key Takeaways

- A surrogate model replaces on-the-fly RCWA with precomputed responses.
- Once trained, the model can be reused across multiple metalens designs.
- Training time scales with angular sampling and diameter steps. Example: 11 × 11 steps angles, 10 nm steps, 5324 RCWAs - 48 minutes.
- Phase and amplitude response can be analyzed for any incidence angle within the trained range.

Next Steps

- Use this surrogate model in a metalens design.
- Study our whitepaper for Surrogate Models to gain deeper insights into the subject.
- Test our distributed computing and see how it cuts computation time.



Used Resources

White Papers

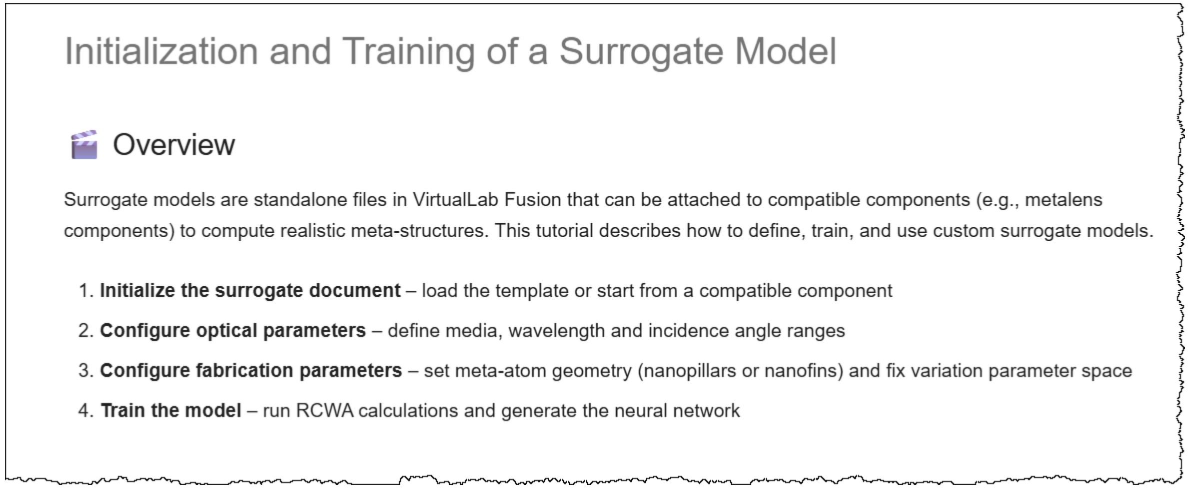
- WP-META-SURROGATE — Surrogate Modeling: Enabling Practical Metalens Design and Simulation

Tutorials

- Tutorial: Initialization and Training of a Surrogate Model

Related Use Cases

- Focusing Metalens Based on Nanopillars
- Aberration Control via Metalens



Initialization and Training of a Surrogate Model

Overview

Surrogate models are standalone files in VirtualLab Fusion that can be attached to compatible components (e.g., metalens components) to compute realistic meta-structures. This tutorial describes how to define, train, and use custom surrogate models.

1. **Initialize the surrogate document** – load the template or start from a compatible component
2. **Configure optical parameters** – define media, wavelength and incidence angle ranges
3. **Configure fabrication parameters** – set meta-atom geometry (nanopillars or nanofins) and fix variation parameter space
4. **Train the model** – run RCWA calculations and generate the neural network