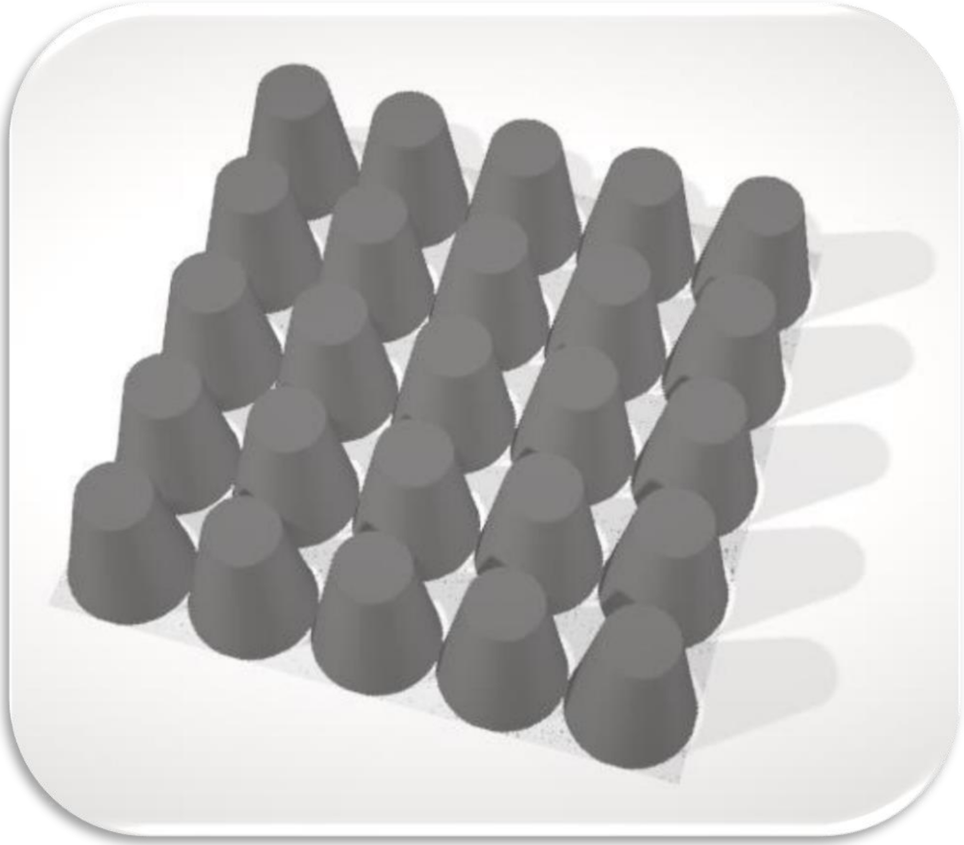
Optimization of Anti-Reflective Moth-Eye Structures

Use Case :Optimization of Anti-Reflective Moth-Eye Structures

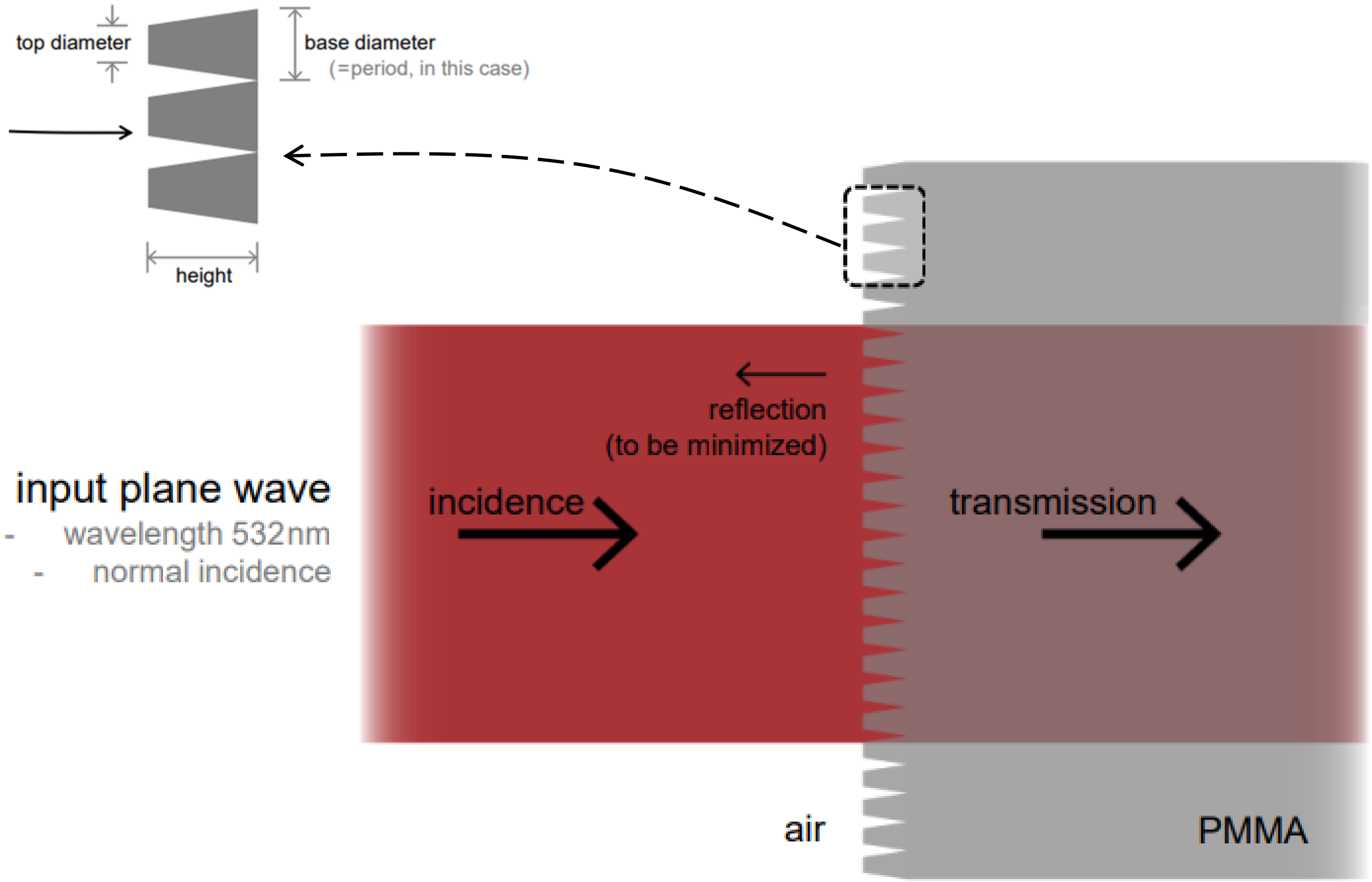


Abstract

Moth-eye structures are frequently utilized to impart anti-reflective (AR) properties to surfaces due to their unique and intricate designs. However, the complexity of these structures often leads to the presence of multiple local minima during optimization processes. To effectively address this challenge, two primary strategies can be employed. The first strategy involves conducting a rough parameter sweep to identify a promising starting point for subsequent local optimization. The second strategy entails initiating the optimization process with a global optimization algorithm.

In this use case, we will investigate and compare these two strategies in the context of an equidistant gridded moth-eye structure, evaluating their efficacy and outcomes in optimizing AR properties.

Optimization Task



Parameter to be Optimized

- Reflection Efficiency

Varied Parameter

- Top Diameter (10~120nm)
- Height (50~500nm)

Algorithm

- Nelder-Mead
- Differential Evolutionary

In this case, we will attempt to **minimize the reflection** from the air-PMMA interface using two different optimization strategies: **a local optimization algorithm (Nelder-Mead)** and **a global optimization algorithm (Differential Evolution).**

More Information Under:

Rigorous Analysis and Design of AR Moth-Eye

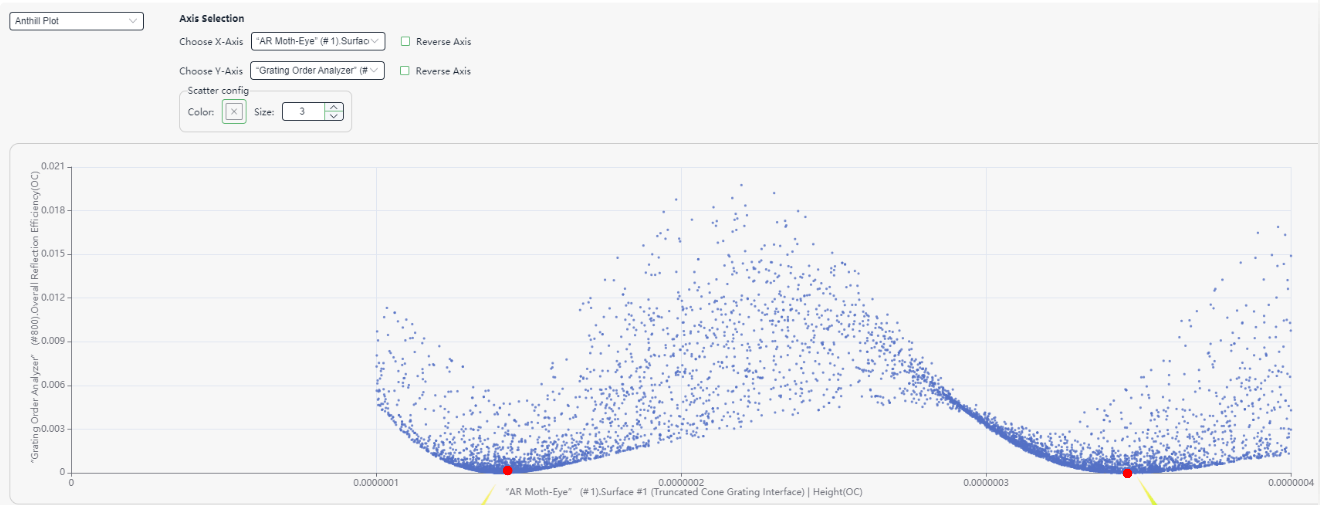
Overview of Results

Local Optimization

- **Final Design #1**
  Height:141.47nm
  Top Diameter:74.25nm
  Overall Reflection Efficiency:< 0.0001%

- **Final Design #2**
  Height:346.0nm
  Top Diameter:68.36nm
  Overall Reflection Efficiency:< 0.0001%

Global Optimization

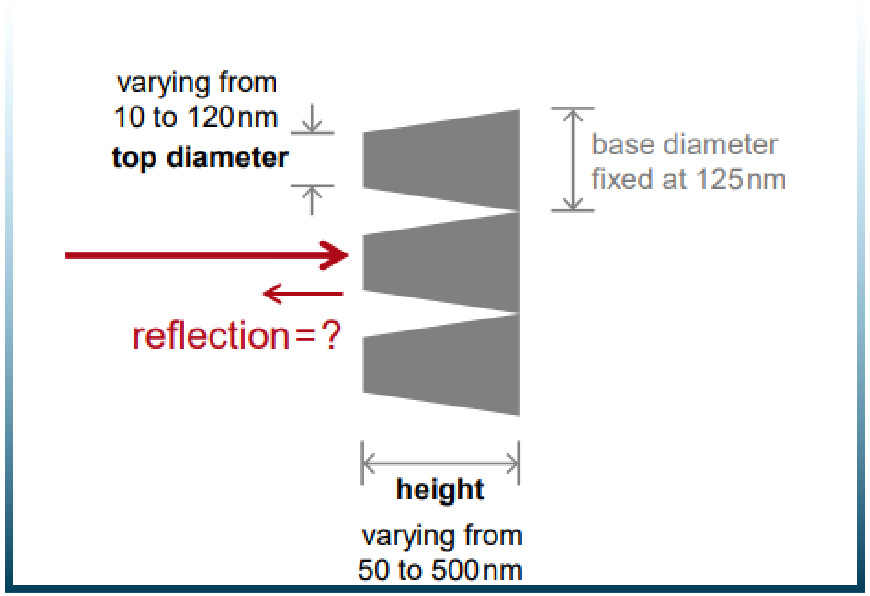


Height:141.46nm
Top Diameter:74.49nm
Overall Reflection Efficiency:<0.0001%

Height:345.5nm
Top Diameter:67.09nm
Overall Reflection Efficiency:<0.0001%

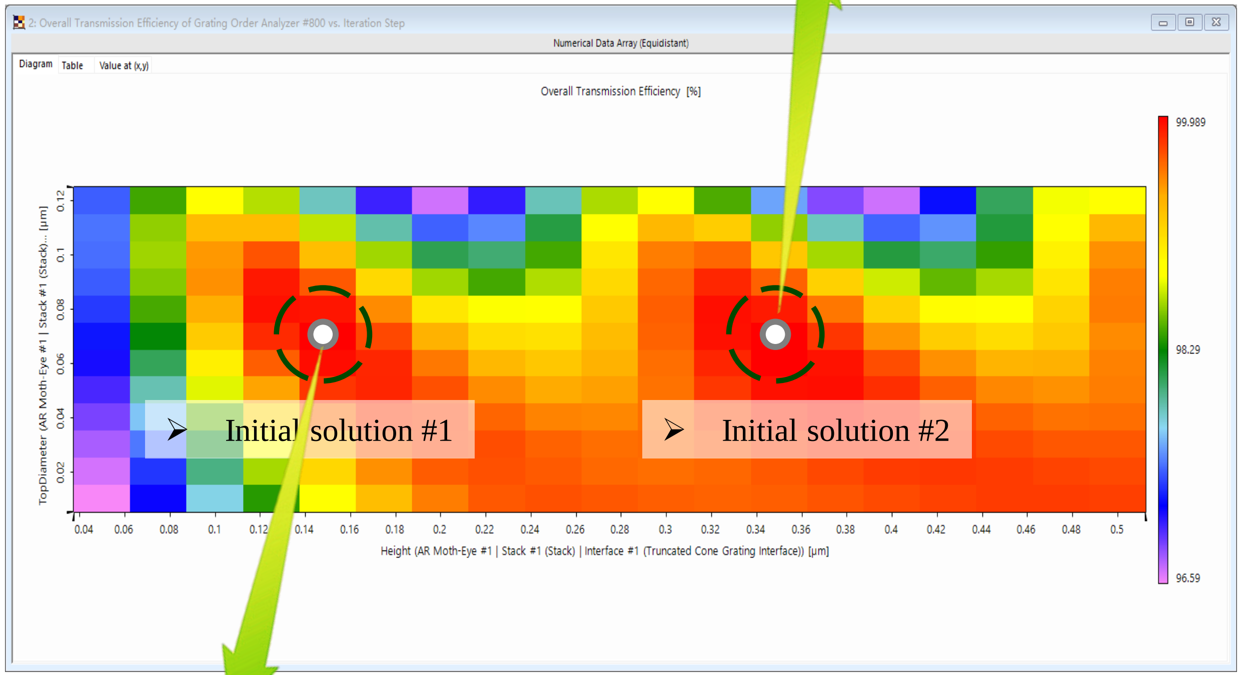
Local Optimization

Scanning over Parameter Space for Initial Solutions in VLF



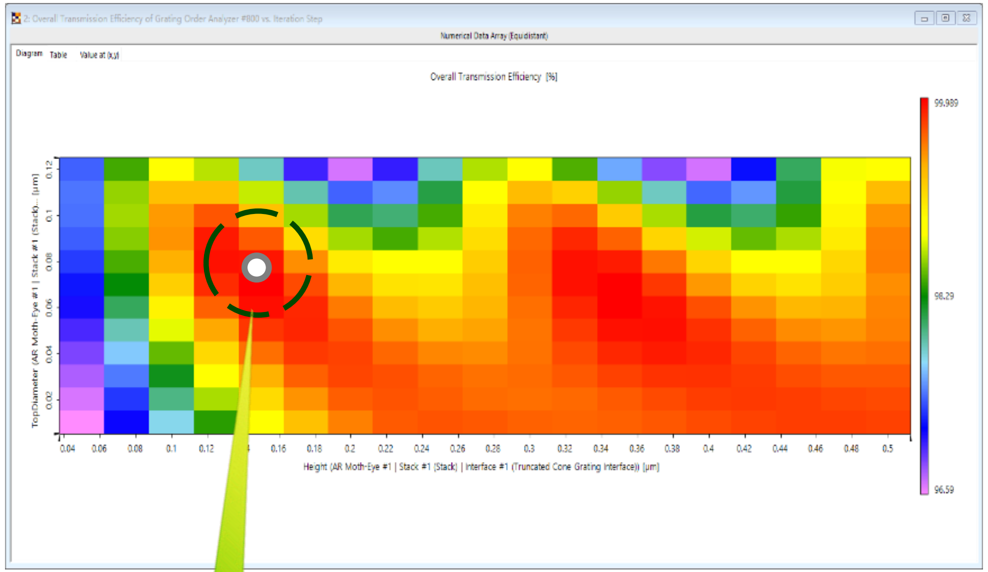
A parameter sweep is performed in order to find an adequate initial solution for the optimization. This is very useful for the upcoming local optimization algorithm, as local optimization is highly sensitive to the choice of starting point. A good starting point can significantly improve the optimization results.

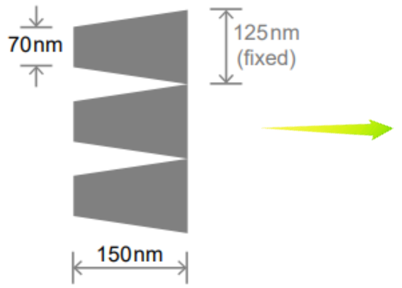
Relatively higher aspect ratio and maybe not the first choice for fabrication



Relatively smaller aspect ratio and there fore preferable for fabrication

Local Optimization-Initial Solutions #1

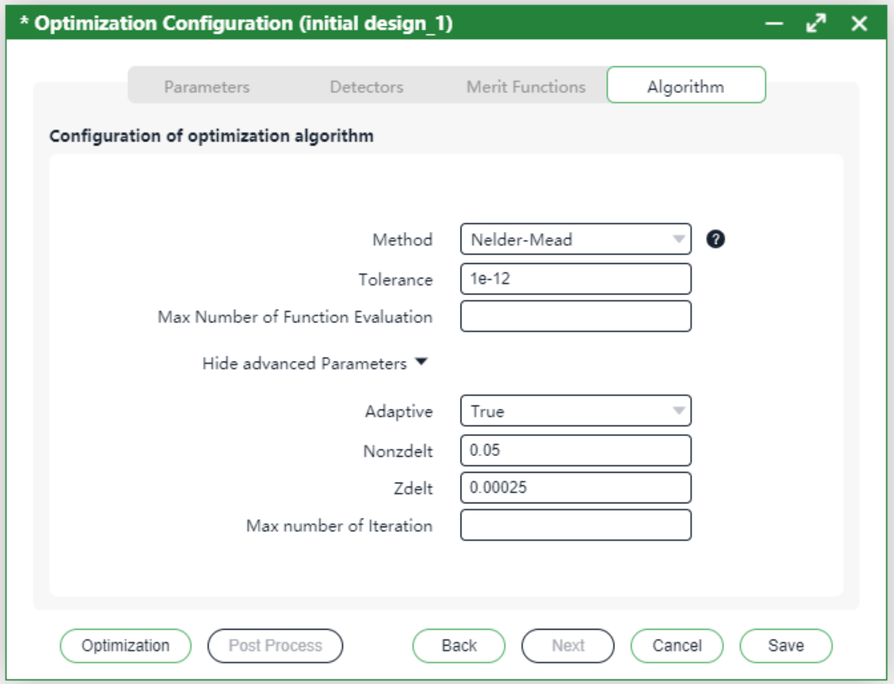




Initial solution #1

Top Diameter:70nm
Height:150nm

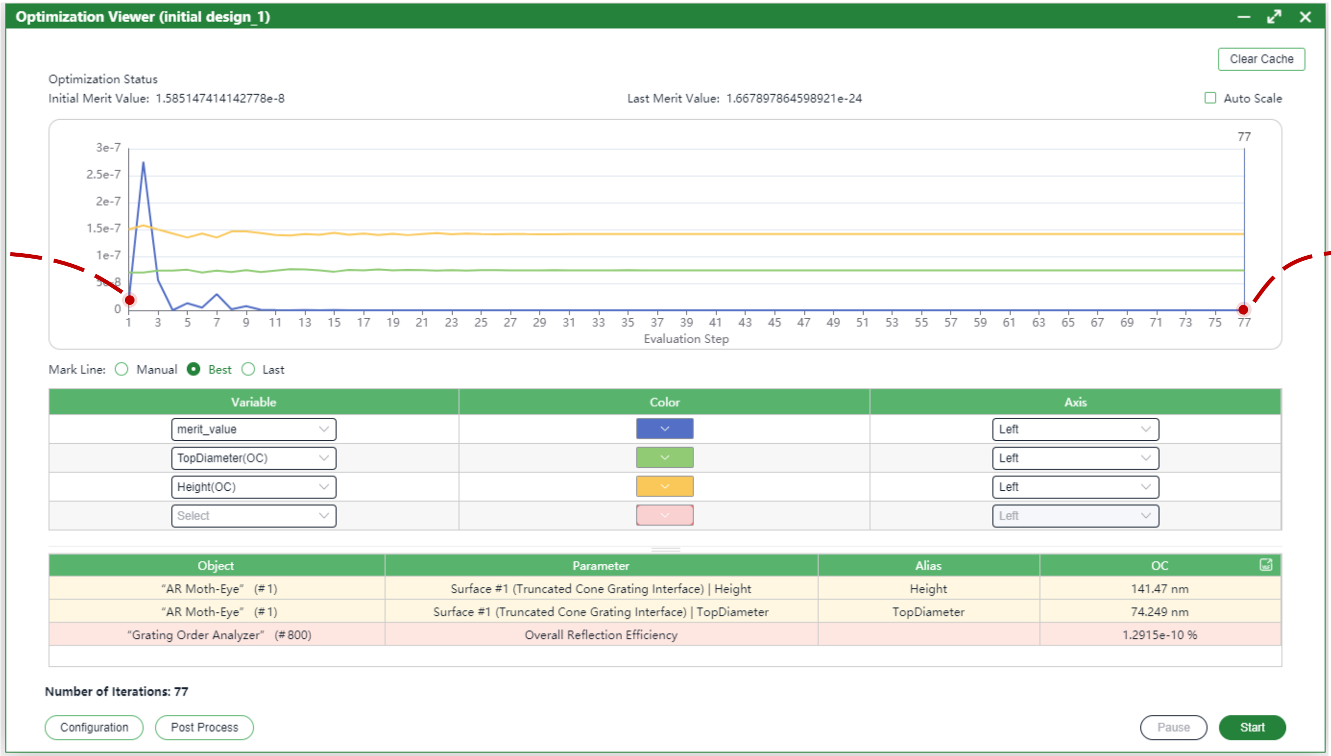
Regarding how to start and configure an optimization project please refer to:
[VirtualLab Fusion Optimization Package Tutorial]



- We began the optimization process with initial solution #1 and employed the Nelder-Mead algorithm for optimization. Renowned as a widely-used local optimization algorithm, the Nelder-Mead algorithm is known for its robustness and broad applicability.

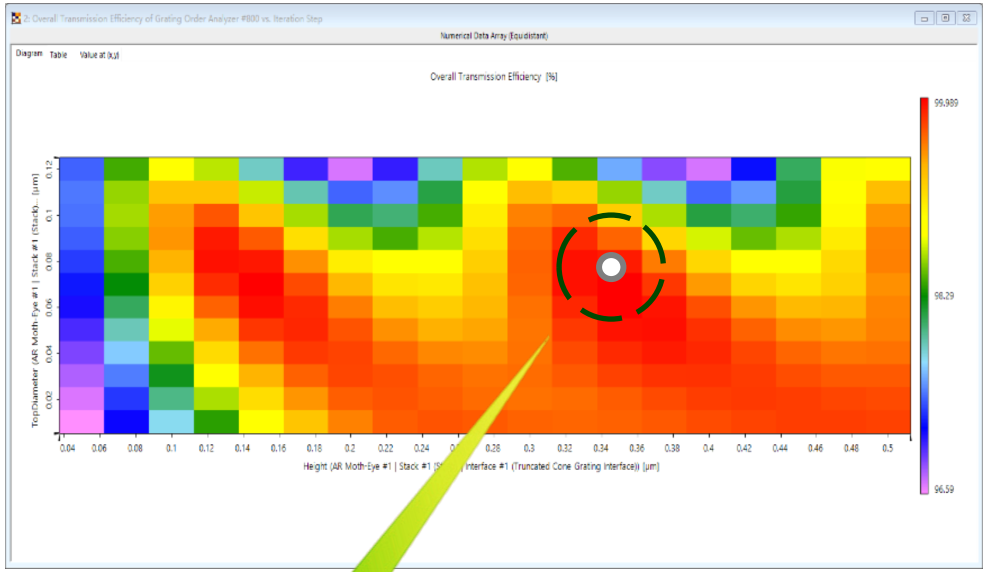
Local Optimization-View the Result of Final Design#1

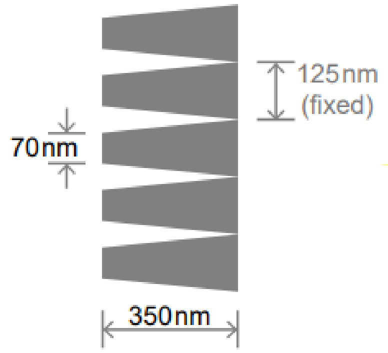
Initial Solution#1
Height:150nm
Top Diameter:70nm
Initial Reflectacne:0.01259%



Final Design#1
Height:141.47nm
Top Diameter:74.25nm
Optimized Reflectance:<0.0001%

Local Optimization-Initial Solutions #2

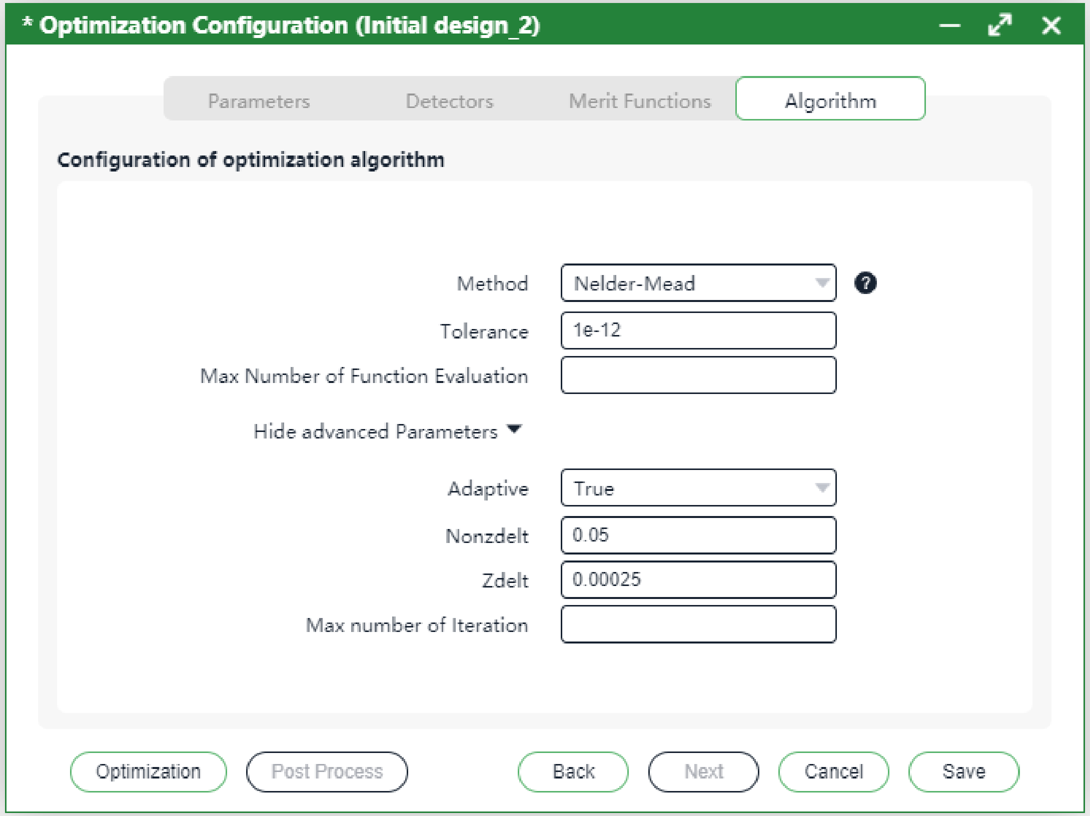




Initial solution #2

Top Diameter:70nm

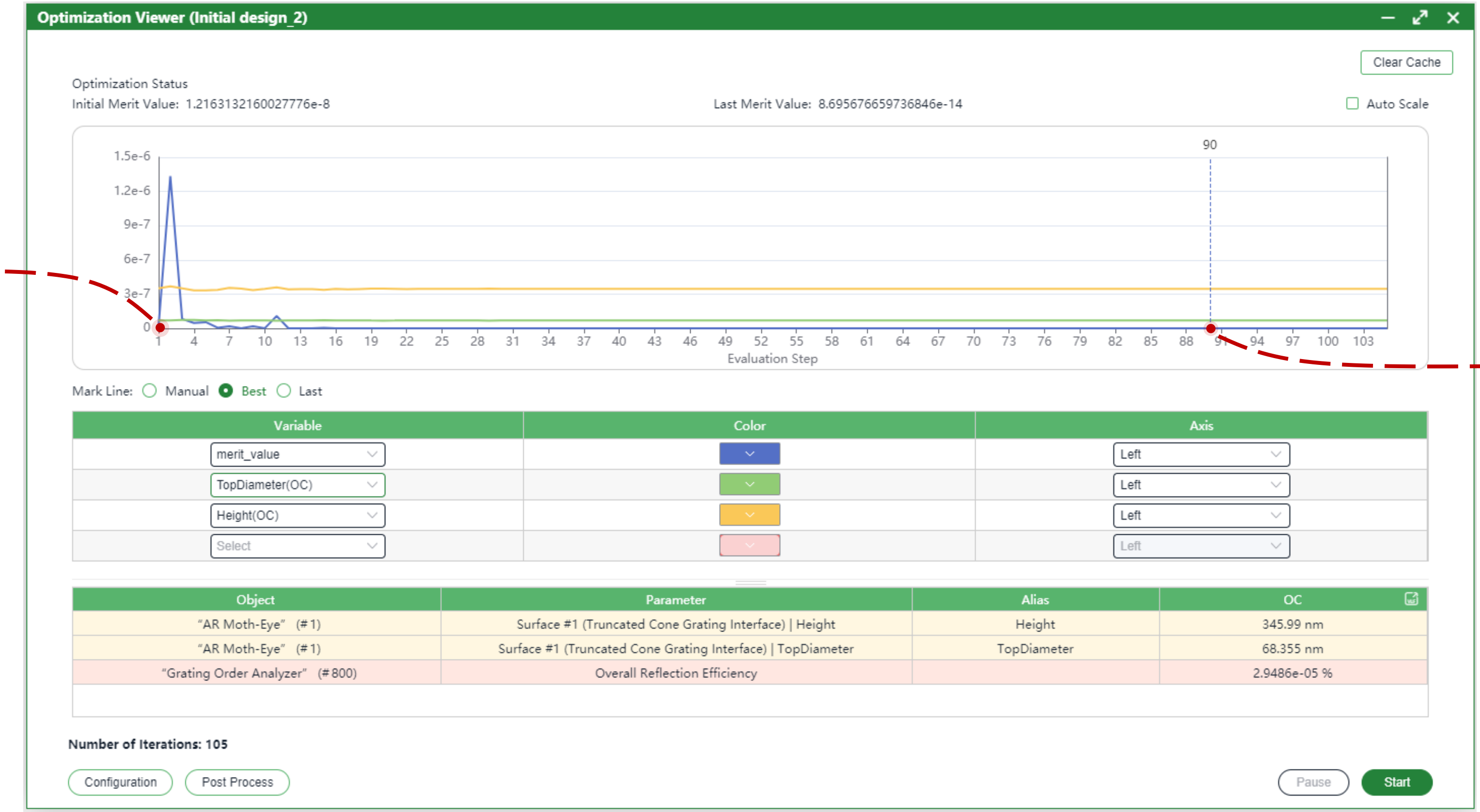
Height:350nm



➢ We began the optimization process with initial solution #2 and similarly employed the Nelder-Mead algorithm.

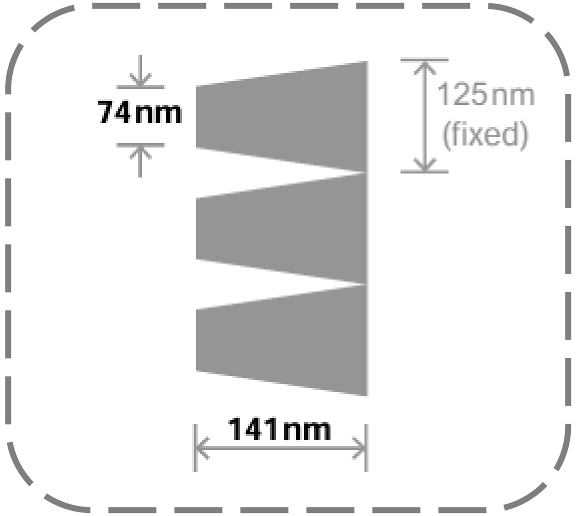
Local Optimization-View the Result of Final Design#2

Initial Solution#2
Height:350nm
Top Diameter:70nm
Initial Reflectacne:0.011029%



Final Design #2
Height:346.0nm
Top Diameter:68.36nm
Optimized Reflectance:0.0001%

Performance Analysis

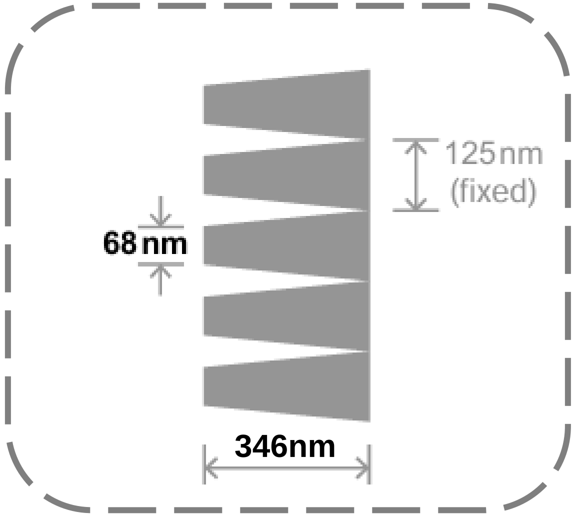


Final Design #1

Height:141.47nm

Top Diameter:74.25nm

Overall Reflection Efficiency:< 0.0001%



Final Design #2

Height:346.0nm

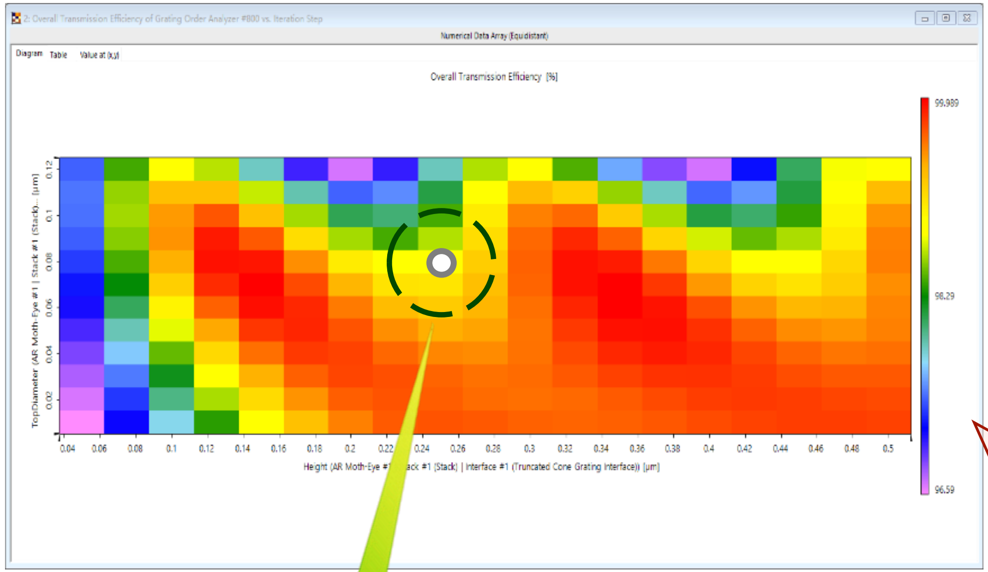
Top Diameter:68.36nm

Overall Reflection Efficiency:< 0.0001%

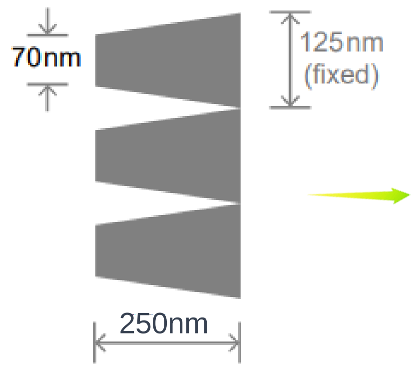
In the specified condition of normal incidence, although both designs can effectively reduce the reflectivity to less than 0.001%, we ultimately chose final design#1 because it has a smaller aspect ratio, making it more suitable for manufacturing.(Gratings with a high aspect ratio are more difficult to manufacture.).

Global Optimization

Global Optimization-Arbitrary Solution



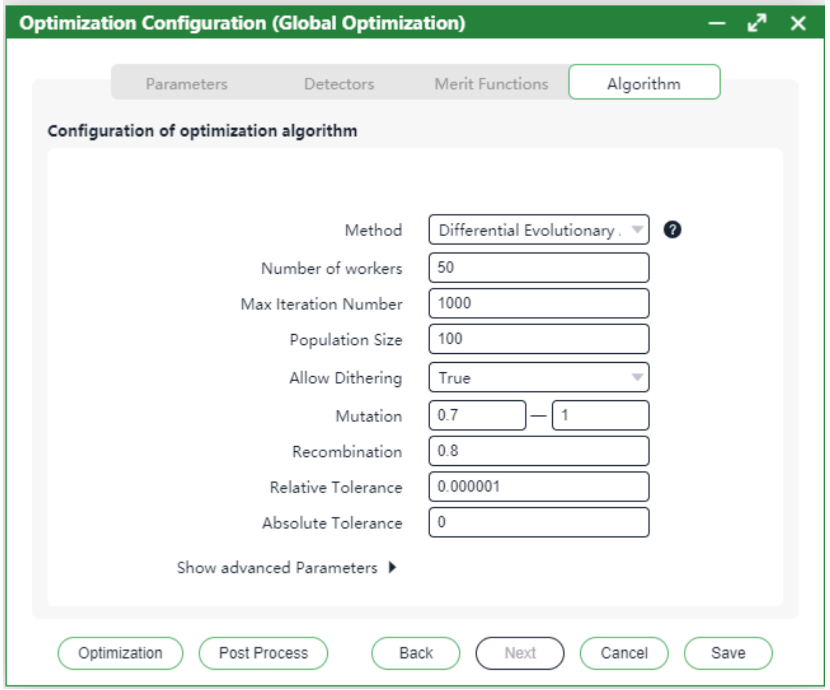
The parameter sweep is not required for global optimization; it is only used to demonstrate that the initial solution is not near a maximum



Arbitrary Solution

Top Diameter:70nm

Height:250nm

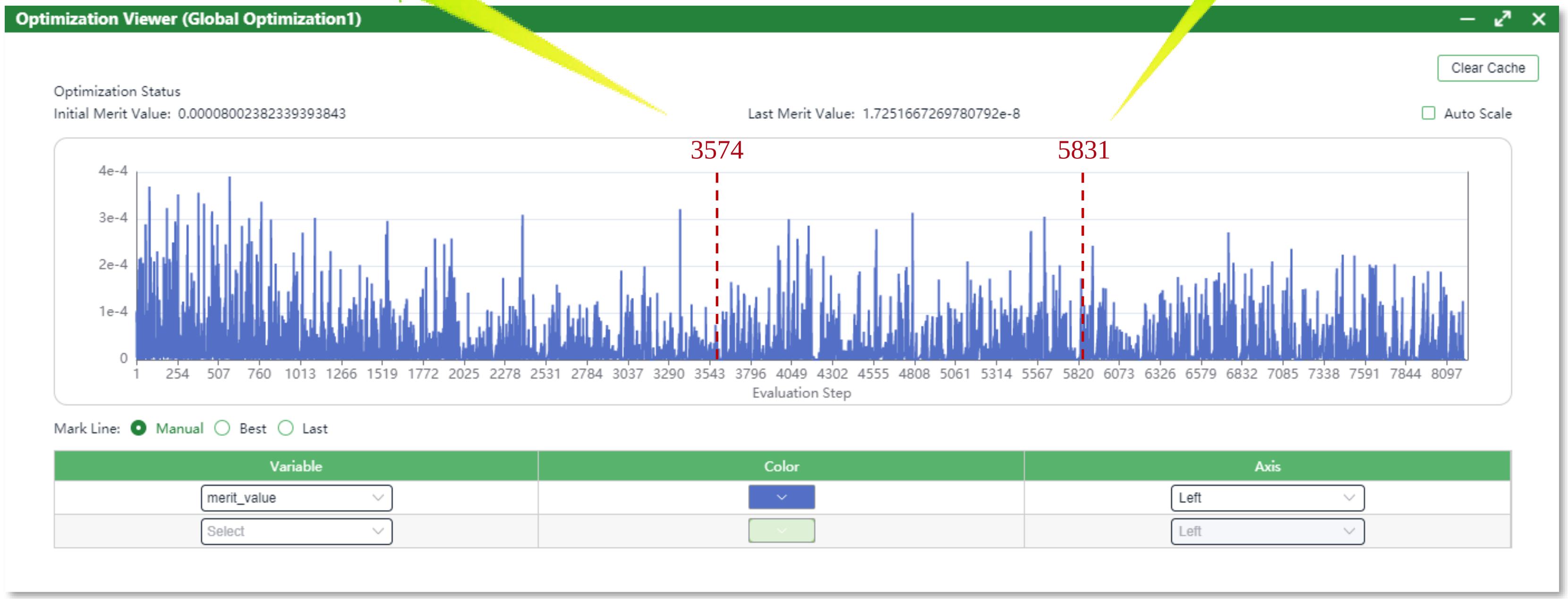


- We selected an arbitrary solution and used the differential evolution algorithm for optimization. The differential evolution algorithm is a global optimization algorithm with strong global search capabilities, fast convergence speed, and broad applicability.

Global Optimization-View Result

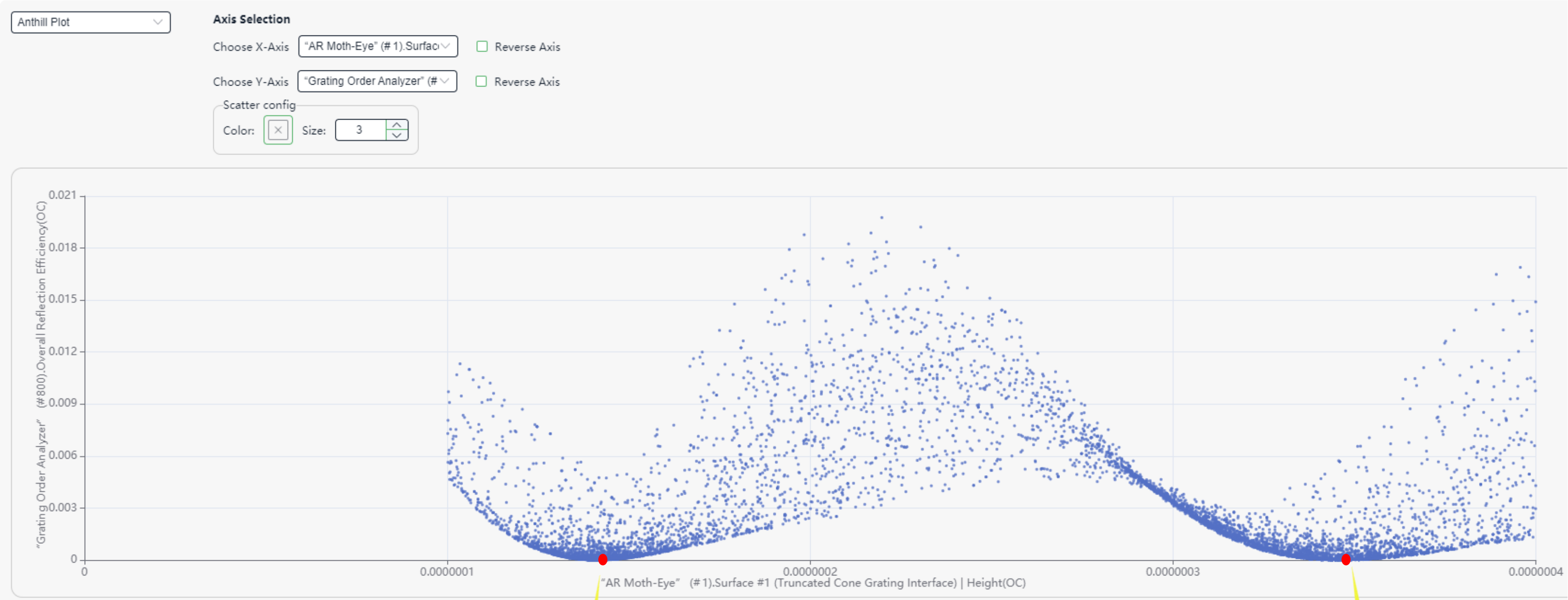
Height:142.43nm
Top Diameter:74.211nm
Overall Reflection Efficiency:< 0.0001%
Close to Final Design #1

Height:344.87nm
Top Diameter:66.992nm
Overall Reflection Efficiency:< 0.0001%
Close to Final Design #2



By observing the optimization results, we can see that some values are close to Design 1, while others are close to Design 2 (as indicated by the red dashed lines in the figure). This suggests that two local optima can be found in the global optimization process. We will use post process to better illustrate this point.

Global Optimization-Post Process



In the Anthill Plot, by setting Height as the x-axis and Reflectance as the y-axis, it can be observed that there are very low reflectance values at two different height positions. These two points correspond closely to the previous Final Design #1 and Final Design #2.This demonstrates the global optimization capability of the DE algorithm, as it found two local optima in the entire parameter space.

Height:141.46nm
Top Diameter:74.492nm
Minima corresponding to Final Design #1

Height:342.13nm
Top Diameter:67.897nm
Minima corresponding to Final Design #2

Document Information

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