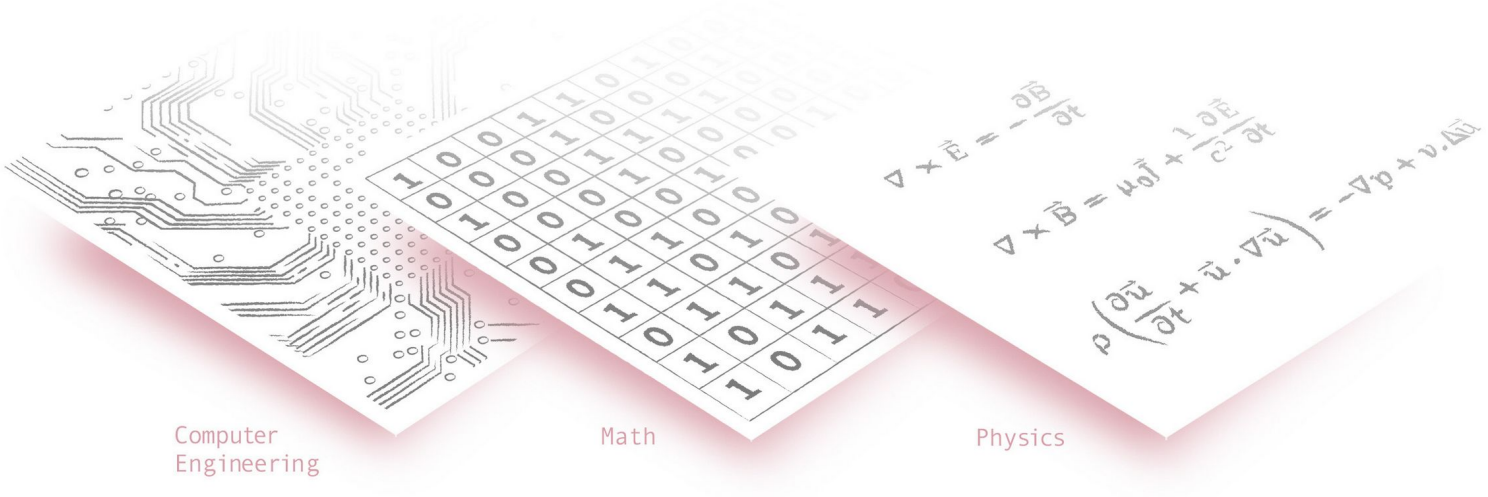


Inverse Design in Photonics

Tutorial 6: Level Set Method

FLEXCOMPUTE

Tidy3D

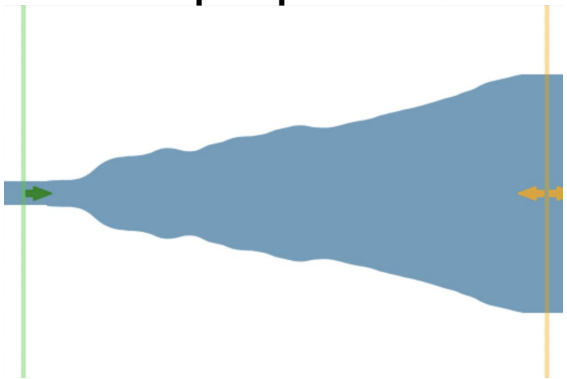
Review: Parameterization Approaches

Introduced a couple ways to parameterize the design region

“Topology Optimization”

- Discretize permittivity (r) on grid of pixels.
- Continuously adjust each value.
- Apply filter + projection for feature size constraints.

“Shape Optimization”

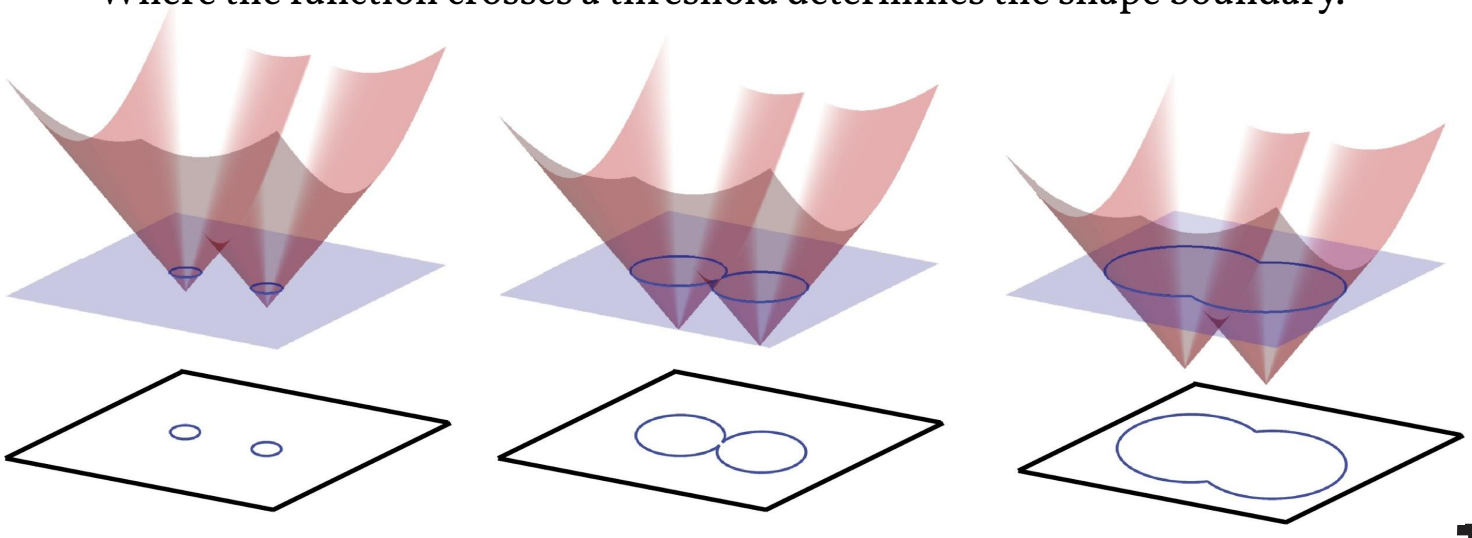


- Parameterize boundary of device.
- Update with boundary adjoint gradient.
- Radius of curvature penalty.

Introduction: Level Set Method

Here, we introduce a new method “level set”, which combines both approaches.

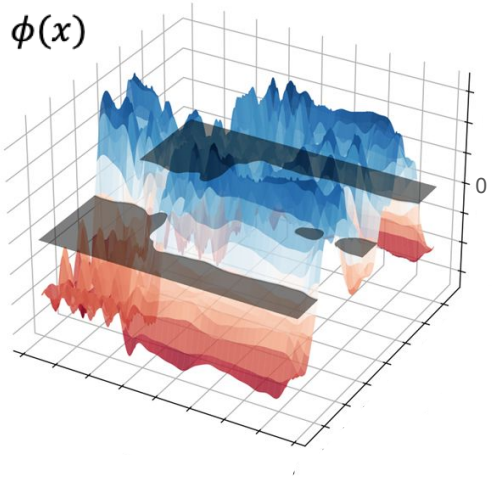
A level set function is a continuous function over space, which defines a shape:
Where the function crosses a threshold determines the shape boundary.



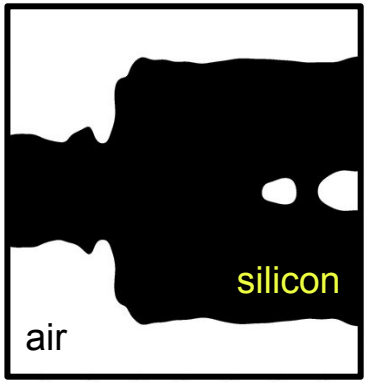
F. Gibou, R. Fedkiw, S. Osher, Journal of Computational Physics 353, 82-109 (2018)

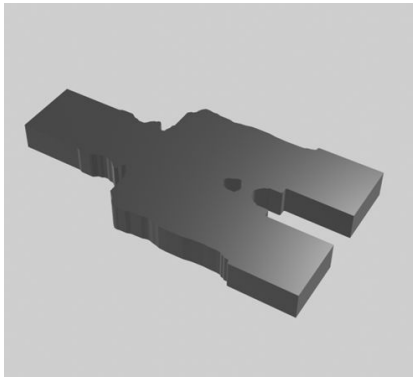
Level Set in Inverse Design

We use level set to parameterize our design region in a photonic device.



$$\begin{cases} \phi(x) > 0, silicon \\ \phi(x) < 0, air \end{cases}$$



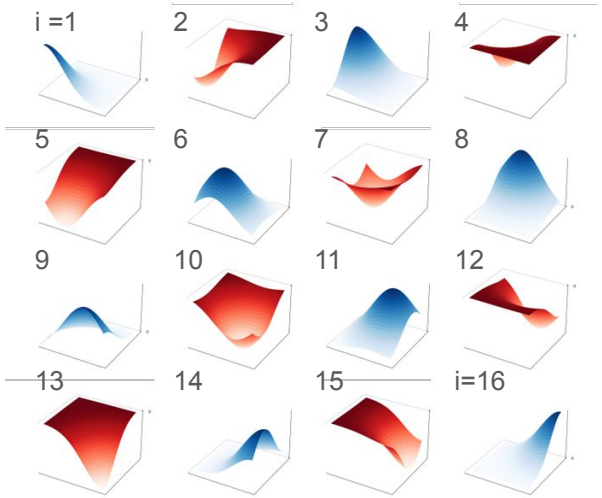


Parameterized Level Set

The level set function itself is parameterized, here by Gaussian Functions on a coarse grid.

BUILT BY FLEXCOMPUTE – A SOLVER TECHNOLOGY COMPANY

Gaussian Radial Basis Functions

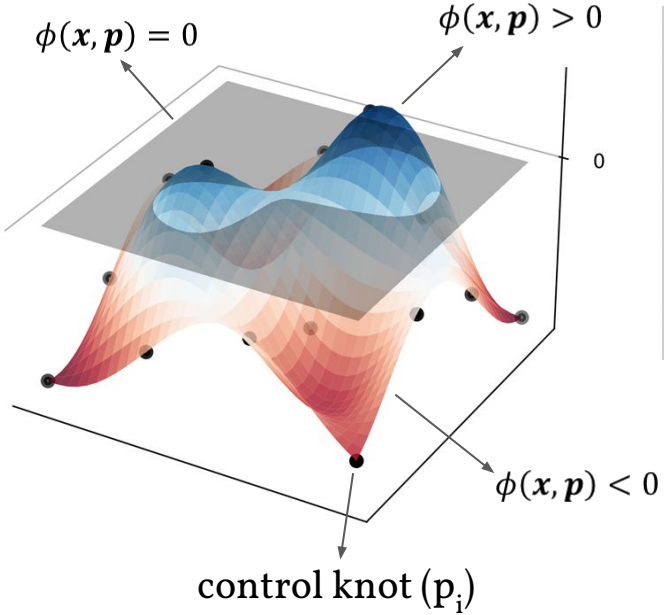


$$\varphi_i(\boldsymbol{x}) = e^{\frac{-r_i(\boldsymbol{x})^2}{2\sigma^2}} \qquad (i = 1, 2, \dots, N)$$

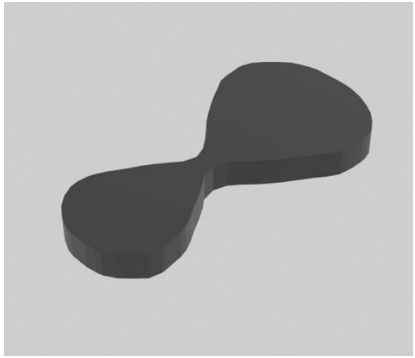
$$r_i(\boldsymbol{x}) = \|\boldsymbol{x} - \boldsymbol{x}_i\|$$

Level Set Surface

$$\phi(\boldsymbol{x}, \boldsymbol{p}) = \varphi(\boldsymbol{x})\alpha(\boldsymbol{p}) = \sum_{i=1}^{N} \varphi_i(\boldsymbol{x})\alpha_i(\boldsymbol{p})$$



Device

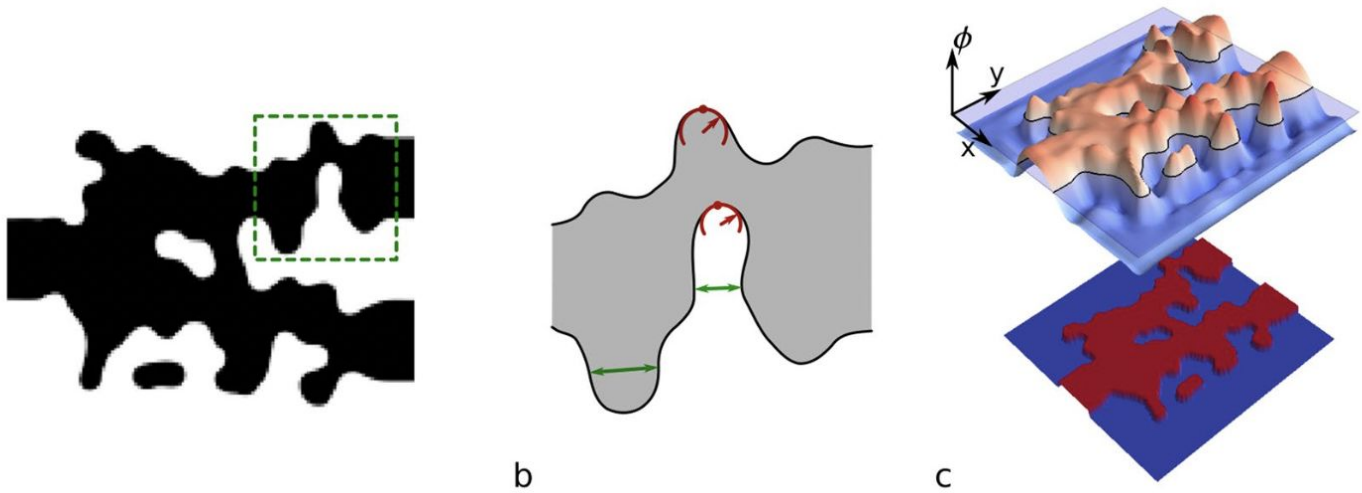


Tidy3D

Feature Size Constraints in Level Set

How do we ensure fabricable structures with large feature sizes?

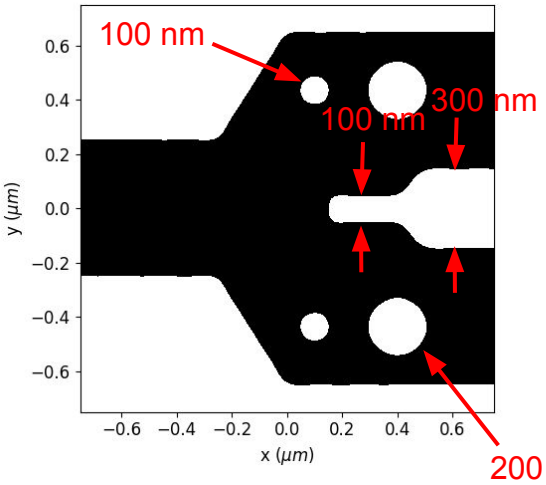
- Analytically define the radius of curvature and feature sizes in level set function.
- Add penalty involving these metrics.



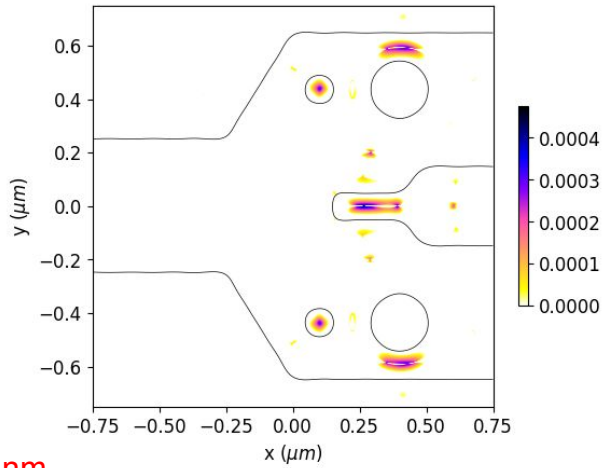
D. Vercruysse, N. V. Sapra, L. Su, R. Trivedi, and J. Vučković, Scientific Reports 9, 8999 (2019)

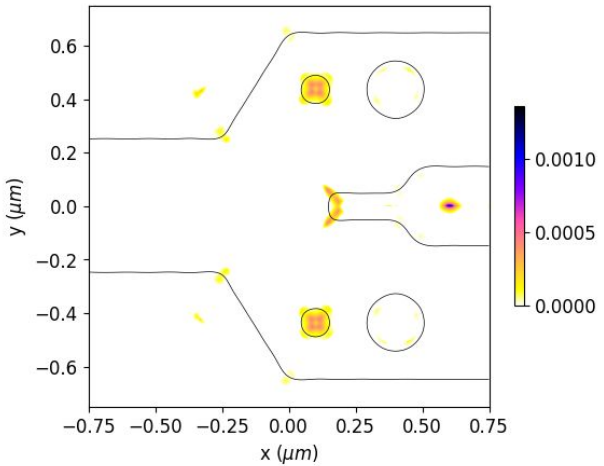
Feature Size Constraints: Example

As an example, let's visualize the penalties over a hypothetical device design

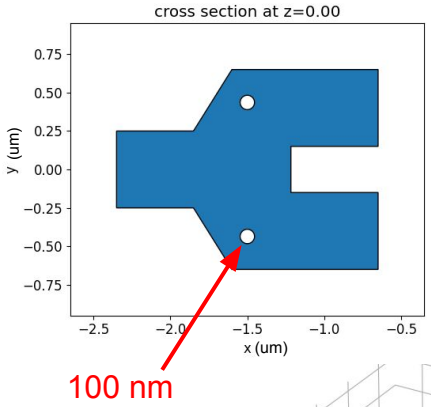


minimum feature size penalty: 160 nm

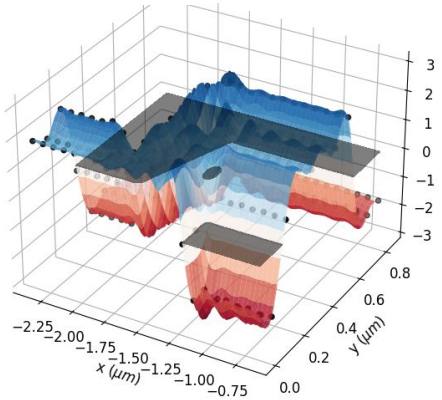




Example: Non-optimized Initial Splitter

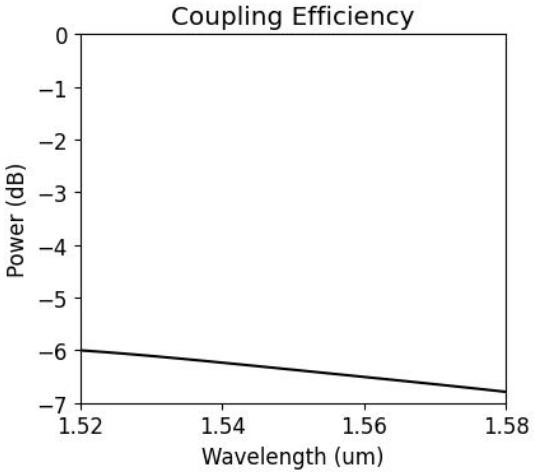


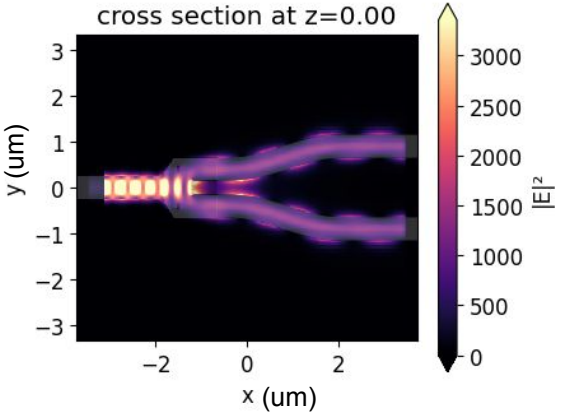
Initial Design



Initial Level Set Surface (upper half domain)

Poor Efficiency

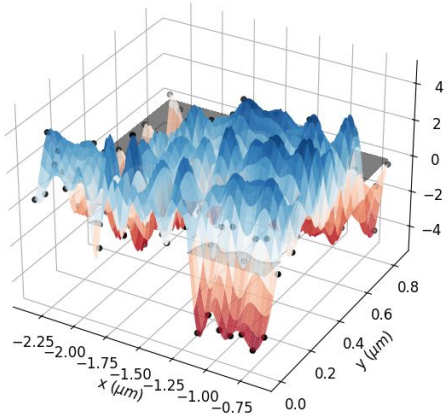


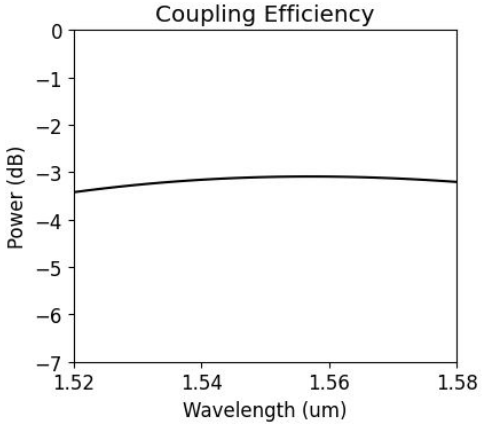


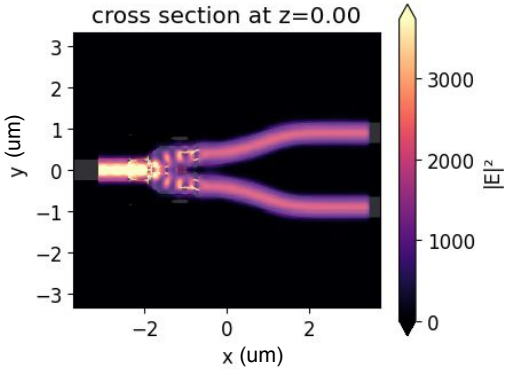
BUILT BY FLEXCOMPUTE – A SOLVER TECHNOLOGY COMPANY

Tidy3D

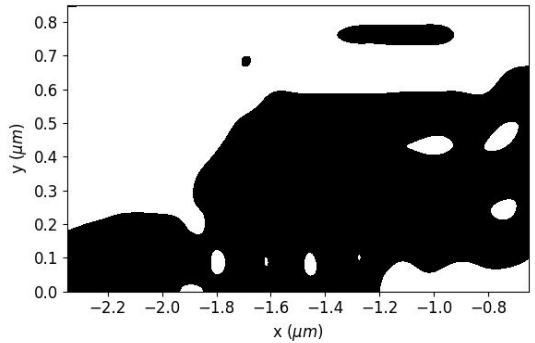
Results: No Feature Size Constraint

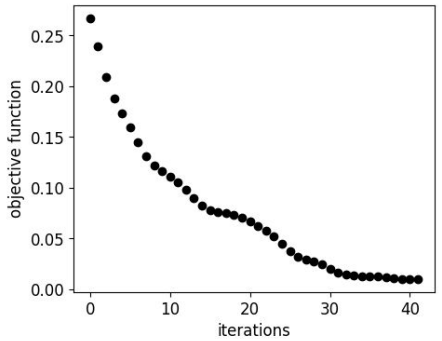




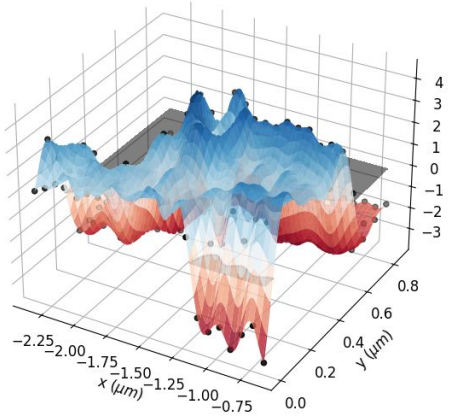


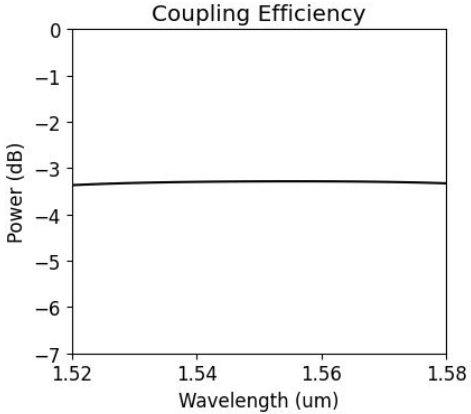
Final Level Set Contour

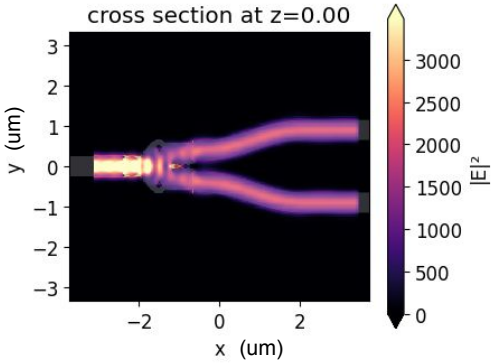


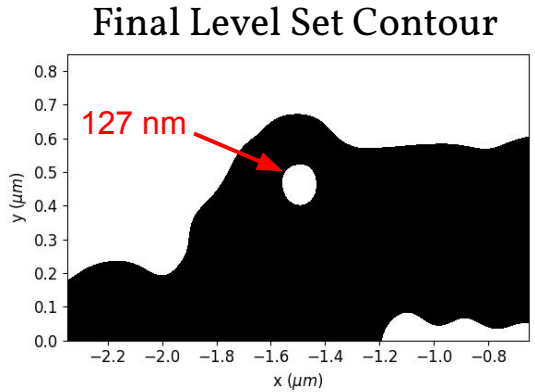


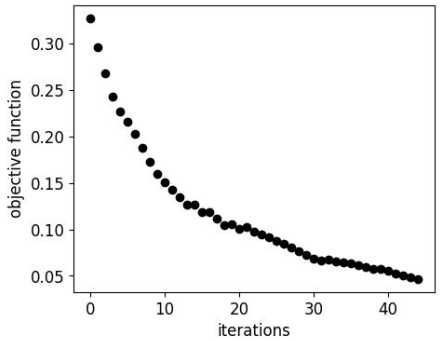
Results: Feature Size Constraint = 120 nm











Summary

- Level set is another way to parameterize the device design, which mixes some benefits of topology (pixel by pixel) optimization with shape optimization.
- Whereas shape optimization can be limited due to the constraints defined by the designer, with level set, one is able to define complex structures with many parameters.
- Level set makes it much more intuitive to binarize the structure.
- It also allows for analytical expressions of penalties for fabrication constraints.
- In general it is a widely used tool, so this is a brief summary to get users familiar with the basic ideas.