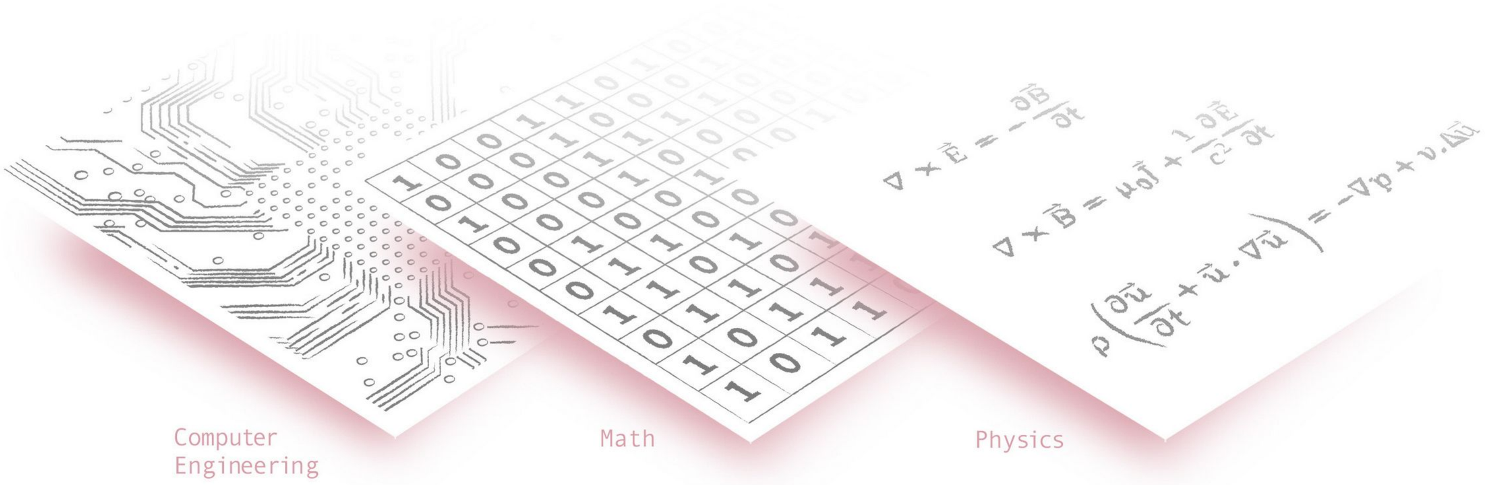

Inverse Design in Photonics

Tutorial 4: Basic Feature Constraints

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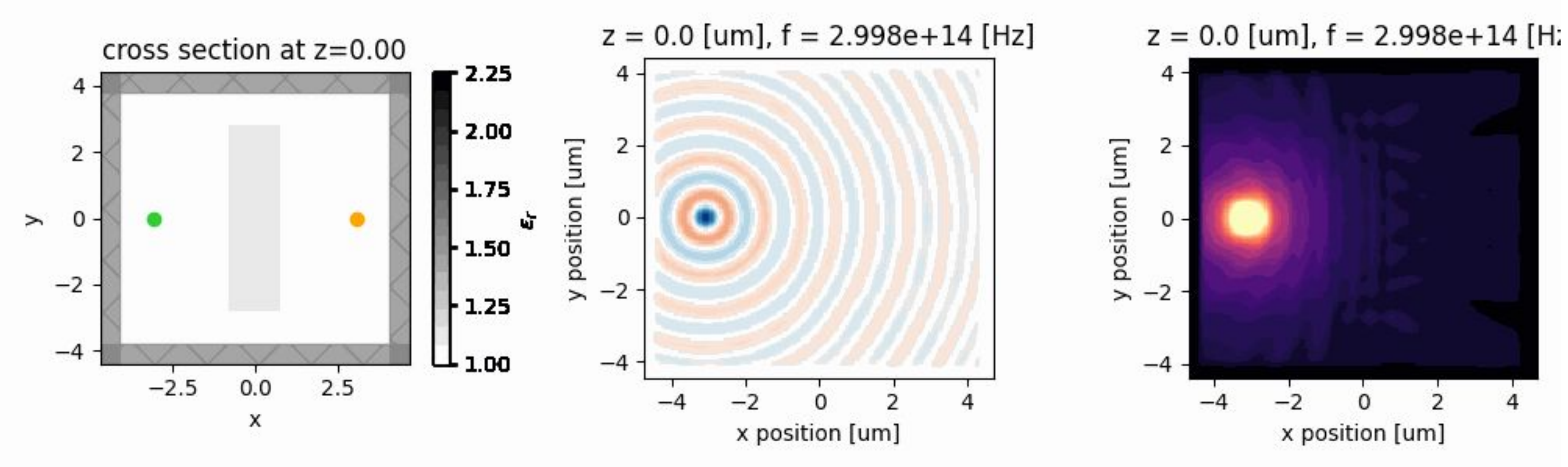
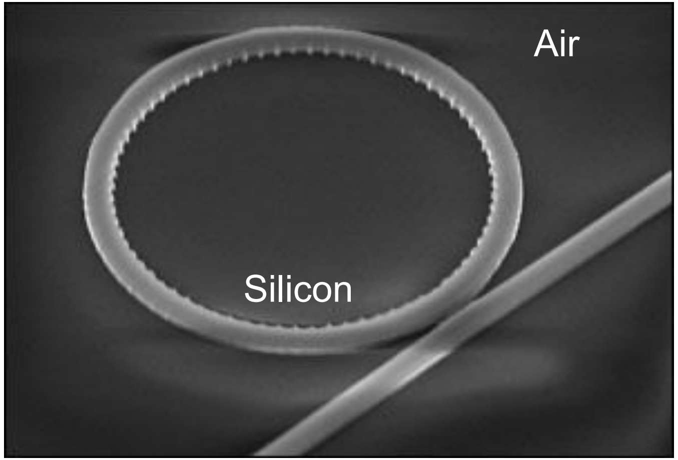
Review: Inverse Design Process

- Last time, we gave a simple demo of using inverse design to make a lens.
- This time we will discuss how to create a more realistic device satisfying fabrication constraints.



Defining Devices

- For example: in Silicon photonics, one can define a device by etching Silicon.
- The structure can only include silicon regions and air regions.
- Typically there are constraints regarding feature size that can be etched.
- Need to take this into account in the optimization algorithm.



https://www.photonics.com/Articles/Optical_Vortex_Beams_Emit_on_Silicon/a52139

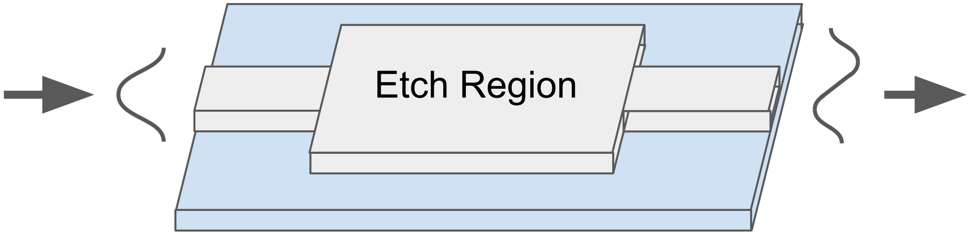
Demo: Si Photonics Mode Converter

System:

- Silicon waveguide on SiO2 structure with waveguide inputs and outputs.
- Rectangular "design region" that can be etched to remove some of the Si.

Goal:

- Design the central region to convert one waveguide mode to another.
- Objective function: maximize mode overlap with desired output mode.



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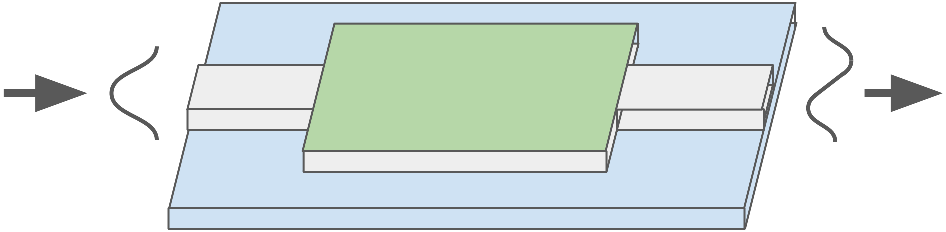
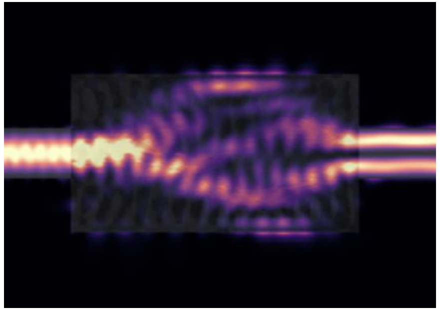
Without Feature Size Constraints

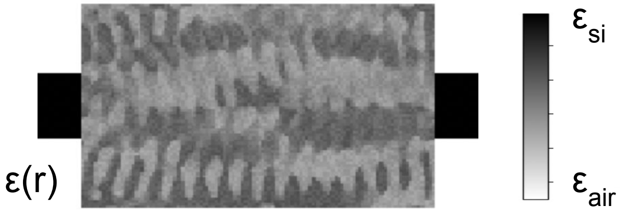
Directly optimize the dielectric function inside of the design region (green):



device works

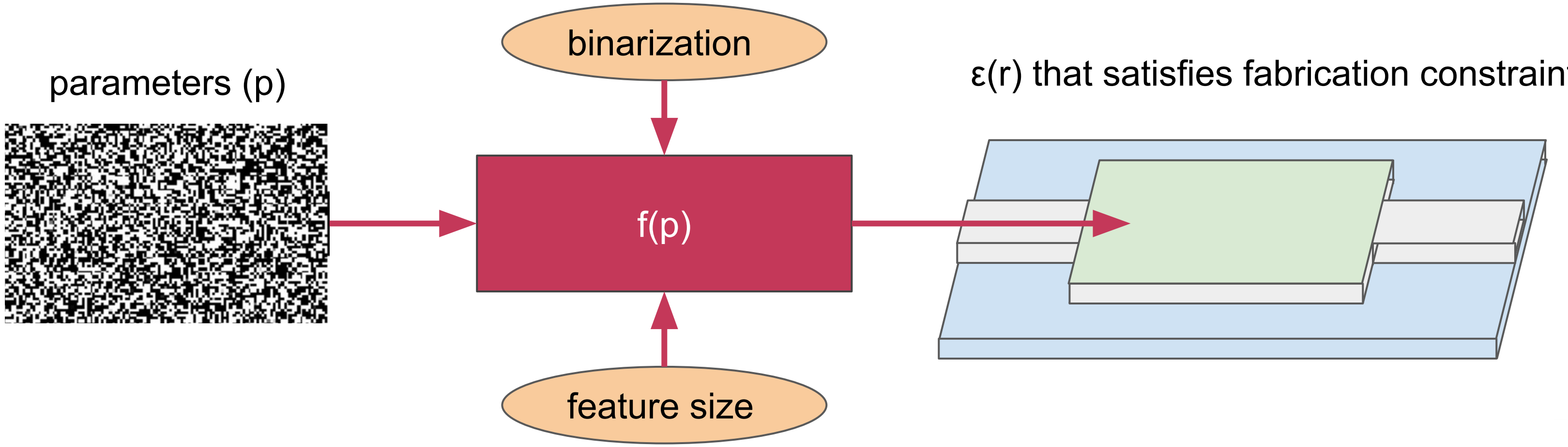


but is not binarized or fabricable



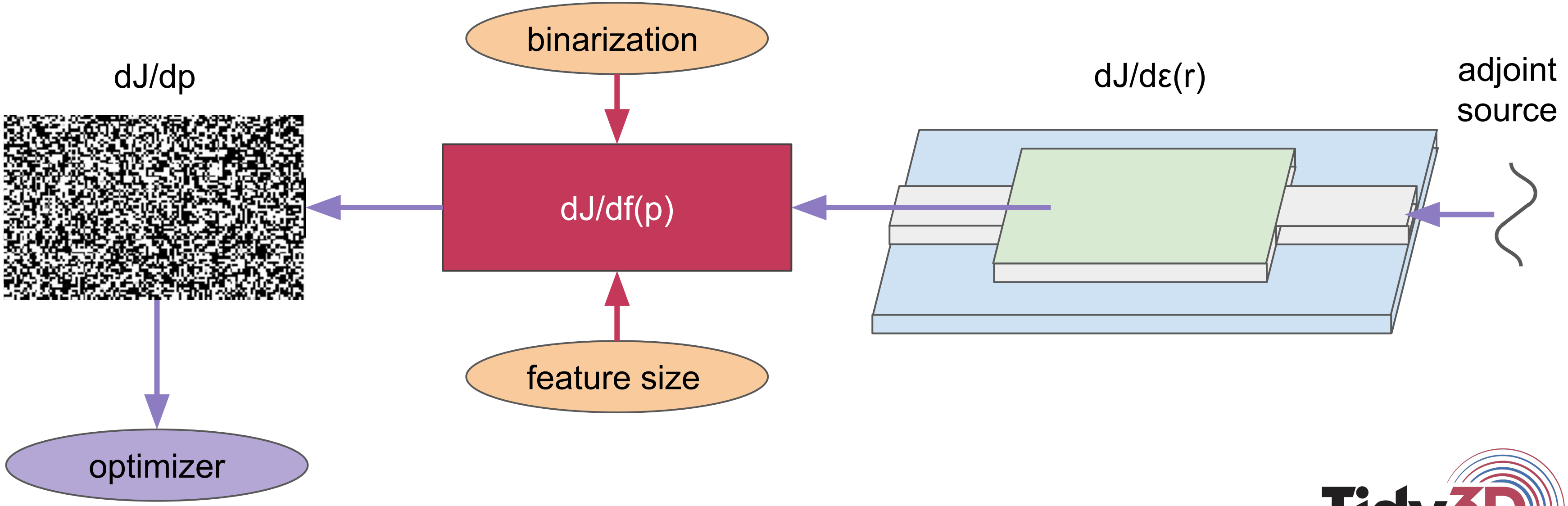
Parameterization

- General idea: express your dielectric function / device as a function of the parameters.
- Choose the function to express your desired fabrication constraints.



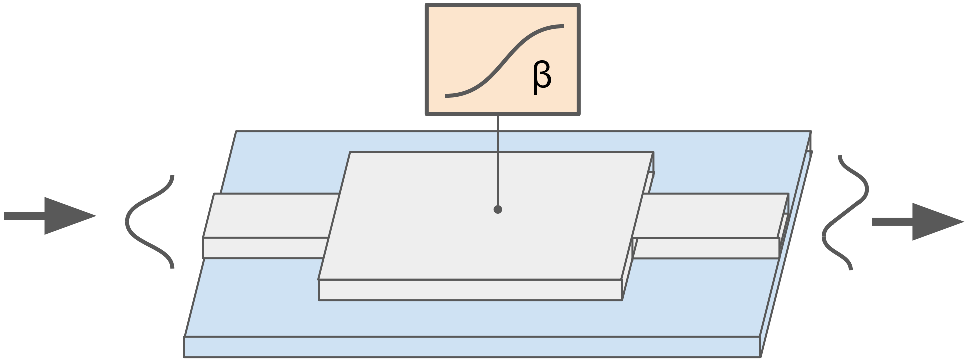
Differentiating Parameterization

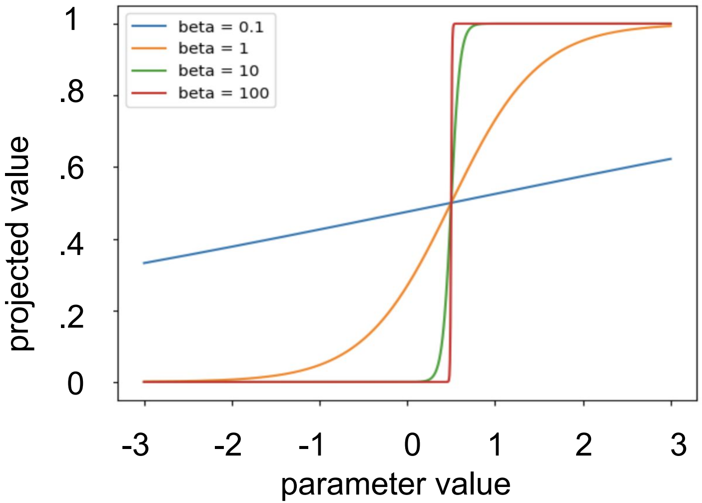
- Important to ensure smooth, differentiable parameterization.
- Use adjoint method to compute gradient (purple) through to the base parameters.



Imposing Binarization

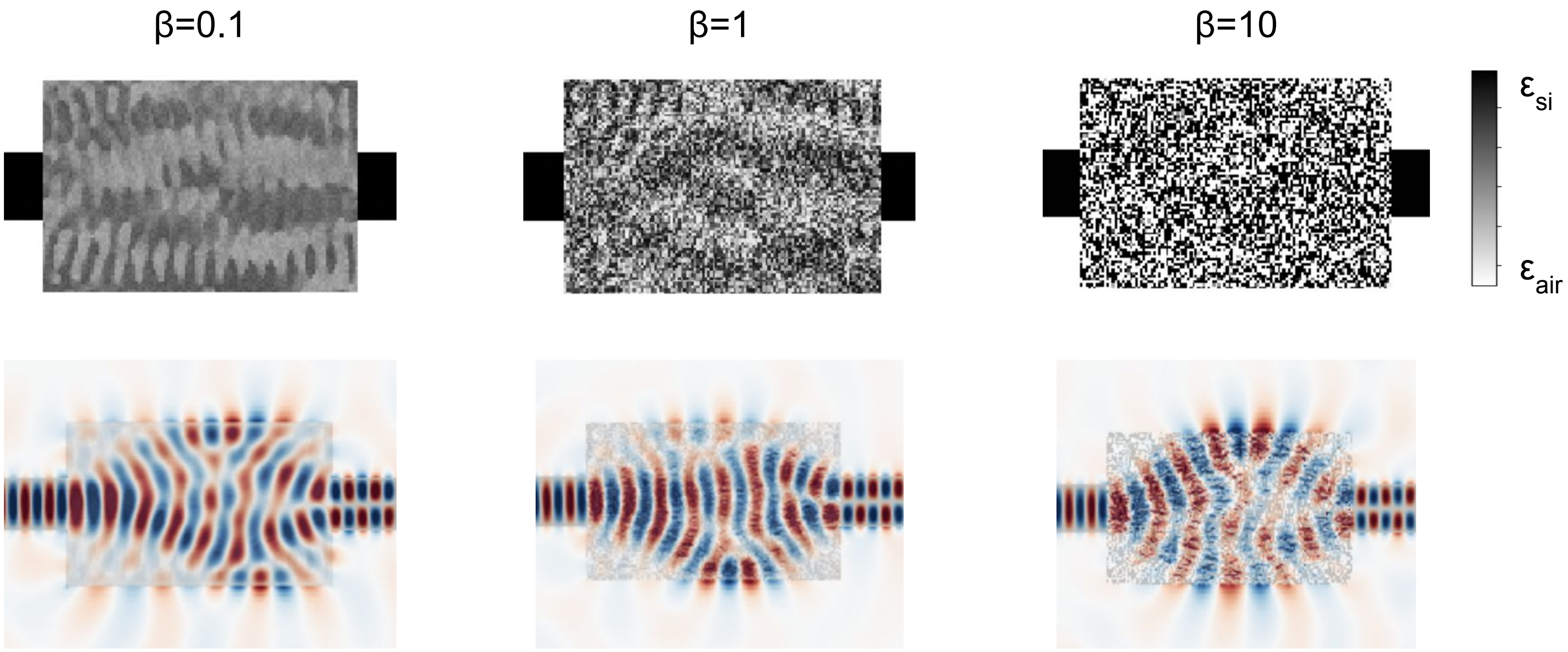
- Introduce a tanh projection to binarize permittivity in each pixel.
- Increase β to make it hard for the pixel permittivity to be in the middle.





$$\epsilon(p) = tanh(\beta p)\frac{\epsilon_2 - \epsilon_1}{2} + \frac{\epsilon_2 + \epsilon_1}{2}$$

Binarization Results

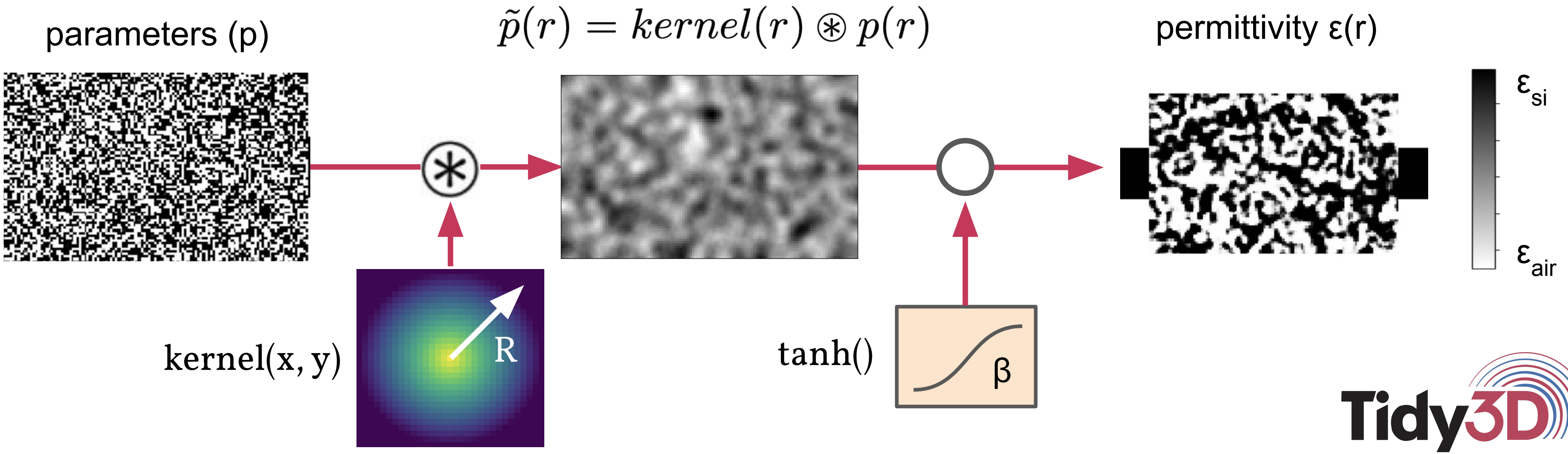


successfully converts modes

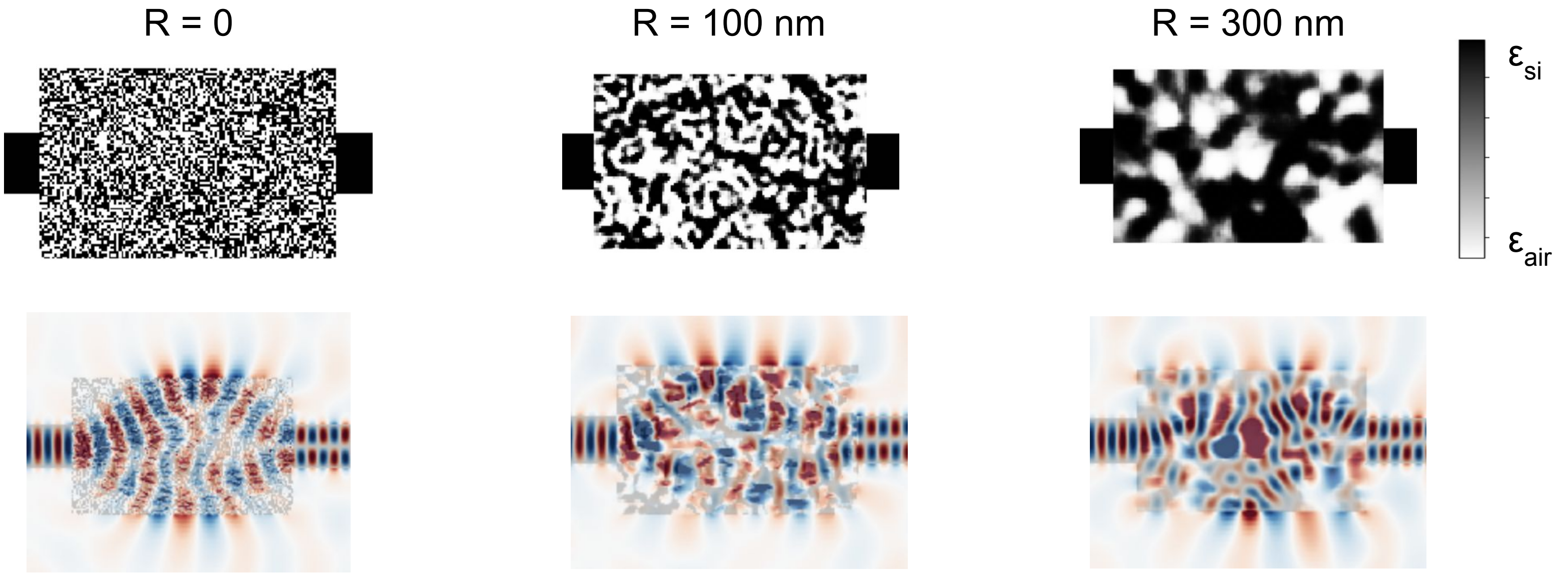
binarized, but not fabricable

Issue: the pixels are too small to fabricate!

- Introduce a “filter” that smooths the influence of each pixel over a radius “R”.
- Increasing “R” enforces larger feature sizes.
- Convolve each parameter with a conic filter before tanh projection.

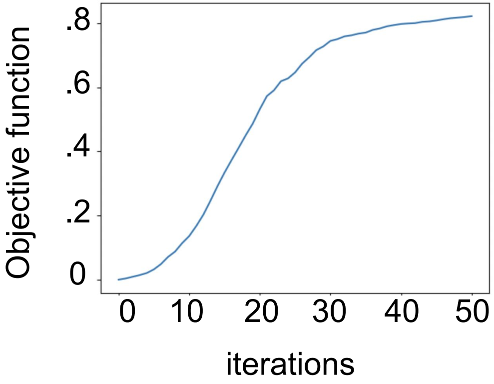


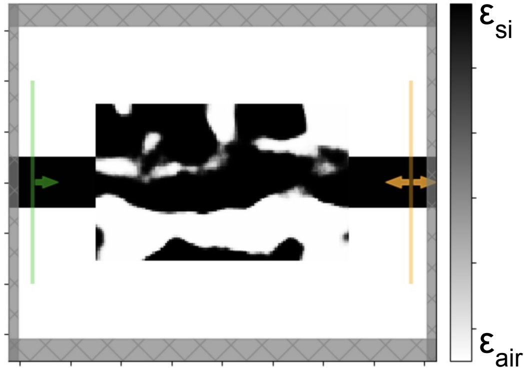
Smoothing Results

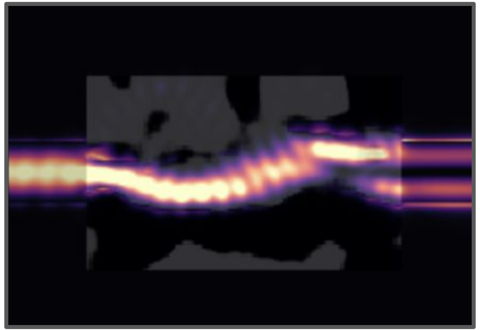


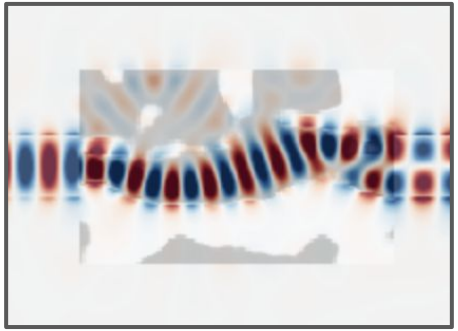
3D Optimization Results

- 50 iterations of optimization.
- Convolve with conic filter w/ radius=500 nm.
- Tanh projection with β=200.









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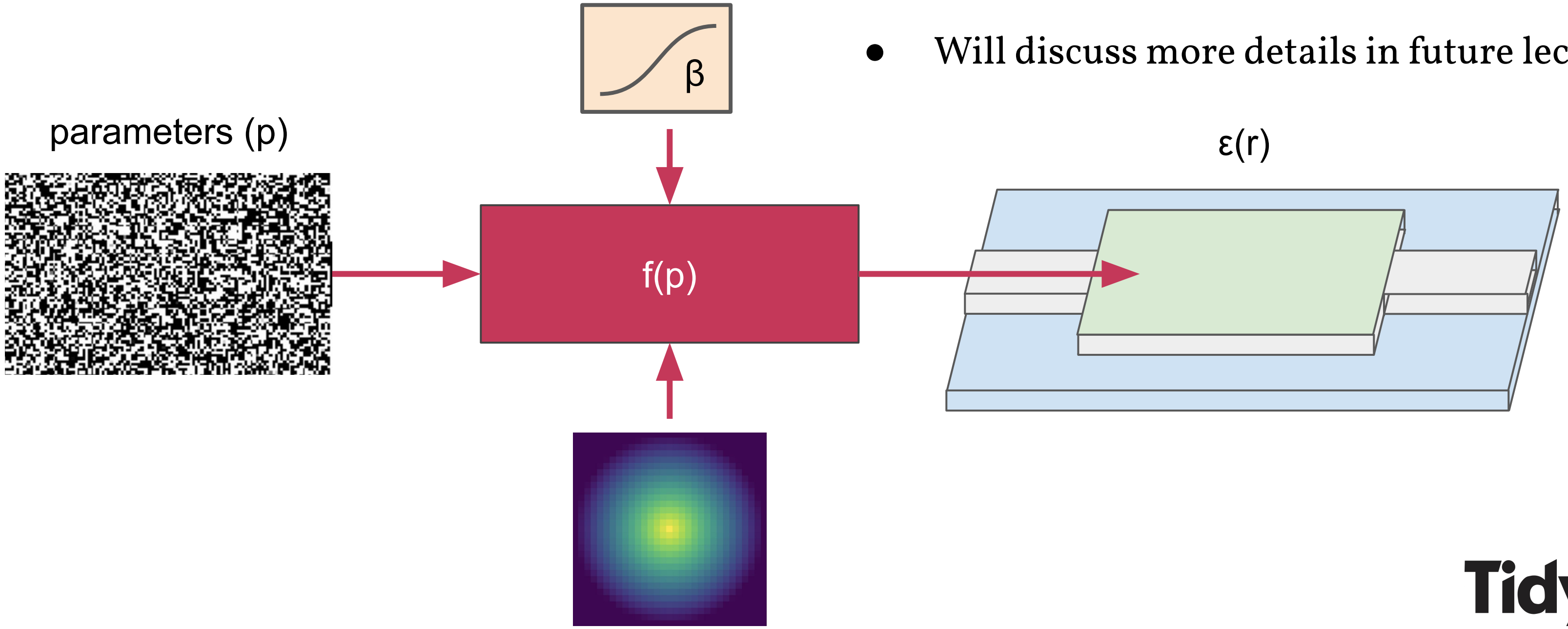
Takeaway

- Important to craft the parameterization that implements the feature constraints you care about.
- Will discuss more details in future lectures.



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