Topology optimization of optical surfaces

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Topology optimization of optical surfaces

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Motivation and goals

For many applications the need for specifying and controlling the optical properties of surfaces is of high importance. Furthermore, the advances in nano-technology allow for fabrication of increasingly complex nano-structured surfaces. The problem of designing nano-structured surfaces with specific optical properties can be extremely challenging. A systematical design method is desireable to design surfaces of complex topology with tailored optical properties and to ensure design robustness considering practical dimensional tolerances.

Goals:

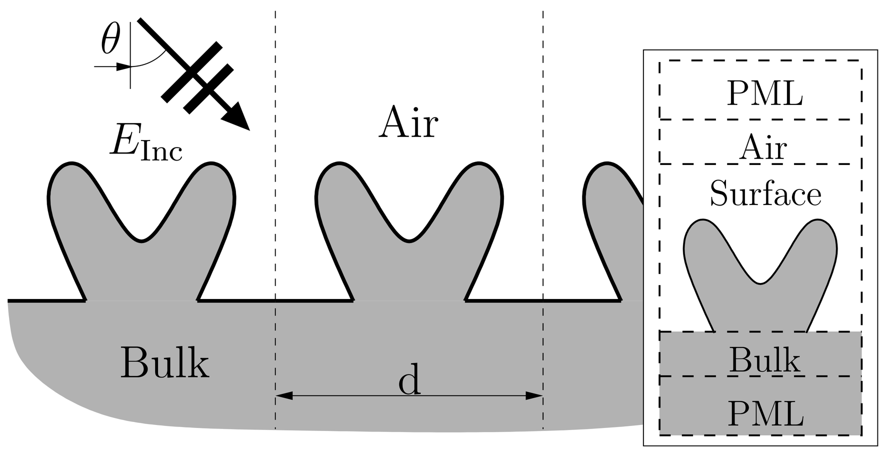
- Development of systematic method for designing optical surfaces
- Consider manufacturing tolerances and minimum length scale
- Verification of method by numerical examples

Example Applications:

- Advanced high performance gratings
- Structural color surfaces
- Optical filters

Modelling

The problem is modelled as a periodic cell



The electro-magnetic field is described by the 2D Helmholtz equation

$$\nabla\cdot(A(\mathbf{x})\nabla u(\mathbf{x})) + \omega^2 B(\mathbf{x})u(\mathbf{x}) = 0$$

with polarisation dependent parameters

$$A_{\mathrm{TM}} = \frac{1}{\mu_r},\ B_{\mathrm{TM}} = \frac{\epsilon_r}{c^2} \qquad A_{\mathrm{TE}} = \frac{1}{\epsilon_r},\ B_{\mathrm{TE}} = \frac{\mu_r}{c^2}$$

Parameterization

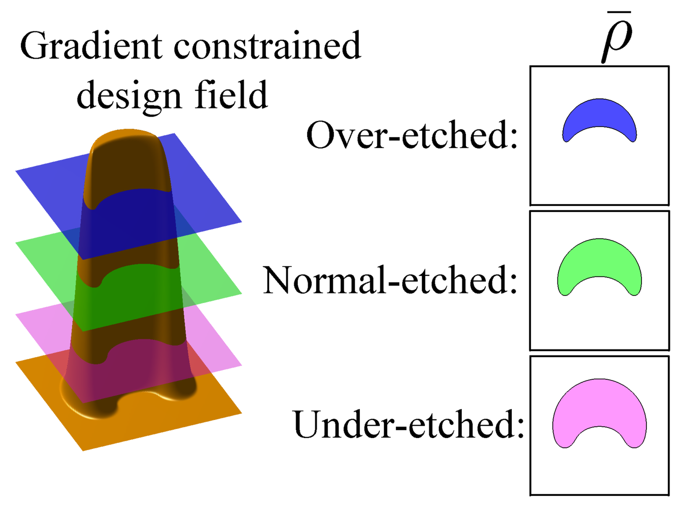
Material properties are interpolated by elemental material parameters

$$A_e = A_1 + \bar{\rho}_e^p(A_2 - A_1)$$
$$B_e = B_1 + \bar{\rho}_e^p(B_2 - B1_1)$$

Elemental density: $0 \le \bar{\rho}_e(\rho) \le 1$, for $e \in \Omega$

Robust design

Simulates eroded, intermediate and dilated design realisations [5]



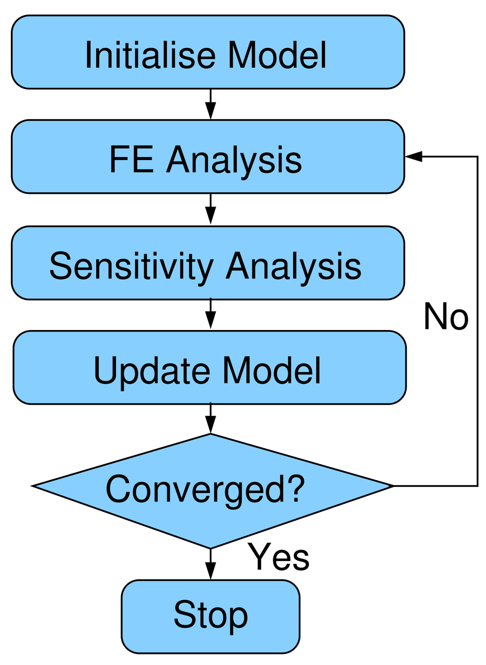
Topology optimisation

$$\min_{\rho_j} : \max_{q} : \max_{i} : \{h_i((\tilde{\rho}_j)^q)\}, \quad 0 < \rho_j \le 1,$$
$$\text{s.t.} :(\mathbf{K}_i^q - \omega^2\mathbf{M}_i^q)\mathbf{u} = \mathbf{f}_i, \quad h_i = \{\mathrm{T\ or\ R}\},$$
$$(\hat{\mathbf{K}}_\mathbf{i} - \lambda_1^q\hat{\mathbf{M}}_\mathbf{i})\mathbf{x} = 0, \quad \lambda_1^q > \delta,\ q = \{e, i, d\},$$
$$i = 1, \dots N_{\omega,\theta,\mathrm{pol}}, \quad j = 1, \dots N_{\mathrm{el}}$$

Design sensitivity

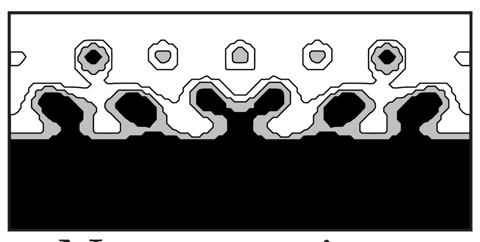
$$\frac{\mathrm{d}\Phi}{\mathrm{d}\rho_i} = 2\Re\left(\boldsymbol{\lambda}^T\frac{\partial\mathbf{S}}{\partial\rho_i}\mathbf{u}\right)$$

$$\mathbf{S}^T\boldsymbol{\lambda} = \sum_{e\in e_{\mathrm{in}}}\frac{i}{4\omega\mu}\mathbf{Q}^e\bar{\mathbf{u}}_e$$

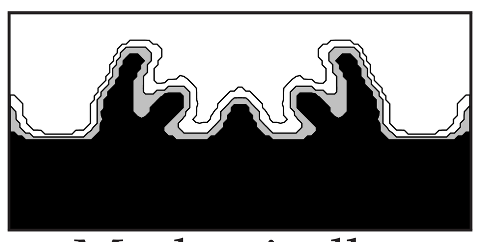


Numerical examples

Max transmittance - multiangles



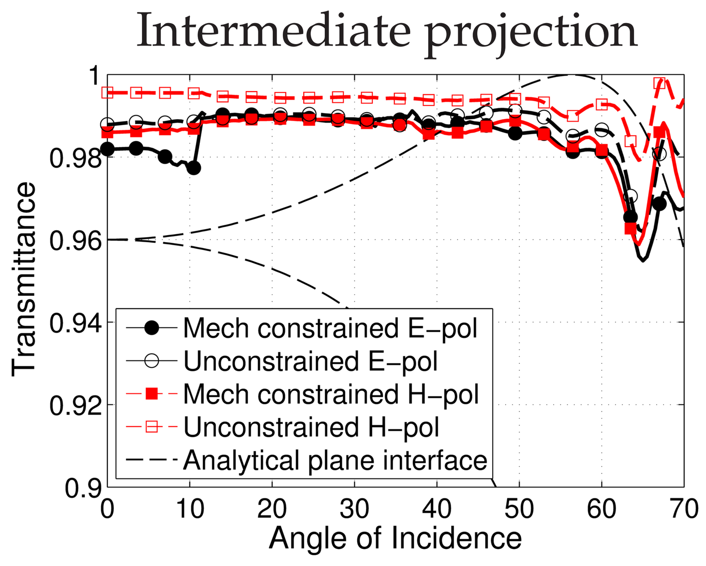
No constraints



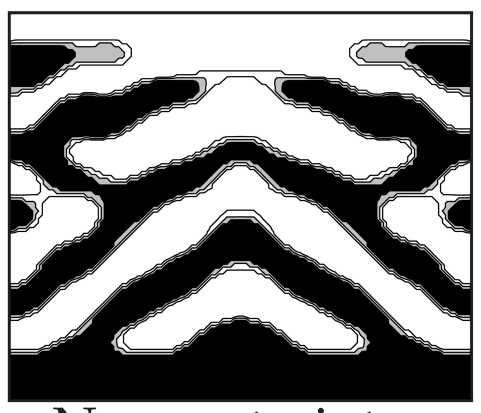
Mechanically constrained

Angle sweep

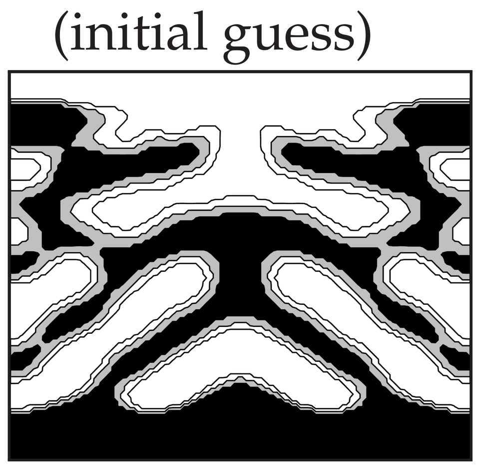
Intermediate projection



Maximise reflectance - multifrequency



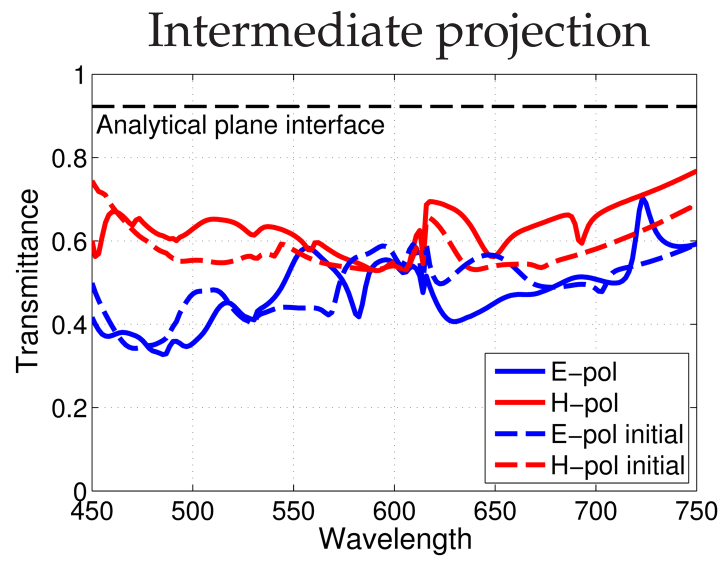
No constraints (initial guess)



Mechanically constrained

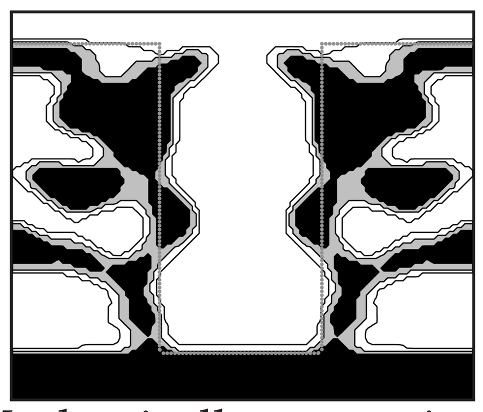
Wavelength sweep

Intermediate projection



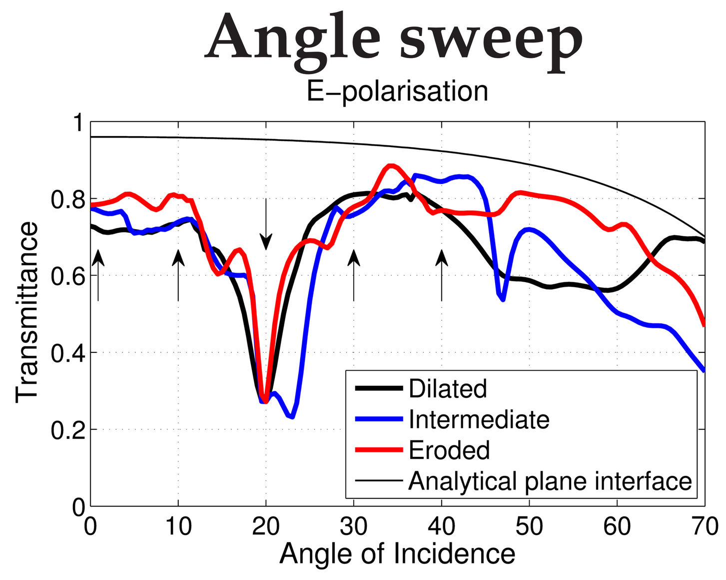
Surface design build by intermediate projection

Selective reflectance



Mechanically constrained

Angle sweep



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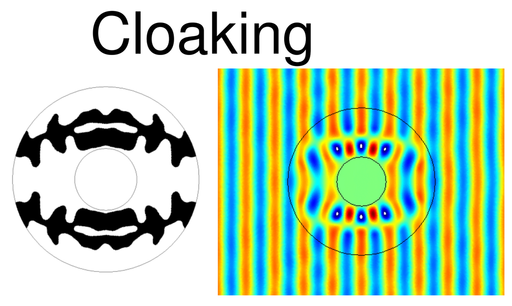
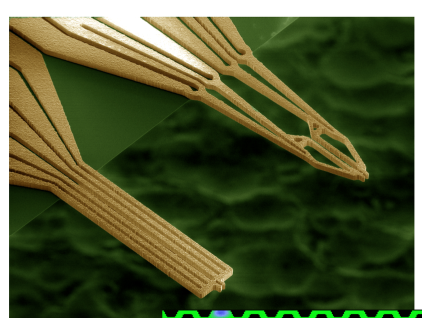
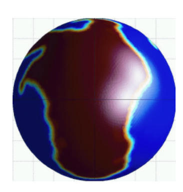
Previous examples

Cloaking



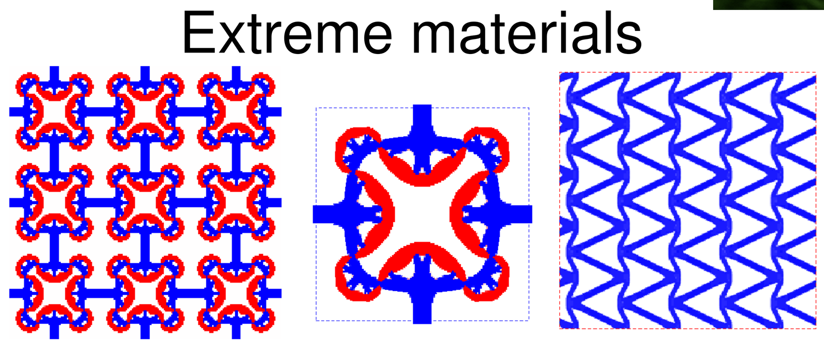


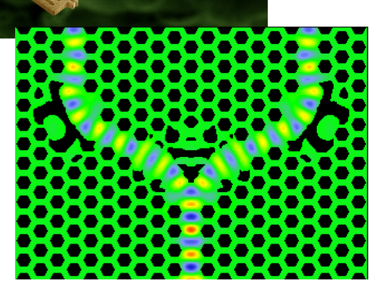
MEMS



TopOpt App

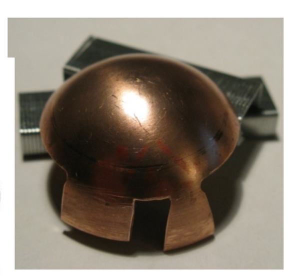
Extreme materials





PGB splitter

Micro Antennas



TopOpt App

iPhone/iPad

Android