Coordinate-based manipulation of guided waves with metamaterial waveguides

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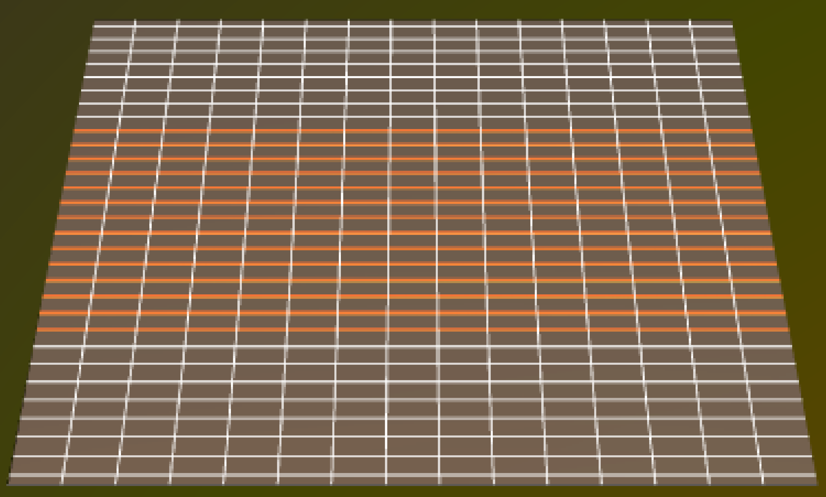
Coordinate-based light flows along metamaterial waveguides may open up new possibilities for the holistic manipulation of two-dimensional light

The straight trajectories of incident guided modes along the plane of a slab waveguide...

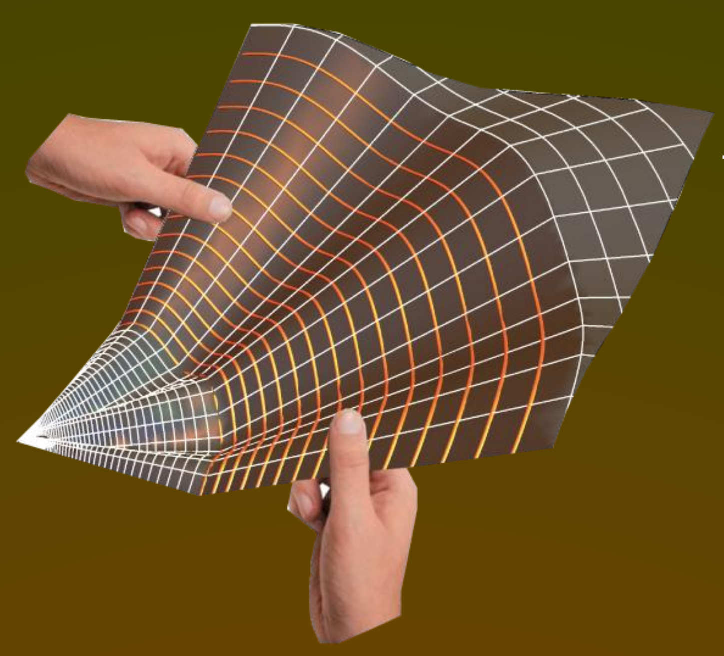
are deformed by a conformal coordinate transformation characterized by a scalar geometry γ(x,y)…

so that they follow desired trajectories along a metamaterial waveguide core.

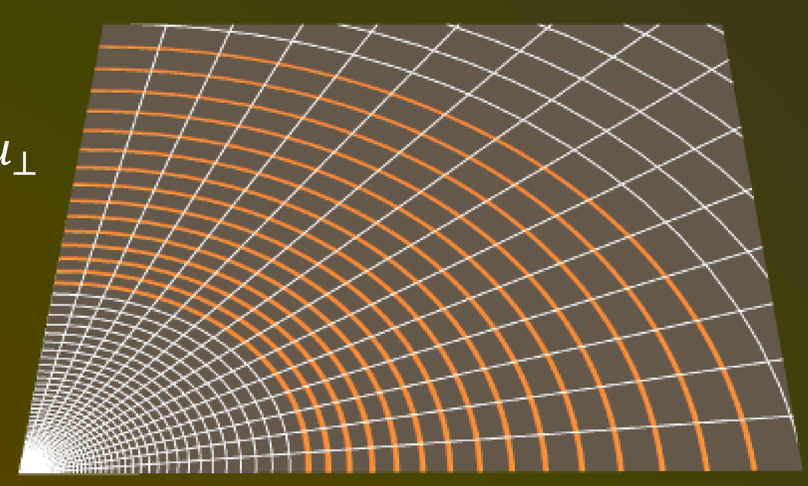


$(\boldsymbol{u}, \boldsymbol{v})$

$$u = Xx,\quad v = Xy,\quad \gamma(x,y) = X^2$$



$$\frac{\epsilon_\perp}{\epsilon(z)} = \gamma(x,y) = \mu_\perp \qquad \frac{\epsilon_{||}}{\epsilon(z)} = 1 = \mu_{||}$$



$(\boldsymbol{x}, \boldsymbol{y})$

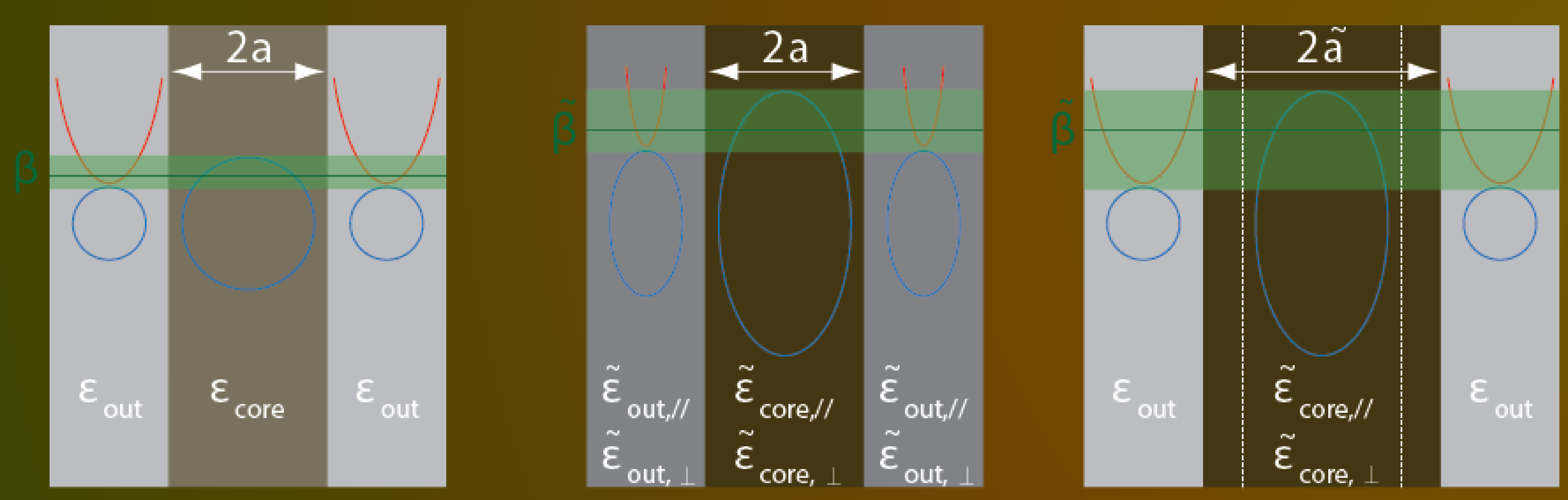
Unfortunately, the traditional transformation-optical implementation requires magnetic and bulky metamaterials

We propose a two-dimensional equivalence:

A metamaterial core of varying thickness preserves the the Helmholtz wave equation and the dispersion relation

$$\epsilon_{||} = \epsilon_{\text{core}}, \qquad \epsilon_\perp = \gamma(x,y)\epsilon_{\text{core}}, \qquad \mu = 1$$

$$\tan(k_{\text{core}}\tilde{a}) = \frac{\epsilon_{\text{core}}}{\epsilon_{\text{out}}} \frac{\sqrt{\gamma(x,y)\beta^2 - \epsilon_{\text{core}}\frac{\omega^2}{c^2}}}{k_{\text{core}}}$$

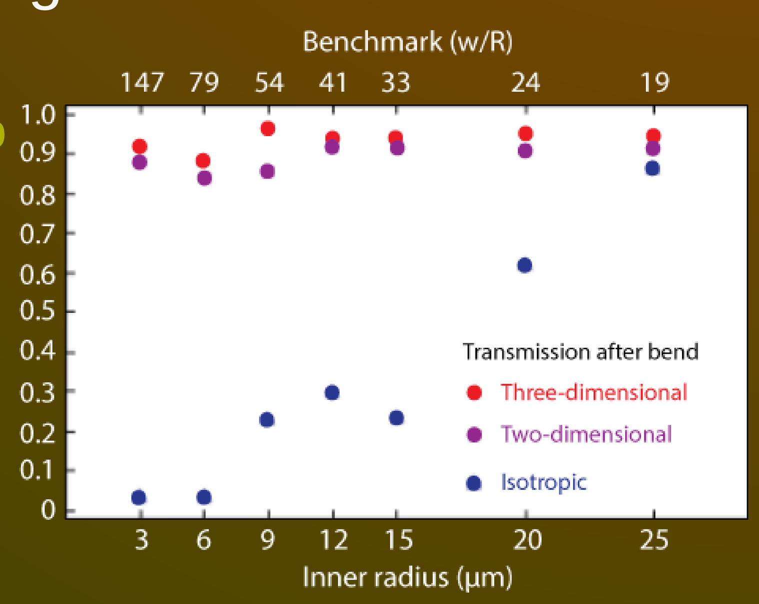


Before | Bulky equivalence | 2D equivalence

Two- versus three-dimensional transformation optics: a quantitative comparison with tight bends

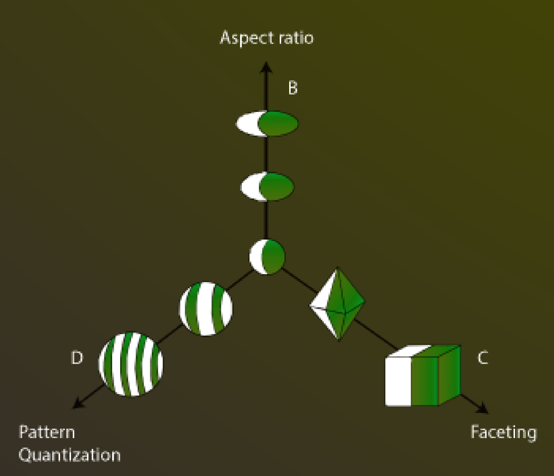
Anisotropy is a necessary ingredient to improve w.r.t. geometrical optics [4]

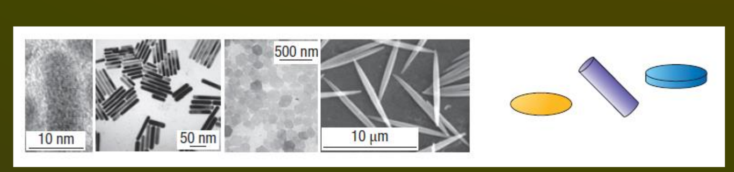
Manipulation with individual fibers in has benchmark $\frac{w}{R} = 19$ [5]



e

Laser writing or self assembly of nanowires and ellipsoids may provide the required waveguide cores

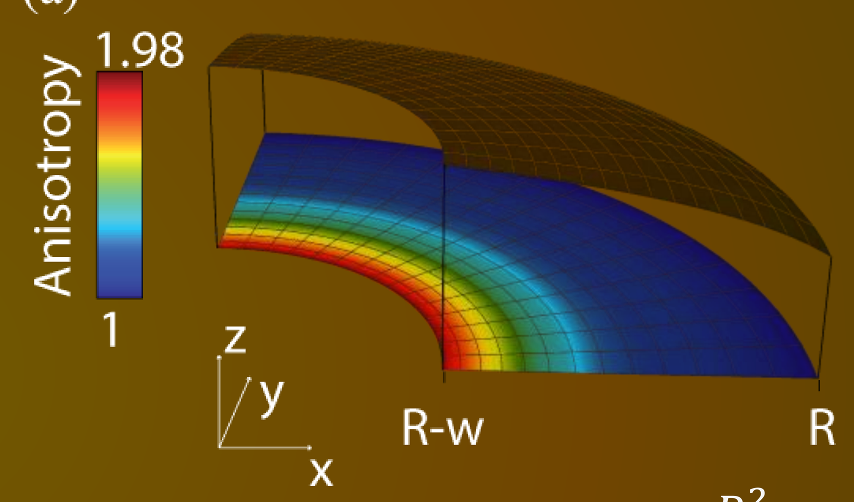




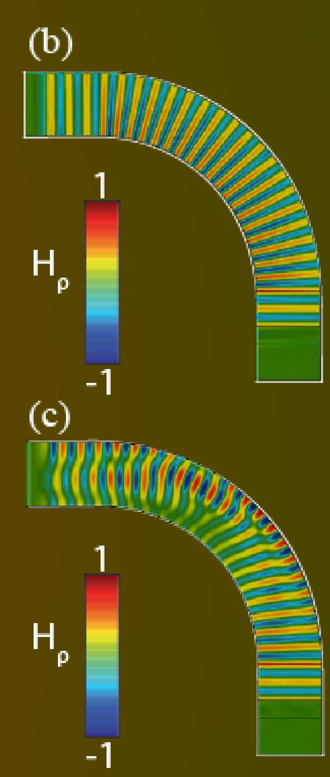
Nanowires and ellipsoids are produced in great variety through self assembly. Figures reproduced from [6]

Our equivalence is validated by three crucial functionalities: bending, splitting and focussing of light

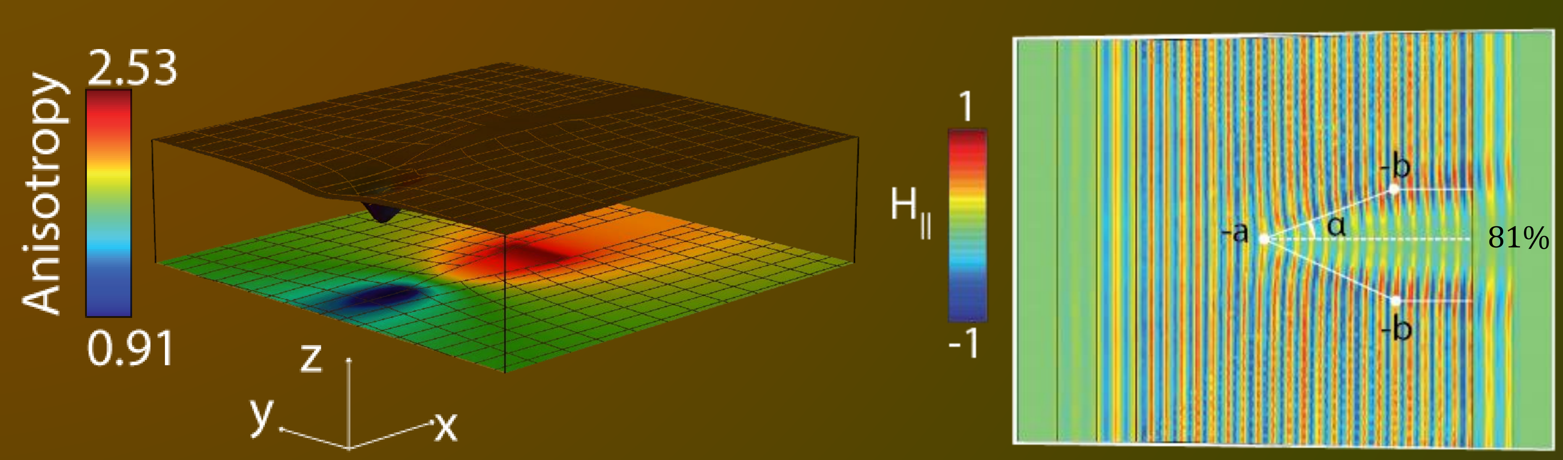
1. A beam bender (Logarithmic map)



$$\gamma(x,y) = \frac{R^2}{x^2 + y^2}$$

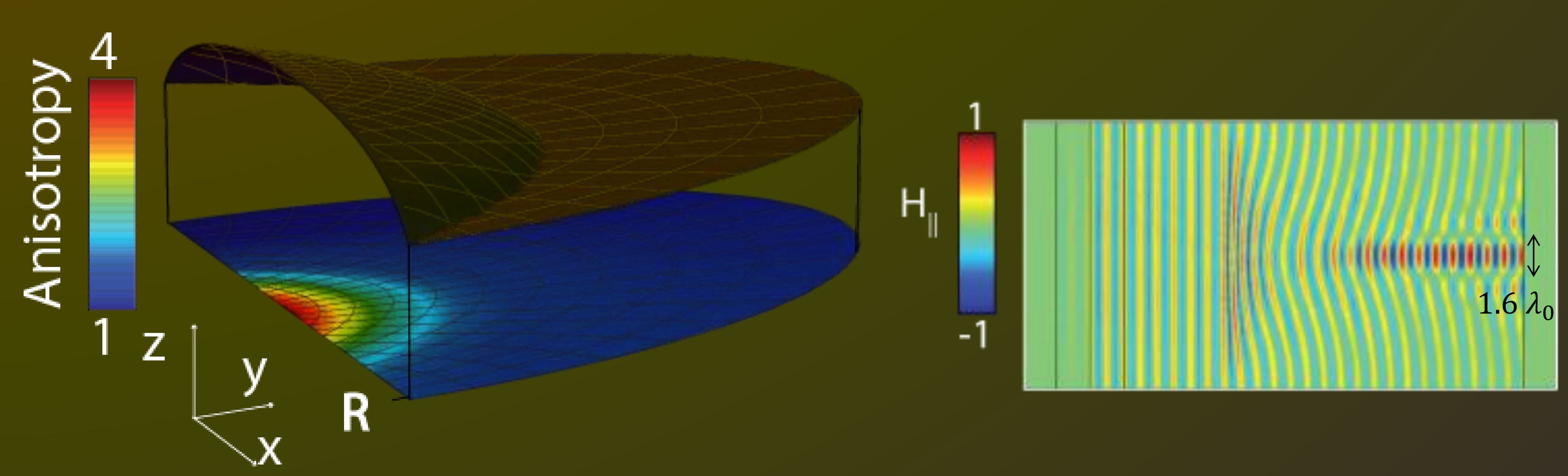


2. A beam splitter (Schwarz-Christoffel)



$$\gamma(x,y) = \frac{(w^2 - b^2)^{\frac{\alpha}{\pi}}}{\left(w^2 - \frac{1}{2}(a^2 + b^2) + i[(w^2 - a^2)(w^2 - b^2)]^{\frac{1}{2}}\right)^{\frac{\alpha}{\pi}}}$$

3. A conformal lens (Möbius)



$$\gamma(x,y) = \frac{4R^4}{(x^2 + y^2)^2}$$

References

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