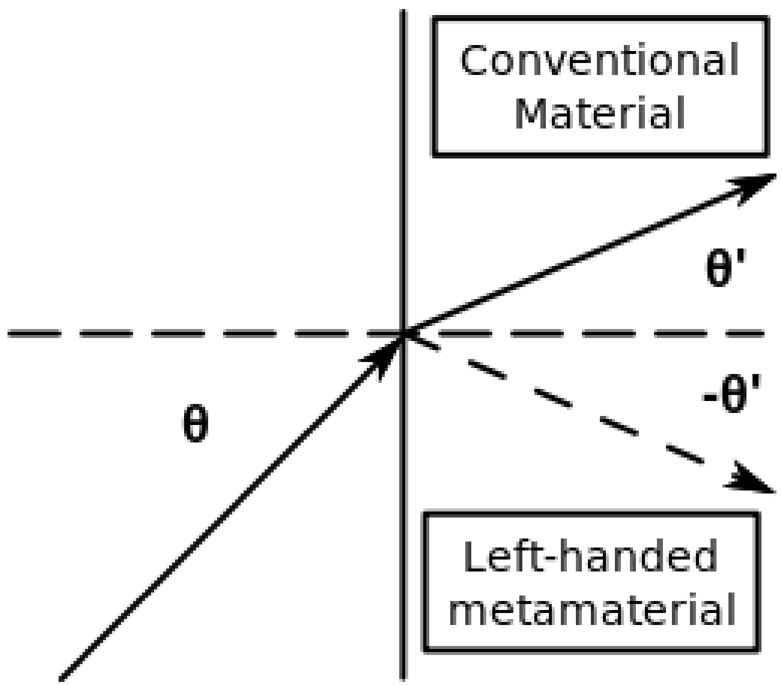
Encomenda: Meta-Materiais

- Definition: Metamaterials are artificial materials engineered to have properties that may not be found in nature. They usually gain their properties from structure rather than composition, using small inhomogeneities to create effective macroscopic behavior.
- Best known example: “Capa de Invisibilidade” - com usuarios como
- Henry Potter, O Sombra, O Predador, Os Klingons, ...

We know the Maxwell equations since the 1860's and we *thought* we understood their content: but it never hurts to re-examine our assumptions-

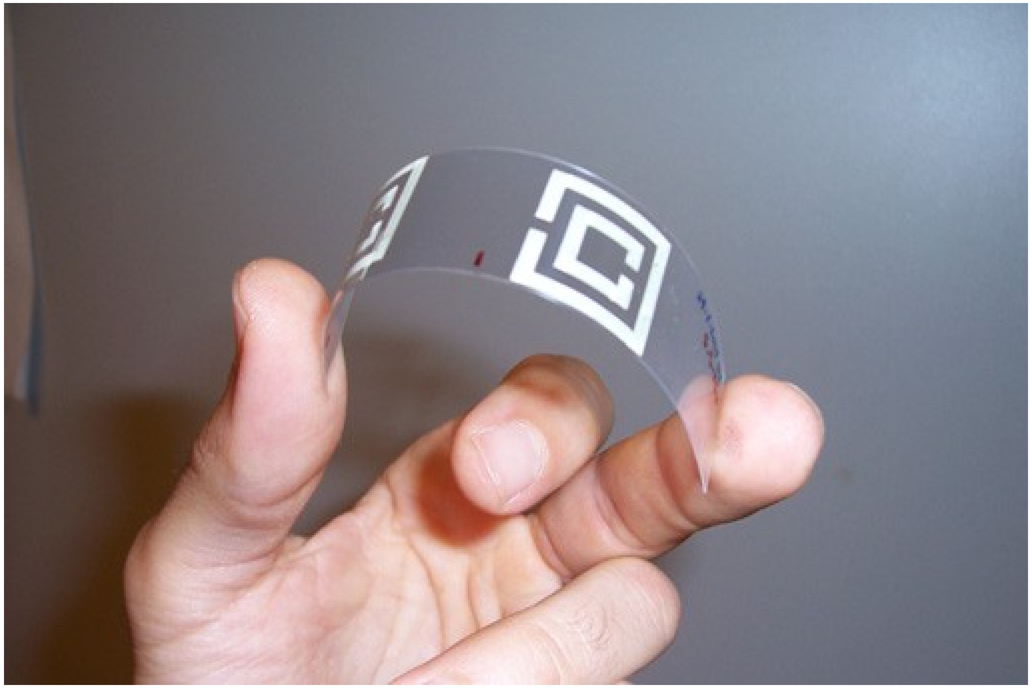
- Almost all materials encountered in optics, such as glass or water, have positive values for both electric permittivity ε and magnetic permeability μ. However, many metals (such as silver and gold) have negative ε at visible wavelengths. A material having either (but not both) ε or μ negative is opaque to electromagnetic radiation.
- Although the optical properties of a transparent material are fully specified by the parameters ε and μ, the refractive index n is often used in practice, which can be determined from $n = (+/-)1/ \sqrt{(\varepsilon \mu)}$. All known "normal" transparent materials possess positive ε and μ. By convention the positive square root is used for n.
- However, some engineered metamaterials have $\varepsilon < 0$ and $\mu < 0$ over a limited frequency range. Because the product (εμ) is positive, n is real. Under such circumstances, it is necessary to take the negative square root for n. Victor Veselago ("The electrodynamics of substances with simultaneously negative values of ε and μ". Sov. Phys. Usp. 10 (4): 509–14,1967), proved that such substances can transmit light. The question then is: can such a material be constructed?????



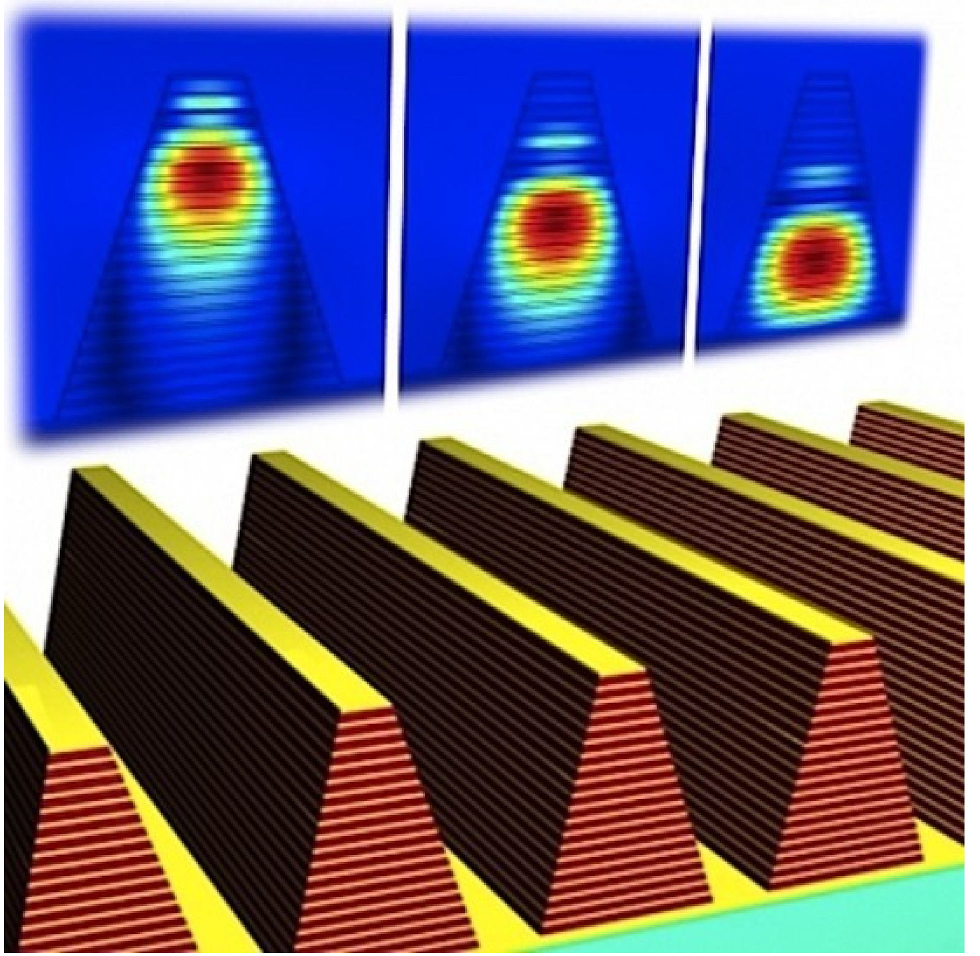
Snell's Law:
$N_1 \sin \theta_1 = N_2 \sin\theta_2$

The resonant network must have features on the same size-scale as the waves being scattered.

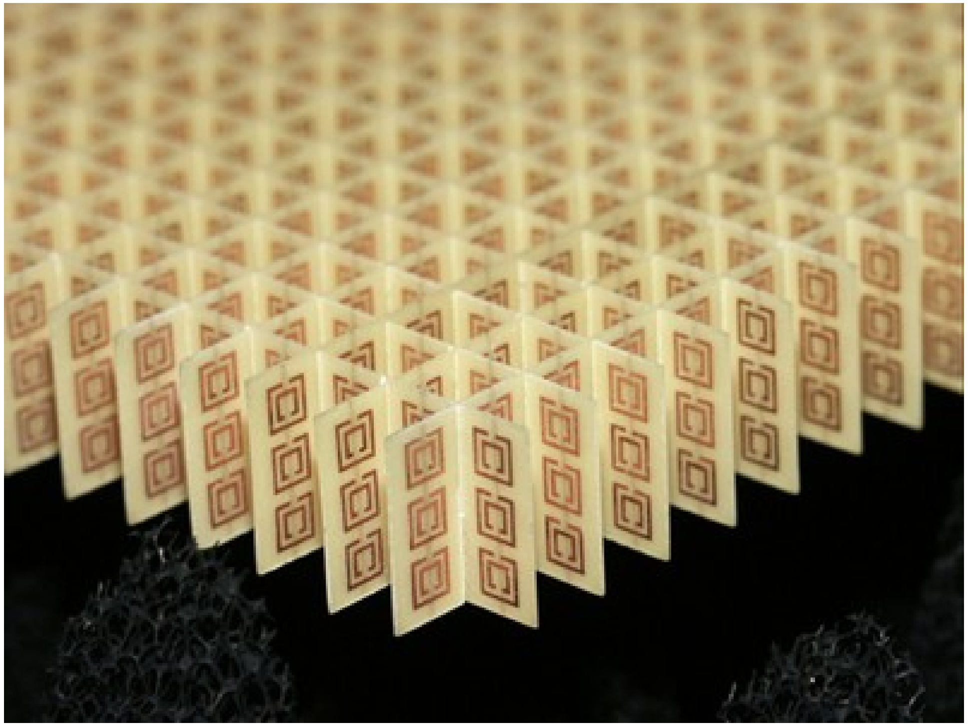
- 2009 : Scientists U. of I (Illinois) have created a new type of metamaterial that could be used to create high-definition ultrasound images
- of babies in-utero,
- help doctors find tiny tumours or
- hide submarines from enemy sonar.



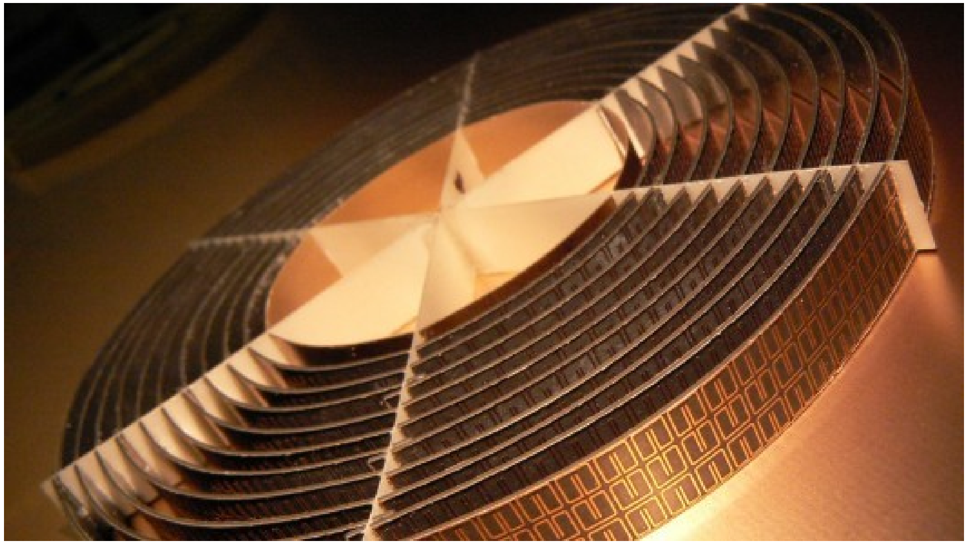
- If you can turn light into a 'Left-Hand Wave' form, you can also slow it down (absorb, then re-emit later) Researchers at MIT have developed (2012) metamaterials — from the atom up — which are meticulously engineered to have qualities that no matter found in nature do. These materials are designed to interact with light in very specific ways and can actually slow down light to less than 1/100th of its normal speed in a vacuum, making it all the easier to catch and absorb for the purposes of energy generation. “When something is going very fast, it’s difficult to catch it,” Lead author Nicholas X. Fang told TG Daily, ”so we slow it down so it’s easier to absorb.”
- The wedge-shaped materials are not only good at absorbing photons, but they’re also good at emitting them, which means that in addition to applications in more efficient solar panels, these metamaterials could also make for more efficient lightbulbs. To boot, while they are constructed on the atomic scale, they can still manage to be relatively cheap, cheap enough that widespread adoption at some point in the future isn’t out of the question. The materials can also be tailor-made to focus on one particular wavelength or another, giving them a lot of potential for use in very specific situations



Practical applications require micro- or nano-engineered arrays of split-ring resonators

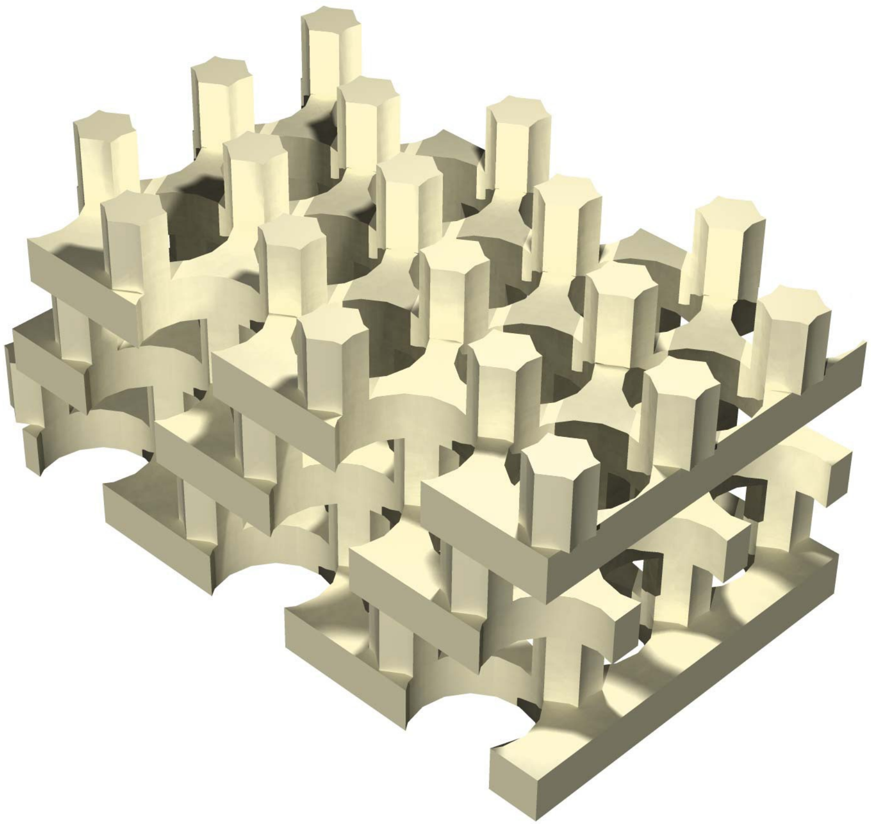


Meta-crystal to be used in a waveguide or spoofing antenna



Super-lens for improved transmission efficiency of Microwave energy.

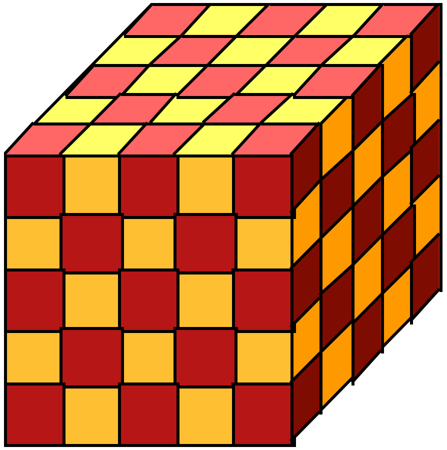
Photonic crystals are 3D metastructures on the size scale of light waves- used as waveguides and filters, main idea is to replace wires on a chip with lightpaths- with orders of magnitude increase in internal data transmission rates



Etched Si photonic crystal- has a linear region, a forbidden bap, and a highly non-linear region of wave-length response. (Following adapted from MIT lectures by Steven Johnson)

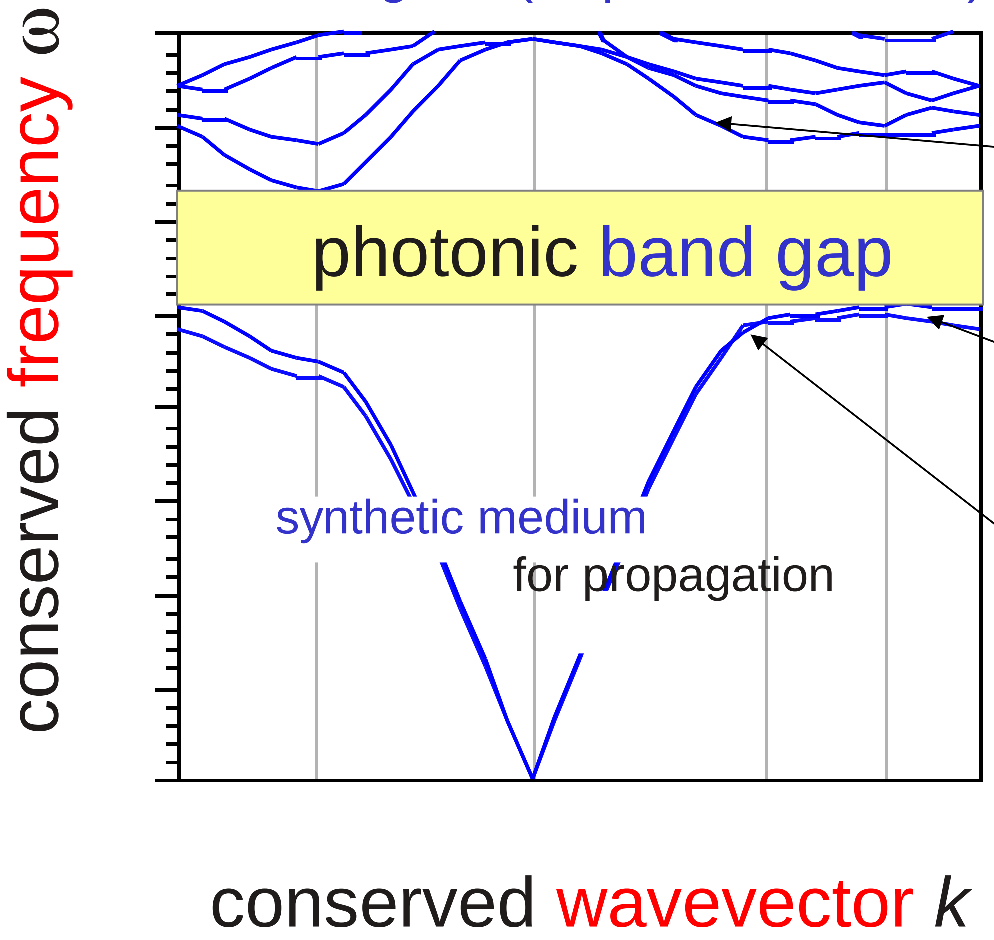
Properties of Bulk Crystals

by Bloch's theorem



(cartoon)

band diagram (dispersion relation)



backwards slope:
negative refraction

$d\omega/dk \rightarrow 0$: slow light
(e.g. DFB lasers)

strong curvature:
super-prisms, …

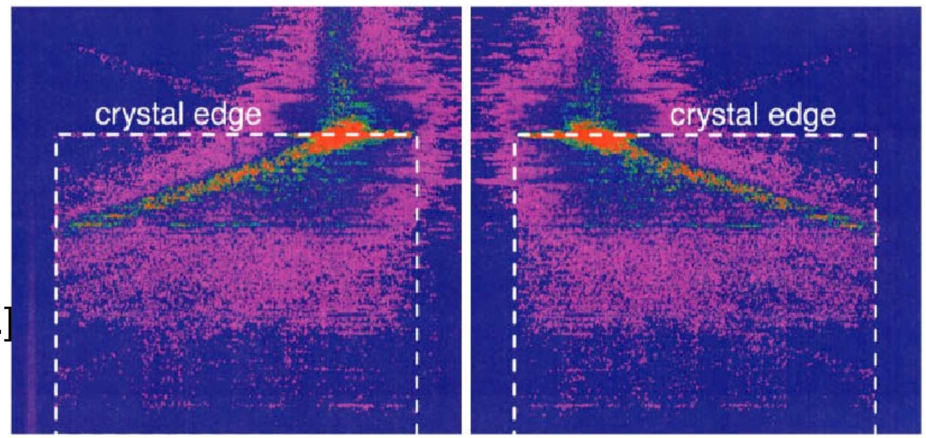
(+ negative refraction)

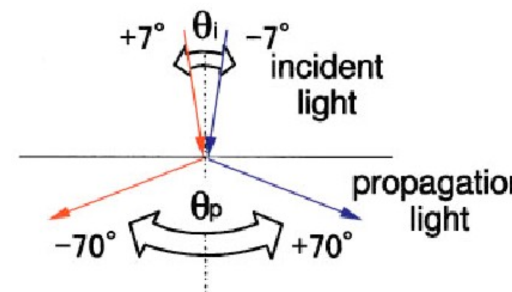
Applications of Bulk Crystals
using near-band-edge effects

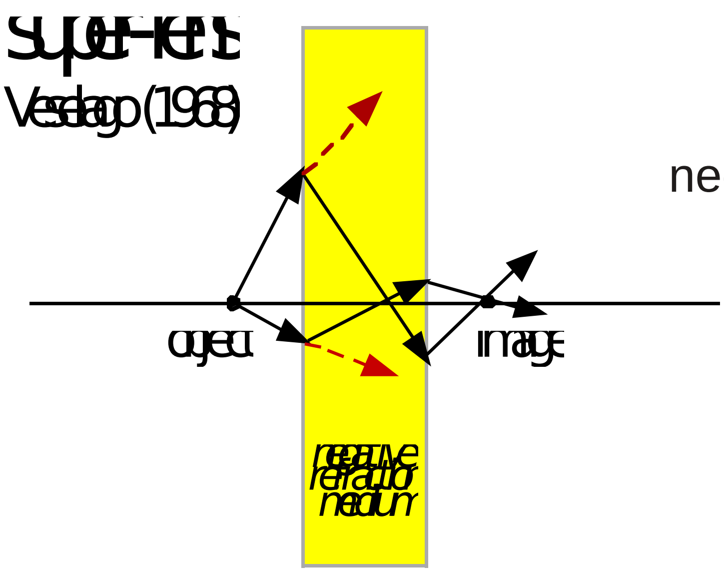
Zero group-velocity dω/dk: distributed feedback (DFB) lasers

divergent dispersion
(*i.e.* curvature):
Superprisms

[Kosaka, *PRB* **58**, R10096 (1998).]

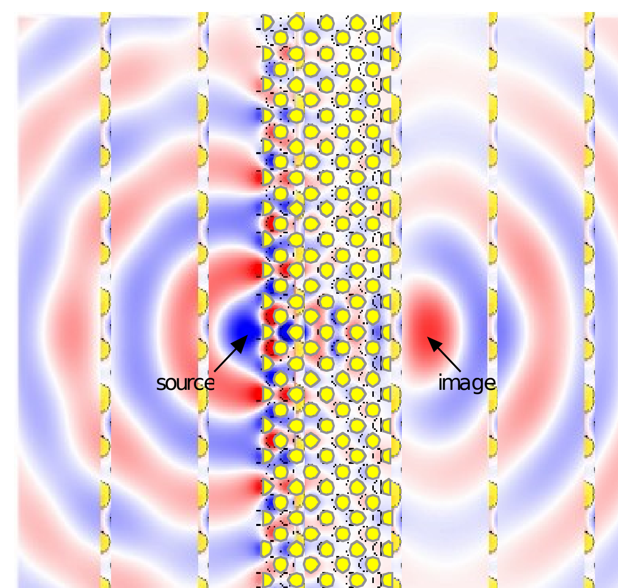




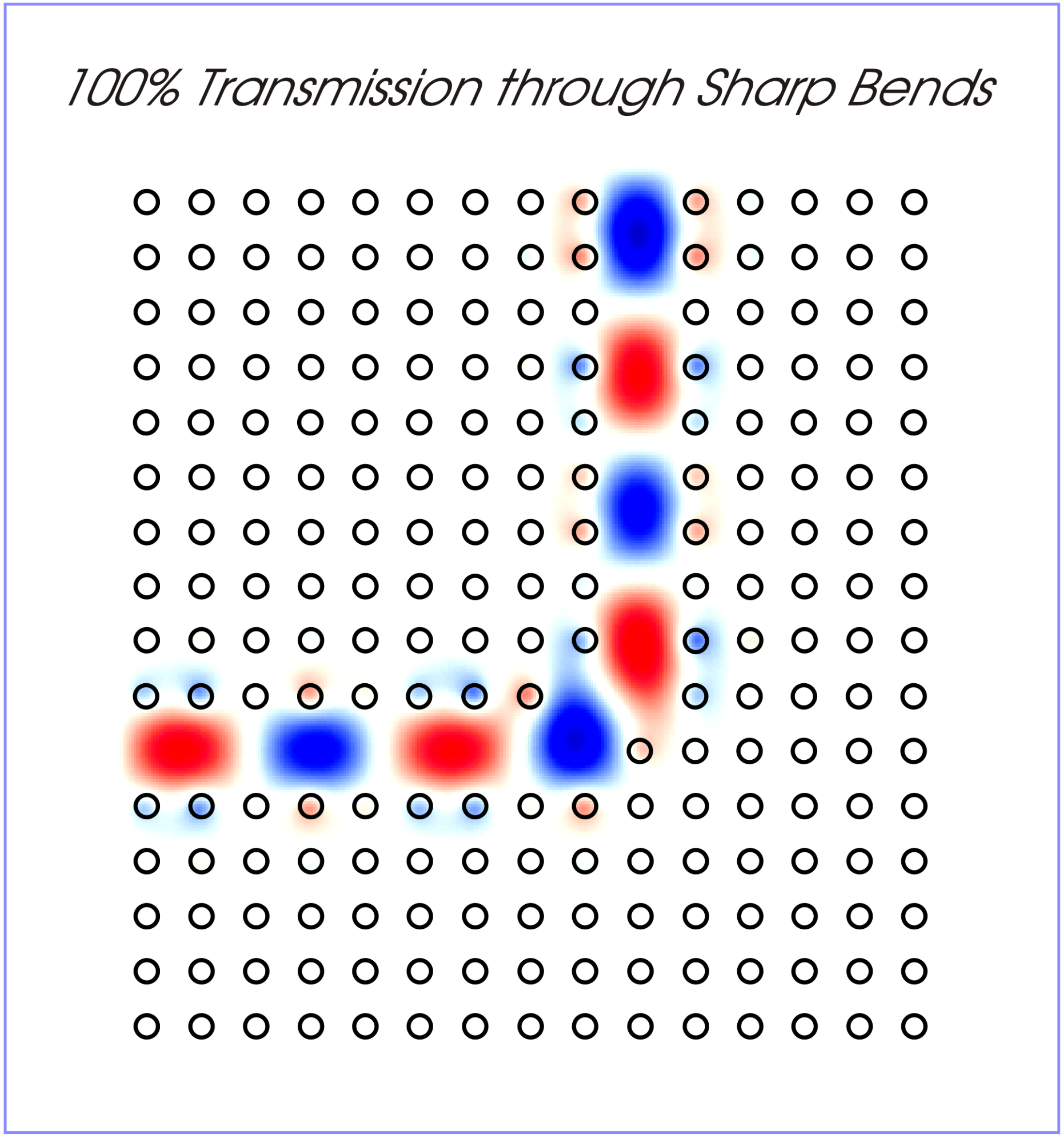


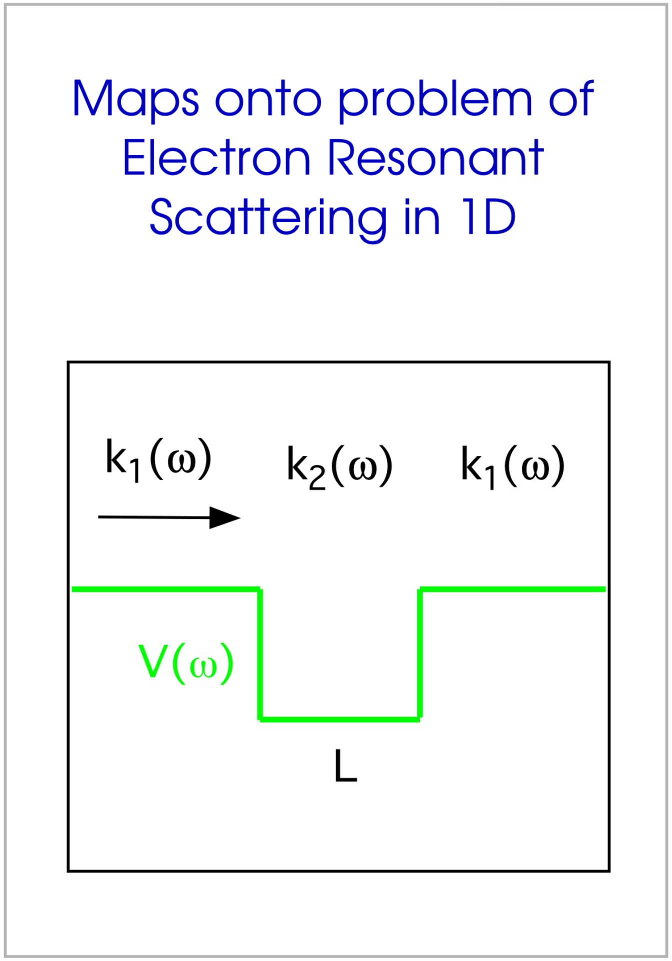
negative group-velocity **or**
negative curvature ("eff. mass"):
Negative refraction,
Super-lensing

[C. Luo *et al.*,
Appl. Phys. Lett. **81**, 2352 (2002)]



Lossless Bends

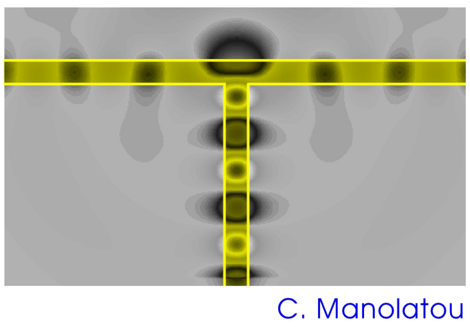


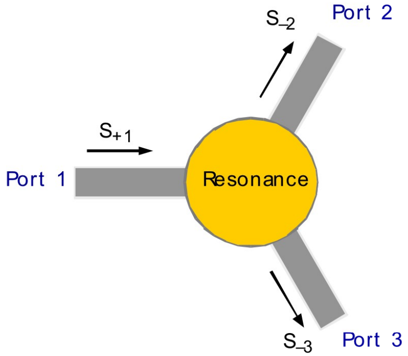


[A. Mekis *et al.*, *Phys. Rev. Lett.* **77**, 3787 (1996)]

ymmetry + single-mode + “1d” = resonances of 100% transmission

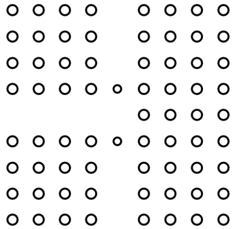
Wide-angle Splitters

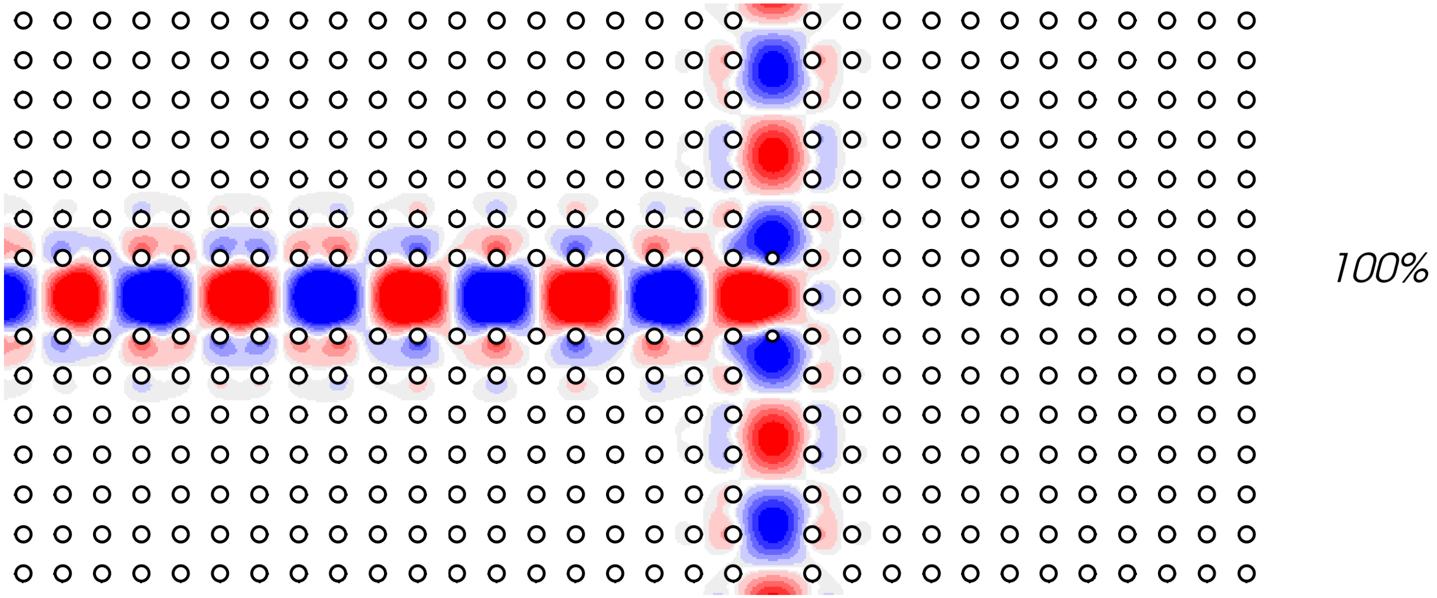




100% Transmission

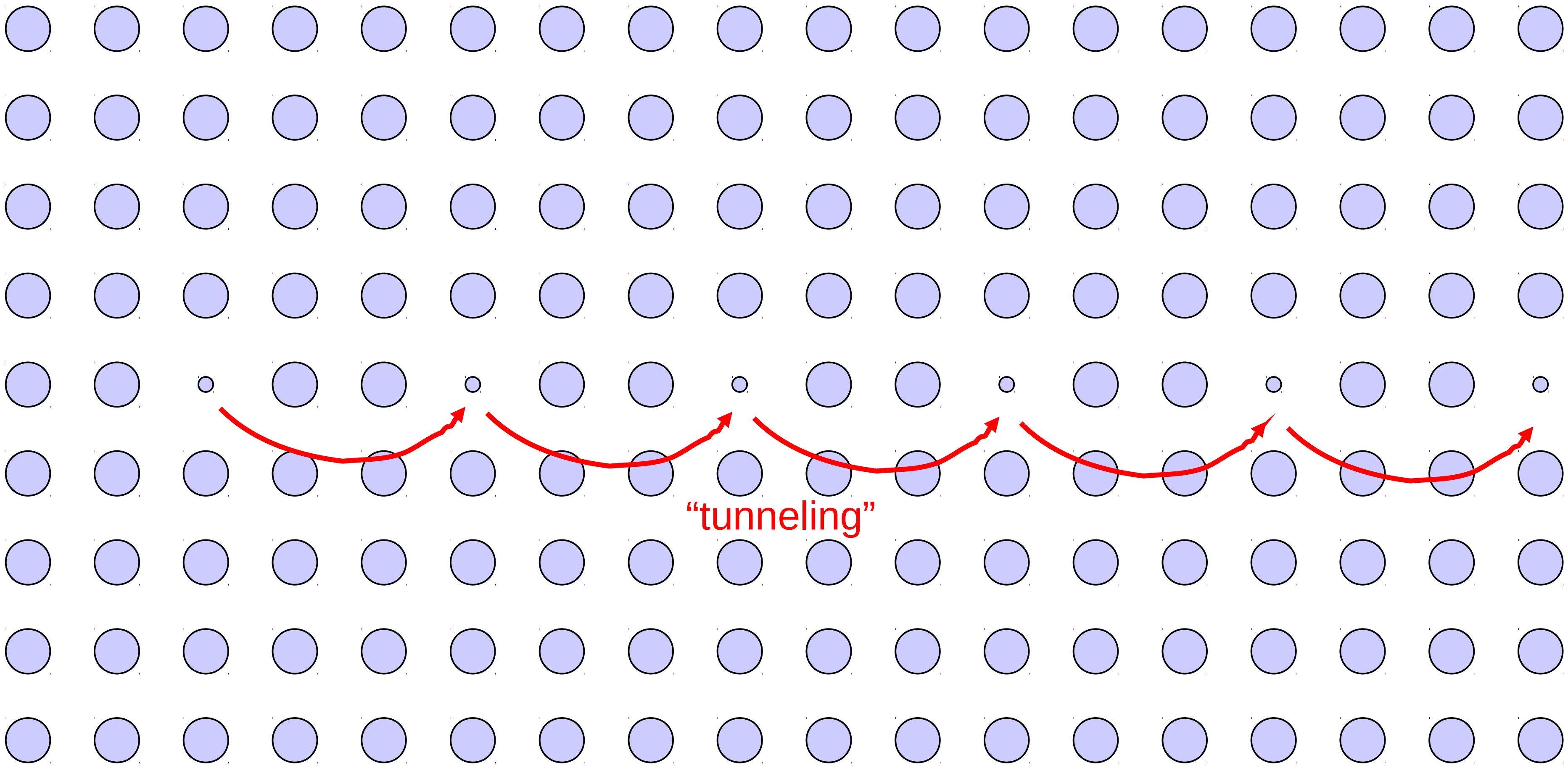
$$1/\tau_1 = 1/\tau_2 + 1/\tau_3$$





[S. Fan *et al.*, *J. Opt. Soc. Am. B* **18**, 162 (2001)]

Cavities + Cavities = Waveguide



coupled-cavity waveguide (CCW/CROW): slow light + zero dispersio

[A. Yariv *et al.*, *Opt. Lett*. **24**, 711 (1999)]