Passive Metamaterial Structures

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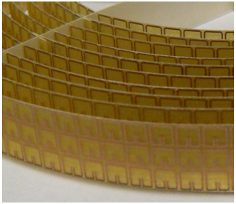
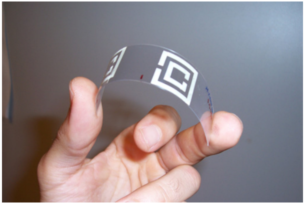
Definition of a Metamaterial

- materials engineered to have properties not found in naturally occurring materials
- left-handed material: has negative index of refraction
- periodic structure of cells (i.e. SRRs, swiss rolls)





Metamaterial Applications

- super lenses
  - surpass the diffraction limit
- invisibility cloaks, stealth technology
- improved antennae capabilities
  - arbitrarily small cell phones
- magnetic resonance imaging, ultrasound
- many more to be discovered

CENTER FOR METAMATERIALS
AND INTEGRATED PLASMONICS

Brief description of Maxwell's Equations

- Four partial differential equations that describe magnetic and electric fields and their interactions
- Two of the equations describe the propagation of light through homogeneous material

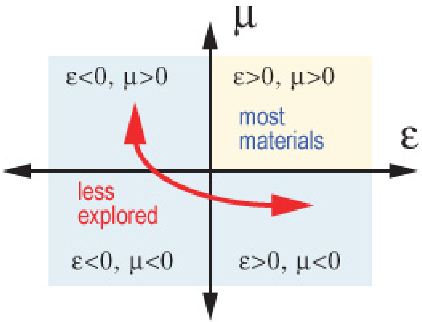
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$

$$\nabla \times \mathbf{H} = \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

where E = electric field, H = magnetic field,
μ = magnetic permeability, and ϵ = electric permittivity

Material Space

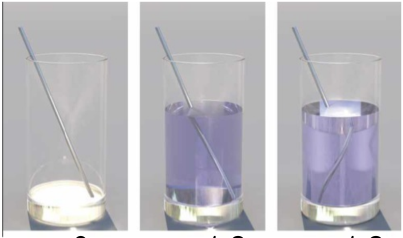
- All materials categorized based on electric permittivity versus magnetic permeability



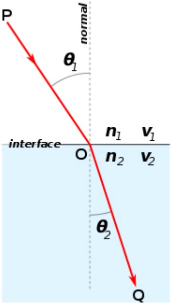
- Third quadrant corresponds to negative index of refraction materials

Indices of Refraction

- $N = \pm\sqrt{\epsilon\mu}$
- Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$



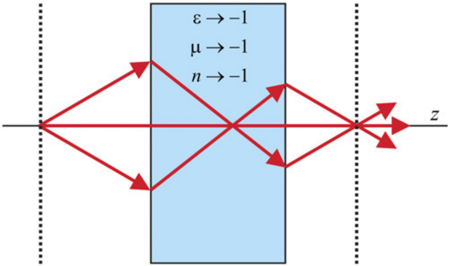
n=0 n=1.2 n=-1.2



- left-handed material (LHM): E, B, wave vector folllow a left-hand rule
- wave propagates in opposite direction of energy

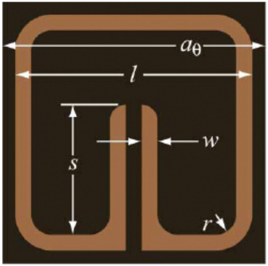
Creating a Super Lens

- The imaging size of traditional lenses is determined by the diffraction limit
  - proportional to wavelength of light over diameter of lens
- Veselago lens created in 2008 that can image 10x better than current (Grbic, Merlin at University of Michigan)



Split-Ring Resonators

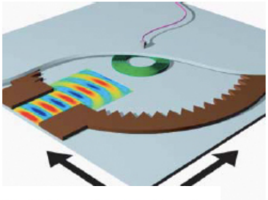
- single metamaterial unit
- scale much less than wavelength of radiation
- negative μ_{eff}
  - magnetic flux induces current
  - "splits" produce large capacitance values
  - high capacitance leads to lower resonating frequency
- dimensions of SRR decides resonant wavelength

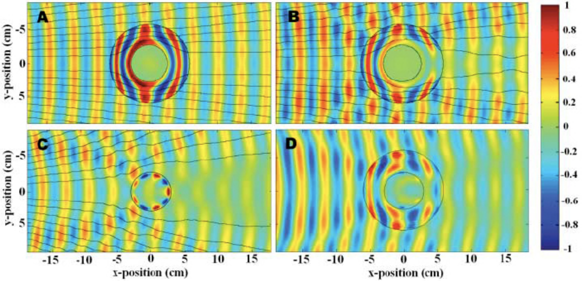


cyl.	r	s	μ_r
1	0.260	1.654	0.003
2	0.254	1.677	0.023
3	0.245	1.718	0.052
4	0.230	1.771	0.085
5	0.208	1.825	0.120
6	0.190	1.886	0.154
7	0.173	1.951	0.188
8	0.148	2.027	0.220
9	0.129	2.110	0.250
10	0.116	2.199	0.279

The Basics of Cloaking

- Schurig 2006: first experimental demonstration of metamaterial cloaking at microwave frequency
- concentric rings of periodically-structured passive metamaterial elements (SRRs)





Limitations

- passive metamaterial structures exhibit
  - significant losses by absorbing energy from EM waves
  - strongly frequency dependent properties means useful only for narrow bandwidth applications
- active metamaterial structures
  - dynamic frequency resonance or wide bandwidth
  - real-time control and manipulation of radiation

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