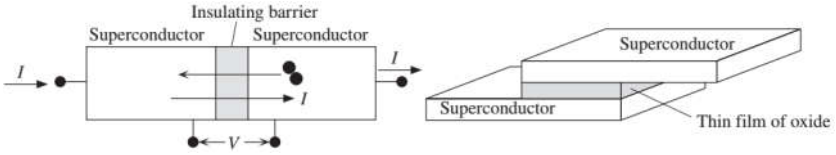
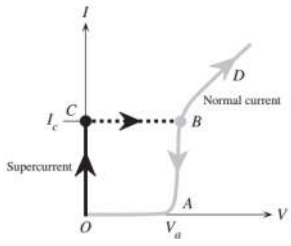
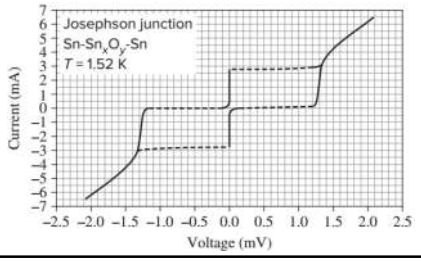
JOSEPHSON EFFECT

Josephson Junction

- The Josephson junction is a junction between two superconductors that are separated by a thin insulator (a few nanometers thick).
- If the insulating barrier is sufficiently thin, then there is a probability that the Cooper pairs can tunnel across the junction.







2

METAMATERIALS

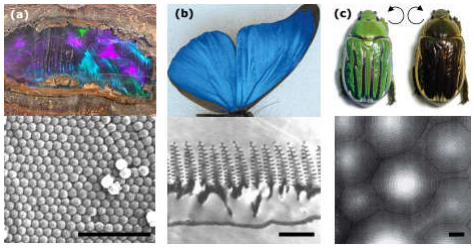
What is Metamaterial?

- A **metamaterial** (Greek word μετά *meta* means "beyond“) is a material engineered to have a property that is not found in naturally occurring materials.
- They are made from assemblies of multiple elements fashioned from composite materials such as metals and plastics.
- The materials are usually arranged in repeating patterns, at scales that are smaller than the wavelengths of the phenomena they influence.
- Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures.
- Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials.

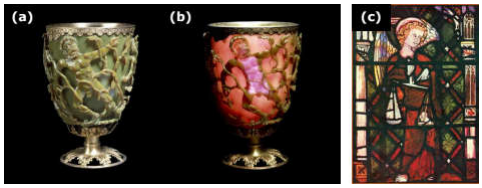
4

Structured Electromagnetic Materials

Nature:



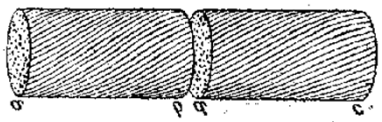
Historical artificial:

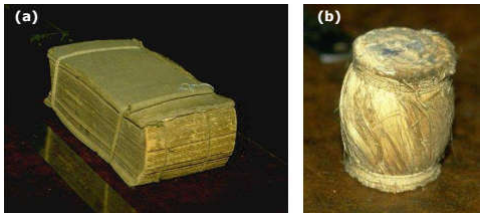


5

Early History: J.C. Bose

- Explorations of artificial materials for manipulating electromagnetic waves began at the end of the 19th century.
- In 1898, J. C. Bose researched substances with chiral properties.





Polarization control using composite media: *(a) Linear polarizer consisting of metal foil in between the pages of a book. (b) Bundle of twisted jute which rotates the polarization state.*

6

World War II and Stealth Technology

- The history of metamaterials begins with artificial dielectrics in microwave engineering as it developed just after World War II. Yet, there are seminal explorations of artificial materials for manipulating electromagnetic waves at the end of the 19th century.

- Stealth attack plane

- Stealth ground vehicle

- French stealth frigate

7

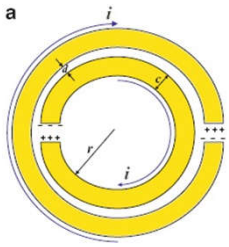
Modern History: John Pendry

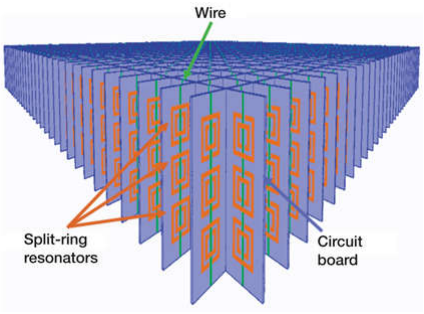
- Conventionally, the function or behavior of materials can be altered through their chemistry.
- During 1990s, while studying radiation-absorbing carbon for stealth technology, **Pendry** discovered that the radiation absorption property did not come from the molecular or chemical structure of the material, i.e. the carbon per se. This property came from the long and thin, physical shape of the carbon fibers.
- He realized rather than conventionally altering a material through its chemistry, as lead does with glass, the behavior of a material can be altered by changing a material's internal structure on a very fine scale.

8

Split-Ring Resonance

A **split-ring resonator** (**SRR**) is an artificially produced structure common to metamaterials. Their purpose is to produce the desired magnetic susceptibility (magnetic response) in various types of metamaterials up to 200 terahertz.





9

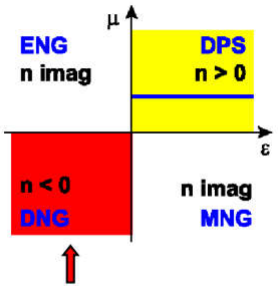
Propagation of EM Waves

Propagation of electromagnetic waves in medium is determined by ε and μ of the medium (J. C. Maxwell):

$$k \equiv \frac{n\omega}{c} = \frac{\omega}{c}\sqrt{\varepsilon\mu}$$

In most natural materials
μ > 0, ε > 0 →waves propagate

Sometimes either ε < 0, or
μ < 0 → no propagation



$$n = \sqrt{(-\varepsilon)(-\mu)} < 0$$

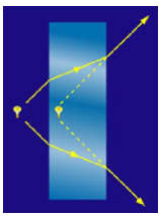
10

Single Negative Metamaterials

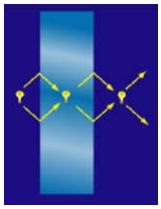
- **Single negative (SNG) metamaterials** have either negative relative permittivity (ε_r) or negative relative permeability (μ_r), but not both.
- **Epsilon negative media (ENG)** display a negative εr while μr is positive. Noble metals such as gold or silver are ENG in the infrared and visible spectrums.
- **Mu-negative media (MNG)** display a positive ε_r and negative μ_r. Gyrotropic or gyromagnetic materials exhibit this characteristic. A gyrotropic material is one that has been altered by the presence of a quasistatic magnetic field, enabling a magneto-optic effect.
- SNGs act as metamaterials when ENGs are combined with a MNGs and jointly acting as a **Double negative (DNG)** medium.
- Metamaterials are innately dispersive, so their ε_r, μ_r and refraction index n, are a function of frequency.

11

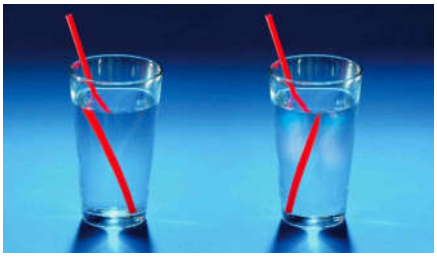
Negative Index Metamaterials



Light enters n > 0 material → deflection

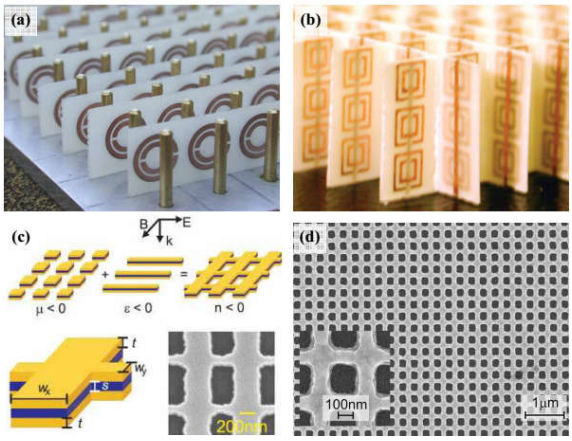


Light enters n < 0 materia → focusing ("Veselago Lens")



12

Negative Index Metamaterials

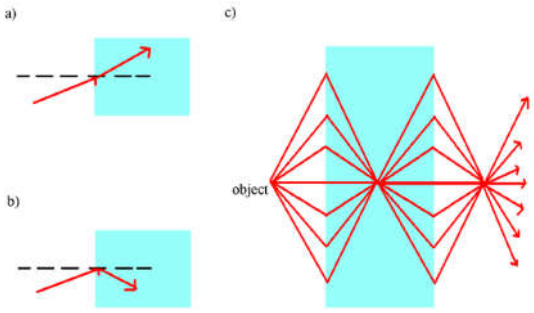


(a) First metamaterial with simultaneously negative permittivity and permeability. (b) The metamaterial used for the first demonstration of negative refraction. (c) Negative refraction in the optical part of the spectrum has been demonstrated for layered fishnet structures. (d) SEM image of a fishnet structure with a negative refractive index at 780 nm.

13

Super Lens

- A **superlens**, or **super lens**, is a lens which uses metamaterials to go beyond the diffraction limit. The diffraction limit is a feature of conventional lenses and microscopes that limits the fineness of their resolution.



a) When a wave strikes a positive refraction index material from a vacuum. b) When a wave strikes a negative-refraction-index material from a vacuum. c) When an object is placed in front of an object with n=−1, light from it is refracted so it focuses once inside the lens and once outside. This allows subwavelength imaging.

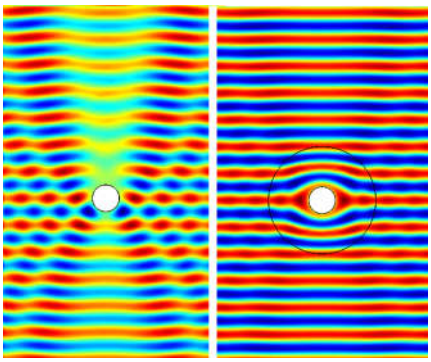
14

Invisible Cloaking

- An invisibility device should guide light around an object as if nothing were there.

Left: The cross section of a PEC cylinder subject to a plane wave (only the electric field component of the wave is shown). The field is scattered.

Right: a circular cloak, designed using transformation optics methods, is used to cloak the cylinder. In this case the field remains unchanged outside the cloak and the cylinder is invisible electromagnetically. Note the special distortion pattern of the field inside the cloak.



15

Harry Potter Film → Reality

16

Harry Potter vs. Invisible Man

- **Harry Potter's Invisible Cloak:** "most of the techniques used to develop invisibility cloaks take advantage of the extraordinary properties of certain materials so that light dodges the object to be invisible."
- **The Invisible Man:** This model to make things invisible precludes the use of potions, since light is forced to interact with the object when exposed to light. "We have used another technique, plasmonic invisibility, which causes the object and the potion to become invisible together ," Serna describes.

17

EEE 307

- ***We have finished EEE 307!***
- You can email me your questions/concerns at anis@eee.buet.ac.bd. Please use "EEE 307" in the subject line.
- You can also meet me in my office if you have something to discuss.
- ***Good luck!***

18