A Prefect Reflector

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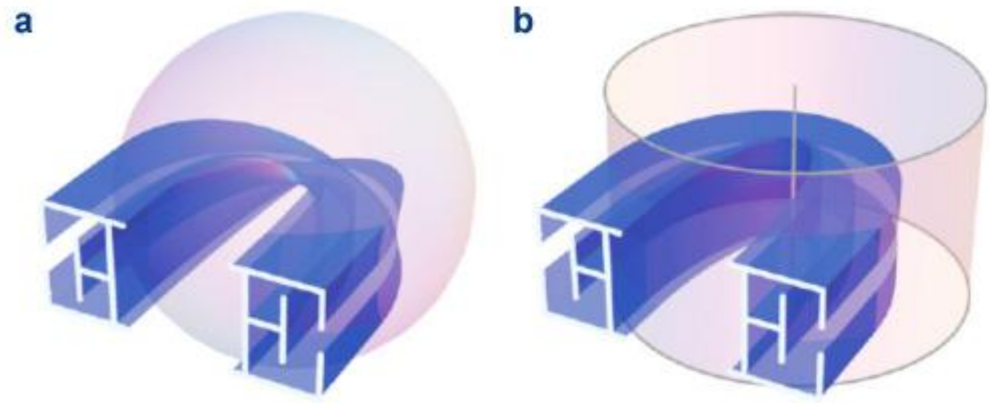


FIGURE 1: Eaton lenses. **a**, Spherical lens. **b**, Cylindrical lens. An artist's impression of the retroreflection of light that carries an image, the letter 'E' for 'Eaton'. In the outgoing light, the image is inverted, but preserved (in a: flipped and upside down, in b: flipped). The implementation of an Eaton lens would require a singularity in the refractive index profile where the index tends to infinity, unless the singularity is transmuted into a harmless topological defect, as we demonstrate in our work for the cylindrical lens with metamaterials for microwaves.

The Omnidirectional Retroreflector is a device capable of reflecting all light back at their source and thus enables high visibility from all directions. It works for a full 360 degree range of incident angles. The ordinary mirror can only reflect an object at 90 degrees. Even the most advanced conventional retroreflector design has a narrow field of view. Historically, the omnidirectional retroreflector was first proposed by JE Eaton in Naval Res. Lab in 1952. In theory, the "Eaton Lens," was capable of reflecting all light rays back to their original source, while faithfully preserving any image the light carried, apart from inverting the image (Fig. 1). However, for the past 57 years, the device was impossible to fabricate because of one seemingly impossible challenge. It requires the light rays passing close to the sphere's centre to be so tightly curved that the refractive index of the sphere diverges at its centre. Such singularity in the refractive index stumped scientists, who for years deemed such a device impossible to construct. The main difficulty lies in the refractive index of an optical material. It changes the speed of light, usually making light a bit slower, for example by a factor of 1.5 for glass. At a singularity the speed of light would be required to go to zero, to complete standstill, which is not possible in practice. Nobody can build a device where, at one point, light should stand still completely. However, the material used to construct the omnidirectional Retroreflector or "Eaton Lens" would need such a singularity.

Prof. Ong and his colleagues have proposed an innovation in the design of the Omnidirectional Retroreflector that is able to circumvent singularities in optical refractive index by the synthesis of new theory and new artificial material. The new theory is the optical transformation optics proposed by Pendry and Leonhardt (Prof Ong's co-author) independently in 2006. The new theory uses electromagnetic theory and the mathematics of coordinate transformation, which is also used in the general theory of relativity. The new material they used is known as a metamaterial, where manmade nano structures create unusual electromagnetic properties. In a normal material it is the atoms and molecules the material is made of that determine its electromagnetic or optical properties. In a metamaterial, the artificial structures act like artificial atoms. The advantage is that they can be designed, whereas natural atoms have properties "as found" in nature. This enabled the impossible device to be successfully fabricated at last. Remarkably, the materials used by Prof Ong and his colleagues are very simple, consisting of copper printed circuit board which is widely found in the semiconductor industry. What make it special are the structured, split rings that are etched into the circuit board. Their Omnidirectional Retroreflector is about one centimetre high, 10 centimetres in diameter, and made of copper circuit boards covered in circles three millimetres across (Fig. 2).

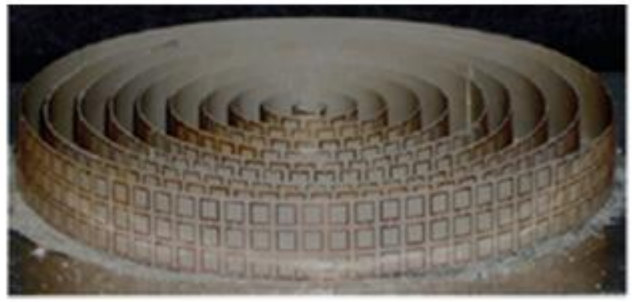
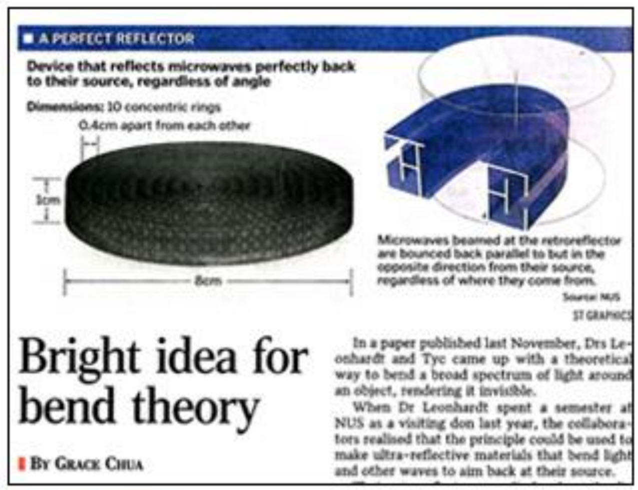


FIGURE 2: The device. The split-ring resonators constitute a metamaterial for microwave radiation with the designed radial magnetic permeability. The rings were then filled with a white dielectric powder that generates the required electric permittivity .



A PERFECT REFLECTOR

Bright idea for bend theory

By Grace Chua

In a paper published last November, Drs Leonhardt and Tyc came up with a theoretical way to bend a broad spectrum of light around an object, rendering it invisible.

When Dr Leonhardt spent a semester at NUS as a visiting don last year, the collaborators realised that the principle could be used to make ultra-reflective materials that bend light and other waves to aim back at their source.

IN THE NEWS: | ***The Straits Times***, Science, pD8, Bright Idea For Bend Theory, 4 July 2009

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Prof Ong and his group are the first in the world to demonstrate that the Omnidirectional Retroreflector (***Nature Materials***, 8; 639-642; 2009), conformed to transformation optics theory and can be constructed by means of properly designed metamaterials. The device has many potential applications, especially in terms of tracking and aggressively shielding or protecting objects from airplane based laser system and many military applications. For example, a retroreflector installed on aircraft, boats or satellites would increase their accuracy in radar tracking by bouncing the radio waves back to their source.

There are many interesting ideas in theoretical physics, but only very few really capable of being implemented in practice. Thus it is very exciting to make an abstract concept like singularity transmutation come true in real life. Their pioneering achievement has definitely demonstrated that even a seemingly impossible barrier like singularities in refractive index is no longer an obstacle towards their implementation. This provides inspiration for other devices hitherto confined to theory to be brought into the realm of physical construction in future.

Publication:

Prof Ong Chong Kim - "An omnidirectional retroreflector based on the transmutation of dielectric singularities" (***Nature Materials***, 2009, 8(8), 639-642)