SINAM
CENTER FOR SCALABLE AND INTEGRATED NANOMANUFACTURING

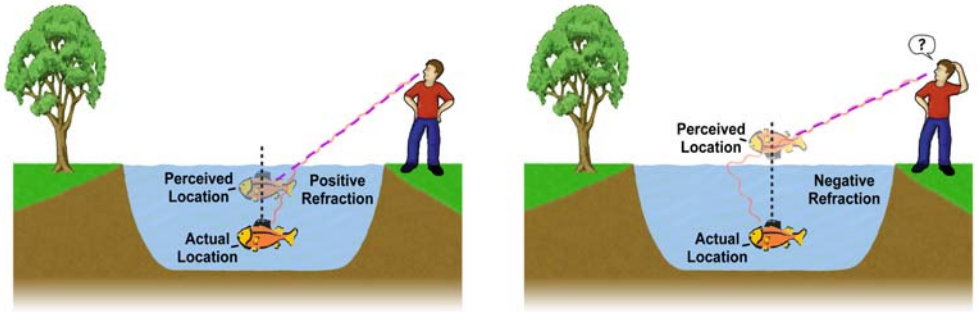
an NSF Nanoscale Science and Engineering Center (NSEC, CMMI-0751621)

3D Optical Metamaterial Exhibiting Negative Refractive Index

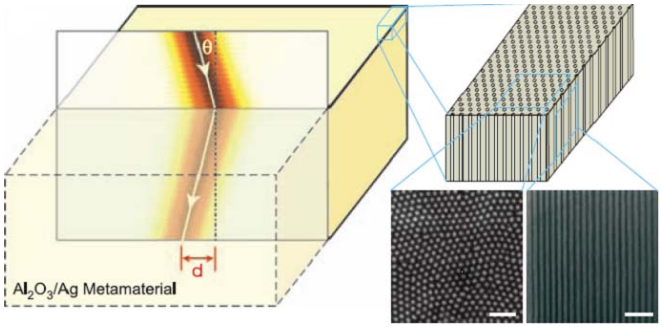
Jie Yao, Jason Valentine, Shuang Zhang, Thomas Zentaraf. Erick Ulin-Avila. Dentcho A Genov. Zhaowei Liu. Yonamin Liu. Yuan Wang, Cheng Sun, Guy Bartal and Xiang Zhang
1. Mechanical Engineering Department, UC Berkeley

Introduction:

Negative index metamaterials (NIMs) have been the subject of intense interest for the past several years due their exotic optical properties. The schematic on the right illustrates how the NIMs work. However, optical NIMs have been experimentally limited to a very thin layer with high losses, which was hard to assign bulk properties. Researchers at the NSF Centre for Scalable and Integrated NanoManufacturing (SINAM) have recently overcome these challenges by creating the first two three dimensional (3D) optical metamaterials exhibiting a negative index of refraction. The research is published in September 2008 issues of ***Nature*** and ***Science***.



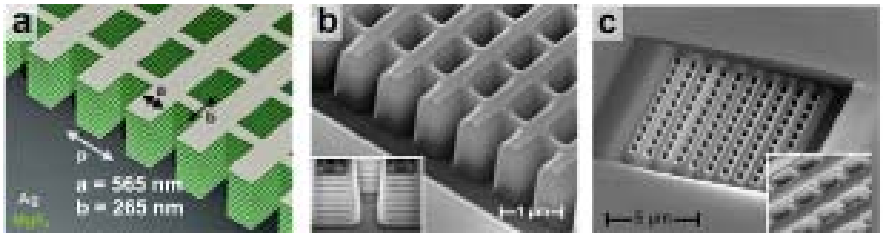
Above is a schematic of how a fish in water is seen by an observer, with the red lines marking the refraction of light and the purple lines representing the path towards the perceived location of the fish, which appears above its actual location in both panels. On the left, the slightly transparent image of the fish indicates where it is perceived by the observer because of the positive refraction of light. If water exhibited negative refraction, the observer would actually see the fish swimming above the water's surface, as shown in the image on the right.



Schematic of negative refraction from air into the silver nanowire metamaterials. Bottom right are the SEM images of the metamaterial

Approach:

In each metamaterial, the unique arrangements of metallic nano-scale objects within an otherwise normal transparent medium lead to the ability of negative refraction. It is observed that light is bent the wrong way as it propagates through the material. The difference between incident and transmitted angles is related to the negative index of refraction. These demonstrations should open the door to studies of the unique effects of a bulk negative and zero index of refraction including imaging devices and highly directional sources.



a) Schematic of 3D fishnet structure. b) SEM image of 3D fishnet structure. c) SEM image of 3D fishnet prism.

Reference:
Jason Valentine, and Xiang Zhang, *et al.,* "Three Dimensional Optical Metamaterial Exhibiting Negative Refractive Index", ***Nature***, Vol. **455**, 376, 2008
Jie Yao, and Xiang Zhang, *et al.,* "Optical Negative Refraction in Bulk Metamaterials", ***Science***, Vol. **321**, 930, 2008.

This work is supported by the NSF Center for Scalable and Integrated NAnoManufacturing (grant No.CMMI-0751621)