# Negative Index due to Optical Activity

**Promising superresolution microscopy and lithography, negative refraction of light is subject to intense research. We demonstrate for the first time experimentally that the index of refraction can be driven negative by exceptionally large optical activity.**

A normal lens cannot focus light to a spot smaller than about half a wavelength. This so-called diffraction limit has immense practical importance, as it limits the resolution of microscopes, the storage capacity of optical disks and the miniaturization of electronic circuits, which are produced by lithography. The origin of the diffraction limit lies in the existence of two types of optical fields, the propagating and the evanescent fields. The latter ones, which carry the finest details of an optical image, decay exponentially with distance and are therefore lost in normal imaging systems.

Tremendous research effort is being spent on finding ways around the diffraction limit. The most popular approach was suggested by John Pendry in 2000. A slab of a hypothetical material with a refractive index of "-1" would exponentially amplify the evanescent waves, thus allowing perfect imaging of all optical fields [1]. However, such materials do not exist in nature and therefore artificial structures are required. A negative refractive index can be achieved in materials with simultaneous negative electric and magnetic responses. Here the first breakthrough was achieved by Smith [2], who used a grid of straight metal wires (electric response ε) combined with split rings (magnetic response μ).

So far all attempts to realize negative index media through combining electric and magnetic responses battle with absorption losses that are too high for practical applications, thus different approaches must be considered. In 2004 John Pendry predicted that negative refraction for circularly polarized waves should also be possible in optically active media, i.e. structures that rotate the polarization state of light [3]. This is because the refractive index n for circularly polarized waves depends not only on the electric permittivity ε and the magnetic permeability μ, but also on the chirality parameter κ, which is a measure of optical activity.

$$n = \sqrt{\varepsilon\mu} \pm \kappa$$

If its polarization rotary power and thus κ is sufficiently strong, an optically active medium will have a negative index of refraction for one circular polarization and a positive index for the other, see Fig. 1 (c).

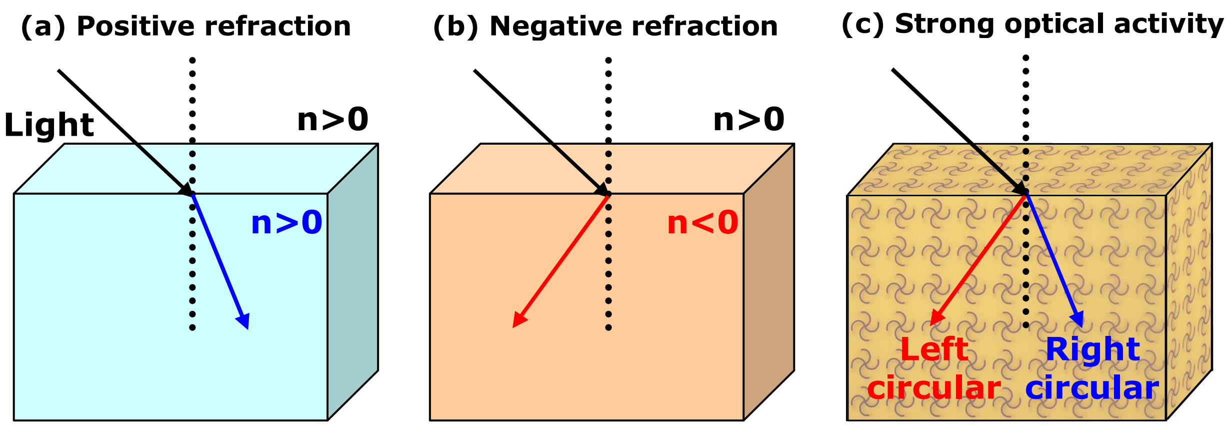


Fig. 1: Positive and negative refraction. (a) Light is positively refracted at interfaces between natural media, which all have a positive index of refraction. (b) Negative refraction occurs at interfaces between media with refractive indices of different sign. (c) Materials with sufficiently strong optical activity have a negative refractive index for one circular polarization (e.g. left) and a positive index for the other.

With respect to the realization of negative refraction due to optical activity little progress was made until we observed very strong polarization rotation for a pair of mutually twisted metal patterns in parallel planes in 2006, see Fig. 2 (a) [4]. The structure featured so-called backward waves, which are a signature of negative refraction. Backward waves have the unusual property that the wave oscillations (phase velocity) and the energy propagate in opposite directions. Using the bilayered twisted structure as the fundamental building block of a metamaterial, which is shown in Fig. 2 (b), we created the first artificial medium with a negative refractive index due optical activity. Both simulations and experiments confirm that in contrast to previous demonstrations of negative refraction, in our case it is indeed the large contribution of optical activity that causes a negative index of refraction for one circular polarization [5].

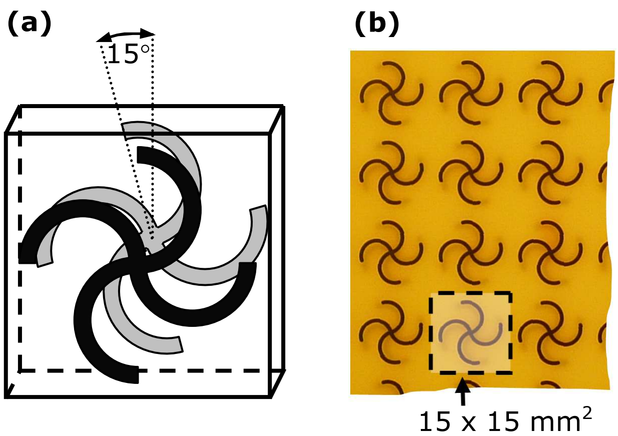


Fig. 2: (a) Mutually twisted metal patterns in parallel planes lead to giant optical activity, see [4]. (b) A metamaterial based on the structure shown in (a) has a negative index of refraction resulting from its exceptionally large optical activity, see [5].

## References

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