Scientists show a new way to absorb electromagnetic radiation

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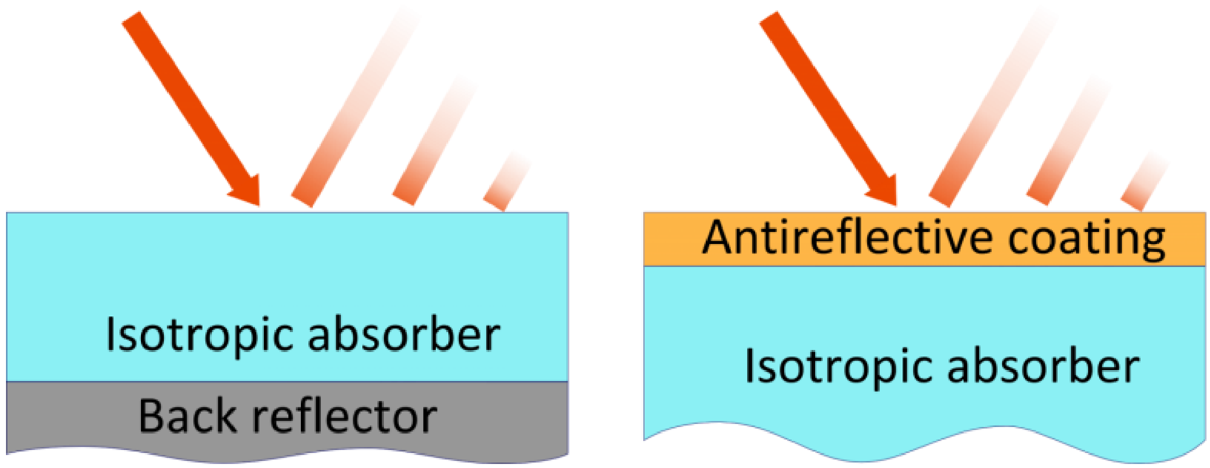


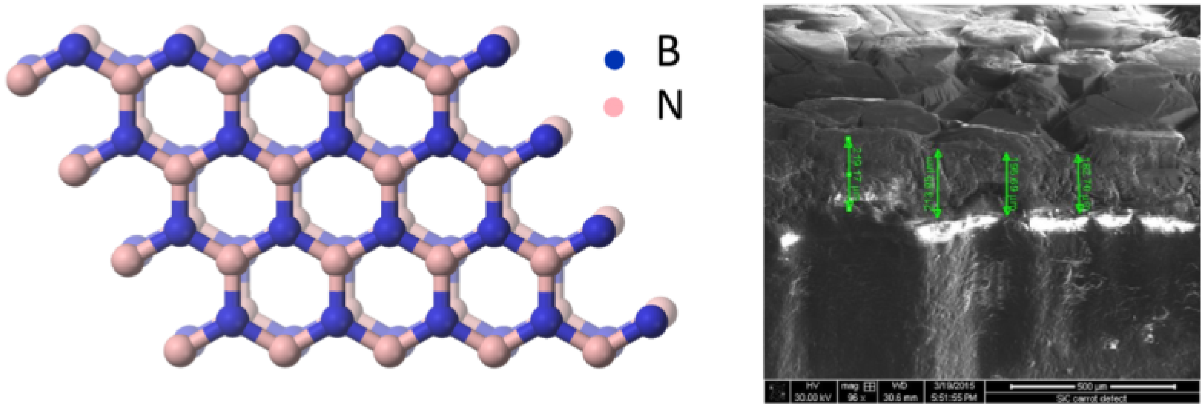
Left – an absorbing medium lying on a reflective substrate. Right – an absorbing medium with an anti-reflective coating applied on top. In both cases the interference of light results in the complete absorption of energy within the artificial structure. Credit: Image courtesy of the authors of the study

A team of authors from MIPT, Kansas State University, and the U.S. Naval Research Laboratory have demonstrated that it is possible to fully absorb electromagnetic radiation using an anisotropic crystal. The observations are of fundamental importance for electrodynamics and will provide researchers with an entirely new method of absorbing the energy of electromagnetic waves. The paper has been published in *Physical Review B*.

Effective absorption of the energy of electromagnetic radiation is the cornerstone of a wide range of practical applications. Electromagnetic energy harvesting in the visible spectrum is very important for photovoltaics – the conversion of solar energy into direct current electricity. Absorbing materials in the microwave range of frequencies have an application that is equally as important – they are able to reduce the radar visibility of an aircraft. Effective absorption of electromagnetic waves is also important for use in sensing, nanochemistry, and photodynamic therapy.

A classic example of an electromagnetic absorber that is familiar to many people is ordinary black paint. It looks black because a significant amount of the light that falls on it is absorbed in the layer of paint and does not reach the observer. However, black paint is a relatively poor absorber – a certain amount of energy from the incident light (typically a few percent) is still reflected back into the surrounding space.

In order to absorb incident radiation completely, we need to use interference. A layer of absorbing material is placed on a reflective substrate or is combined with a specially designed anti-reflective coating. According to the laws of classical electrodynamics, there emerges a sequence of waves having different amplitudes and phases that are reflected from the structure. Such reflection also occurs in a soap film. When white light falls on the film, reflected light of a certain colour appears, depending on the thickness of the film. When light falls on an absorbing system, if the coating parameters have been chosen properly, the reflected waves cancel each other out – reflected radiation vanishes completely and the absorption becomes perfect. This type of interference is called *destructive interference*. Absorption in such systems is very sensitive to the geometry of the structure. With the slightest variation in thickness or refractive indices of the layers the absorption is no longer perfect and reflected radiation reappears.

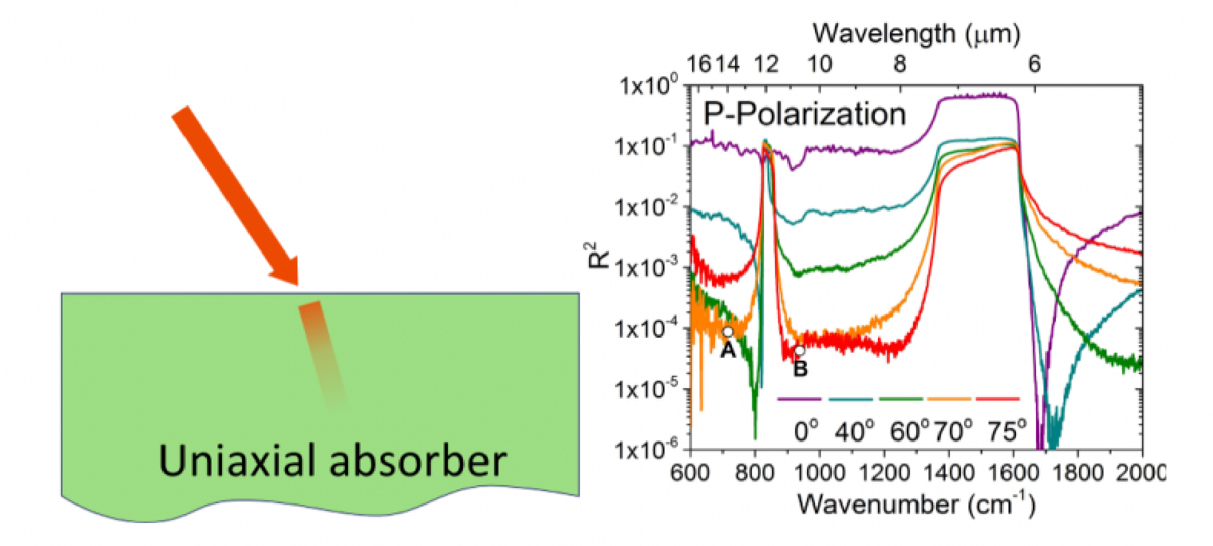


Left: a schematic diagram of the crystal lattice of hexagonal boron nitride. Image: Wikimedia/Benjah-bmm27 Right: SEM image of the sample studied by the authors of the paper.

In their paper, the researchers from Russia and the US showed that destructive interference is not a necessary requirement for perfect absorption. The scientists used an anisotropic crystal – hexagonal boron nitride – as their specific absorbing system.

This medium belongs to the class of unique van der Waals crystals which consist of atomic layers bound together by van der Waals forces from adjacent layers. Van der Waals forces occur between atoms and molecules that are electrically neutral but possess a dipole moment – the charges in them are not uniformly distributed. Due to this arrangement of the lattice, the dielectric permittivity of the crystal in the mid-infrared range (wavelength of about 10 microns) differs considerably for the in- and out-of-plane directions – it becomes anisotropic and is not described by a single number, but by a *tensor* – a matrix of numbers (each number is responsible for its own direction). It is the dielectric permittivity tensor that determines how light is reflected from the surface of any substance.

Due to the unusual properties of its crystal lattice, hexagonal boron nitride has already found a number of applications in optics and nanoelectronics. In this particular case, the strong anisotropy of dielectric permittivity helps to absorb [electromagnetic waves](). Incident infrared radiation at a certain wavelength enters the crystal without reflections and is completely absorbed within the medium. There is no need for any anti-reflective layers or a substrate to provide destructive interference – reflected radiation simply does not occur, unlike in an isotropic (i.e. identical in all directions) absorbing medium.



Left: schematic of the absorbing system demonstrated by the authors of the paper. Right: the reflectance spectrum from an optically thick layer of hexagonal boron nitride at different angles of incidence. Points A and B indicate the position of the conditions of complete absorption predicted theoretically. Credit: Image courtesy of the authors of the study.

"The ability to fully absorb electromagnetic radiation is one of the key areas of focus in electrodynamics. It is believed that destructive interference is needed to do this, which therefore requires the use of anti-reflective coatings, substrates and other structures. Our observations indicate that interference is not a compulsory requirement and perfect absorption can be achieved using simpler systems," says Denis Baranov, the corresponding author of the paper.

For the experimental observation of the predicted phenomenon, the researchers grew an optically thick sample of hexagonal boron nitride and measured the reflectance spectrum in the mid-infrared range. At the wavelengths and angles of incidence predicted analytically, the authors observed a strong drop in the reflected signal – less than 10^{-4} of the incident energy was reflected from the system. In other words, more than 99.99% of the incident wave energy was absorbed in the anisotropic crystal.

The approach proposed by the researchers is currently able to achieve perfect absorption only for a fixed wavelength and angle of incidence, both of which are determined by the electronic properties of the material. However, for practical applications, the possibility of energy absorption in a wide range of wavelengths and angles of incidence is of more interest. The use of alternative strongly anisotropic materials such as biaxial absorbing media will likely help to bypass these limitations in the future, making this approach more flexible.

Nevertheless, this experiment is of interest from a fundamental point of view. It demonstrates that it is possible to completely absorb radiation without the incorporation of destructive interference. This effect offers a new tool for controlling electromagnetic absorption. In the future, these materials could give a greater level of flexibility when designing absorbing devices and sensors that operate in the infrared range.

More information: D. G. Baranov et al. Perfect interferenceless absorption at infrared frequencies by a van der Waals crystal, *Physical Review B* (2015). DOI: 10.1103/PhysRevB.92.201405

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