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Seeing a ghost: hybrid waves in anisotropic crystals

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The most common type of waves of any nature—either electromagnetic or acoustic—are the so-called uniform plane waves. They exhibit uniform phase oscillations in the propagation direction, and carry energy along that direction. When projection of the wavenumber exceeds the maximal allowed value k_0, determined by the material properties of the medium (for example, $k_0 = n\omega/c$ in isotropic media for electromagnetic waves, where n is the refractive index), the wave becomes evanescent—its wavevector acquires an imaginary component and an exponentially decaying field profile. The energy in such a wave is carried in the direction of phase oscillations, with zero energy flux in the direction of attenuation. These two properties (phase oscillations and exponential attenuation) can be combined in one direction by a wave propagating in a lossy medium (for example, in a Drude metal), but such a wave will still carry energy along its "main" direction.

In this issue of *Advanced Photonics*, Narimanov[1] demonstrated theoretically that a lossless anisotropic material may support so-called ghost waves, which combine oscillatory and evanescent behaviour in the same direction. The name originates from studies of dynamical systems, where extensions of regular solutions to complex-valued frequencies or wave vectors have been referred to as "ghost orbits."[2] The system that enables such a propagation regime is a nonmagnetic biaxial dielectric, meaning that it has different refractive indices in all three directions. Above a certain frequency, the anisotropic crystal supports ordinary propagating modes with real-valued wavevector components. Below the critical frequency, however, a bifurcation point gives rise to a pair of new solutions with complex-valued wavevector $k_z = \pm k_z' \pm i k_z''$. The only additional requirement for these ghost waves is that they need to have a real-valued in-plane wave vector component q perpendicular to its "main" propagation direction.

Remarkably, in contrast to ordinary propagating waves, a ghost wave does not carry energy along its "main" direction. In this sense, ghost waves inherit the property of evanescent waves, which do not carry energy along the direction of their exponential decay.

The discovered phenomenon of ghost waves can be particularly useful for imaging applications. For resolving subwavelength details of an image, it is crucial to capture and restore evanescent components of the electromagnetic field, which carry all the information about subwavelength features of an image. A superlens, theoretically proposed in 2000,[3] does that with a metamaterial slab, which amplifies evanescent waves. However, metamaterials rely on lossy plasmonic components,[4] which eventually limit the resolution. As the proposed system is essentially an anisotropic dielectric, it can be considered nearly lossless and thus overcome the resolution limits imposed by lossy metals.

References

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Denis Baranov received his PhD in physics from Moscow Institute of Physics and Technology, in 2016, and is currently a postdoctoral researcher at Chalmers University of Technology. His interests include perfect electromagnetic absorption and lasing, ultrafast and nonlinear interaction of light with resonant nanophotonic structures, and extraordinary regimes of light–matter interaction.

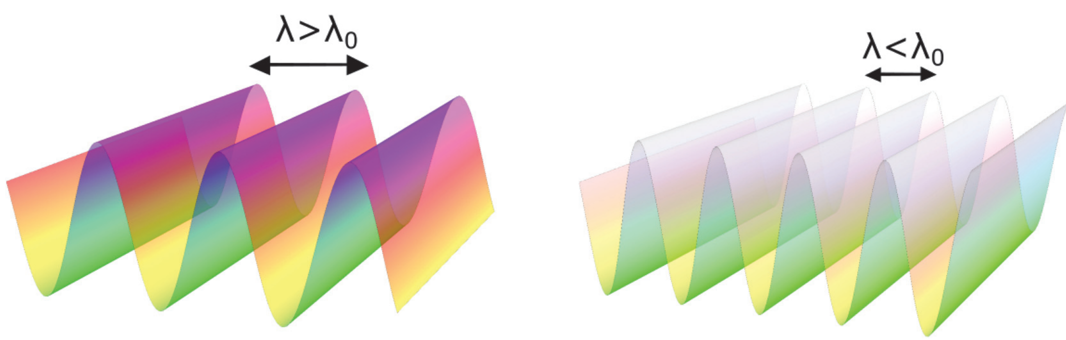

Fig. 1 Illustration of a homogeneous wave with its wavelength longer than $\lambda_0 = 2\pi/k_0$ (left), and that of an evanescent wave with a wavelength shorter than λ_0 (right). Alternating hue reflects the local phase of the field, whereas the color saturation encodes the field intensity.

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