Professor Andreas Tünnermann
Jena

Following Nature's **Footsteps**

The discovery of optical microstructures and nanostructures has opened completely new technological perspectives.

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The azure blue of a Morpho cypris butterfly is based on periodic photonic nanostructures. A sample produced with the help of electron beam lithography is shown in the background.

For many thousands of years, humankind has learned to obtain from nature many materials that offer desirable properties for a multitude of applications. There are now numerous organic and inorganic materials with controllable properties that have become a normal part of our daily life.

The best-known example in optics are optical fibers based on quartz glass. These fibers allow the diffracton-free propagation of light over tens of thousands of kilometers in the near-infrared spectral range. The transmission of information was revolutionized by this discovery.

The demand for constantly increasing transmission capacities has required even greater efforts to fully control the propagation and propagation properties of light in optical networks. In principle, microstructures and nanostructures offer unique possibilities in this field. For example, by producing a special waveguide geometry, it is possible to shift the zero point of the dispersion curve over a broad wavelength region. So-called air-silica microstructured (ASM) fibers show the best design flexibility. With these fibers the jump in the refractive index between air and quartz glass is used to create unique guiding properties for the light in the waveguide structures. The mode field diameter of the guided light in ASM fibers is thus generally limited to a few micrometers.

Bragg reflection is the basic principle

However, optical microstructures and nanostructures also have the potential to regulate the propagation and the propagation properties of light on extremely short scales of length.

Analogous to the behavior of electrons in crystal lattices, it was discovered that photons, which are used here as a synonym for light, can behave similarly in extended dielectric structures with periodically varying refractive indexes. A Bragg lattice represents the simplest photonic crystal. For the incident light beam, only the minus first order exists in such a lattice structure – in addition to the zeroth diffraction order. This diffraction order is called the Bragg reflection and forms the basic principle of every dielectric mirror.

In such periodic media, light has new, specific propagation properties that are not found in conventional materials. The positive aspect of these novel materials is the fact that the properties can be adjusted by the geometry of the photonic crystals. As in the case of the Bragg lattice mentioned before, it is possible to produce three-dimensional structures that prevent the propagation of light in all directions for certain frequency ranges. By introducing local defects into the structures, the light can be localized at them on extremely small areas or can be guided along a certain path. Future applications of such periodic systems can be envisioned in optical networks. In addition, light will have new, specific properties in periodic media that manifest themselves through relations between the frequency and the wave vector (dispersion relations).

Examples in nature as models

It is interesting to note that such structures have existed in nature for many millions of years. For instance, the special optical properties of the opal semiprecious gem are based on the same basic principles. The same is true for a butterfly wing or a sea mouse.

Future development will provide various optical components based on the principle of such periodic photonic structures. These

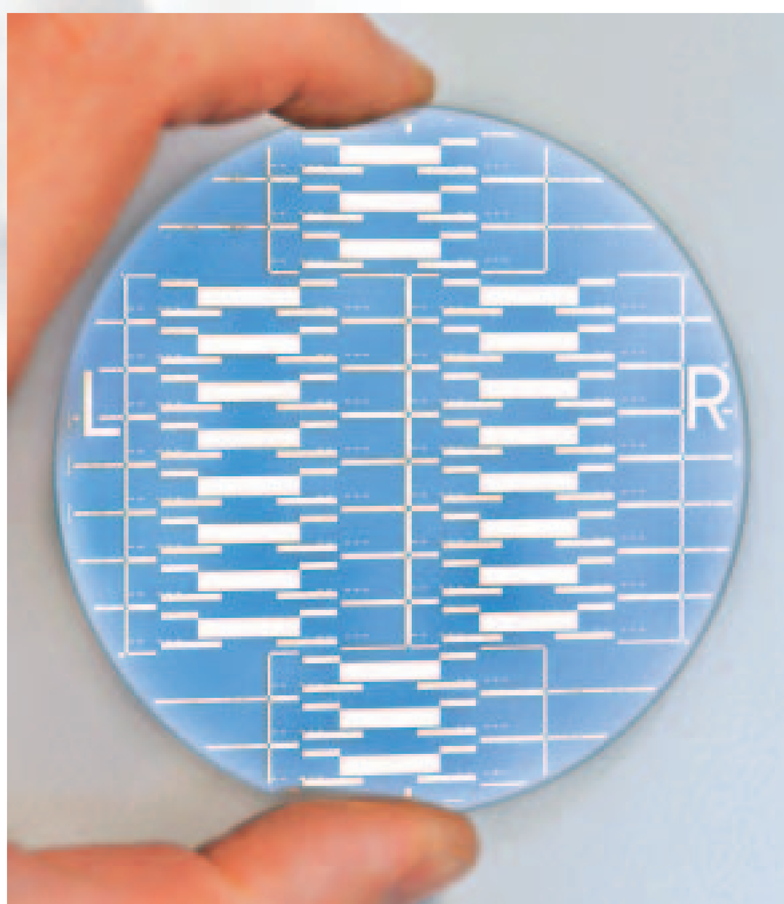
could take the form of miniaturized versions of known optical elements or the implementation of totally new optical functions.

Another kind of artificial optical material is obtained if the grating period of the structure imprinted on the material has been made so small that no other than the zeroth diffraction order can occur. The grating then acts like an effective medium, i.e. a thin coating whose refractive index lies between those of the two materials involved.

Examples of applications are $\lambda/4$ phase plates or anti-reflection surfaces (moth-eye structures). Metallic strip gratings with such small periods show an anisotropy of absorption and reflection (polarizing filters). The way these gratings function can be explained by means of the electric field: for parallel oscillations it is possible to imagine an effective dielectric with a parallel connection of areas of high and low dielectric constants. If the electric field oscillates perpendicular to the strip grating, it is a serial connection.

Artificial materials are the future

The application of these artificial materials will revolutionize optical technologies in the years to come. Due to the many different areas of applications, the current aim is to produce optical systems with cross or even complete functionalities. With microstructured and nanostructured optical components the basic elements are now available for an optical system technology that will allow the move from discrete components to fully integrated functional units. ◀



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Integrated optical components regulate the propagation of light in waveguide structures. The components are produced using lithographic methods.