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True colours

Most definitions of nanotechnology focus on the control of matter, not light, but research in nanophotonics is thriving in areas as diverse as quantum optics and biological imaging.

The wavelength of visible light (~400–700 nm) is considerably longer than the upper limit of 100 nm or so that is generally used to define the nanoscale. This disparity — and the fact that the diffraction limit prevents light from being focused to dimensions of less than half a wavelength or so — is a challenge that must be overcome when we try to use light to, say, fabricate semiconductor structures or image objects with nanoscale features. Electron microscopes succeed where their optical counterparts fail by exploiting the very short de Broglie wavelengths of electrons to image objects with a resolution that far exceeds what is possible with light. Likewise, scanning probe microscopes (SPMs) rely on atomically sharp tips to image surfaces with atomic resolution, although lasers also play an integral part in SPMs.

However, if we look at the matter again, from the bottom up this time, we start to see the overlap between optics and nanotechnology. First, it is rather obvious that many materials emit and absorb photons at the level of individual atoms and molecules as electrons move up and down between different energy levels. Indeed, at the most fundamental level, all optical phenomena are due to interactions between photons and electrons. Second, there is not a simple relationship between size and wavelength: the size of an atom (or molecule) does not dictate the wavelengths of light that it can emit or absorb; rather, these wavelengths depend on the electronic structure of the atom, and emission and absorption can occur at many different wavelengths, all of them much longer than the size of the atom.

In the nanoworld, the size of a quantum dot or nanoparticle (and also its chemical composition) determines the energy level structure, which in turn determines the emission and absorption wavelengths — hence the phrase 'artificial atom'. For instance, a gold nanoparticle with a diameter of about 100 nm appears purple–pink and has an absorption peak at 575 nm, but the colour shifts to red for particles with diameters around 20 nm, and then to brown–yellow (with an absorption peak at 420 nm) when the diameter reaches about 1 nm (ref.1).

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It is clear that visible light goes hand-in-hand with nanostructured materials, and the fact that there are lots of non-optical methods for controlling matter on the nanoscale — and that the resulting nanostructures can have useful optical properties — is driving research into nanophotonics. Two such examples appear in this issue. On page 555, Arto Nurmikko and colleagues describe the possibilities offered by combining organic and inorganic materials to produce nanocomposites with improved optical performance. In this case the effective absorption cross-section of semiconductor quantum dots is increased tenfold by the presence of a polymer. And on page 549, Teri Odom and co-workers show how interference lithography — an optical technique that uses ultraviolet light — can be combined with soft lithography (which is a sort of printing process) to produce plasmonic metamaterials that are patterned on a range of length scales from the nanoscale upwards. Surface plasmons — collective excitations of free electrons in a metal — play a central role in this work, and also in many areas of nanophotonics, including the SERS (surface enhanced Raman spectroscopy) technique that is widely used in analytical chemistry and biology.

Metamaterials and plasmonics are also the subject of intense research in physics, where phenomena such as negative refraction and subwavelength focusing are causing the textbooks to be rewritten and, at the same time, are opening up new possibilities for devices. Other areas of interest include nanowire lasers[2,3], combinations of photonic crystals and quantum dots[4], and re-runs of many of the classic experiments of quantum optics in artificial atoms[5]. And elsewhere a variety of clever optical techniques with colourful names such as PALM[6,7] and STORM[8] are being exploited to look inside cells at the nanoscale. There would appear to be no limit on what nanophotonics might do.

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