PERSPECTIVE

A glint of the future

The same property that gives stained glass windows their sublime beauty is being crafted in the latest nanophotonic technologies, says **Anatoly V. Zayats**.

We live in what could be described as the era of photonics: in information technologies, data are transmitted in pulses of light; light-emitting diodes (LEDs) provide energy-efficient lighting; and optical sensors are able to detect diseases and explosives.

For many years, gold and other metals have been used in optics and photonics as a mirror coating — a function based on the metal's freely moving electrons, which also allows them to conduct electricity. Shine white light on a gold bar and you'll see a yellowish reflection. However, it is possible to tune the colour of gold nanoparticles to green, orange, red or anything in between. The phenomenon gives rise to the brightly coloured stained glass windows in medieval palaces and cathedrals, for example.

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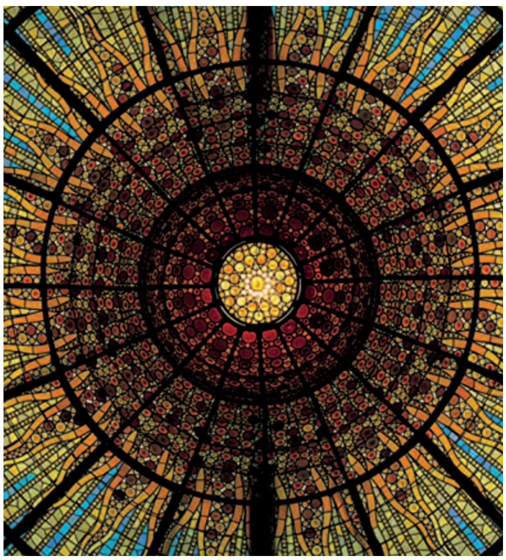
The apparent colour of gold nanoparticles is determined by oscillations of the nanoparticles' free electrons, which are excited by photons striking the metal's surface. Light forces the electrons in the metal to move together, creating a so-called plasmon — a collective of electrons vibrating in phase with each other[1]. It's the plasmons that influence the scattering and absorption of light by metal nanostructures and lead to the colourful stained glass. With plasmonic nanostructures, one can manipulate light at a much finer scale than it is possible to achieve in conventional photonic devices.



Can gold plasmonics be as useful as it is beautiful?

Plasmonics underlies several important nanotechnology applications, including nanoscale lasers, optical data processors, biological and chemical sensors, cancer therapy, high-density data storage, and improved photodetectors and solar cells, thanks to the metal's ability to confine light to dimensions smaller than its wavelength.

Gold is not actually the best metal in terms of optical properties alone. That prize goes to silver, which absorbs less light in the visible and infrared ranges. Silver's optical response is almost the ideal response of free electrons. In gold, electron transitions between energy levels correspond to the visible wavelengths. These transitions, which give rise to gold's characteristic yellow glitter, are also responsible for the metal having a higher optical absorption than silver. This drawback may exclude the use of gold from some applications, such as 'perfect' (diffraction-limit-free) lenses that can focus light with unprecedented precision. But in other plasmonic applications, gold is turning out to be ideal.

Biosensors are a good example. Gold exhibits unmatched chemical stability in the ambient environment, and gold nanostructures preserve their properties for many years. By contrast, silver, which may initially provide better performance, loses its lustre and plasmonic properties within days. Another big advantage of gold for biosensing is that its chemical interaction with organic compounds is extremely well understood. Take, for instance, so-called 'label-free biosensing techniques', which negate the need for dyes or radioactive tracers in biochemical assays. Achieving sensing selectivity requires initial 'functionalization' of a gold surface — the attachment of sensed molecules — which then modifies the plasmonic resonance, leading to a detectable colour change. The current drive is towards miniaturization. The ability to add precise nanostructures to gold surfaces makes it possible to incorporate this technique in lab-on-a-chip systems[2].

Gold's properties also make it well suited to nanophotonics, in which plasmonic signals are used to guide and control optically transmitted information. Such manipulation involves a plasmonic device with nonlinear optical properties[3]. One approach to building such devices is to combine metal nanostructures with conventional dielectrics. But this requires more complex fabrication steps, and such dielectrics limit the switching speed that is fundamental to digital information processing. It's better to avoid the use of dielectrics altogether and rely on the high-speed nonlinear responses of a metal.

In gold, the nonlinear response determined by plasmonic lifetime is less than 10 femtoseconds — about five times faster than in silver[4]. The nonlinearity is also stronger than in silver. In fact, gold's high and fast nonlinearities may lead to optical switches that are faster than electronic ones — a development that could have enormous consequences as information processing migrates into the optical realm.

What may prevent the widespread use of gold in some plasmonic applications is incompatibility with silicon and its low melting point (1,064°C), which might be especially problematic for engery concentration, for example, in heat-assisted data storage.

As plasmonics grow in technological importance, other materials will vie for attention. They will probably be less expensive than gold, but also less versatile. With its combination of chemical and optical properties, gold is likely to take the winner's medal in the plasmonics competition for many years to come. ■

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