Focusing in on applications

What practical applications can the field of plasmonics and metamaterials deliver?

The prospect of controlling the properties of light with nanometre-scale precision by coupling electromagnetic fields to the oscillation of free electrons in metals has driven the field of plasmonics for around the past two decades. Through a merging of nanotechnology and optics, this has led to remarkable fundamental insights into the interaction between light and matter at the nanoscale; allowed the diffraction limit to be beaten and novel imaging techniques to be created; produced ways to modify the properties of light emitters; and enabled materials with optical properties with no counterpart in nature to be developed[1]. However, the initial expectations of the field, which were in part linked to potential practical applications in photovoltaics and optical computing, have not yet been met, and scientists are coming to terms with certain fundamental limitations in the physics of plasmons. In this issue of *Nature Nanotechnology*, in a focus on plasmonics applications, we explore what can, and cannot, be realistically achieved in the field.

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To start, in a Commentary article on page 2, Jacob Khurgin analyses the problem of losses in plasmonics and metamaterials, a problem that is hampering practical applications in the visible and near-IR spectral region and is arguably the principal fundamental hurdle facing the field. The piece takes a theoretical approach to explain, with hard facts, why some of the initial proposals have not yet been realized, and suggests that research attention should be focused on regions of the electromagnetic spectrum where losses are manageable, such as the mid-IR. Continuing to work in the visible and near-IR, however, might mean abandoning the use of gold and silver, and instead looking for natural or artificial materials with negative permittivity and lower losses[2].

The health of a research field can often be gauged by its ability to attract young researchers, as their choice of topic usually implies a positive long-term vision for the possibilities of a field. On page 11, we present a series of short commentaries from early-career researchers in which they explain their motivations for pursuing research in plasmonics and nano-optics, with a particular emphasis on potential practical applications. Though these snapshots do not provide a complete picture, they do highlight the range of possibilities for plamsonics and nano-optics to make real-world impact: metasurfaces for more sensitive analytical instrumentation and on-chip integration with miniaturized electronics; nanohole arrays for point-of-care diagnostics; coupling light with mechanical modes for mass sensors; solar energy harvesting using chaotic resonators; and photonic interconnects for faster computers that consume less energy.

One application of plasmonics that has already been successfully demonstrated at the laboratory scale, and is now garnering industrial interest, is the use of nanohole and nanopillar arrays for imaging devices. This technology is CMOS compatible and overcomes certain limitations of present dye-based filters and displays. These limitations have emerged as the pixel size in the devices has decreased to the nanoscale. In a Feature article on page 15, Nicky Dean reports on this intriguing line of applied research.

Another exciting development concerns the generation of hot electrons and hot holes, which result from the absorption of light by a metallic surface and the subsequent relaxation of plasmons. Advances in nanotechnology mean that we now have the opportunity to design nanostructured surfaces that can maximize light absorption and harvest, to a degree, these hot carriers. In a Review Article on page 25, Mark Brongersma, Naomi Halas and Peter Nordlander look at some of the possibilities offered by hot electrons and hot holes generated by plasmon decays, such as localized heating for cancer therapy, doping of two-dimensional materials and photodetection. Although the physics of hot electrons dates back to Heinrich Hertz and the discovery of the photoelectric effect, it is clear that a lot still needs to be done to understand the relaxation pathways of hot carriers before they thermalize. Ultrafast spectroscopy techniques should be able to provide insights on these relaxation dynamics on the femtosecond timescale and help refine current targets for practical applications. Particularly noteworthy are the possibilities that emerge through a combination of plasmonics and chemistry. Hot electrons can, for example, be injected into specific molecular orbitals of molecules adsorbed on metallic surfaces to help catalyse chemical reactions, including industrially important ones such as the epoxidation of ethene.

Furthermore, in a Commentary on page 6, Martin Moskovits makes the case for hot electron photoelectrochemical (photovoltaics and water splitting) devices in which metals replace semiconductors as the active component for charge generation. Although the efficiencies of these devices is still low there is a wide margin for improvement given the large number of hot electrons that are created by plasmon decay per unit area.

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While there is still much to learn about the fundamental physics of plasmons, the field has now reached a level of maturity and knowledge that means it is ready to contribute to other fields, potentially providing innovative new approaches to existing problems both fundamental and applied. There are already several examples in which plasmonics has successfully bled into other areas, including microfluidics[3], non-hermitian quantum mechanics[4], DNA nanotechnology[5] and self-assembly[6]. Such interdisciplinary work suggests that the applications outlined in this focus issue might just be the beginning of what plasmonics can do.

As 2015 begins, a year that has been designated by the United Nations as the International Year of Light and Light-based Technologies, we hope that this focus on the practical applications of plasmonics will be stimulating to researchers in the field and beyond. ❐

References

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