Not so small

'Nanophotonics' is no longer just the realm of plasmonics researchers. Fields like metamaterials and 'flat' two-dimensional systems based on atomically thin materials are expanding the boundaries of nanophotonics.

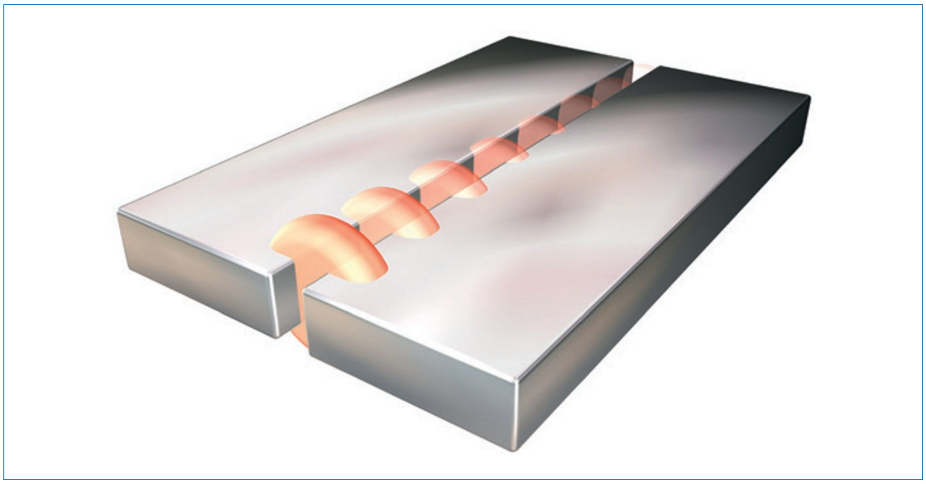
Over the past decade or two we have seen the resurgence of the field of plasmonics due to a number of factors, including the accessibility of nanoscale lithographic and imaging approaches such as focused-ion-beam lithography and near-field scanning optical microscopy (NSOM). The direction of plasmonics, or 'metal-optics', is also driven by the desire to localize light in subwavelength dimensions and exploit strong field enhancements within such small regions. You could argue that this gave rise to the modern field of nanophotonics.

Nanophotonics has since increased its scope beyond plasmonics, as is highlighted by the range of topics covered in this Focus, which by no means provides exhaustive coverage of all of the spawned fields.

NSOM was one of the key advancements that aided plasmonics research, and it is a tool that is now used in all fields of nanophotonics. In the early days of development, various types of probes were compared based on their ability to couple light into a fibre efficiently (or scatter light, which is subsequently collected by bulk optics) while perturbing the electromagnetic field as little as possible. In recent years there has been a push to take NSOM beyond merely detecting the intensity of electromagnetic fields. Now it is possible to measure the phase and amplitude of separate electromagnetic field components, including those attributed to the magnetic field.

On page 919, Nir Rotenberg and Kobus Kuipers review the techniques that allow NSOM to obtain the phase and amplitude of vector components of the electromagnetic field as well as access ultrafast temporal or spectral information in nanostructures.

As is well known, one of the major issues in plasmonics is the trade-off between electromagnetic field confinement and loss that results in short propagation distances and lifetimes or low *Q*-factors. Although there is arguably still no clear and complete solution to the problem, especially if we look strictly at true nanophotonic systems, great strides have been made by research groups incorporating active gain media into metal systems to partially compensate for, or overcome loss, that is, provide net gain.



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Something that is occasionally lost in the plasmonics gain media debate is that some demonstrations do not (or only barely) exhibit sub-diffraction-limit light confinement and thus their performance should be compared to non-plasmonic yet compact conventionally confined active systems, such as VCSELs (vertical-cavity surface-emitting lasers). With this view in mind, Martin Hill and Malte Gather carefully chose the title 'Advances in small lasers' for their Review Article on page 908. They review various metal and dielectric cavity-based systems and provide an outlook on the most promising directions for each type of small laser.

Metamaterials, aimed at achieving otherwise unavailable, or tailored, optical properties, can also be included under the nanophotonics umbrella as the optical responses are achieved by exploiting subwavelength material structuring. Metasurfaces that draw on the concept of phased-array radio frequency antennas to provide control over phase on the subwavelength scale are a particularly interesting direction that has emerged in recent years. Nina Meinzer, William Barnes and Ian Hooper provide a review of recent progress on metamaterials and metasurfaces on page 889.

Although plasmonic resonators are the workhouse for achieving strong optical responses from small subwavelength features, recent research on dielectric metamaterials shows promise. Loss (intrinsic or scattering) will always remain an issue in systems with large interaction times, but dielectrics may offer intrinsically lower loss than plasmonic approaches, with some trade-offs of course.

On page 899 Fengnian Xia and colleagues review the emerging directions in nanophotonics related to so-called flat or two-dimensional optics. Atomically thin sheets of carbon (that is, graphene) have been explored for subwavelength applications, especially at infrared and longer wavelengths where the permittivity is negative and metal-like (including plasmonic) properties exist. Now, a range of similarly exciting material possibilities, such as insulating hexagonal boron nitride and semiconducting transition metal dichalcogenides like molybdenum disulphide, are being explored for nanophotonic (and other) applications.

Clearly the field of nanophotonics encompasses a wide range of exciting directions, some of which are still rapidly evolving. Pierre Berini, who is one of the pioneers of modern plasmonics and nanophotonics with key contributions on surface plasmon waveguiding, sensing and active systems, gives some big-picture perspective in the Focus Interview on page 878. Berini explains that although loss is still a big issue for metal-based nanophotonics, we can expect further breakthroughs, likely in unexpected directions. ❒