Metallic metamaterials and plasmonics

Our ability to control and harness light is undergoing a revolution, one that exploits the special properties of metals and our ability to structure them on a subwavelength scale. The materials that enable such control involve plasmonic and metallic metamaterials, materials that provide challenges for physicists and engineers that demand a multi-disciplinary approach. In June 2010, Alastair Hibbins, Roy Sambles and I brought together scientists from different subdisciplines to exchange knowledge and forge new ideas at the first Theo Murphy Royal Society Discussion Meeting held at the Royal Society’s new meeting venue, the Kavli Centre at Chicheley Hall. The papers in this issue are drawn from that meeting and provide a fascinating cross section in the development of this new interdisciplinary area.

The same conduction electrons in metals that are responsible for their highly reflective character are being exploited to yield many new and fascinating possibilities ranging from invisibility cloaks to perfect lensing. These new possibilities rely on our ability to structure metals at the subwavelength scale, thereby creating novel materials with properties that allow one to transcend the boundaries of traditional optics. The two realms of metamaterials and plasmonics both depend critically on sub-wavelength structure, in plasmonics it is primarily single or a small number of structures that are of interest, while in metamaterials it is usually arrays of structures that are important. There is an increasing overlap between these two fields, one we sought to pursue in this Discussion Meeting.

Metamaterials have attracted great interest beyond just the research community, primarily because of a plethora of recent theoretical and experimental results that have sparked the public’s imagination. For example, suitably structured metallic metamaterials have been found to give negative refractive index, sub-wavelength confinement and control of light and to provide very strong optical field enhancements. However, it is perhaps the demonstration of electromagnetic cloaking, rendering objects invisible, which has generated the most excitement. In plasmonics also new developments continue, which include exciton–plasmon coupling, coherent control of sub-wavelength optical manipulation and plasmon-assisted high harmonic generation. Taken together, these and other developments have led to an explosion of interest worldwide in metallic metamaterials.

These new materials pose fascinating challenges for experimentalists and theorists, challenges that are driving forward new techniques and new conceptual approaches. Experimentalists are developing procedures to fabricate and characterize new metallic structures, while theorists are grappling with the
challenge of modelling their electromagnetic response. A particular focus as the field progresses is to go beyond just passive materials and find ways to provide active control. These topics formed the backbone of many of the discussions at the meeting, and many of them are represented in this special issue.

The issue of fabricating and characterizing metamaterials is discussed in the first three papers presented here. Jie et al. [1] explore the use of bottom-up approaches to make effective media for metamaterials applications using silver nano-wires as the metallic elements. Their aim was to produce materials with broad-band properties, important if many of the applications discussed in recent years are to be pursued effectively. Pryce et al. [2] address another important and related aspect, that of tunability. They exploit the deformable nature of polymers when used as substrates for metamaterials, with an emphasis on looking at how mechanical deformation limits elastic tunability. Meanwhile, Prangsma et al. [3] look at how electrons may be used to uncover the optical properties of metamaterial structures. Most work in this area exploits light (photons) for such characterization work, but electrons have been very successfully used in plasmonics, and Prangsma et al. [3] continue and extend that work; it may prove a powerful way to explore local effects and local defects in metamaterial structures.

Mulvaney et al. [4] and Csaki et al. [5] focus directly on plasmonic structures. Mulvaney et al. [4] explore trimers of gold nanorods. The optical properties of small numbers of metallic nanoparticles have received long-standing attention owing to the importance they have in controlling the optical properties of molecules in their vicinity. As the authors point out, there is very considerable added value in combing experiment and theory in one study, as they have done here, they also point to the important role that higher order modes make in small particle clusters, something that one would not necessarily anticipate from single particle work. Csaki et al. [5] provide a more application-oriented discussion of the interaction between the plasmon modes of metallic nanoparticles and molecules—a sub-field known as molecular plasmonics. Their emphasis is on the area of biosensing, focusing on some of the key challenges in implementing plasmonics in developing biological diagnostics platforms. Much has been promised by proponents of plasmon-based biosensing, the challenges identified by Csaki et al. [5] will need to be addressed if that potential is to be delivered.

The remaining three papers all look at various nonlinear aspects of metamaterials and plasmonics. Nonlinearity is vital if functional metamaterials and plasmonics are to be achieved, and the topic was one that led to much discussion during many of the sessions at the meeting. Palomba et al. [6] use four-wave mixing to study the nonlinear optical response of a ‘simple’ metal surface. Such work is essential, without understanding this simple system properly it is difficult to move the more complex structures found in metamaterials with confidence. The last two papers address the much-debated issue of gain in metamaterials. In the first of these contributions, Stockman [7] focuses on a comparison of loss compensation in metamaterials and spasing action of plasmonic structures using an analytical approach. By contrast, Wuestner et al. [8] adopt a numerical approach in which gain is incorporated using rate equations. These two papers provide an interesting snap-shot of some of the issues that are still much-debated in this area, they were certainly the focus of much debate at the meeting. It will be interesting to look back at these and the other contributions in years to come and to see how the topic evolves.
I would like to conclude with two notes of thanks. First, as all organizers know, successful meetings rely on the willing participation of the attendees: the speakers, the presenters of posters, etc. Without exception, all those who attended did so with such a sense of willingness and enthusiasm that the job of organizing the meeting was a great pleasure, thank you to all of you. Second, open debate is a vital part of the scientific process, and the Theo Murphy Royal Society Discussion Meetings provide a superb forum for such dialogue. The combination of magnificent surroundings, excellent facilities and above all impeccable organization from the Royal Society produced an opportunity for debate that sets a gold standard, and I would like to thank all of those at the Royal Society and Chicheley Hall for their wonderful support. Attendees of future meetings have a treat in store.

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References


