

Focus Issue on surface plasmon photonics introduction

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Abstract: The 7th International Conference on Surface Plasmon Photonics (SPP7) was held in Jerusalem, Israel from May 31st to June 5th, 2015. This independent series of biennial conferences is widely regarded as the premier series in the field, and the 7th edition maintained the tradition of excellence. This Focus Issue collects 23 papers related to research presented at SPP7. While this number is small compared to the total number of papers presented at the conference, the issue is representative and provides a good overview of the field at this point in time.

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Introduction to the focus issue on surface plasmon photonics

Surface plasmon photonics is an evolving field and is well considered as a major driving force for cutting edge research in optical science and engineering. In general, the field takes advantage of enhanced interactions of light with metallic structures (materials ranging from noble metals, over doped semiconductors and two-dimensional layered materials, to nanocrystals and macro-molecules), over a broad spectral range, ranging all the way from THz to UV wavelengths. The research is driven by interests in both fundamental aspects and applications. These applications are becoming more advanced, side by side with the maturation of the field. Typical applications include devices for telecommunications, energy harvesting, sensors, medical devices and more. The 7th International Conference on Surface Plasmon Photonics (SPP7) was held recently in Jerusalem, Israel from May 31 to June 4, 2015 [1]. This independent series of biennial conferences is widely regarded as the premier series in the field, and the 7th edition maintained the tradition of excellence established at previous editions (SPP6 Ottawa, SPP5 Busan, SPP4 Amsterdam, SPP3 Dijon, SPP2 Graz, SPP1 Granada, and the precursor to the series in 2001).

SPP7 brought together over 400 plasmonics experts from around the globe, both junior and senior, from academia and industry, to share their latest results and set the agenda for future developments in the field. About 450 abstracts were received from 34 countries across several science and engineering disciplines. The technical program of the conference was constructed from submissions on fundamental and applied topics. The large number of high-quality abstracts received for SPP7, the representation of diverse science and engineering disciplines, the international scope, and the emergence of new topics and trends, all serve as evidence that the field of plasmonics is very healthy indeed and that it continues to expand. A short review summarizing some of the achievements reported during the conference has been recently published [1].

This feature issue includes 23 invited papers related to research presented at SPP7. While this number is a small subset of the papers presented at the conference, the issue is representative and provides a good overview of the field at this point in time. A wide range of topics are covered in this feature issue, including several devices for telecommunication, controlled beam shaping, sensors and others, nonlocal effects, light matter interactions with enhanced emission and nonlinearity as well as strong coupling, advanced characterization

techniques, and advanced plasmonic materials and structures. Next we briefly mention the papers included in this feature issue [2–24], grouped into the above mentioned categories.

Plasmonic devices: following the latest advancements in the field of plasmonics, new devices and applications are being reported more frequently. Plasmonic devices play a role in diverse disciplines, from communication and data processing to energy harvesting, medical devices, imaging systems, high resolution lithography, sensing and more. The rapid growth in the field of plasmonic devices is reflected by the large number (nine) of papers related to devices published in this Feature Issue. A high speed plasmonic modulator array has been reported by Heni *et al.* [2]. Taking advantage of high field confinement, together with the presence of metal electrodes in close proximity to the electromagnetic mode, and combined with an electro-optic polymer, a small-footprint device with a capacity of 4 x 36 Gbit/s was demonstrated. This array is compatible with a multicore fiber with channel spacing as small as 50 microns. While this work deals with transmission of data, Birr *et al.* [3] proposed a plasmonic model system for the realization of all-optical logic operations including NOT, AND, OR and XOR. Their proposal is based on interference effects in waveguides. Two crossed waveguides with an additional output waveguide were used to demonstrate ultrafast switching and logic operation. Plasmonic structures can also be controlled at a lower time scale by adjusting their shape and structure, as reported by Yang *et al.* [4]. An external laser was used for the purposes of tuning the magnetic properties of metamaterials, with the freedom of choosing the wavelength range. Several devices for sensing applications have been reported. Hong *et al.* [5] demonstrated the benefits of combining surface plasmon resonance (SPR) together with Faradaic electromechanical impedance spectroscopy for the purpose of simultaneous detection of biological analytes. With this approach, they demonstrated biotinylated surface capture of neutravidin concentrations as low as 10 nM with a 5.5 nM limit of detection. Another biosensor was reported by Wong *et al.* [6]. This device is based on long-range surface plasmons in Y-junctions. The usefulness of this device was demonstrated for the purpose of bulk refractive index sensing using five solutions of different refractive indices, as well as for protein sensing using physisorption of bovine serum albumin on a carboxyl-terminated Au strip. In another work by Babicheva *et al.* [7] long-range plasmonic waveguides with a dielectric core and a hyperbolic cladding were studied. Such waveguides can support propagation lengths of up to a millimeter and provide better performance in terms of propagation length and mode confinement compared with other designs such as metal-insulator-metal waveguides.

Building on the success of the metasurface concept, three papers are included on this topic in the feature issue. Højlund-Nielsen *et al.* [8] demonstrated a polarization-dependent metasurface operating at blue wavelengths. By using aluminum-based elongated rectangles of dimensions 180 nm by 110 nm, it was shown that for the proper choice of polarization, the reflectivity can drop to below 2% in the blue part of the spectrum. Ng *et al.* [9] studied all-metal nanostructured substrates for the purpose of subtractive color reflectors with near perfect absorption. Their design is capable of achieving over 95% absorption from a bulk silver layer, applying fabrication constraints of constant nanostructure height and pitch. Finally, the work of Pors *et al.* [10] studies the unidirectional scattering of light along the propagation direction via the application of the generalized Kerker conditions. This is achieved via the optimization of disk-shaped gap surface plasmon resonators. The theoretical work was followed by a proof of principle experiment showing the asymmetric scattering from these resonators.

Nonlocal effects: In recent years it was shown by various groups that the assumption of locality, namely the assumption that the electric displacement is directly proportional to the electric field at the same position may not hold at the nanoscale, e.g. when the metal size becomes infinitesimally small, or when the gap between adjacent metallic structures nearly vanishes. In such cases, nonlocal effects should be taken into account. Nonlocality produces a smooth redistribution of the induced charges followed by a weaker plasmon confinement and

field enhancement. This Feature Issue includes three papers on the topic of nonlocal effects, one of them will be discussed later in the context of enhanced light-matter interactions. As for the other two papers, Correias-Serrano *et al.* [11] analyze the nonlocal response of an ultrathin hyperbolic metasurface by applying an effective medium approach. The results establish an upper bound set by nonlocality to the maximum field confinement and light matter interactions achieved in practical ultrathin hyperbolic metasurfaces. Wubs [12] classifies and compares scalar and tensorial nonlocal response models. It is found that some models predict novel plasmonic resonances below the plasma frequency, whereas the hydrodynamic model predicts standing pressure waves only above the plasma frequency.

Plasmonic enhanced light matter interactions: one of the most important properties of plasmonic structures is the ability to confine electromagnetic field at the subwavelength scale and enhance the interactions of light with matter, *e.g.*, by increasing the local density of states. In doing so, one may enhance phenomena such as the emission of light, nonlinear effects, spectroscopy, strong coupling and more. Guo *et al.* [13] study the control of quantum dot emission coupled to the optical modes of silver nanoparticle arrays, observing enhancement of emission in photoluminescence spectra and fluorescence lifetime measurements. Khurgin *et al.* [14] study the impact of surface collisions on the enhancement and quenching of luminescence near metallic nanoparticles. They show that the surface-induced damping rate increases with the degree of electromagnetic mode confinement, and thus the damping of higher-order nonradiative plasmonic modes in spherical particles is enhanced in comparison to the damping of the fundamental mode. As a result, the amount of attainable luminescence enhancement is limited. Tumkur *et al.* [15] demonstrate the strong coupling of dye molecules to surface plasmons in a Kretschman configuration. They observe the splitting of the dispersion curve into three branches and avoided crossing. Furthermore, it turns out that the plasmonic environment couples very differently to absorbing and emitting molecules. Plasmonic enhancement of light-matter interactions can also be used for promoting nonlinear effects. In their paper, Segovia *et al.* [16] demonstrate numerically the potential of a hyperbolic medium in the design of a metamaterial antenna capable of detecting and tracking a nonlinear object based on its second harmonic signature. Their antenna provides three orders of magnitude intensity enhancement of the second harmonic generation from a nanoparticle through evanescent interactions between the metamaterials and the nonlinear object. Finally, Ueno *et al.* [17] show that plasmonic enhancement of light-matter interactions can also be useful for the benefit of signal enhancement in Terahertz spectroscopy. This is achieved by depositing amino acid molecules on a gold rod structured silicon substrate and observing localized surface plasmon resonances in the Terahertz region. By exciting longitudinal plasmon resonance modes in a spectral band overlapping the molecular or the intermolecular vibrational mode, distinct spectroscopic peaks could be observed.

Advanced characterization techniques: The rapid progress in plasmonic research brings about the need for advanced experimental characterization techniques. In this feature issue, two papers describe such techniques for the benefit of characterizing plasmonic modes. Melchior *et al.* [18] use three-photon photoemission electron microscopy (PEEM) to investigate the interference of coherently excited dipolar and quadrupolar resonant modes of plasmonic whispering gallery resonators. Using this approach, the authors could directly resolve the interference between the modal field distribution of dipolar and quadrupolar modes that are coherently excited under oblique incidence. Grajower *et al.* [19] used scanning thermal microscopy (SThM), with the original goal of characterizing thermal effects in nanophotonic structures. Yet, it turns out that the signal originated by the high absorption of light in the antenna-like apex of the metallic probe outperforms the signal which originates from heat transfer between the sample and the probe. As a result, it is possible to measure electromagnetic near-field distributions simply by using the SThM approach without the need for an optical system. In the paper, the SThM approach has been used for the characterization

of several nanophotonic structures. Side-by-side with advanced experimental tools, advanced modeling is also important for the characterization of plasmonic properties. Martinez-Herraro *et al.* [20] investigated the evolution and the polarization properties of a SPP packet propagating along a planar interface between a dielectric and a lossy metal using exact solutions of Maxwell's equations. The obtained results provide a step forward in the effort to understand SPP optics beyond the single mode description.

Advanced materials: Advanced materials are expected to play a key role in plasmonic applications. For example, it is possible to achieve plasmonic effects by using highly doped semiconductors instead of metals, with the immediate advantage of controlling the properties of the materials by controlling the doping density. Indeed, two papers take advantage of this concept. Kalusniak *et al.* [21] used a highly-doped semiconductor to demonstrate negative dispersion and negative refraction at telecommunication wavelengths through plasmon-photon hybridization. Taliercio *et al.* [22] used a silicon-doped InAsSb alloy to realize plasmonic resonators for the purpose of demonstrating Fano-like resonances in the mid-infrared with a controllable Fano asymmetric parameter.

Advanced structures: Another rapidly developing aspect is the study of plasmonic properties in advanced structures, drawing often on novel concepts and developments in neighboring fields such as condensed-matter physics and quantum physics. Chen *et al.* [23] study the plasmonic resonances of double nanoholes in a metal film. They observed gap-mode Fabry-Perot modes as well as wedge modes which are controlled by the curvature of the structure. It was found that the intensity of the gap modes increases with the decrease in gap width, while the wedge mode intensity saturates. Finally, Spektor *et al.* [24] proposed and experimentally demonstrate a plasmonic cavity enabling both nanoscale light confinement and control of SPP spin angular momentum towards coupling to topological-insulator surface states. The resulting SPP field components within the cavity are arranged in a chess-board-like pattern, each square exhibits approximately a uniform circular polarization (spin angular momentum) of the local in-plane field interleaved by out-of-plane field vortices (orbital angular momentum).

To summarize, it is our great hope that this feature issue will serve at least two major purposes: first, it should be of great interest to the researchers in the field, and second, it should attract the attention of further scientists to get engaged with plasmonic research and its emerging applications. We would like to extend to all a keen invitation to the 8th edition of the SPP conference series which will be held in Taiwan, May 22-26, 2017.