We present a number of new materials and hybrid structures for active and reconfigurable nanoplasmics. In particular, we use the metal-to-insulator transition of Yttrium hydrides to completely switch the particle plasmon on and off in nanoantennas with their spectral response tuned to the near infrared. A key challenge for the development of active plasmonic nanodevices is the lack of materials with fully controllable plasmonic properties. In this work we demonstrate that a plasmonic resonance in top-down nanofabricated yttrium antennas can be completely and reversibly turned on and off using hydrogen exposure. We fabricate arrays of yttrium nanorods and optically observe in extinction spectra the hydrogen-induced phase transition between the metallic yttrium dihydride and the insulating trihydride. Whereas the yttrium dihydride nanostructures exhibit a pronounced particle plasmon resonance, the transition to yttrium trihydride leads to a complete vanishing of the resonant behavior. The plasmonic resonance in the dihydride state can be tuned over a wide wavelength range by simply varying the size of the nanostructures. Thus, our nanorod system serves as a versatile basic building block for active plasmonic devices ranging from switchable perfect absorbers to active local heating control elements. Additionally, we are going to demonstrate switching functionalities in phase change hybrid plasmonic materials.
Hexagonal boron nitride nanostructures: Spectral tuning of a natural hyperbolic material for mid-infrared resonators

J D Caldwell¹, A Kretinin², Y Chen³, V Giannini³, M Fogler⁴, Y Francescato³, C T Ellis⁵, J G Tischler¹, C R Woods², A J Giles², M Hong⁶, K Watanabe⁷, T Taniguchi⁷, S A Maier³ and K S Novoselov²

¹U.S. Naval Research Laboratory, USA, ²University of Manchester, UK, ³Imperial College London, UK, ⁴University of California-San Diego, USA, ⁵NRC Postdoctoral Fellow (residing at NRL, Washington, D.C.), ⁶National University of Singapore, Singapore, ⁷National Institute for Materials Science, Japan

One of the key objectives of investigating metamaterials like metal/dielectric multi-stack structures and plasmonic nanowires embedded in a dielectric matrix is to achieve hyperbolic optical response, which is of great importance in applications like super resolution and nonlinear optics. Hyperbolicity requires simultaneously metallic (negative real permittivity) and dielectric (positive real permittivity) optical responses along orthogonal optical axes, and it was believed that only through artificial materials hyperbolicity could be realized. In this work we show that natural hexagonal boron nitride (hBN) can achieve this extraordinary optical response. Two hBN hyperbolic bands are identified in mid-infrared, one (12.1-12.8 μm) has εz < 0 while εx,y > 0, and the other (6.2-7.3 μm) has εz > 0 while εx,y < 0. Moreover, by illuminating conical-shaped hBN nanostructure array at near-normal and grazing incident angles, localized surface phonon polariton (SPhP) modes within these two hyperbolic bands are carefully studied. Anomalous scaling behaviors are observed in the upper band (6.2-7.3 μm), where higher order modes are found at lower frequencies. Due to the low-loss nature of SPhP, quality factors approaching 300 are recorded in these modes. This work opens the door to the investigation of extraordinary optical properties from naturally occurring materials, which holds promise for low-loss nanophotonic applications in the mid-infrared and single digit Terahertz regions.
Monday 1 September
Session 1: Metamaterials Nanophotonics and Plasmonics – Hybrid Structures (11:30 – 11:45, Huxley LT308)

Hybrid plasmonic strip and slot waveguides for deep subwavelength nanofocusing of TE and TM modes

L Lafone, T P H Sidiropoulos and R F Oulton
Imperial College London, UK

Surface plasmons offer the possibility of manipulating light on an unprecedentedly small scale and this new level of control has led to predictions of widespread technological applications. However, a number of additional conditions must be met if successful commercial implementation is to become a reality. Appropriate devices must combine long range transport with short range confinement and also offer: an efficient method of coupling light in to the structure, a simple fabrication process that produces the structure in a predetermined location and compatibility with the standard semiconductor materials such as silicon or indium phosphide.

We present two hybrid plasmonic waveguides that satisfy all of these criteria. Both geometries are designed for operation at $\lambda=1550\text{nm}$ and are capable of supporting bound modes around two orders of magnitude below the diffraction limit, whilst maintaining propagation lengths in excess of $10\mu\text{m}$. We utilize a silicon on insulator (SOI) platform and the structures are fabricated using a single lithography step followed by metal deposition and lift-off. Given this simple fabrication process and the chosen materials, our designs offer direct compatibility with current semiconductor technologies.

The structures consist of a metal strip or slot atop a silicon slab waveguide where the width ($W$) of the slot or strip controls the size of the mode. It is observed that by tapering this width light can be efficiently focused into areas as small as $\lambda^2/400$. This creates an important bridge between plasmonics and silicon photonics. The intensity enhancement that results from this focusing process could also allow generation of nonlinear processes in extremely small length scales.
Monday 1 September  

Session 1: Metamaterials Nanophotonics and Plasmonics – Hybrid Structures (11:45 – 12:00, Huxley LT308)

Z-scan characterisation of epsilon-near-zero metamaterial

K P M Rishad¹, C Li¹, T Roger¹, M Pietrzyk², A Di Falco², D Faccio¹ and M R Kaipurath¹

¹Heriot-Watt University, UK, ²St Andrews University, UK

We report here, an experimental investigation of the nonlinear parameters of an Epsilon-Near-Zero (ENZ) metamaterial using the Z-scan technique. ENZ metamaterials are artificially structured materials with both the real and, ideally also the imaginary part of their permittivity close to zero. An ENZ material was fabricated by depositing alternating layers of titanium dioxide (TiO₂) dielectric of 60 nm thickness with silver metal layers of 15 nm thickness, as shown in Fig 1(a). Samples with 3, 4 and 5 bilayers were fabricated and characterised. The real part of the effective refractive index (evaluated from the measured real and imaginary parts of the dielectric permittivity) was found to be of the order of 0.3 for all samples at a wavelength of 800 nm. The nonlinear properties were then characterised by the Z-scan technique using 800 nm, 100 fs laser pulses with a rep. rate of 100 Hz (in order to avoid thermal effects). We found a very large nonlinear refractive index $n_2 \approx 3 \times 10^{-10}$ cm$^2$/W, which is six orders of magnitude larger than that of bulk dielectrics and three orders of magnitude more than that of metals. The nonlinear absorption coefficient of the ENZ material was measured to be, $\beta \approx 10^6$ cm/W, a value three orders of magnitude larger than that of dielectrics. The results of the open and closed aperture Z-scan measurements of the ENZ metamaterial are shown in Figures (1.b) and (1.c), respectively.

Figure 1: (a) A schematic representation of a multilayer metal-dielectric(Ag-TiO₂) ENZ metamaterial slab. (b),(c) Normalised transmittance of an open and closed aperture z-scan measurement with theoretical fit (dotted lines) using femtosecond laser source.
Monday 1 September  
Session 1: Metamaterials Nanophotonics and Plasmonics – Hybrid Structures (12:00 – 12:15, Huxley LT308)

Tunable hybrid plasmonic modes in cut-wire waveguide arrays

J J Wood, L Lafone, J M Hamm, R F Oulton and O Hess  
Imperial College London, UK

Hybrid Waveguide Plasmon Polaritons (WPPs) [1] are resonances produced through the coupling of plasmonic and waveguide modes; as the plasmonic element is used only for the control of this resonance these can be low-loss. In this work we combine coupled-resonator optical waveguides [2] (CROWs) and WPP concepts to design low-loss metallo-dielectric resonators with highly tunable properties that can be tailored for devices, for instance nano-lasing and slow-light applications.

Figure 1: (a) Tuning the cut-wire resonance alters the shape of the dispersion curve at the band edge; inset shows overall band structure. (b) Higher order modes present in a finite array of 20 wires, where the field envelope determines how lossy the mode is.

The presented structure consists of metallic cut-wire arrays placed on a photonic waveguide to create tunable plasmonic resonator arrays with a resonance frequency that can be adjusted by changing the lengths of the cut-wire segments and gaps in between. At the edge of the Brillouin zone the resulting hybrid mode is a superposition of the bare waveguide modes only. As such, the dispersion at the band edge is independent of the plasmonic resonator and held fixed at a specific frequency, allowing the shape of the band close to this point to be tuned through the plasmonic resonance (Fig. 1a).

For finite arrays the loss rates decrease with an increasing number of cut-wires. Furthermore, as the modes approach the band edge the Q-factor increases since fewer cut-wires are excited (Fig. 1b).

By arranging the array resonances and analysing the decay rates the finite arrays can be tuned for applications, such as single mode nanolasers.