Ultrafast Active Plasmonics

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Abstract: We report on the experimental demonstration of femtosecond optical modulation of plasmonic signals and analyse the nonlinear propagation and active manipulation of short plasmon pulses.

Here we report that femtosecond plasmon pulses can propagate along a metal-dielectric waveguide and can be modulated on the femtosecond timescale by direct ultrafast optical excitation of the metal, thereby enabling femtosecond optical modulation and offering terahertz plasmonic bandwidth, a key missing component in the development of SPPs as information carriers. The demonstrated switching concept provides at least a five order of magnitude improvement in plasmon switching time compared to the best existing technologies.

In essence, we have discovered a nonlinear interaction between a propagating SPP and light that takes place in the skin layer of the metal surface along which the plasmon wave is propagating [1]. A femtosecond light pulse incident on the metal surface disturbs the equilibria in the distributions of electron energies and momenta, thereby influencing plasmon propagation along the surface. The nonlinear interaction between propagating SPP waves and light has been demonstrated in a pump-probe experiment wherein a pulsed plasmonic probe signal was generated on an Al/silica interface by grating coupling from a pulsed 780 nm laser beam. After travelling across the interface, the plasmon wave was decoupled to light by another grating and subsequently detected. Optical control (pump) pulses, originating from the same laser, were incident on the waveguide region between the coupling and de-coupling gratings (see Fig. 1). The transient effect of control pulse excitation on the propagation of the SPP excitation and optical pump pulses. It is found that an optical pump influence of about 10 mJ/cm^2 leads to around 7.5% modulation of the plasmon wave intensity.

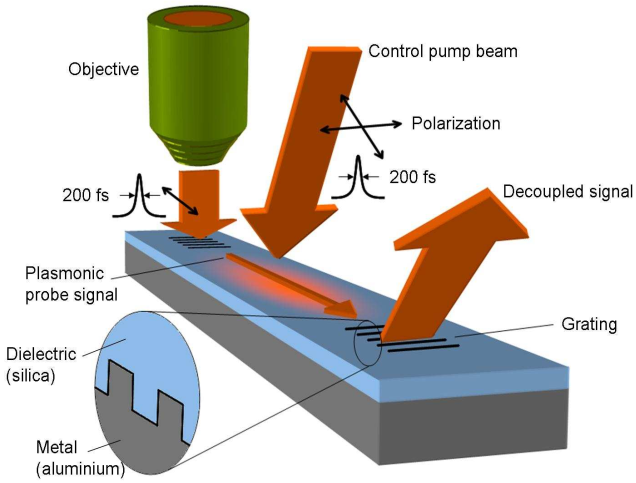

Figure 1: Ultrafast optical modulation of SPP propagation: A plasmonic signal, coupled to and from the waveguide by gratings on an aluminium/silica interface, is modulated by optical control pulses as it travels between the gratings.

To analyse what can ultimately be achieved in nonlinear and active plasmonics, in particular for the purposes of high-bandwidth interconnects, SPP modulation and all-plasmonic switching we numerically analyse pulse broadening and distortion resulting from dispersion of group velocity and losses, and investigate nonlinear regimes of plasmon pulse propagation including self-focusing, pulse self-modulation, compression and solitons.

[1] K. F. MacDonald *et al.*, arXiv:0807.2542v1 (2008).