Dynamic Mode Multiplexing with Plasmonic Metasurfaces

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Since metamaterials have enabled the design of almost arbitrary landscapes of static optical properties and functionalities, dynamic temporal and spatial control over metamaterial properties has become the next big challenge. Recently, it has been demonstrated that the interaction of two coherent waves of arbitrarily low power on a metasurface can provide ultrafast control over the material excitation and thus over the expression of the nanostructure's functionalities [1]. Here we report simultaneous spatial and temporal control of metasurface excitation including first proof-of-principle demonstrations of spatial mode multiplexing, image processing and logical operations.

A functional thin film of sub-wavelength thickness may be placed at a node or anti-node of the standing wave pattern formed by counter-propagating coherent waves, leading to suppression or enhancement of its excitation. In our case, coherent material excitation is achieved by splitting a 785 nm laser beam into coherent signal and control beams illuminating front and back of an absorptive thin gold film perforated with an array of asymmetrically split ring slits (Fig. 1(a)). Spatial control is realized by imaging masks onto the absorptive thin film, while phase modulation of the control beam provides temporal control.

Below, we illustrate coherent image processing using mode separation for space-division multiplexing as an example. Space-division multiplexing increases the information carrying capacity of optical fibres by using higher order modes as additional information channels. Such a multimode optical signal beam is simulated using a mask with 5 holes (Fig. 1(b)). A control signal for deleting or enhancing the fundamental mode is simulated using a mask with a single hole (Fig. 1(c)). Depending on the relative phase of the control and signal beams, simultaneous illumination of the thin film with both control and signal beams leads to three-fold coherent enhancement of the fundamental mode (mode selection, Fig. 1(d)) or its deletion (mode removal, Fig. 1(e)) from the signal beam.

Beyond image processing and mode selection, this concept allows the spatially resolved ultra-fast modulation of the expression of all sorts of optical properties a metasurface or thin film may exhibit as well as logical operations (e.g. and, or, xor) and massively parallel all-optical polarization and intensity modulation.

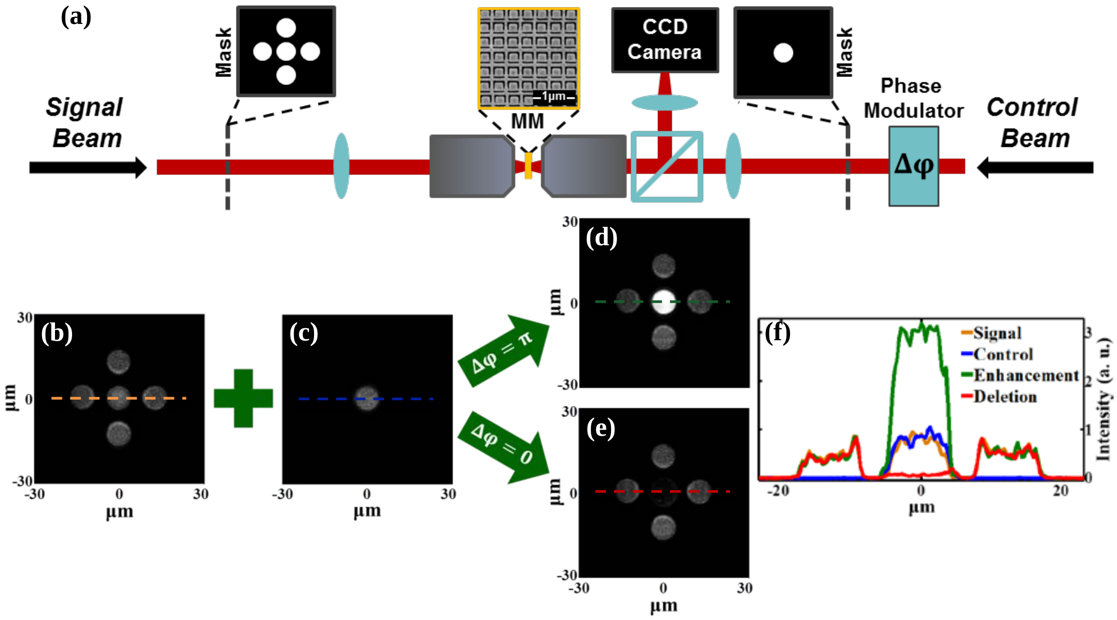

Fig. 1.: (a) Schematic of the experimental setup where spatial modulation of the coherent control and signal beams is provided by masks and temporal modulation is provided by a phase modulator. Images of a metasurface illuminated by (b) signal beam only; (c) control beam only; (d) signal and control beams with coherent enhancement (mode selection); (e) signal and control beams with coherent cancellation (mode deletion). (f) Intensity cross sections along the coloured dashed lines of images (b)-(e).

References

[1] J. Zhang, et al., "Controlling light-with-light without nonlinearity," Light: Science and Applications **1**, e18 (2012).

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