Metaoptics for Active Photonics

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Abstract

Metaoptics offer unique opportunities for light control through dispersion engineering and optical nonlinearities. Here we demonstrate ultrashort pulse shaping with metasurfaces and new schemes for spatial light modulation and Gigahertz speed transmission modulation based on Mie resonances and on organic layers with giant electrooptic coefficient.

Transparent materials do not absorb light but have profound influence on the phase evolution of transmitted radiation. One consequence is chromatic dispersion causing ultrashort laser pulses to elongate in time while propagating. We experimentally demonstrated ultrathin nanostructured coatings that resolve this challenge: we tailored the dispersion of silicon nanopillar arrays such that they temporally reshape pulses upon transmission using slow light effects and act as ultrashort laser pulse compressors.[1] The coatings induce anomalous group delay dispersion in the visible to near-infrared spectral region around 800 nm wavelength over an 80 nm bandwidth. We characterized the arrays' performance in the spectral domain via white light interferometry and directly demonstrate the temporal compression of femtosecond laser pulses. Applying these coatings to conventional optics renders them ultrashort pulse compatible and suitable for a wide range of applications.

Tailored nanostructures also provide at-will control over the properties of light using nonlinear optics, with applications in imaging and spectroscopy. Nanomaterials with $\chi(2)$ nonlinearities achieve highest switching speeds. Current demonstrations typically require a trade-off: they either rely on traditional $\chi(2)$ materials, which have low non-linearities, or on quantum well heterostructures that exhibit a high $\chi(2)$ in a narrow band. We have shown that a thin film of organic electro-optic molecules JRD1 in polymethylmethacrylate combined with nanograting provides excellent performance for free-space optics: broadband record-high nonlinearity (10-100 times higher than traditional materials at wavelengths 1100-1600 nm), a custom-tailored nonlinear tensor at the nanoscale, and engineered optical and electronic responses.[2] We demonstrated a tuning of optical resonances by $\Delta\lambda = 11$ nm at DC voltages and a modulation of the transmitted intensity up to 40%. We realize 2×2 single- and 1×5 multi-color spatial light modulators and demonstrated their potential for imaging and remote sensing.[2] The compatibility with compact laser diodes, the achieved millimeter size and the low power consumption are further key features for laser ranging or reconfigurable optics emitters.

We have also employed a metasurface from sub-wavelength Mie resonators that support quasi bound states in the continuum (BIC) as a key mechanism to demonstrate electro-optic modulation of 34 free-space light with high efficiency at GHz speeds. Our geometry relies on hybrid silicon-organic 35 nanostructures that feature low loss ($Q = 550$ at λ=1594 nm) while being integrated with GHz compatible coplanar waveguides. We maximize the electro-optic response by using high-performance electro-optic molecules (whose electro-optic tensor we engineer in-device to exploit $r_{33} = 100$ pm/V) 38 and by nanoscale optimization of the optical modes. We demonstrate both DC tuning and high -speed modulation up to 5 GHz .

1. M. Ossiander, Y.-W. Huang, W. T. Chen, Z Wang, X Yin, YA Ibrahim, M Schultze, and F. Capasso. Nature Communications, 12, 6518 (2021)
2. Ileana-Cristina Benea-Chelmus, M. L Meretska, D. L Elder, M. Tamagnone, L. R Dalton, and F. Capasso. Nature Communications, 12, 5928 (2021)