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FLAT OPTICS: ARBITRARY WAVEFRONT CONTROL WITH PASSIVE AND ACTIVE METASURFACES

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Metaoptics offer fresh opportunities for structuring light as well as dark as well as for active control. I will discuss metasurfaces that enable light's spin and OAM to evolve, simultaneously, from one state to another along the propagation direction1,2, along with nonlocal supercell designs that demonstrate multiple independent optical functions at arbitrary large deflection angles with high efficiency.3 In one implementation the incident laser is simultaneously diffracted into Gaussian, helical and Bessel beams over a large angular range and in another one a compact wavelength-tunable external cavity laser with arbitrary beam control capabilities including hologram lasing was demonstrated. 3 2D phase and polarization singularities ("structured dark") have been realized, which open up new opportunities for the detection of point defects in transparent materials for failure mode detection.4

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.5 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. 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.6

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 showed their potential for imaging and remote sensing.6 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 free-space light with high efficiency at GHz speeds7 . 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 maximized the electro-optic response by using the high-performance electro-optic molecules of Ref. 6 and by nanoscale optimization of the optical modes. We demonstrated both DC tuning and high -speed modulation up to 5 GHz. 7

1. Ahmed H. Dorrah, Noah A. Rubin, Aun Zaidi, Michele Tamagnone & Federico Capasso Nature Photonics 15, 287 (2021)
2. Ahmed H Dorrah, Noah A Rubin, Michele Tamagnone, Aun Zaidi, & Federico Capasso Nature Communications, 12, 6249 (2021)