

Controlling light with nano-optics

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Synergistic advances in nanofabrication, computation and theoretical concepts have led to a unique opportunity for a revolution in optics. A new class of negative index metamaterials has emerged, based on metal-dielectric nanocomposites prepared using both top-down nanofabrication and bottom-up self-assembly. Unprecedented control of material structure at the nanoscale enables tailor-made optical properties in the form of real-space graded refractive index profiles, or k-space dispersion engineered refractive response. Using computation and analytic techniques, arbitrary refraction profiles can be designed, where indices can be varied spatially, or may depend on incident angle or polarization, and can be realized through advanced nanofabrication techniques. These developments have led to the emergent paradigm of nanoscale transformation optics, by which control and manipulation of wave fields is utilized to achieve a variety of revolutionary applications.

Nanoscale optical elements offer the potential of entirely new modalities of imaging with sub-wavelength resolution utilizing the phenomenon of negative refraction. Significant recent results include new types of superlenses and ultra-short focal microlenses using nanolithographic techniques in InP/InGaAsP and SOI semiconductor heterostructures at near infrared frequencies.

Controlling the speed of light, in addition to the direction, is a fundamental challenge that can lead to new physical phenomena and applications. New ideas have been proposed to stop and trap light pulses that utilize anomalous wave propagation in semiconductor heterostructure waveguides with negative index metamaterial core or cladding. These metamaterial waveguides offer the prospect of on-chip slow light devices where light speeds are reduced by orders of magnitude, enabling ultra-compact optical delay lines and buffers.

The novel electromagnetic properties of negative index materials have tremendous potential for revolutionizing optical physics and technology. Sub-wavelength resolution of the image formed by negative-index optical components has several applications in near-field imaging. The semiconducting platforms used for these devices enable their direct integration into optoelectronics. Some immediate commercial applications are integrated nano-optical platforms, optical switching devices and demultiplexers, and myriad uses in imaging, from cameras to surveillance devices to non-invasive imaging of sub-cellular biological structures. Semiconducting structures that can slow or stop light are essential for optical buffers in future optoelectronic platforms.

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