Relativistic plasma optics enabled by near-critical density nanostructured material

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The nonlinear optical properties of a plasma due to the relativistic electron motion in an intense laser field are of fundamental importance for current research and the generation of brilliant laser-driven sources of particles and photons. Yet, one of the most interesting regimes, where the frequency of the laser becomes resonant with the plasma, has remained experimentally hard to access. We overcome this limitation by utilizing ultrathin carbon nanotube foam targets allowing the strong relativistic nonlinearities at near-critical density to be exploited for the first time. We show how relativistic non-linearities in near-critical density plasmas can be used to enhance and manipulate lasers at the extreme of achievable intensities. In our case we achieve the enhancement of a laser with $2 * 10^{20}$ W/cm$^2$ by almost one order of magnitude by spatial and spectral shaping of the pulse. Moreover, we apply those superior laser pulses to substantially increase the properties of ions accelerated from a secondary target by almost a factor of 3. Our results represent a novel optical approach to manipulating lasers at highest intensities by means of relativistic nonlinear plasma optics with wide ranging applications beyond our first proof of principle possible.