Optical nonlinearity driven by hydrodynamic free electrons in semiconductor nanostructures

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The development of nanoscale nonlinear elements in photonic integrated circuits is hindered by the physical limits to the nonlinear optical response of dielectrics, which requires that the interacting waves propagate in transparent volumes for distances much longer than their wavelength. We present experimental evidence that optical nonlinearities in doped semiconductors are due to free-electron and their efficiency could exceed by several orders of magnitude that of conventional dielectric nonlinearities [1]. Our experimental findings are supported by comprehensive computational results based on the hydrodynamic modeling (see figure 1a), which naturally includes nonlocal effects, of the free-electron dynamics in heavily doped semiconductors. By studying third-harmonic generation (THG) excited with femtosecond mid-infrared pulses from plasmonic nanoantenna arrays made out of heavily n-doped InGaAs with increasing levels of free-carrier density (see figure 1b and figure 1c), we discriminate between hydrodynamic and dielectric nonlinearities. As a result, the value of maximum nonlinear efficiency as well as its spectral location can now be controlled by tuning the doping level. Having employed the common material platform InGaAs/InP that supports integrated waveguides, our findings pave the way for future exploitation of plasmonic nonlinearities in all-semiconductor photonic integrated circuits.

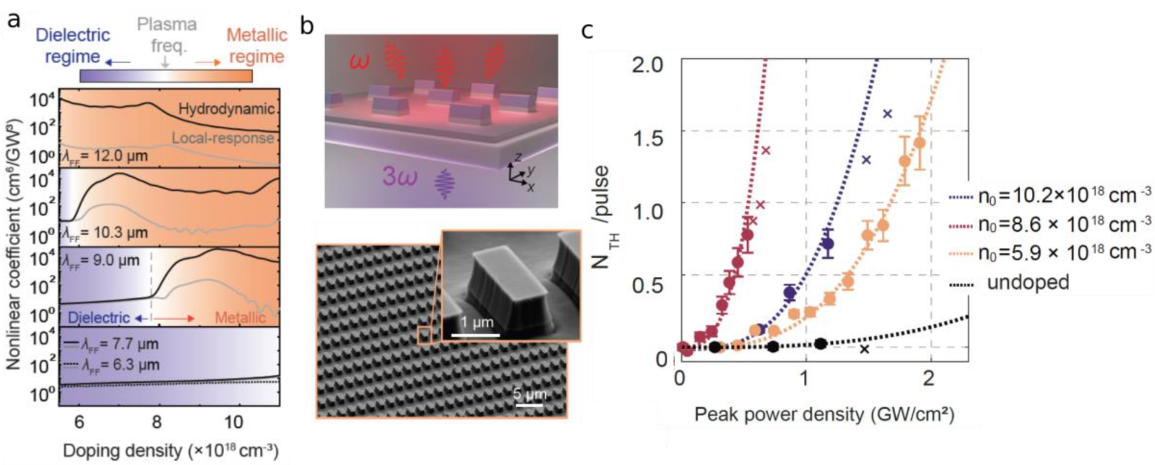

Fig.1. (a) Numerical calculations of the nonlinear optical third-order coefficient as a function of doping density of the material and at different mid-infrared pump wavelengths as used in the experiment. (b) Sketch and SEM image of the fabricated nanoantennas. (c) Peak power dependence of the THG for the different doping levels and 10.3 μm excitation wavelength. More details in Reference [1].

References

[1] A. Rossetti et al., *arXiv*:2402.15443 (2024).