Temporal Soliton Propagation and Second Harmonic Generation in Epsilon-Near-Zero Plasmonic Waveguides

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Metamaterials with near-zero-permittivity (ENZ), or equivalently plasmonic waveguides operated near their cut-off frequency, when loaded with nonlinear materials, may efficiently boost the naturally weak nonlinear optical responses. In general, they can spatially extend the nonlinearity enhancement, producing even larger efficiencies and lower power needs, with a moderate Q-factor of the associated resonance. The effects have been shown to effectively enhance the Kerr ($\chi^{(3)}$) third-order nonlinear susceptibility by several orders of magnitude (C. Argyropoulos *et al.*, *Phys. Rev. B* 85, 045129, 2012). Moreover, the Purcell factor can also be enhanced at the ENZ operation without the usual restrictions of small volumes and high Q-factor resonances. This may be interesting for future optical nanocircuits and laser designs.

Kerr optical nonlinearities may also introduce self-phase modulation at propagating optical pulses. This interesting property can potentially balance the pulses' dispersion and may lead to ultraslow guided light pulses, which can effectively propagate without dispersion and with unaffected shape for long propagation lengths. These types of ultraslow optical pulses are called temporal solitons and are widely used in telecommunications. In this presentation, we will show that nonlinear ENZ channels can also sustain efficient temporal soliton waves (slow-light) at TLC wavelengths $\lambda \simeq 1.5\mu m$, triggered by much lower input intensities compared to conventional optical fiber systems. In this case, the efficiency of optical data storage may be enhanced. These devices can be used as efficient all-optical switches, data synchronizers and robust slow-light systems.

Moreover, we will demonstrate giant second harmonic generation and frequency mixing based on the anomalous tunneling properties of ENZ ultranarrow cross-slit waveguides loaded with second-order $\chi^{(2)}$ nonlinear materials. This is due to their novel phase matching capabilities and their uniform enhanced fields inside the channels, which consist ideal conditions to achieve high second harmonic conversion efficiencies for backward and forward signals with theoretically infinite coherence length. The results can potentially lead to novel nonlinear plasmonic nanocircuit components obtained in a wide range of frequencies, such as efficient electromagnetic wave mixers and parametric amplifiers.

These devices will be demonstrated at the conference. We envision that the current work will lead one step closer to highly efficient and intriguing nonlinear electromagnetic devices at different frequency ranges.