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Parametric Amplification of Few-cycle Laser Pulses

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The amplification of intense, ultrashort laser pulses nearly four decades ago revolutionized ultrafast and strong field physics, creating many active fields of research such as femtosecond and attosecond science, and laser-based surgeries. More recently, optical parametric amplifiers (OPAs) are driving the next generation of ultrafast and intense light sources because of their phase stability, wavelength tuneability, and high pulse contrast. However, the bandwidth of OPAs is limited by the phase matching of the crystal, increasing the pulse duration. In this talk, we theoretically and experimentally investigate the amplification of few-cycle pulses by exploiting the nonlinear index of refraction, which we refer to as Kerr instability amplification (KIA).

We find that there is a modification to the phase matching condition in KIA, which leads to the possibility of single-cycle pulse amplification. As in all nonlinear effects phase matching plays a vital role in the efficiency of the process. In KIA, the frequency dependent index of refraction, the nonlinear index of refraction, the pump intensity, and the transverse momentum of the signal all determine the phase matching. For example, in our simulations in magnesium oxide (MgO), when pumped at intensities $> 10^{13}$ W/cm^2 in the near-infrared (IR), the phase matching is optimized at 4° over an octave of spectrum, allowing for the amplification of 5 fs pulses. When pumped in the short-wave IR, we calculate multi-octave amplification from $1 - 6$ μm, well-suited for ultrafast strong-field physics experiments in condensed matter.

We verify our simulations experimentally. We find compression through amplification in the case of 100 fs pulses. Using a 100 fs Ti:Sapphire laser as the pump, we amplify pulses by nearly four orders of magnitude from the visible to the infrared in a 0.5 mm MgO crystal. The amplification of these longer pulses leads to spectral broadening, and when measured with a frequency resolved optical gating setup (FROG), we find that the pulses are nearly transform limited. The experimental findings, such as resulting dispersion, amplification, tuneability, and angle dependence agree with our simulations.

Primary authors: Ms ARACHCHIGE, CJ (University of Windsor); Mr GHOSH, Sagnik (Manipal Institute of Technology); HAMMOND, TJ (University of Windsor); STEPHEN, Jake

Presenter: HAMMOND, TJ (University of Windsor)

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