65 THz beat frequency observed from a scalar modulation instability experiment

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In addition to the numerous applications for photonic crystal fibers (PCFs), their study has lead to a better understanding of nonlinear guided wave propagation. In particular, scalar modulation instability (SMI) can be described as the time domain analog of four-wave-mixing in both the anomalous and normal dispersion regimes when higher-order dispersion is taken into account. Building on previous results from wave propagation experiments with PCFs in the normal dispersion regime [1], we have observed up to 65 THz beat frequencies from the bre output of a SMI experiment. This represents, to our knowledge, the highest frequency amplitude modulated light ever observed and confirms the coherent nature of the sidebands created in a normal dispersion regime SMI process.

SMI sidebands were generated in a PCF with a zero-dispersion wavelength of 650 nm by pumping the bre with 647.1 nm light from a mode-locked cavity-dumped Krypton ion laser. The temporal width of the pump pulses was about 70 ps. As the pump wavelength was shorter than the zero-dispersion wavelength of the bre, the experiment was conducted in the normal dispersion regime. Consequently, higher-order dispersion terms (beyond b2) were necessary to understand the SMI gain. [1]

The beating of the generated anti-stokes wave with the pump wave was observed when the experiment was modified from a single pass through the PCF to include a feedback loop. The feedback loop stabilized the power and reduced the spectral width of the MI sidebands as shown in Fig. 1(a). In addition, the feedback reduced the depletion of the pump wave. These important improvements in the SMI experiment allowed us to observe the beating of the anti-stokes wave and the pump wave by a second-harmonic generation (SHG) cross-correlation technique. The interferometer was set in an autocorrelation configuration where both the anti-stokes wave and the pump wave travelled in both arms. The SHG crystal was tuned to phase-match the addition of the anti-stokes wave with the pump wave. Because of the limited bandwidth of the crystal, all other frequencies combinations were not phase-matched resulting in a background free symmetric cross-correlation. When the cross-correlation was conducted over the central region of the pump with fs resolution, we observed an amplitude modulation with a frequency of 65 THz. This corresponds extremely well to the beating of the 528.2 THz (568 nm) anti-stokes wave with the 463.6 THz (647.1 nm) pump wave.

The modulation depth in Fig 1(b) is about 30 %. Because of the differing heights and widths of the generated anti-stokes sideband and pump pulse [2], we did not expect the modulation depth to be 100 %. A modulation depth of 40 % was obtained when a symmetric cross-correlation was simulated with Gaussian pulses of 70 ps and 35 ps at the pump and anti-stokes frequencies, respectively. Due to pump depletion and bre irregularities, the measured modulation depth is well within experimental uncertainties.

In summary, we have observed an optical modulation with a period of about 15 fs by beating the anti-stokes wave and the pump wave exiting a photonic crystal bre. These results confirm the coherence of the sidebands generated by scalar modulation instability in the normal dispersion regime. Future experiments will be conducted to measure the beating of the stokes and the anti-stokes waves.

![Fig. 1](image_url)

Fig. 1 – (a) Experimentally measured spectra generated with 28 W peak pump power. (b) Measured modulation in the symmetric cross-correlation of the anti-stokes and pump waves.
