

Beyond noise, it is important to determine if an amplifier generates pre- or post-pulses. We created a post-pulse by misadjusting the timing of the second Pockels cell in the amplifier. The noise statistics for the amplifier output were 1% for fundamental and 2% for SHG signals, which implies pre- and post-pulses cannot be detected by intensity fluctuations. Fidelity measurements for fully compressed amplified pulses that have a post-pulse are shown in Fig. 5(a). Pre- or post-pulses show marked differences for positive and negative chirp and therefore a large difference in the fidelity values for positive or negative chirps. We compare the sensitivity for detecting pre- and post-pulses in an amplifier between fidelity measurements, a fast photodiode, and an oscilloscope in Fig. 5(b). We find approximately similar sensitivity for both types of measurements. The inset shows how the oscilloscope waveform of the signal looks when the second Pockels cell delay time is set to 211.5 ns. The post-pulse can be seen at ~ 10 ns. Most commercial lasers have the same amount of dispersion in the regenerative amplifier per round trip, and therefore the appearance of pre- or post-pulses occurs near positive or negative $8,000 \text{ fs}^2$, respectively.

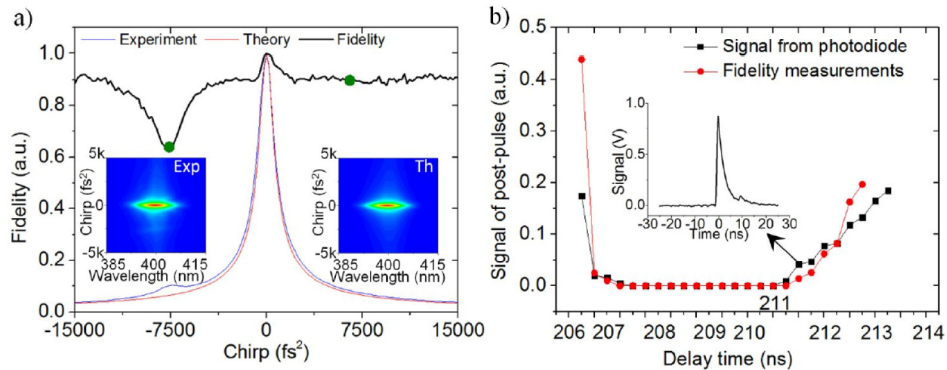


Fig. 5. Fidelity measurements of a Ti:sapphire amplifier with a post-pulse. The pair of insets in (a) shows experimental and theoretical 2D SHG chirp MIIPS scans. The fidelity parameters equal to 0.63 and 0.90 respectively (at the green dots). (b) Pre- and post-pulse detection using fidelity measurements and using a fast photodiode. The inset shows the oscilloscope waveform with post-pulse ~ 10 ns after the main pulse.

4. Conclusion

We have performed fidelity measurements to characterize the random noise present in high-repetition rate titanium sapphire femtosecond laser systems and have found that oscillators can be very quiet, with fidelity values approaching unity. On the other hand, we find that regenerative amplifiers introduce spectral phase and amplitude bandwidth noise that reduces fidelity to ~ 0.95 . By exploring situations that decrease the fidelity of the amplified output, such as opening the stretcher to air and improper adjustment of Pockels cells, we showed that autocorrelation measurements for these situations fail to detect problems in the output. We demonstrate that fidelity measurements provide a robust approach to further characterize the output of ultrafast laser sources, especially for detecting spectral amplitude and phase noise, and for amplified systems to detect pre- or post-pulses. We note that fidelity measurements are sensitive to high-order dispersion such as third order dispersion in the laser pulses. We have shown that one is able to numerically correct the MIIPS trace in order to obtain an accurate value of fidelity, even without measurement and compression of high-order dispersion [1]. While titanium sapphire lasers are very well behaved, laser sources that derive a large portion of their spectrum from self-phase modulation are more prone to spectral amplitude and phase fluctuations. We are in the process of characterizing the fidelity of such laser sources; however, our goal in this paper is to establish a benchmark based on well-understood laser systems.