A Quasi-Autocorrelation System Based on Carbon-Nanotube Saturable Absorber

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Abstract: Quasi-autocorrelation system based on carbon-nanotube saturable absorber is demonstrated at 1550nm with 75fJ pulses measured. The nanometer-level thickness and femtosecond-level decay time of nanomaterials allow compact and ultrafast light interaction for future chip-scale pulse characterization.

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Autocorrelation (AC) allows characterization of ultrashort pulses. Second harmonic generation (SHG) based AC technologies has been a great success in the last few decades [1]. Meanwhile, two-photon absorption (TPA) effect in semiconductors has also been utilized in AC measurement recently [2]. However, for SHG based AC technologies, phase-matching alignment is required to maximize the SHG efficiency. The SHG crystal is also difficult to integrate with conventional integration platforms (e.g., Si, Si_3N_4, SiO_2, InP, etc.). For TPA based AC technologies, the decay time of TPA is usually from a few tens of picosecond to nanosecond. This limits the measurement of ultrafast pulses. Integration of TPA semiconductor on insulator materials (e.g., Si_3N_4, SiO_2) is still challenging. Therefore, it is meaningful to find some novel materials which allow ultrafast light interaction with short decay time and are easy to be integrated onto various semiconductor and insulator platforms.

In this work, we demonstrate a proof-of-concept quasi-AC technology based on the power dependent transmission, i.e., saturable absorption, of carbon nanotubes (CNTs). A minimum measurable pulse energy of 75 fJ is obtained limited by the system loss. The corresponding average-power-peak-power product ($P_{av}\cdot P_{pk}$) is 5.44×10^{-7} W^2 and the measurement error is 9.0 fs. Nanometer-level thickness and femtosecond-level decay time of nanomaterials allow ultrafast light interaction in a very compact footprint. The nanomaterials can also be easily integrated on most photonic platforms. This work may pave the way to a new type of quasi-AC technology for future chip-scale pulse characterization.

The experimental setup is shown in Fig. 1(a). The system is made of fiber for alignment free. Pulses to be measured are split by a polarization beam splitter (PBS) first. One output of PBS is connected to a tunable delay line (DL) and a variable attenuator (ATT). The other output of PBS is connected to an electro-optic modulator (EOM). Two paths are combined by another PBS and the signal is fed into the CNT saturable absorber (SA). The output from CNT SA is detected by a photodetector (PD) and a lock-in amplifier (LIA). The Mach-Zehnder interferometer is made of all polarization maintaining fiber and devices to avoid residual polarization interference. The use of EOM is for the LIA measurement.

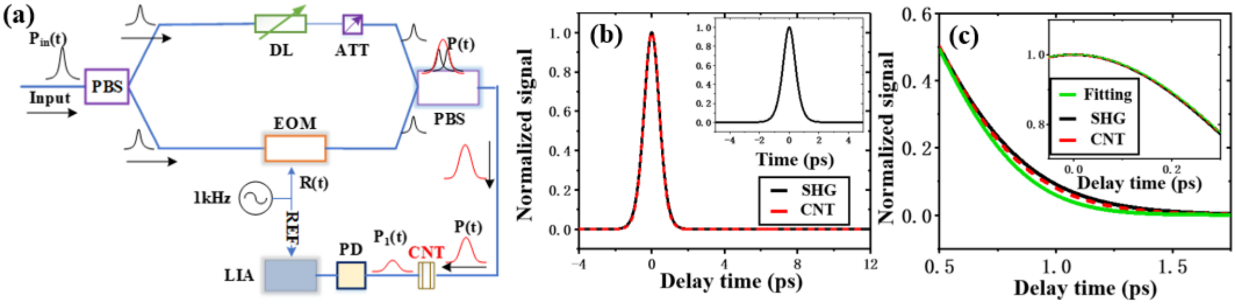

Fig.1 (a) Experimental setup. (b) AC traces based on SHG (black) and CNT (red). Inset: input soliton pulse. (c) Wing region of SHG (black) and CNT (red) based AC traces and Gaussian fit (green). Inset: peak region.

The technology is called quasi-AC technology because the measured trace of our system is not identical but very similar to an ideal AC trace. An ideal AC measurement requires the material to have a response proportional to the square of input pulse intensity, which is not satisfied by CNT SA. A simulation example is shown in Fig. 1(b). The inset is the input soliton pulse ($sech^2$). The black curves and red dashed curves are the traces generated by SHG based AC and CNT based quasi-AC technologies, respectively. It can be seen that they are very similar. A detailed view of the peak and wing regions is shown in Fig. 1(c). Indeed there is slight difference. Moreover, we fit the quasi-AC trace with a Gaussian curve in Fig. 1(c) (green curve) and obvious difference in the wing region can be observed. This means our quasi-AC technology can also separate soliton and Gaussian pulses which are commonly used in standard SHG based AC technology.

For our CNT based quasi-AC technology, the pulse widths of input pulse (τ_{in}) and measured quasi-AC trace (τ_{AC}) are related by the linear relation $\tau_{in}=\tau_{AC}/C_{con}$ where C_{con} is an conversion coefficient. For ideal AC, C_{con}=1.414 for Gaussian pulse and 1.54 for soliton. In our quasi-AC system, C_{con} is dependent on the transmission property of the nanomaterial CNT.

The experimental results are summarized in Fig. 2. Fig. 2(a) and 2(b) show the quasi-AC traces of Gaussian pulse and soliton pulse, respectively. The fitting curves match the data very well. The insets are the AC traces measured by a standard SHG autocorrelator. Fig. 2(c) shows the measured quasi-AC traces with different input pulse width. Due to the fiber dispersion, the pulse width is broadened. Fig. 2(d) shows the relation between the input pulse width (measured by a SHG autocorrelator) and the pulse width of quasi-AC traces. A linear relation of $\tau_{in}=(\tau_{AC}\text{-GDD}\cdot\Delta\lambda)/C_{con}$ is fitted where GDD is the group delay dispersion and $\Delta\lambda$=57.2 nm is the bandwidth of input pulse. For our system, C_{con}=1.217 and GDD=0.187 ps/nm.

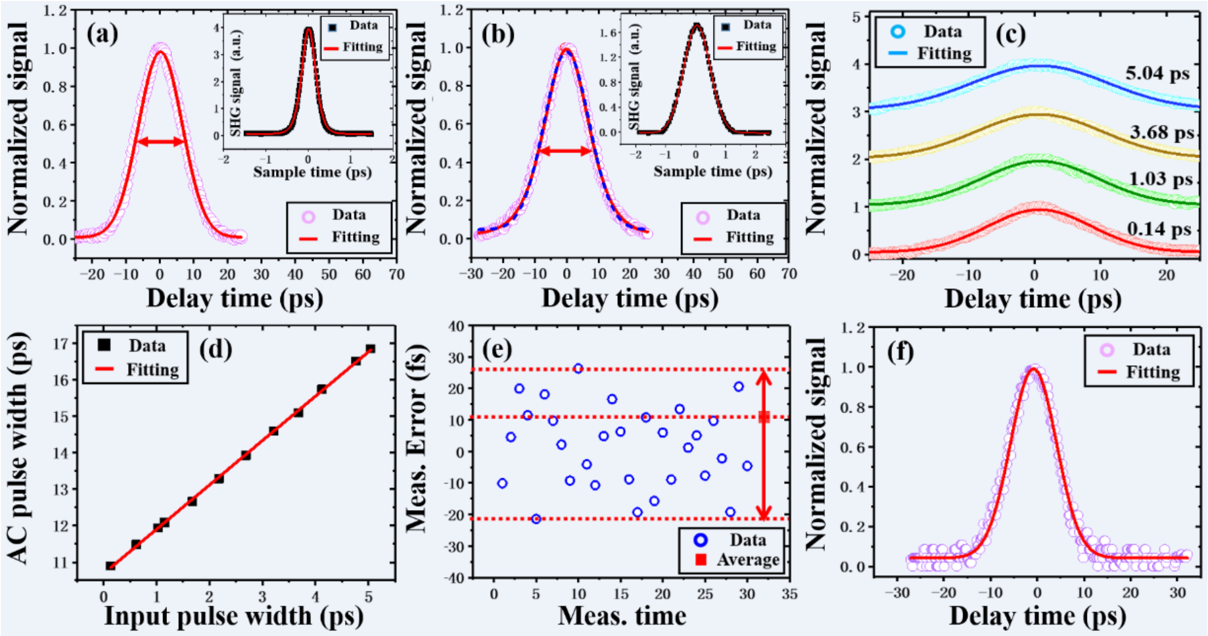

Fig.2 Quasi-AC traces for (a) Gaussian pulse and (b) soliton. Insets: SHG AC traces. (c) Quasi-AC traces with different input pulse width and (d) linear fit. (e) Measurement error over 30 measurements. (f) Quasi-AC trace at 75 fJ input pulse energy.

Fig. 2(e) summarizes 30 time of measurements to investigate the measurement error. The measurement error is compared to the pulse width obtained by SHG AC. The root-mean-square error is found to be 10.96 fs for AC pulse width and 9.0 fs for actual pulse width (by dividing C_{con}=1.217). The sensitivity of our system is also studied. A variable optical attenuator with negligible excess dispersion is inserted before the input port to adjust the input average power. Fig. 2(f) shows a typical quasi-AC trace with a minimum detectable input power of -21.26 dBm which in fact has exceeded the minimum measurable power of our SHG autocorrelator. The measured FWHM of AC pulse is 11.78 ps corresponding to an input pulse width of 895 fs. This calculated result has acceptable deviation (13.5%) in this low power condition compared with the actual input pulse width of 1 ps measured at high power with SHG autocorrelator. The corresponding single pulse energy is 75 fJ with a $P_{av}\cdot P_{pk}$ of 5.44×10^{-7} W^2.

In conclusion, we have proposed and demonstrated a quasi-autocorrelation technology by using nanomaterial based saturable absorber. In a proof-of-concept experiment with CNT SA, the quasi-AC system has a minimum measurable pulse energy of 75 fJ, an average-power-peak-power product $P_{av}\cdot P_{pk}$ of 5.44×10^{-7} W^2, and a measurement error of 9.0 fs. This work may pave a new way for AC measurement which potentially supports chip-scale ultrashort pulse characterization with high resolution.

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