[26], which indicates a few-cycle pulse with a duration of 12.8 fs (FWHM). The maximum signal-to-noise ratio of the traces is about ~700. The spectrum reconstructed by Fourier transforming the retrieved pulse temporal envelope is represented in Fig. 4(d) (black-dashed curve), which shows almost perfect agreement with the measured one (red-solid curve). Although the width of the molecular alignment gate function we used here was much longer than that of the ultrashort pulse, the result presented here strongly demonstrated that the M-XFROG could be used in such ultrashort circumstances. This was benefited from the cross-correlation essential of the M-XFROG, where the ultrashort target pulse was used to scan the relatively long molecular alignment gate. We confirmed with numerical simulations that the M-XFROG is estimated to be applied to diagnose pulse with its pulse duration not less than 3 fs at the current experimental condition. However, this value will be reduced if a shorter gate function is used in an optimized experimental condition.

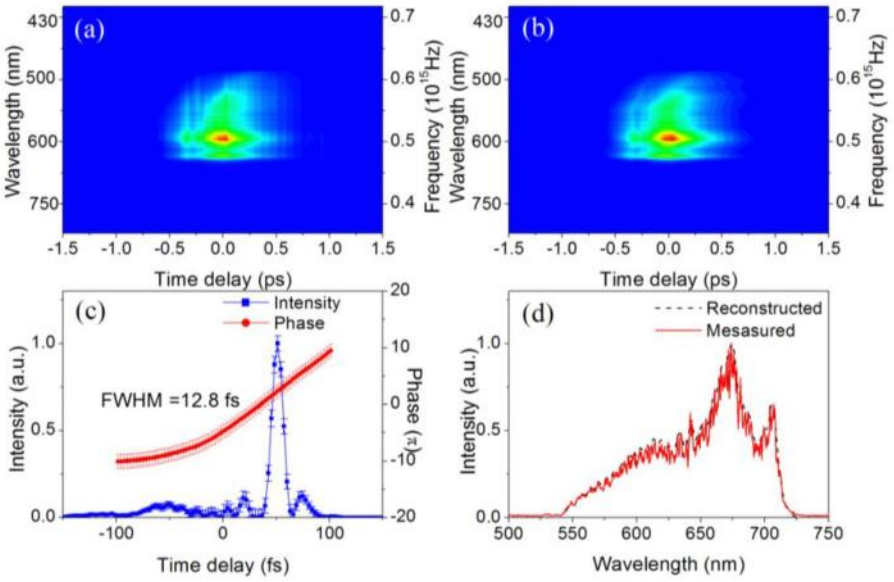

Fig. 4. (a) The measured M-XFROG trace. (b) The retrieved M-XFROG trace of the ultrashort pulse. (c) The retrieved temporal profile (blue-squared curve) and phase (red-circular curve) of the ultrashort pulse, with error bars obtained using the bootstrap method. (d) The reconstructed (black-dashed curve) and the measured (red-solid curve) spectra of the ultrashort pulse.

4. Summary

In summary, we have demonstrated that the M-XFROG could be used to fully characterize the complex SC pulse, which showed great advantages over the nonlinear frequency mixing based XFROG methods. Without the phase-matching constraint, the M-XFROG technique provides us a promising approach for SC pulse measurements, which can be readily extended for other laser pulse measurements where the low intensity or broadband spectral range that the nonlinear frequency mixing based XFROG technique is difficult to handle, such as weak pulses in the ultraviolet spectral region.

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