Non-Intrusive Sub-Two-Cycle Carrier-Envelope Stabilized Pulses Using Engineered Chirped Mirrors

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Abstract: An octave spanning carrier-envelope phase stabilized frequency comb is demonstrated using selective output coupling of the *f* and 2*f* frequency components, enabling use of the full output power of the laser.

OCIS codes: (320.7090) Ultrafast lasers; (120.5050) Phase measurement.

1. Introduction

Nonlinear *f*-to-2*f* interferometry [1] is a well established technique for carrier-envelope phase (CEP) locking of ultrashort pulse lasers. The nonlinear nature of the process requires significant optical power, and a significant portion of the laser output is typically dedicated to the interferometer so as to achieve sufficient signal to noise of the RF beat signal. While this method allows for extremely stable CEP-locking, previously resulting in jitters below 40 attoseconds, it comes at the expense of sacrificing a significant portion of the useful output of the laser.

We have developed a solution to this problem by designing specially optimized [2] double-chirped mirrors that directly out-couple just those wavelengths used in the *f*-to-2*f* scheme. We demonstrate the use of these mirrors in a ring laser. In Figure 1(a), a schematic of the demonstration ring laser [3], mirror M3 has a reflectivity profile that allows bands centered at 1140 and 570 nm to pass through at half the intracavity power, with little dispersion. These wavelengths are sent directly into a standard *f*-to-2*f* interferometer for CEP-locking [4]. The phase stabilized pulse train is output to another port using a near-brewster angle 2% output coupler created by a multilayer coating on a fused silica wedge (OC). The full output power from the laser is available for experimental use.

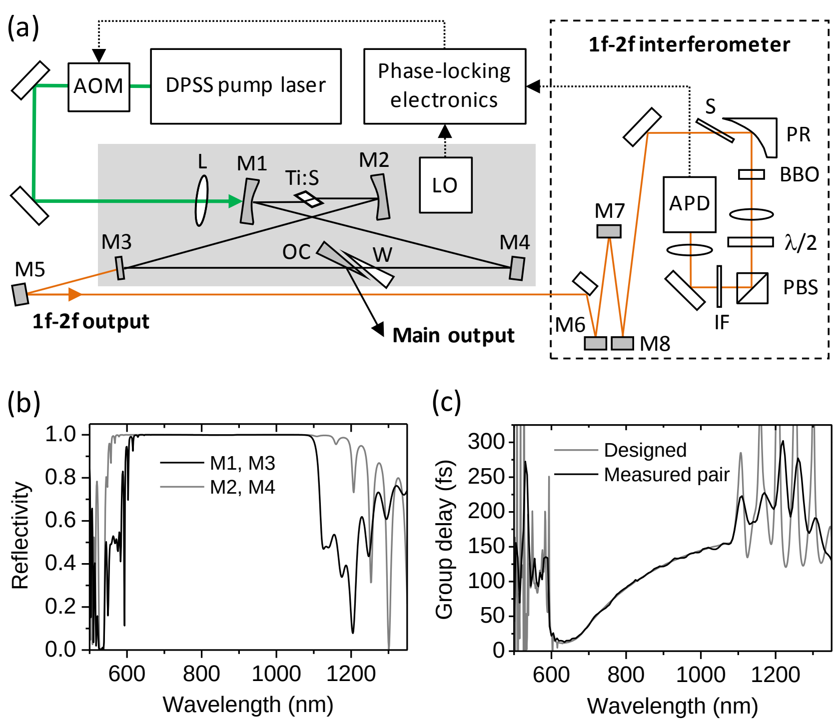

Fig. 1: (a) Schematic of ring laser and f-2f interferometer. (b) Theoretical reflecticity of double chirped mirror pair. (c) Measured and theoretical spectral group delay of DCM pair.

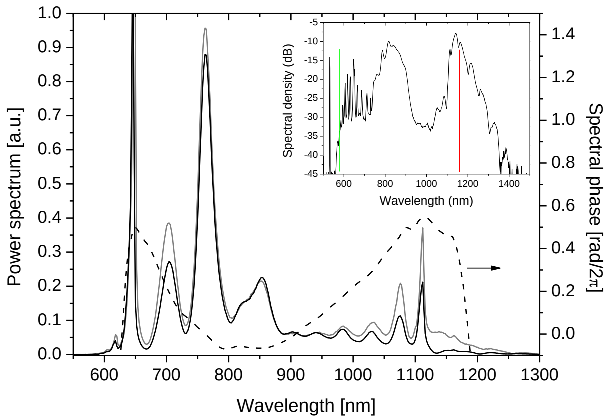

Fig. 2: Power spectral density of laser output, with extracted spectral phase overlayed. Inset: spectral density of transmitted light from M3, showing enhancement of wings.

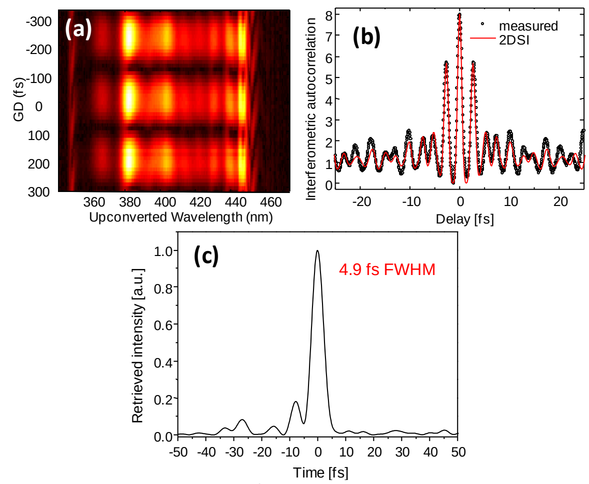

Fig. 3: (a) Raw 2DSI interferogram. (b) Measured and retrieved interferometric autocorrelations. (c) Recovered pulse intensity in the time domain.

2. Results

Modelocking is self-starting and unidirectional, and the laser generates 0.35–0.65W (depending on intracavity dispersion) when pumped with 6.5W from a DPSS laser, with an output spectrum exceeding an octave as measured on a linear scale (see Fig. 2). The oscillations in the spectrum match the residual oscillations in the GD of the double-chirped mirror pairs, as measured by a home-built white light interferometer (Fig. 1c). The oscillations are due to manufacturing errors, and will be improved in future coating runs. Second-harmonic generation in the BBO crystal generates an *f*-2*f* beat signal with ~50 dB SNR measured in a 100 kHz bandwidth directly from the avalanche photodiode output.

To confirm the generation of sub-two-cycle pulses, the pulses were characterized using both broadband SHG interferometric autocorrelation (IAC) and two-dimensional spectral shearing interferometry (2DSI) [5], which yielded the trace given in Fig. 3a. The retrieved spectral phase is shown in Fig. 2. The measured and retrieved IAC traces (Fig. 3c) exhibit very good agreement, lending credence to the measurement. The retrieved sub-two-cycle pulse (Fig. 3b) has a FWHM duration of 4.9 femtoseconds.

To estimate the phase jitter of the CEP lock, an in-loop noise measurement was performed, the results of which are shown in Fig. 4. A relatively large source of phase noise turned out to be 60 Hz interference (and its harmonics) from the power supply. The total error (including the interference) integrated from 10 KHz to 10 MHz yields a timing jitter of only 33 attoseconds.

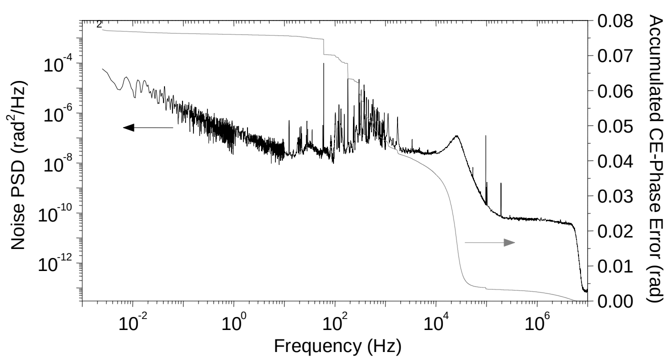

Fig. 4: Phase noise spectrum (black) and resulting integrated phase error (grey).

References

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