Radially polarized Yb-fiber MOPA producing 10 W output using SLM based pulse shaping for efficient generation of arbitrary shaped picosecond pulses

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Abstract: We demonstrate beyond 10W simultaneous temporal and spatial pulse-shaping on a picosecond fiber laser system. Our proposed technique can substantially enhance the capability and efficiency of the existing ultrashort fiber laser systems for high precision material processing.

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1. Introduction

High energy short pulse lasers are widely used for material processing in research laboratories [1, 2], as well as in industrial and military applications [3]. Fiber lasers, owing to their merits of compactness, ultrahigh optical efficiency, reliability, and easy thermal management, etc.[4], are playing an increasingly important role in this field. To pave the way for more practical applications, people are exploring the usage of different pulse shapes [5] and in the nano-second regime it is widely recognized that the ability to provide tailored temporal profiles dramatically improves the precision and efficiency of the laser-material interaction [6]. However in the picosecond regime, electronic modulators are not fast enough to shape the temporal profile presenting an unmet need for new techniques. Spatial light modulator (SLM) based pulse shapers, widely used in telecoms and in femtosecond systems have recently become available in robust fiberized format required for industrial applications and we here demonstrate the use of a so-called 'Waveshaper' (Finisar) to carve picosecond pulses with arbitrary profiles and hence providing a new dimension of control for users. We use the dispersive Fourier transform technique where a strong linear chirp creates a linear map between wavelength and time and hence shaping the spectrum directly enables us to control the time-profile of the pulses. Spatial shaping is currently an exciting avenue being explored because ring-shaped annular beams, especially in the TM_{01} mode and with radial polarization provide faster cutting and more precise marking in applications, such as Laser Assisted Oxygen cutting and they enable substantially reduced laser power requirements [7]. Considering the physical, chemical and mechanical properties of different materials or even of each individual sample, the pulse energy and pulse shape in the time domain need to be controlled precisely, which is generally a significant challenge for many laser technologies. Hence, to facilitate future efficiency gains for precision micromachining the ability to create an arbitrary pulse shape concurrently in both temporal and spatial domains is reported here, for the first time to our knowledge. We demonstrate square, stepped and multi-peaked picosecond pulses with radially polarized TM_{01} mode output and over 10W of average power.

2. Experimental setup

The master oscillator power amplifier (MOPA)–based Yb-fiber laser system was built, as shown in Figure 1.

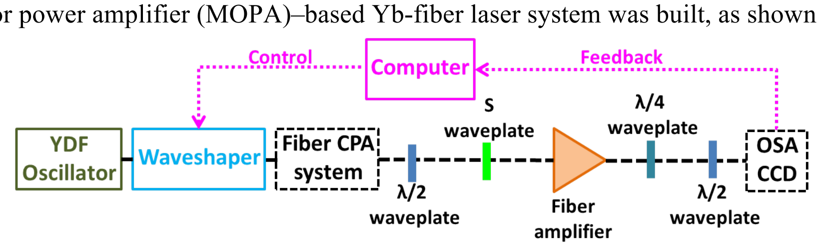
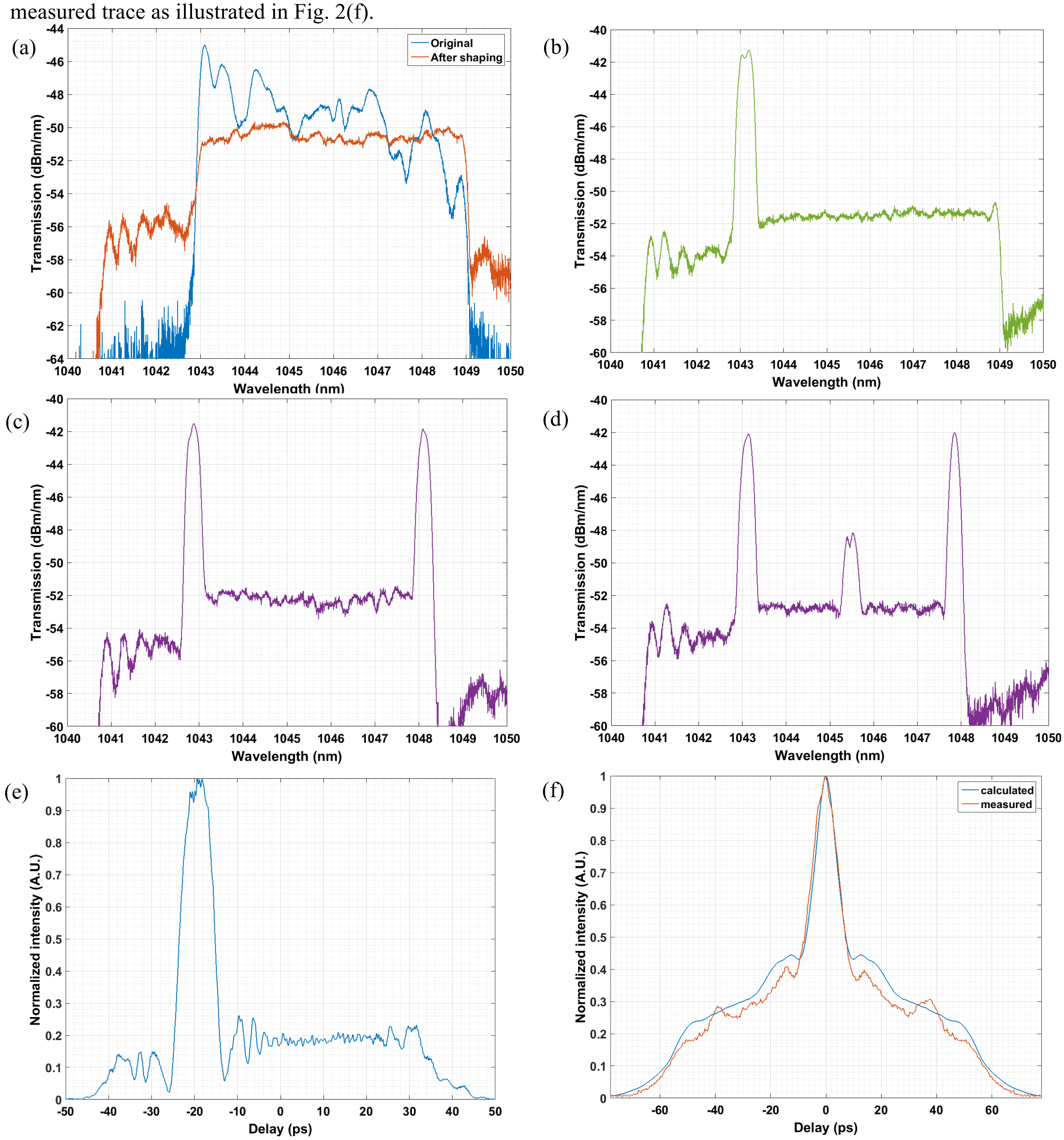


Fig. 1. Schematics of the picosecond MOPA fiber laser system.

A single-mode chirped-pulse amplification system (CPA) provides the seed, shaping and pulse stretching required at the input to the final amplifiers. We generated pulses with full-width half maximum (FWHM) pulse durations ranging from 300 fs to 60 ps, and here we have set the FWHM to be ~60ps. The wavelength to time conversion factor of the chirped-pulse output was then 1nm:10ps. A fiberized SLM-based Waveshaper was embedded in the system to control the spectral amplitude and phase. We developed our own algorithm to control the Waveshaper, which uses feedback from an optical spectrum analyzer (OSA) at the output of the system and optimizes the attenuation profile so that after some gain-shaping in the MOPA the correct target pulse shape is achieved. Finally, to convert the laser beam from a fundamental mode into a ring mode, we include a tailor made S-waveplate [8] at the input of the final amplifier stage. The TM_{01} mode is selected by tuning the waveplates in the system whilst getting feedback from the charge-coupled device (CCD) camera monitoring the final output beam.

3. Experimental results

We firstly used our optimized algorithm and generated a range of pulse shapes from the CPA system, including square pulse, step pulse, double peak energy bridge (DPEB) pulse, and triple peak energy bridge (TPEB) pulse, as shown in Fig. 2(a-d). The corresponding pulse shape in the time domain of the step-shaped spectrum in Fig. 4(b) is plotted in Fig. 2(e), and the autocorrelation trace calculated based on the pulse shape matches well with the measured trace as illustrated in Fig. 2(f).



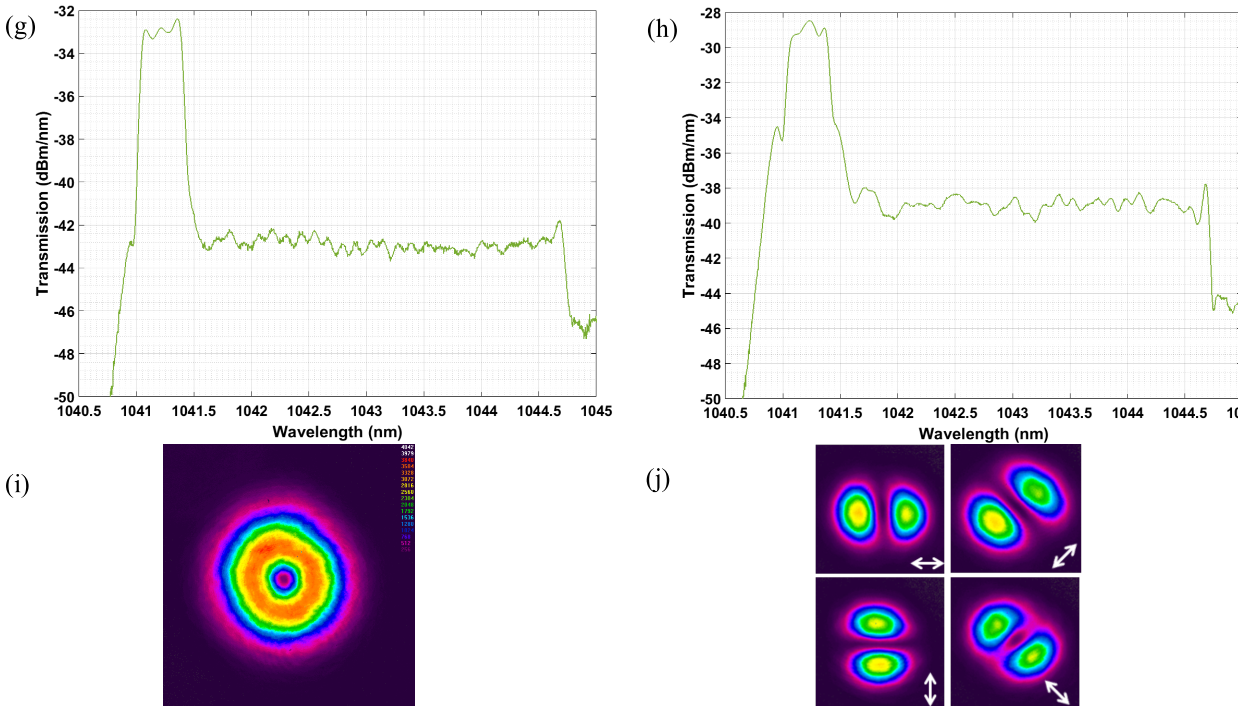


Fig. 2. Pulse shaping results in frequency domain, time domain and spatial domain (a) The spectrum before shaping and the square-shaped spectrum after shaping using the algorithm. (b) A step pulse with 10dB extinction ratio and 1:19 FWHM ratio. (c) DPEB pulse with 10dB extinction ratio and 1:18:1 FWHM ratio. (d) TPEB pulse with 10dB:5dB:10dB extinction ratio and 1:8.5:1:8.5:1 FWHM ratio. (e)The corresponding pulse shape in the time domain of the step-shaped spectrum. (f) Comparison of the measured and calculated autocorrelation traces. (g) Step pulse at the final stage with 6W output power. (h) Step pulse at the final stage with 11W output power. (i) The ring mode distribution observed from the final output beam. (j) Confirmation of the TM_{01} mode using a polarizer.

Our algorithm still performs well after the final ring mode amplifier. At average output power of 6W and 11W respectively (Fig. 2g-h), the top of the spectra are still flat with small fluctuations around 1dB. The TM01 mode profile is confirmed by observing the mode distribution using the CCD (Fig. 2(i)) and with a polarizer in front of it oriented in the direction indicated by the white arrows in Fig. 2(j).

4. Conclusions

For the first time, we have demonstrated simultaneous arbitrary pulse shaping in both temporal and spatial domains for picosecond pulses. Our algorithm is robust for picosecond laser pulses at high output power and with different transverse mode outputs. By adjusting the compressor grating separation to change the pulse duration from femtosecond to picosecond regime and increasing the pump power for the amplifiers to get higher pulse energy, our technique will be highly promising for an impressive range of fundamental science and practical laser applications. (This work was supported by the UK EPSRC under grant EP/M014029/1 (ERM) and AFOSR under grant FA9550-14-1-0382.)

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