ULTRAFAST SEMICONDUCTOR LASER DIODE SEEDED Cr:LiSAF REGENERATIVE AMPLIFIER SYSTEM

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ABSTRACT

An ultrafast modelocked semiconductor laser diode system has been used to seed a flashlamp pumped Cr:LiSAF regenerative amplifier system, producing subpicosecond pulses with millijoule output pulse energy. This system has the potential to eliminate argon ion pumped based ultrafast laser systems.

2. INTRODUCTION

Compact and efficient sources of ultrashort, high power optical pulses will play an important role in novel technologies ranging from x-ray generation for photolithography, high spatial resolution medical imaging, advanced RF photoinjectors and high speed measurement and characterization systems. In this paper, we present experimental results of an ultrafast modelocked semiconductor laser diode system which is used as an injection seed source for a flashlamp pumped Cr:LiSAF regenerative amplifier system. The combined laser system produces optical pulses of 880 fsec in duration with pulse energies of 1 mJ. The system described in this paper has the potential to replace large frame, high power ultrafast laser systems.

In the past, high power ultrafast optical pulses have been generated by employing a low power master oscillator, such as a modelocked solid state or dye laser oscillator. High pulse energies, on the order of mJ's, are then produced by incorporating an amplifying scheme, based on either multiple single pass amplifiers [1], a single multi-pass amplifier [2], or by regenerative amplification [3]. These lasers systems have assisted in pioneering many new advances in ultrafast science, however, for commercial applications, these laser systems are hindered by the necessity of large frame ion lasers for the excitation of the modelocked master oscillator. In this paper, we investigate the potential of utilizing a hybrid modelocked external cavity semiconductor laser as the injection seed source for a high power ultrafast regenerative amplifier system.

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3. EXPERIMENTAL METHOD

The experimental configuration is illustrated in Fig. 1. Ultrashort optical pulses are generated from a hybrid modelocked external cavity semiconductor diode laser system. The system generates optical pulses with temporal durations of 850 femtoseconds in duration with pulse energies on the order of 30-35 picojoules. The system consists of a GaAs/AlGaAs semiconductor traveling wave optical amplifier in an external cavity with a GaAs/AlGaAs multiple quantum well rear reflector which serves as a saturable absorber. The external cavity diode laser is excited with both d.c. currents and ~ 1 watt of r.f. current at a frequency of 274 MHz, corresponding to the longitudinal mode spacing of the external cavity, to achieve hybrid modelocking. The generated optical pulses are passed through an optical isolator and injected into a second semiconductor traveling wave optical amplifier to increase the optical pulse energy to ~ 75 picojoules. The pulses are then stretched to 120 picoseconds using a standard grating pulse stretcher and injected into another semiconductor optical amplifier to select every tenth pulse from the pulse train. This initial pulse slicing was performed prior to the main regenerative amplifier pulse slicer to reduce the diode laser system repetition rate to be compatible with the regenerative amplifier system pulse slicer. In Fig. 2(a,b), sampling oscilloscope traces are displayed, illustrating the optical pulse train before and after the semicondutor optical amplifier/pulse slicer. The contrast provided by the optical gate was measured to be greater than -23 dB. It should be noted that owing to the hybrid modelocked nature of the diode laser system, direct electrical triggering of the regenerative amplifier pulse slicer can be employed, avoiding the use of a fast photodetector to provide triggering pulses. The final pulse selection is performed by a standard Pockel's cell and injected into the regenerative amplifier, which consists of a linear cavity configuration and a pulse slicer placed at the output coupler of the regenerative amplifier system [3]. The single selected pulse is the directed to a pulse compressor and diagnostics.

The amplified single pulse along with the rejected pulse train is shown in Fig. 2(c,d). These results were obtained by injecting ~ 20-40 picojoule pulses from the diode system into the regenerative amplifier. The large depth of modulation, illustrated in Fig. 2(d), demonstrates that sufficient injection of the semiconductor optical pulse has been accomplished, while Fig. 2(c) illustrates large constrast obtained from the tandem Pockel's cell gate. Analyzing the rejected pulse train shows that ~ 55 round trips are required for the injected pulse to reach maximum gain. The single selected pulse energy was measured to be 1.5 mJ, representing a gain of over 30 million.

An additional concern regarding the use of semiconductor diode lasers as an injection seed source to the regenerative amplifier system, is the mode mismatch between the modelocked diode and the regenerative amplifier cavity. It is well known that semiconductor diode lasers possess a large degree of asymmetry in the transverse mode profile of the output optical beam. The semiconductor optical amplifier devices employed in these experiments are without exception and possess an elliptical output transverse optical beam cross section, with an ellipticity ratio of aproximately 7:1. The main resulting detrement owing to the mismatch in the transeverse mode profiles is a reduction in the coupling efficiency between the semiconductor laser oscillator and the regenerative amplifier. This reduction in the coupling efficiency results in a required increase of the injected optical power. Despite the cavity mode mismatch problem, the regenerative amplifier acts as a spatial filter and produces a clean TEM_{00} transverse model profile output beam. To quantitatively demonstrate this, in Fig. 3(a,b), are the transverse mode profiles of the modelocked semiconductor diode laser and the output of the regenerative amplifier, respectively, as measured by an optical beam profiler. The salient feature, as demonstrated by the figure, is the production of a clean TEM_{00} output beam from the regenerative amplifier when the injected optical beam posseses a large degree of transverse ellipticity, e.g., 7:1.

To demonstrate the overall temporal system performance, it is necessary to measure the minimum possible pulsewidth generated from the hybrid modelocked external cavity semiconductor diode laser system. Second order autocorrelation traces were obtained from the modelocked semiconductor diode laser when the system was configured for minimum pulse duration. In this case, the optical pulses are directed from the diode laser master oscillator/power amplifier into a dual grating dispersion compensator with an internal 1:1 telescope. This is to compensate for dispersive and nonlinear optical effects impressed on the optical pulse during the hybrid modelocking process [4]. In Fig. 4(a,b) are the second order autocorrelation trace and the corresponding optical spectrum of the dispersion compensated modelocked diode laser system, respectively. The oscilloscope traces show a deconvolved optical pulse duration of 850 fsec, assuming a sech^2 optical pulse, with a 2.4 nm bandwidth, centered at 840 nm., implying a time bandwidth product of 0.64. The sech^2 optical pulse shape was chosen for the deconvolution owing to conventional theories associated with passive and hybrid modelocked lasers. In Fig. 4(c,d) are the second order autocorrelation trace and corresponding optical spectrum obtained after the passing through the regenerative amplifier and compressor system. This figure shows a deconvolved optical pulse duration of 890 fsec with a spectral width of 2.4 nm. This demonstrates that minimal pulse distortion has occured within the amplification and compression stages.

To demonstrate the usefulness of this laser system, the amplified, compressed output optical pulses were used to generate a broadband continuum pulse via the process of self phase modulation and parametric mixing [5]. The output pulses were focused by a 15 cm singlet lens into a 2 cm cell of H_2O. The resultant continuum pulse was subsequently spatially dispersed by passing the amplified optical pulses through a prism. The resulting spatially dispersed spectrum was recorded on color photographic film to obtain a measure of the spectral width of the generated continuum pulse. Performing a detailed analysis of the generated continuum pulse showed that amplified pulse produce a broadband continuum spanning 400 nm to over 1660 nm.

4. CONCLUSIONS

In conclusion, we have demonstrated the first experiments, to our knowledge, of a femtosecond diode laser system seeding a flashlamp pumped Cr:LiSAF regenerative amplifier system, producing subpicosecond optical pulses with millijoule pulse energies. The resultant output showed that minimal temporal and spectral distortion occured during the stretching, amplification and subsequent recompression of the amplified optical pulses. In addition, the generated optical pulses were used to generate a broadband continuum pulse spanning from less than 400 nm to over 1.6 μm, which will be useful for a variety of ultrafast spectroscopic applications. It is believed that this laser system has the potential to replace ion laser based ultrafast, high power laser systems.

5. REFERENCES

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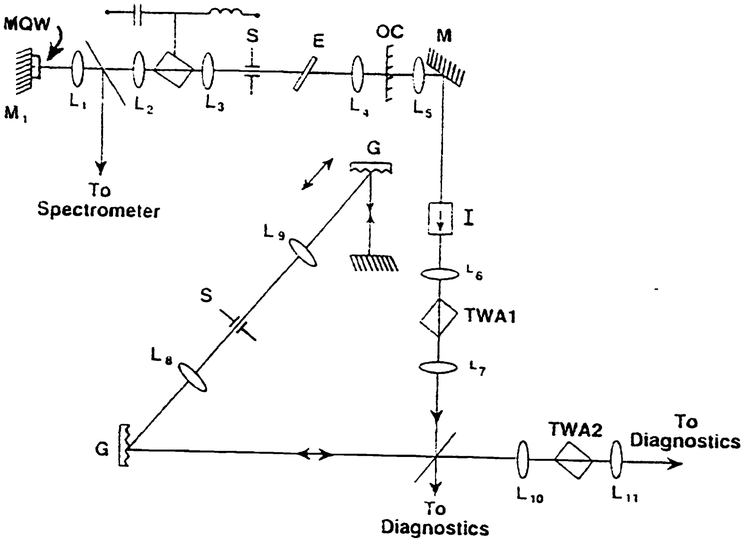
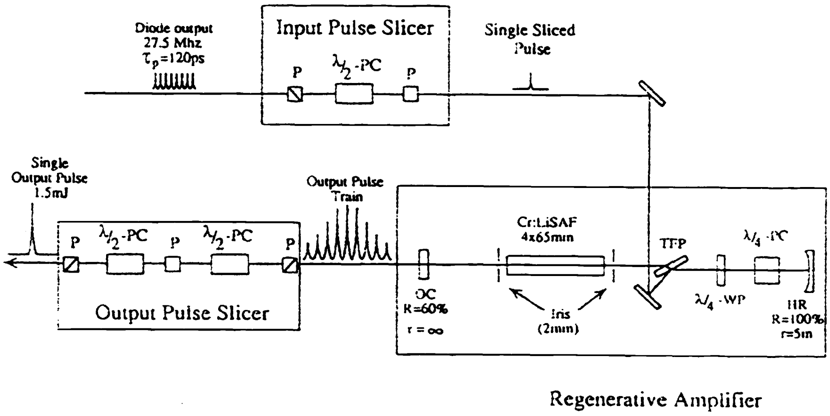


Fig. 1. Schematic of the experimental setup. Top figure: External cavity modelocked semiconductor diode laser system. Bottom figure: Regenerative amplifier system.



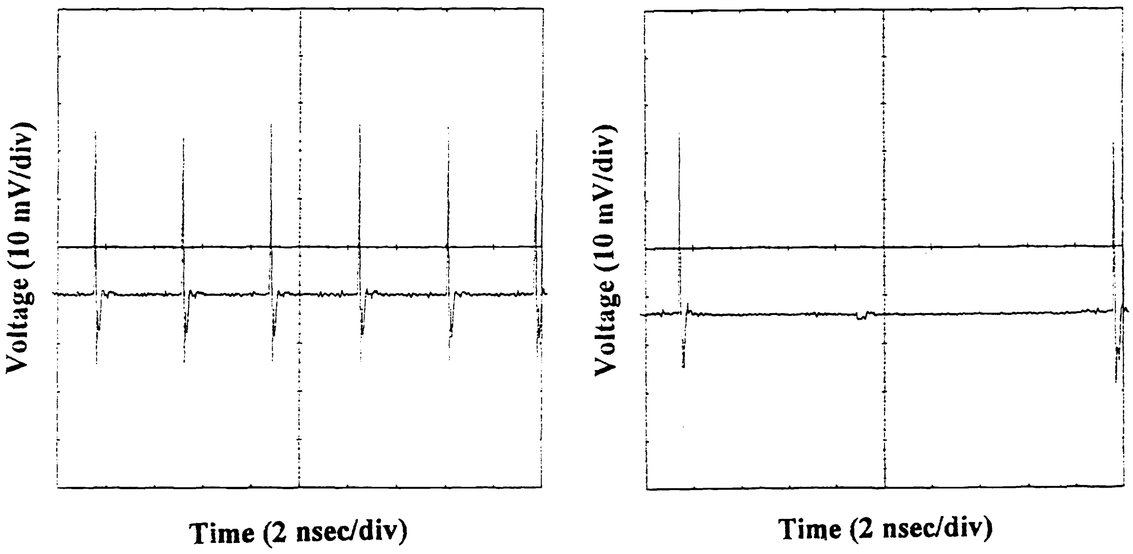


Fig. 2(a,b). Oscilloscope trace of (a) the output modelocked diode laser pulse train prior to the pre-pulse selection traveling wave amplifier, (b) after the traveling wave amplifier pulse selector.

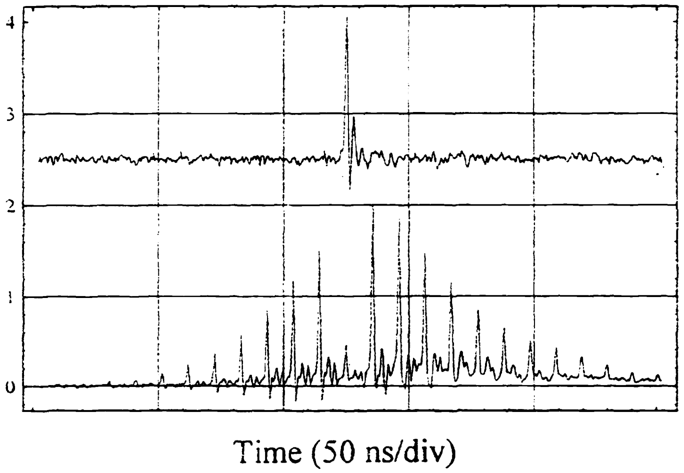


Fig. 2(c,d) Top: Oscilloscope traces of the single selected output amplified pulse. Bottom: The rejected amplified output pulse train.

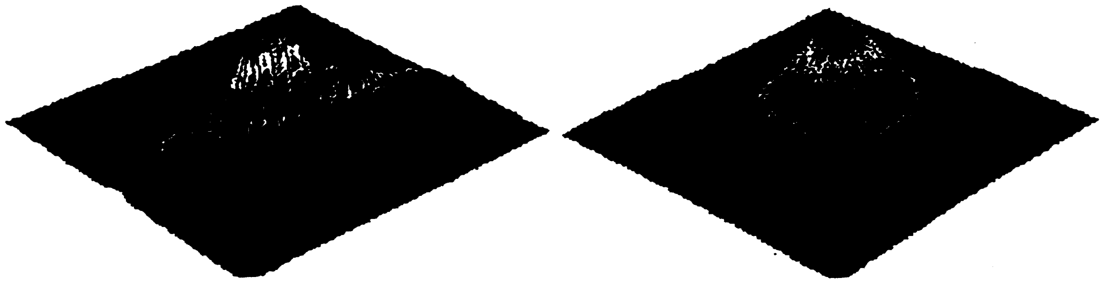


Fig. 3(a,b). Transverse mode profiles of (a) the injected diode laser beam, and (b) the regenerative amplifier output beam.

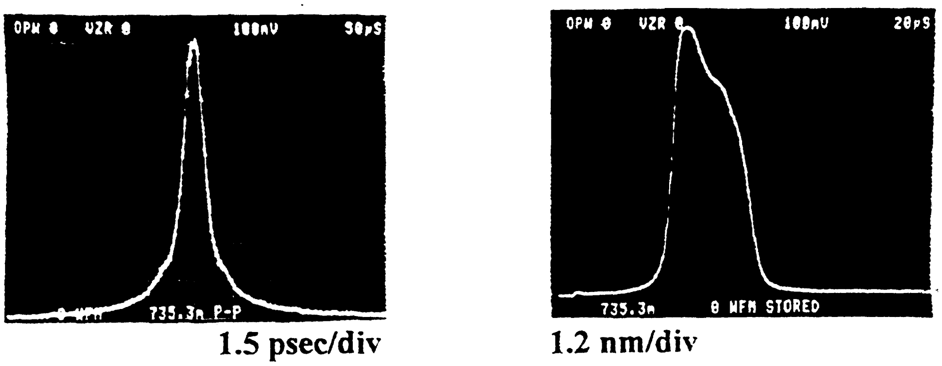


Fig. 4(a,b) Second order autocorrelation and optical spectra of the optimized modelocked semiconductor laser diode system.

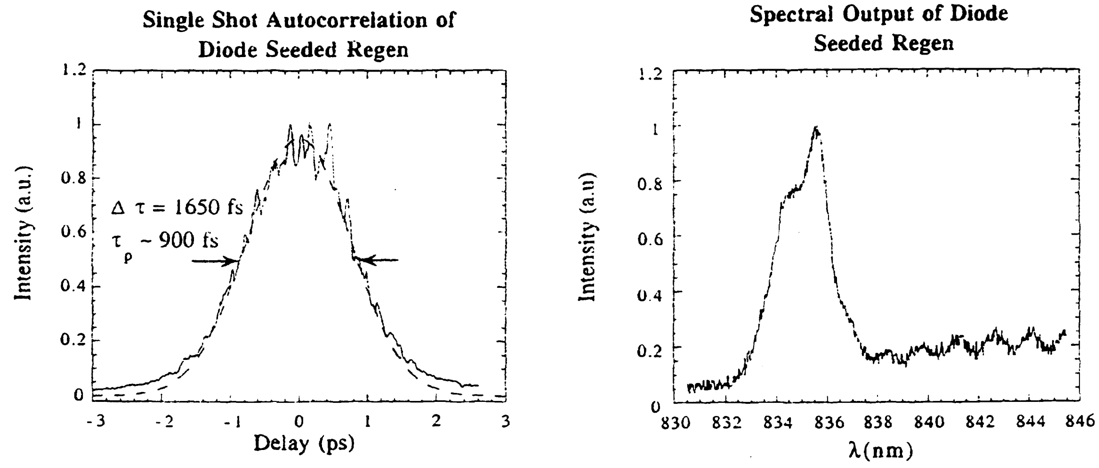


Fig. 4(c,d) Second order autocorrelation and optical spectra of the regenerative amplifier output.