Burst-Mode Ultraviolet Laser Pulses at Megawatt Peak Power in a Doubly-Resonant Enhancement Cavity

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Abstract: We demonstrate power enhancement of burst-mode UV (355 nm) laser with 50 ps pulse width and 402.5 MHz repetition rate. Peak intracavity power of >1.5 MW has been achieved for bunches with 10 μs at 10 Hz rate in a doubly-resonant optical cavity under high vacuum.

OCIS codes: (120.223) Fabry-Perot; (140.341) Laser resonators; (140.361) Lasers, ultraviolet

1. Introduction

Recently, we reported a novel technique that can effectively enhance the burst-mode pulses in a doubly-resonant enhancement cavity [1]. In this technique, auxiliary laser pulses that have a constant phase relationship to the burst-mode pulses are used to generate error signals for the cavity locking while the double resonance of the cavity is achieved by properly compensating the phase shift between two beams using an acousto-optic frequency shifter (AOFS). We experimentally demonstrated that this technique enables coherent enhancement of burst-mode laser pulses with arbitrary burst durations and repetition rates in enhancement cavities. Enhancement cavities have been routinely employed in high harmonic generation [2], THz generation [3] and x-/γ-ray generations from relativistic electron beams [4]. Following a recent success of laser-assisted charge exchange for 10 μs duration Hydrogen ion beams at the Spallation Neutron Source (SNS) [5], there is a strong motivation to develop a high-power laser with 1.0 ms duration at 60 Hz repetition rate necessary for efficient stripping of Hydrogen ion beams at full duty cycle. In this talk, we present results from our latest experiment which demonstrates a successful enhancement of UV pulses operating at 10 μs/10 Hz with peak intracavity powers exceeding 1.5 MW under high vacuum with no degradation of cavity mirror performances.

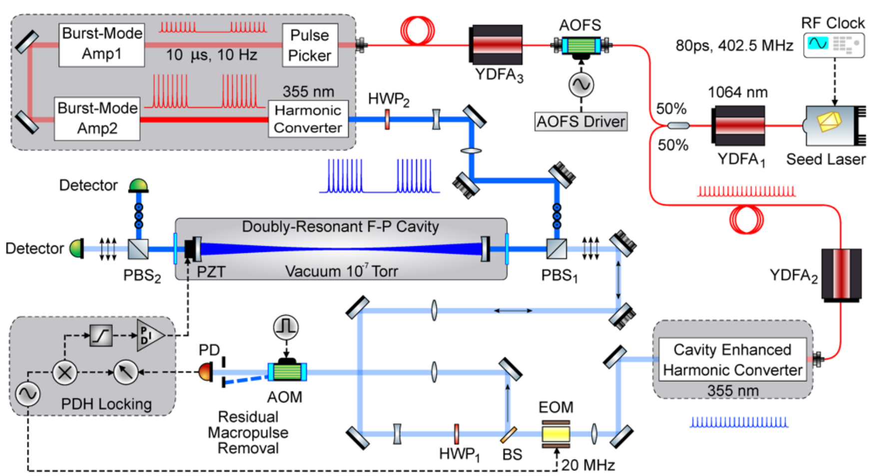

Fig. 1. Experimental setup of burst-mode Fabry-Perot cavity under high vacuum for ultraviolet pulse enhancement in a doubly-resonant configuration.

2. Experimental Results

In order to overcome the laser induced damage from high energy UV laser pulses in cavity mirrors, we chose a Fabry-Perot cavity with large mode sizes on the cavity mirrors. For our UV laser with 50-ps/402.5-MHz, we chose a cavity length of 744.8 mm with mirror radius of curvature of 372.5 mm and reflectivity of 99.5%. It would allow us to have a nominal beam waist diameter of 3.2 mm on cavity mirrors with cavity staying at the stability edge (~-0.999). The cavity is made of a stainless-steel structure to achieve a high structural stability and low thermal expansion. The entire cavity is enclosed in a vacuum chamber (10^{-7} Torr) and equipped with vibration isolation materials. Alignment of cavity mirrors and coarse tuning of cavity length are conducted by using remote controlled pico-motor actuators. The experimental setup consists of a master oscillator, a burst-mode Nd:YAG amplifier with harmonic converters, a Fabry-Perot cavity and a feedback system (Fig. 1). The detailed description of the laser and amplifier system can be found in Ref.[6]. The burst-mode UV beam is coupled into the cavity collinearly with the auxiliary UV beam by polarized beam combiner to establish double resonance. The double resonance of burst-mode and auxiliary UV beams is achieved by a two-channel fiber AOFS with a continuous frequency tuning range of 450 MHz at UV wavelength. The AOFS is driven by an external Voltage Controlled Oscillator (VCO) to produce desired frequency shift in the burst-mode beam. The cavity is locked to the auxiliary UV beam using the standard Pound-Drever-Hall (PDH) technique (Fig. 2(a)). Fig. 2(b). shows the waveform of the burst-mode UV beam transmitted from the output coupler when the cavity is locked to a TEM_{00} mode (Fig. 2(c)) with a double resonance frequency setting (Fig. 2(d)). At the double resonance condition, the peak intracavity power of the burst-mode UV pulses is estimated to be 1.5 MW for this case. At this power level, no laser-induced mirror degradation has been observed. Fig. 2(e) shows average intracavity power and corresponding normalized enhancement factor achieved at each input power. Fig. 2(f) shows a long-term stability of intracavity power over 10 minutes.

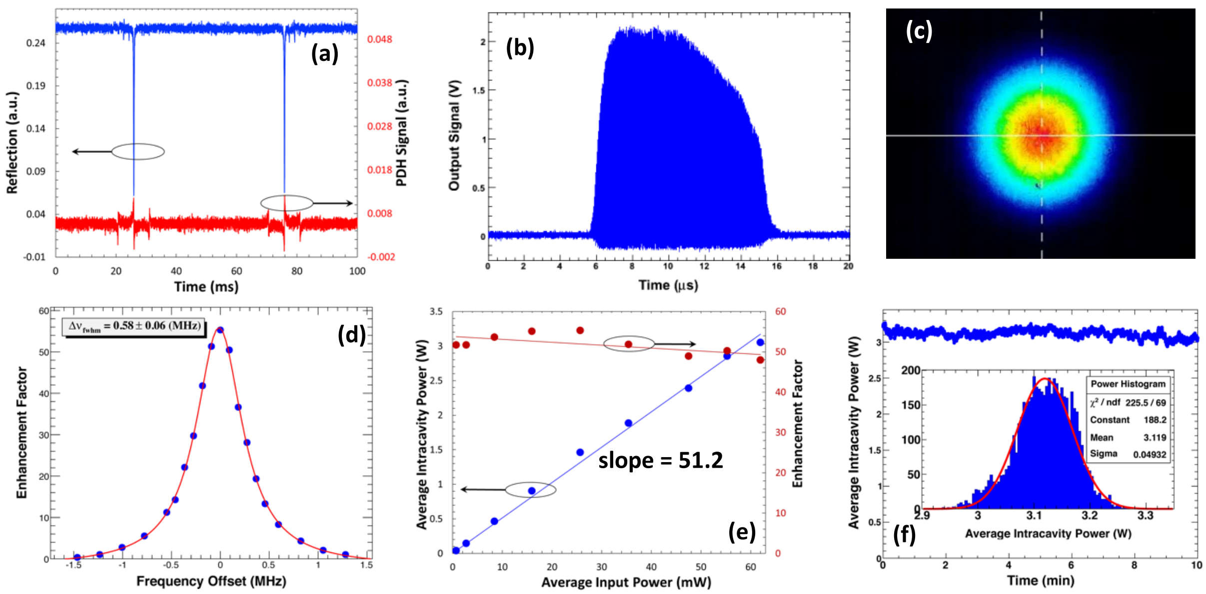

Fig. 2. (a) Reflection signal of the auxiliary beam shows >75% light coupling to the cavity when the cavity length is scanned. (b) Temporal waveform of the 10 μs burst transmitted through the output coupler when the cavity is locked in a double resonance frequency setting. (c) Spatial profile of cavity transmission with 3 W of average intracavity power (1.5 MW peak power) (d) The bandwidth (0.58 MHz) of the frequency tuning curve of cavity by AOFS allows us to estimate the finesse to be ≈350 with >60% of the burst-mode pulses being coupled to the cavity. (e) Measured intracavity power and corresponding normalized enhancement factor as a function of input power. (f) Long-term stability of intracavity power was measured over 10 minutes. Inset shows a histogram of average power measured at the end of output coupler.

3. Conclusions

We have developed a doubly-resonant enhancement cavity capable of storing megawatt peak power UV laser pulses in a burst-mode. The maximum peak intracavity power for 10 μs/10 Hz bursts is estimated to be 1.5 MW. A direct application of this technique is to achieve the necessary laser power at 1.0 ms/60 Hz required for the laser-assisted hydrogen ion stripping at full duty cycle for charge-exchange injection at the SNS.

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