Large-Mode Optical Cavity for UV Laser Power Recycling

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Abstract: A large-mode Fabry-Perot cavity has been developed for power enhancement of UV laser. Megawatt peak power has been realized inside the cavity through power recycling of 50ps/402.5MHz UV pulses operating in a 10μs/10Hz burst mode.

OCIS codes: (140.3410) Lasers resonators; (120.2230) Fabry-Perot; (140.3610) Lasers, ultraviolet.

1. Introduction

External optical cavities have been routinely used to recycle the laser beam in laser-particle interaction experiments to mitigate the laser power requirement. In many laser-particle interaction experiments including X-/γ-ray generations via inverse-Compton scattering from relativistic electrons [1] and laser-assisted ion beam stripping [2], it is often desirable that the laser be operated in a burst mode to match the temporal structure of the particle beam. Recently, we proposed a double-resonance enhancement cavity (DREC) scheme and demonstrated a locking technique to realize cavity enhancement of UV laser operating in the burst mode [3]. In this talk, we describe the design and implementation of a Fabry-Perot cavity that supports large mode size. The cavity is applied to the power enhancement of high power UV pulses. A megawatt peak power of the UV pulses is achieved inside the cavity with no laser-induced damage on cavity mirrors.

2. Optical Cavity

A critical issue in the power recycling of high power UV pulses is the laser-induced damage of the mirror coating. For 50-ps/402.5-MHz/355-nm pulses used in our recent laser-assisted ion beam stripping experiment at the Spallation Neutron Source (SNS), the experimental investigation indicated that the laser induced damage threshold is around 100 MW/cm^2. For 1 MW peak power UV pulses, the spot size on the mirror surface needs to be larger than 2 mm to avoid laser-induced damage on the mirror surface. For this purpose, a Fabry-Perot cavity that enables large mode size has been studied. Two features have been considered in the design to maximize the mode size: 1) the free spectral range of the cavity is set at a sub-harmonic of the laser pulse repetition rate and 2) the radius of curvature (ROC) of the cavity mirror is carefully chosen so that the cavity is operating at a near-concentric configuration. In the present setup, the cavity length is 744.8 mm and the ROC of the cavity mirror is around 372.5 mm. The resulting beam size on the mirror surface exceeds 2 mm in diameter. The cavity finesse is measured to be around 450 with the current reflection coating. As the cavity parameters are in very close proximity of the stability boundary ($|g| > 0.99$), special attentions are given to the structure of cavity body, mechanical stability, and cavity tuning. The cavity mirrors were assembled on a stainless-steel platform that was designed to have a high structural stability and low thermal expansion. The cavity platform is positioned in a customized vacuum chamber with vibration isolation from all directions. Alignment of cavity mirrors and coarse tuning of cavity length are conducted by using pico-motor actuators. All motion control can be performed in a vacuum level of 10^{-6} - 10^{-7} Torr.

The experiment on power recycling of the burst-mode UV laser has been conducted in the SNS laser lab using the customized seed laser and a 10-μs macropulse amplifier. The experimental setup is shown in Fig. 1. The seeder is an in-house-built 80-ps/402.5-MHz fiber-based laser source operating at 1064 nm [4]. The narrow linewidth of the seeder is especially favorable for power recycling in optical cavity. The seeder output is split into two optical amplification paths for generation of two different modes of pulsed beams, both at the wavelength of 355 nm. In the first amplification path, a ytterbium-doped fiber amplifier (YDFA) followed by a cavity-enhanced harmonic converter generates a continuous-mode UV pulses at 50 ps/402.5 MHz, which is used to lock the optical cavity based on a Pound-Drever-Hall (PDH) locking scheme. In the second amplification path, macropulse amplifiers and their subsequent harmonic conversion crystals will generate burst-mode UV pulses with adjustable macropulse width. In the present experiment, the macropulse width is 10 μs and the repetition rate is 10 Hz. Both the continuous-mode and the burst-mode UV pulses are coupled into the DREC through a polarization beam splitter. An acousto-optic frequency shifter (AOFS) is used to adjust the frequency difference between the burst-mode and continuous-mode UV beams.

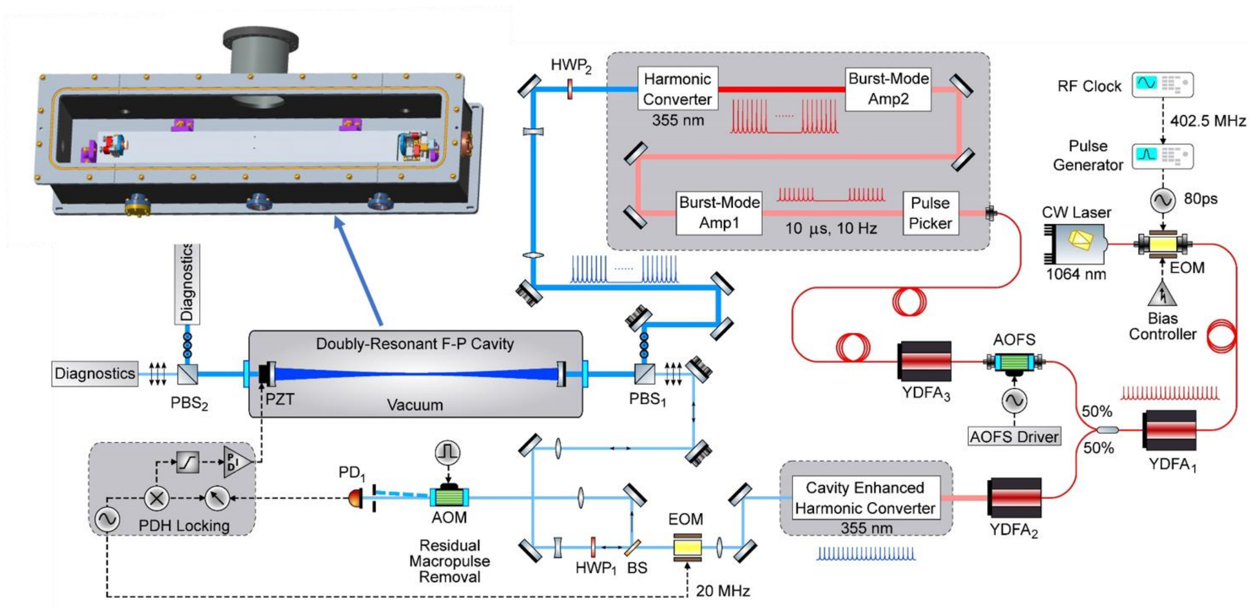

Fig. 1. Experimental setup of double-resonant Fabry-Perot cavity for power recycling of burst-mode UV laser pulses. Inset picture: assembly of the optical cavity platform in the vacuum chamber.

3. Experimental Results

The cavity is locked to the continuous-mode UV beam with a PDH locking scheme. When the cavity is locked, the frequency of the burst-mode UV beam is tuned with the AOFS to achieve its resonance to the cavity. Fig. 2 shows the waveform of the burst-mode UV beam transmitted from the optical cavity. At the double resonance condition, the peak power of the burst-mode UV pulses is measured to be 1.05 MW. At this power level, no laser-induced mirror coating damage has been identified. The estimated cavity enhancement factor is close to 100. The cavity lock is very robust against vibration and ambient noise. This experiment demonstrated that the DREC can be used to recycle burst-mode picosecond UV pulses with MW peak power required for the laser stripping of hydrogen ion beams [2].

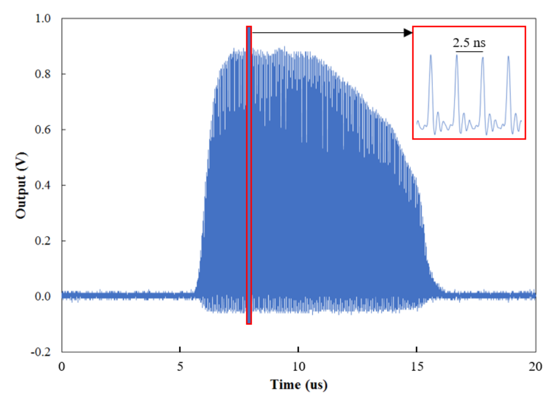

Fig. 2 Macropulse waveform of transmitted UV beam from the DREC. The micro-pulse width is measured to be 50 - 55 ps.

4. Conclusion

We have described the development of large-mode optical cavity and it locking to a burst-mode UV laser. A power enhancement of burst-mode picosecond UV pulses with megawatt peak power has been demonstrated.

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