Diode-pumped single-frequency UV laser for wind doppler lidar

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A direct-detection Doppler lidar system offers improved features for measuring wind velocity.

Doppler lidar (light detection and ranging) is a useful technique for remote measurement of atmospheric wind profiles. For assessing global wind profiles, the direct-detection Doppler method has an advantage over coherent Doppler lidar in that it can use both the aerosol and molecular backscattered signal. But measuring wind velocity using direct detection Doppler in a lidar system places special demands on the frequency characteristics of the pulsed laser transmitter in terms of stability and spectral purity. The standard means of achieving this is to seed a high-power pulsed oscillator with a frequency-stable continuous-wave (CW) seed laser.

A critical element of the injection seeding system requires adjusting the length of the pulsed oscillator to stay in resonance with the seeded laser. Two techniques have been developed to achieve highly stable frequency output without mode jumping. One is minimized buildup time, which involves monitoring the buildup time of the Q-switched output pulse for each shot and then minimizing that time by feedback-loop-controlled changes of the cavity length. The other is so-called ramp-hold-fire: the length of the pulsed laser cavity is rapidly altered until a resonance with the seed laser is optically detected and the pulsed laser is fired. We have developed a compact diode-pumped single-frequency UV laser that incorporates these two cavity-control methods. Here we describe the ramp-hold-fire approach (see Figure 1). A detailed account of the laser system using the buildup time approach has been published elsewhere.

The first step is to develop a single-frequency oscillator, which is a diode-pumped injection-seeded Nd:YAG (neodymium yttrium aluminum garnet) laser. The electro-optic Q-switched oscillator is designed to decrease sensitivity to misalignment from thermal and vibration effects. As a passive resonator, the two mirrors build up an unstable resonator. But pumping of the gain medium by diode arrays makes the configuration thermally stable: the diverging properties of the concave mirror are counteracted by the focusing action of the laser rod. Partial compensation of the thermal lens by the concave mirror makes a large mode volume possible. Two 1/4 wave plates are set at both sides of the laser rod to eliminate spatial hole burning. The laser rod is uniformly side-pumped from nine directions at identical angles. Nine laser-diode arrays arranged symmetrically around the Nd:YAG rod work to optimize the uniformity and radial profile of the pump distribution within the gain medium. Moreover, good spatial overlap between the pump radiation and the low-order modes in the resonator lead, in turn, to high-brightness laser output.

The pulsed oscillator is seeded through the high reflector end of the laser cavity. The high reflector mount is mechanically connected to a piezoelectric driven assembly that modulates the cavity. The seeder laser is a Mephisto OEM200 CW NPRO Nd:YAG laser manufactured by Innolight. The ramp-hold-fire method obtains over 38mJ per pulse in TEM00 mode at 100Hz with a stable single frequency. The energy jitter is ±5%, M2x, and M2y, measured by a Spiricon M2-200 beam-propagation analyzer, are 1.4 and 1.45, respectively (see Figure 2). The pulse width is ~17ns.

The laser is then configured as a master oscillator power amplifier (MOPA). The output from the oscillator is single-way

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amplified. The amplifier is designed to compensate for thermally induced birefringence. The amplifier contains 45 bars of laser diodes, with a peak power of 100W from each diode array, for side pumping the Nd:YAG crystal. The Nd:YAG crystal is a 75mm-long rod crystal, 5mm in diameter. The pumping structure is similar to that of the laser head. The amplifier is set to operate at a pulse duration of 220µs and a repetition rate of 100Hz. When the oscillator energy is 30mJ and the pump energy is 841.5mJ, 108.4mJ output energy is obtained. The amplification factor is \( \sim 3.6 \).

We use sum-frequency generation to realize a 355nm laser, which is straightforward to explain. Laser beams at two frequencies \( \omega_1 \) and \( \omega_2 \), interact in a nonlinear crystal and generate nonlinear polarization \( \omega_3 = \omega_1 + \omega_2 \). Second harmonic generation results from summing two input frequencies that are the same. Third harmonic generation is the outcome of mixing the first and second harmonics. In our system, this frequency tripling is obtained using type-II potassium tytanyl phosphate (KTP) and type-I \( \beta \)-barium borate (BBO) crystals. The BBO crystal has a small acceptance angle, and a concave mirror is used to compensate the thermal lens of the amplifier. After compensation, \( M_{2x} \) and \( M_{2y} \) measure 1.42 and 1.40, respectively (see Figure 3), and the divergence of the two directions is 0.663mrad and 0.666mrad. The 355nm UV laser operating at a single frequency yields \( \sim 25.5 \) mJ.

This diode-pumped single-frequency UV Nd:YAG laser has been applied in a mobile direct-detection Doppler lidar system for measuring wind velocity profiles. It also provides data that is fundamental in understanding mesoscale dynamic processes, transport, and exchange in the atmosphere. We plan next to investigate a higher-repetition-rate (1KHz) single-frequency UV laser system with narrower linewidth and even better frequency stability.

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References