Single-Frequency CW Sum-Frequency Generation at 589 nm for Sodium Guidestar Excitation

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We report on the laser design, development, and operational tests of a 50-watt, continuous-wave, single-frequency, 589-nm laser based on a doubly resonant sum-frequency ring containing LBO pumped by 1064nm and 1319nm continuous-wave Nd:YAG injection-locked lasers.

Atmospheric turbulence distorts light waves received from space objects and severely limits the image quality of large ground-based telescopes. These distortions can be corrected in real time using adaptive optics, where the measured wave front of light waves received from a bright 'guide' star is used to adjust the surface of a thin flexible mirror within the beam path of the telescope. Adaptive optics using natural guidestars has severe limitations, since the guidestar must be bright and very close in viewing angle to the object to be imaged. To increase this limited sky coverage, laser-generated guidestars are created. The most widely accepted method uses a laser tuned to the sodium D_{2a} line to excite sodium atoms in a 10-km thick mesospheric layer with an average altitude of 92 km. Figure 1 shows a time-elapsd photograph of a 10-W beam from our previously tested 20-watt sodium guidestar excitation source projected into the night sky. The beam is highly visible due to Rayleigh backscatter, which decreases in intensity as the beam exits the atmosphere. The laser must generate a guidestar of sufficient brightness that the photon return is sufficient for the wave-front sensor at the required frame rate. Various spectral and temporal formats for the laser source have been studied and shown to have a significant effect on the photon return [1].

In 2002 we demonstrated the operation of a doubly resonant sum-frequency generation (SFG) ring containing a lithium triborate (LBO) crystal, pumped by 1064-nm and 1319-nm continuous-wave Nd:YAG injection-locked ring lasers, producing a 20-W diffraction-limited, single-frequency, 589-nm beam [2]. This excitation source was used for guidestar sky tests during 2002-2003 at the Starfire Optical Range at Kirtland AFB, NM [3]. Concurrently, we began the design and development of a 50-W facility-class guidestar laser system for mounting directly on the Starfire Optical Range 3.5-m telescope in late summer of 2004, as depicted in Fig. 2. [4]. The laser is to be mounted to and rotate with the azimuthal base of the telescope. The optics and lasers are contained in a 60 cm x 180 cm x 25 cm high hermetically sealed enclosure. The beam exits the box vertically through a window and is expanded to 20-cm diameter with a refractive beam expander telescope and projected into the sky from a mirror attached to the elevation axis of the telescope mount. The beam is 3.1 m from the optical axis of the telescope, a distance chosen to permit blocking Rayleigh scatter with a field stop without serious performance degradation due to off-axis viewing of the guidestar. A computer is used to monitor and control the laser parameters such as wavelength, polarization, power, injection-locking status of the power oscillators and sum-frequency generator and maintenance of lock to the sodium D_{2a} resonance. A unique feature being designed into the control system is the ability to rapidly switch on and off the sodium D_{2a} peak at constant power as a means to subtract any residual Rayleigh backscatter background from the wavefront sensor. Three short racks of electronics are also mounted on the azimuthal base of the telescope. Water chiller and laser diode power supplies are mounted off gimbal under the dome floor.

A natural coincidence produces sodium resonance radiation at 589 nm by sum-frequency generation of the Nd:YAG laser lines at 1064 nm and 1319 nm. A conceptual block diagram for the laser system is illustrated in Fig. 4 using the theoretical power levels required to generate 50 watts at 589 nm. The power ring oscillators developed for our 50 W 589-nm source have produced nearly 80 W at 1064 nm and 50 W at 1319 nm; clearly designed with a good level of overhead. Both lasers operate with a TEM₀₀ mode and linear polarization. The SFG takes place in a 20x5x5 mm LBO crystal with noncritical type-I phase matching at a temperature of approximately 40 C [5]. The SFG cavity is made simultaneously resonant with single longitudinal modes of the pump and signal lasers by the Pound-Drever-Hall locking technique. A piezoelectric actuator adjusts the position of a cavity mirror to lock the SFG cavity to the 1319-nm laser, while the frequency of the 1064-nm laser is adjusted by temperature tuning its master oscillator to

Fig. 1. Photograph of a sodium guidestar created through resonant pumping of the roughly 10-km-thick layer of atomic sodium in the mesosphere at about 90-km altitude.

Fig. 2. Illustration showing 50-watt facility-class sodium guidestar excitation source mounted to the Starfire Optical Range 3.5-m telescope.

make it resonant with the SFG cavity, and then locked using the master oscillator internal piezoelectric actuator. Sodium resonance is assured by tuning the wavelength to the D_{2a} Doppler-free absorption line at 589.159 nm using a sodium vapor cell or a high-resolution wavemeter. The cw guidestar was observed in the mesospheric sodium layer with a 3.5-m diameter reflecting telescope, using a calibrated photometric camera and photomultiplier tube. Using our 20-watt guidestar excitation source, sky tests during March 2003 using only 12 W of circularly polarized laser power on the sky (limited due to beam projection throughput) produced a guidestar magnitude of 7.1, corresponding to a return of 1015 photons/cm²/s.

Our presentation will discuss laser design, performance results, and the development progress toward our facility-class, 50-W, continuous-wave guidestar laser system.

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Fig. 3. Three racks of support electronics to be mounted to the azimuthal base of the telescope (left) and the completed 80-watt 1064 nm injection-locked laser (right) taking up one-third of the 589-nm laser box.

Fig. 4. Block diagram showing four major functional components of the 50-watt cw single-frequency 589-nm laser system.