Tunable single-frequency yellow laser for sodium guidestar applications

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A vertical external-cavity surface-emitting laser designed to operate around 1178nm is persuaded to generate high-output single frequency at 589nm.

High-power single-frequency laser sources operating in the 570–590nm range are of great interest in many applications, such as quantum computing, medical flow cytometers, and specifically sodium guidestar lasers. Earth-based telescopes are limited in their resolution of distant objects by the effects of atmospheric turbulence caused by a varying refractive index of the atmosphere. A system using adaptive optics senses and corrects for atmospheric aberrations to achieve better resolution. One technique for doing this is to use a laser guidestar to create a reference anywhere in the sky by induced resonance fluorescence of atomic sodium in the mesosphere. Even though there is a need for single-frequency lasers in this yellow-orange range, development has been limited, largely due to a lack of gain materials. We have designed a vertical external-cavity surface-emitting laser (VECSEL) to produce the desired 589nm output corresponding to the sodium D2 line needed for sodium guidestar applications.

Vertical external-cavity surface-emitting lasers are capable of providing powerful output with excellent beam quality in a simple, compact, and robust device setup. The semiconductor quantum wells can be designed for a wide range of operating wavelengths (670nm–2.4 μm) that are difficult to access with other laser concepts, making the VECSEL a flexible laser source. By taking advantage of the open cavity configuration of the device, frequency-selective elements and nonlinear optical components can be employed to generate high-power single-frequency output at a desired wavelength. Therefore, a VECSEL based on strained multi-quantum wells combined with intracavity frequency conversion is an excellent solution for the yellow-orange regime.

Figure 1. Cavity design for intracavity frequency doubling of the 1178nm vertical external-cavity surface-emitting laser (VECSEL). A distributed Bragg reflector (DBR) and multi-quantum-well (MQW) stack form one end of the cavity. Folding the cavity enables placement of the lithium triborate crystal (LBO) at the beam waist for maximum conversion efficiency. The highly reflective (HR) flat end mirror allows all 589nm output to be extracted from the curved fold mirror.

To generate the fundamental 1178nm wavelength, and the frequency-doubled 589nm yellow laser, we used the folded cavity configuration shown in Figure 1. The VECSEL chip consists of highly strained indium gallium arsenide multi-quantum wells with peak gain around 1175nm, surrounded by gallium arsenide phosphide strain compensation layers and gallium arsenide barriers. The VECSEL chip also includes a high-reflectivity distributed Bragg reflector stack on the top of the active region to form one end of the external cavity. A highly reflective curved mirror is used as a fold, and a flat mirror completes the cavity. Thermal management is achieved by water-cooling the device, which is mounted on a chemical vapor deposition diamond heat sink.

To achieve narrow-linewidth single-frequency operation and wavelength tuning for the second harmonic, we used a combination of a 1mm-thick intracavity birefringent filter (BF) inserted at Brewster’s angle and a low-finesse 150 μm-thick...
Figure 2. Measured single-frequency linewidth of the fundamental frequency at 1178nm using a scanning Fabry-Pérot interferometer. A resolution-limited measurement at full width half-maximum (FWHM) of 10MHz was obtained.

Figure 3. Plot of yellow output power versus net pump power. A maximum output of 4.11W at 589.991nm corresponding to the sodium D2 line.

Fabry-Pérot (FP) etalon. This combination of low-loss filters allowed us to achieve single-frequency operation with a fundamental linewidth narrower than 10MHz (see Figure 2).

We used an intracavity lithium triborate nonlinear crystal to generate the second harmonic frequency. By rotating both the BF and the FP etalon, we were able to tune the frequency of the laser around the desired output wavelength of 589nm. With the VECSEL tuned to the sodium D2 line of 588.991nm, we measured the maximum output power to be 4.11W. Figure 3 shows the yellow output power reaching 4.11W with a slope efficiency of ~16%.

With the single-frequency tunable yellow source, we measured the power transmission through a sodium reference cell. Figure 4 shows that by tuning the wavelength, we were able to measure dips in transmission at 588.991 and 589.595nm corresponding to the sodium D2 and D1 lines, respectively. We were still able to measure 10% dips in transmission at the spectral line locations, despite the system suffering from vibrations from the thermal management system as well as air movement from the uncovered setup.

In conclusion, we have developed and demonstrated a high-power tunable single-frequency VECSEL operating around 589nm with a fundamental linewidth less than 10MHz. Using two intracavity frequency selective elements, we can tune across and measure the sodium D2 and D1 lines, showing that the VECSEL is a viable source for applications such as sodium guidestar lasers. By further refining our setup with active linewidth stabilization, we should be able to further reduce the linewidth and refine the measurements through the sodium reference cell.

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Continued on next page
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References