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An Ultra-Coherent Monolithic-Cavity VECSEL

RESEARCHERS

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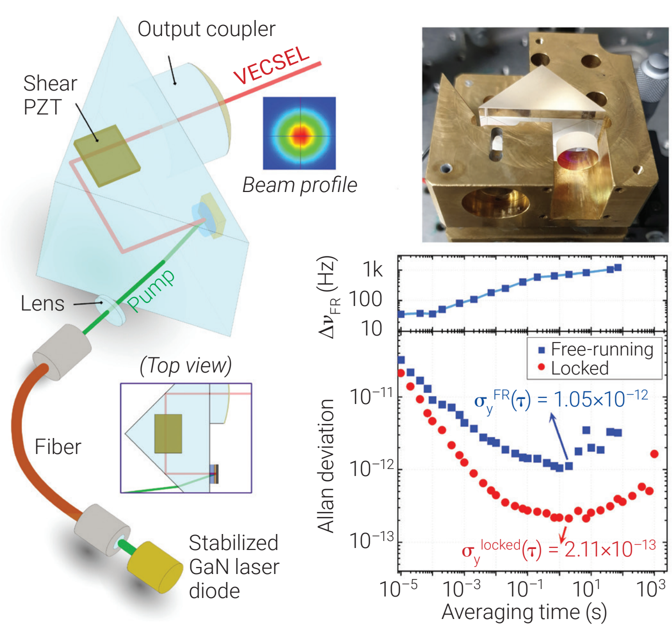
Highly coherent, stable and compact lasers play a critical role in the advancement of quantum technologies for applications ranging from health care to position, navigation and timing. The performance of such lasers directly affects not only the efficiency and stability of quantum systems but also their accuracy. Vertical-external-cavity surface-emitting lasers (VECSELs), with key differences from more conventional technologies such as diode and solid-state lasers, are thus being explored for quantum systems. VECSELs feature advantages such as high brightness, extended wavelength coverage and ultralow noise (frequency, intensity and phase), while having extremely narrow intrinsic linewidths (on the order of mHz). Further, this performance is achieved without the addition of external modules, resulting in compact packaging.

We have previously demonstrated high-power (>100 mW), sub-kHz-linewidth operation of GaInP-based VECSELs emitting at deep-red wavelengths, particularly at 689 and 698 nm, for neutral strontium (Sr) optical lattice clocks.[1,2] Now, in work published in the past year,[3,4] we have demonstrated a novel laser system by extending the concept of monolithic-cavity architectures—used, for example, in nonplanar ring oscillators[5]—to VECSELs. Such a design significantly reduces the impact of environmental noise and, our work has shown, can achieve laser performance suitable for high-precision applications.

The new monolithic VECSEL we demonstrated is a wavelength-customizable, high-stability, low-noise laser platform formed using a total-internal-reflection resonator created inside a right-angle prism. The frequency is electronically tunable without mode-hopping, with frequency stabilization available via a shear piezoelectric transducer on the prism.

In our recent studies, we built two monolithic VECSELs with emission at 672 and 689 nm.[3,4] The latter, developed to target the second cooling transition of Sr atoms, had output power of 40 mW (limited by the power of the diode laser pump) with ultralow frequency and intensity noise, resulting in a free-running linewidth of 720 Hz. The sub-kHz free-running linewidth—which was stable even at long averaging times (40 s)—is also referred to as the integrated linewidth, given that at this timescale external noise and drifts are averaged in the noise spectrum. We estimated the intrinsic linewidth to be as low as 64 mHz, with frequency stability reaching 10^{-12} over 1 s.

Our results together show the potential of this novel VECSEL design for high-performance applications. Further, we believe our first demonstration is just a starting point for this laser architecture. Mechanical, electronic and thermal noise can be further reduced, and future work will explore different cavity geometries to enable power scaling. Even as demonstrated, however, the novel monolithic-cavity VECSEL reaches new levels of brightness, intensity and frequency noise performance, linewidth, and frequency stability, particularly for a wavelength-versatile laser format. We believe it will enable practical advances in high-precision quantum technology applications. OPN



Schematic (left) and photograph (top right) of the monolithic-cavity VECSEL. Chart (bottom right) shows heterodyne beat-note linewidth with averaging time (top) and frequency stability (bottom), with and without frequency locking.

REFERENCES

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