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Ultra-coherent monolithic-cavity VECSEL for quantum technologies

Highly coherent and stable compact lasers play a critical role in the advancement of quantum technologies being developed for wide-ranging applications; from healthcare to position, navigation, and timing. Such laser performance directly affects not only the efficiency and stability of quantum systems, but also their accuracy. With key differences compared to other, more conventional laser technologies, such as diode- and solid-state lasers, vertical-external-cavity surface-emitting lasers (VECSELs) have been explored for quantum systems given their advantages such as high brightness, extended wavelength coverage, and ultra-low noise (frequency, intensity and phase), while having extremely narrow intrinsic linewidth (~mHz). Further, this performance is achieved without the addition of external modules, resulting in compact packaging. In this context, we have demonstrated high power (>100 mW), sub-kilohertz 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].

In work published this year[2,3], we demonstrated a novel laser system by introducing the concept of monolithic-cavity architectures - used, for example, in nonplanar ring oscillators (NPROs)[4] - to VECSELs, to significantly reduce the impact of environmental noise and to achieve laser performance for high precision applications. The new monolithic VECSEL is a wavelength-customizable, high-stability, low-noise laser platform formed by 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 piezo-electric transducer on the prism. Two monolithic VECSELs were built with emission at 672 and 689 nm[2,3]. The latter, developed to target the second cooling transition of Sr atoms, had output power of 40 mW (diode-pump-power-limited) with ultra-low frequency and intensity noise resulting in a *free-running* linewidth of 720 Hz. The sub-kilohertz free-running linewidth was stable even at long averaging times (40 s), also referred to as the integrated linewidth[5] given that, at this time scale, external noise and drifts are averaged in the noise spectrum. In addition, the intrinsic linewidth was estimated to be as low as 64 mHz, with frequency stability reaching 10^{-12} over 1 s, thus demonstrating the potential of the novel VECSEL for high performance applications.

The first demonstration is just a starting point for this laser architecture. The mechanical, electronic and thermal noise can be further reduced, and we will also explore different cavity geometries to enable power scaling. Nevertheless, the novel monolithic-cavity VECSEL reaches a new level of performance in terms of brightness, intensity and frequency noise, linewidth, and frequency stability, particularly for a wavelength-versatile laser format, and will enable practical advances in high precision quantum technology applications.

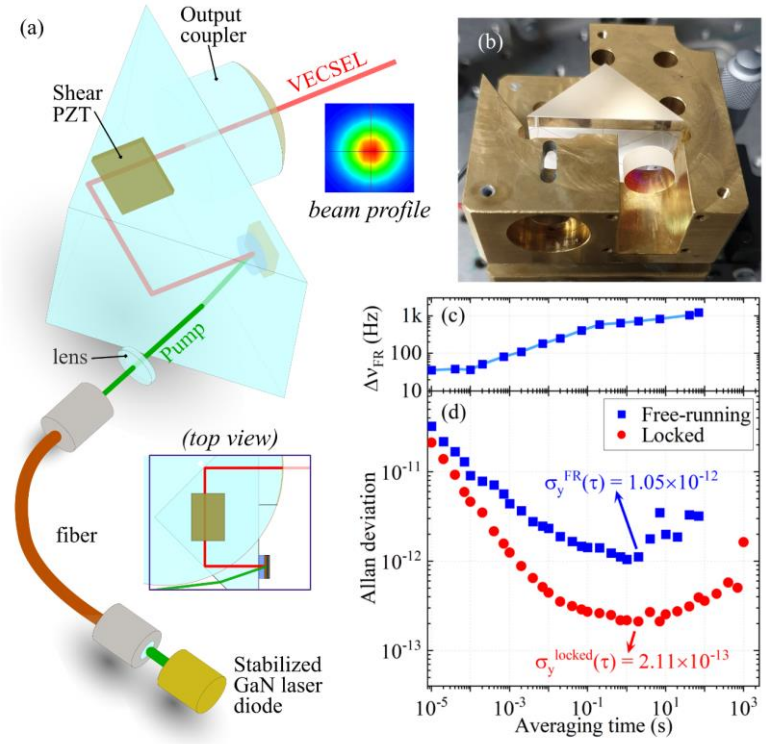

Figure. Monolithic cavity VECSEL (a) schematic, (b) photograph, (c) heterodyne beat note linewidth with averaging time, and (d) frequency stability.

References

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Two-sentence abstract: Ultra-coherent compact lasers are fundamental for high precision applications, such as quantum technologies. Recently, we demonstrated a new platform for a single frequency laser source with high stability and spectral purity, by combining ultra-low-noise, wavelength-versatile VECSELs with the robustness to environmental noise of monolithic cavity architecture.