Development of high performance, ultra-low-noise VECSELs for optical lattice clocks

Paulo Hisao Moriya[1] and Jennifer E. Hastie[1]
[1]Institute of Photonics, Department of Physics, SUPA, University of Strathclyde, 99 George Street, Glasgow G1 1RD, United Kingdom
Author e-mail address: paulo.moriya@strath.ac.uk

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The development of high performance and stable lasers with ultra-low noise is critical for further advancement of quantum technologies, such as optical lattice clocks and atom interferometers. In addition, as several lasers with different wavelength, brightness, and linewidth are required for such quantum systems, lasers are the major factor in not only the bulkiness and complexity of the technology but also the overall efficiency. Here, we present progress on the development of compact, ultra-low-noise, narrow-linewidth AlGaInP-based VECSELs with direct emission at 689 and 698 nm, of interest for neutral strontium optical clocks.

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Development of high performance and stable lasers with ultra-low noise is critical for further advancement of quantum technologies (QT), such as optical lattice clocks and atom interferometers. Depending on the atomic or molecular species being exploited, several laser sources with different wavelength, brightness, and linewidth are required, and are therefore the major factor in not only the size, weight, power and cost (SWaP-C), but also the overall efficiency of the QT system. In addition, if ultra-narrow transitions are targeted, such as optical clock transitions, further intensity, frequency and phase stabilization stages need to implemented, increasing complexity. In contrast to other laser technologies, vertical-external-cavity surface-emitting-lasers (VECSELs) combine extended wavelength coverage and high brightness with relaxation-oscillation-free, low-noise performance thanks to their class-A carrier dynamics. In addition, the precise positioning of the nanometer-scale layers of gain material with respect to the resonating optical field means that they can be engineered to have no spatial hole-burning and a fundamental linewidth limit at the mHz-level, thus providing an ideal platform for the achievement of ultra-narrow linewidths. Our group has demonstrated sub-kHz linewidth AlGaInP VECSELs at wavelengths from ~670-700 nm with output power exceeding 100 mW when frequency-stabilized to a moderately-high-finesse, air-spaced reference cavity. Recently, we demonstrated sub-kHz *free-running* linewidth using a novel, electronically-tunable monolithic cavity VECSEL, robust to environmental noise. Here, we review our development and characterization of these compact lasers at 689 and 698 nm, of interest for QT and metrology applications such as neutral strontium optical lattice clocks.