Narrow-linewidth, diamond cooled, monolithic vertical-external-cavity surface-emitting laser for quantum technologies.

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Modern quantum optics applications require high performance, tuneable, narrow-linewidth laser sources to target specific atomic transitions. Semiconductor laser diodes offer great flexibility in wavelength selectivity and tunability but suffer from poor beam quality, low power and require multiple stages of frequency stabilization. Vertically emitting, external cavity semiconductor disk lasers (VECSELs) provide a significant improvement both beam quality and power whilst retaining the wavelength flexibility inherent to semiconductor bandgap engineering. In a VECSEL, gain is provided by a vertical stack of quantum wells which are grown on top of a high reflectivity (>99.9%) distributed Bragg reflector, forming the so-called gain mirror. An external output coupler is used to complete the high finesse laser cavity, allowing for intra-cavity elements such as non-linear crystals, birefringent filters and etalons to be used, increasing the versatility of this laser system.

When optically pumping these devices the large thermal load results in the need for efficient heat removal. High quality, optical grade diamond is the ideal candidate for heat dissipation in VECSELs due to diamonds large thermal conductivity. Typically, the diamond is bonded directly on top of the VECSEL gain mirror resulting in strict requirements on the absorption and birefringence of the intra-cavity diamond element. With modern CVD diamond growth, high quality diamond heat-spreaders are available and have been successfully exploited in many scientific grade VECSELs. This makes VECSELs a true example of using diamond as a key component in an advanced technological application.

With the high laser cavity finesse, short carrier lifetime and small gain volume VECSELs exhibit very narrow intrinsic linewidths. This leaves environmental and pump noise as the dominant frequency instability contributions. Here we present a new monolithic-cavity VECSEL design that aims to remove contributions to the environmental noise from mechanical mount instabilities, thermal air flow fluctuations and alignment drifts. The monolithic schematic is well established in the solid-state laser industry with the use of non-planar-ring-oscillators to provide very stable, narrow linewidth laser operation. Using a right-angle prism as the bulk of the monolithic-cavity, the individual VECSEL components (gain mirror, diamond heat spreader, prism and output coupler) have been capillary bonded to form a compact cavity free from any air space.