290 Hz intrinsic linewidth from an integrated optical chip-based widely tunable InP-Si$_3$N$_4$ hybrid laser

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Abstract: We present an integrated chip-based InP-Si$_3$N$_4$ hybrid laser with unprecedented high spectral purity. A record-narrow fundamental laser linewidth of 290 Hz with a widest-ever spectral coverage (81 nm at 1550 nm) is experimentally demonstrated.

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Widely tunable, narrow linewidth diode lasers have found a wide range of important applications, reaching from fiber-optic communications [1] or optical sensing [2] to applications in space, for instance in GPS clocks [3] or for fundamental metrology (LISA [4]). Monolithic diode lasers, i.e., distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) lasers, approach their limits since they typically show either a small tuning range [5] or larger spectral linewidths at the MHz level [6]. In contrast, these limitations are not present in external cavity hybrid lasers. In such lasers, the gain from a semiconductor optical amplifier chip is receiving spectrally filtered feedback from a second chip fabricated from dielectric material. The second chip carries an integrated-optical, low-loss waveguide circuit that provides the spectral filtering and a long photon lifetime.

Fig. 1. (a) Schematic drawing of the InP-Si$_3$N$_4$ hybrid laser. The feedback chip carries a widely tunable narrowband Vernier-mirror, which incorporates three sequential and temperature tunable high-Q microring resonators (MRRs) with different radii ($R_1 = 102$ $\mu$m, $R_2 = 99$ $\mu$m, $R_3 = 1485$ $\mu$m); (b) An example of laser wavelength tuning map obtained via adjusting the heating voltage applied to the two smaller MRRs.

The scheme of the two-chip hybrid laser is shown in Fig. 1 (a). Optical gain around a wavelength of 1.54 $\mu$m is provided with an InP reflective semiconductor optical amplifier (RSOA). Optical feedback is based on a low-loss Si$_3$N$_4$ waveguide circuit of significant optical length (50 cm on a chip), which is chosen to impose a small intrinsic (Schawlow-Townes, quantum-limited) linewidth [7]. Single mode oscillation is achieved by incorporating three temperature tunable high-Q microring resonators (MMRs, with $Q_1 \approx 20000$, $Q_2 \approx 20000$, $Q_3 \approx 260000$) and a tunable
phase section in the waveguide feedback circuit, terminated with an adjustable loop mirror. The laser shows a record-wide wavelength tunability of about 81 nm, see Fig. 1 (b), extending from 1500 nm to 1581 nm with a maximum fiber-coupled output power of 13 mW.

![Image](JTh5C.9.pdf)

Fig. 2. (a) Measured power spectral density of the frequency noise of the hybrid laser at two driving currents (50 mA, blue trace; 120 mA, red). The intrinsic laser linewidth is retrieved via multiplying PSD value of the white frequency noise by $2\pi$; (b) Overview on previously reported coherence times of other external cavity hybrid diode lasers.

The laser’s intrinsic linewidth is retrieved from the measured frequency-noise spectral power density [see Fig. 2 (a)] obtained with self-heterodyne measurements, as the limit-value towards high noise frequencies. The smallest linewidth observed is 290 Hz. We ascribe the narrow linewidth to a well-balanced choice of laser parameters, specifically, an efficient mode coupling of the InP and Si$_3$N$_4$ waveguides via tapered waveguide cross sections, a long cavity length enabled by the low losses of the used waveguide platform (LPCVD-grown stoichiometric Si$_3$N$_4$), and highly frequency selective intra-cavity filtering with high-Q MRRs. In Fig. 2 (b) we present an overview on previously reported intrinsic coherence times ($1/2\pi$ times inverse intrinsic linewidth) of other external cavity hybrid diode lasers. It can be seen that the demonstrated coherence time is far above that of any other reported chip-based and tunable hybrid laser. This result may mark a new paradigm in employing semiconductor lasers for providing light with ultra-high coherence in an application relevant format.

References