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Universally self-injection locked photonic integrated laser with efficient and highly linear piezoelectric actuation

Frequency-agile ultra-low-noise lasers are essential tools in a wide variety of applications, including data communication [1], light detection and ranging (LiDAR) [2], quantum computing and sensing [3], and optical metrology [4]. However, legacy laser architectures have not yet overcome the trade-off between exceptional ultra-low noise and frequency agility. Recent advances in integrated photonics have enabled performance that exceeds that of conventional laser systems [5]. In particular, self-injection locking (SIL) is an effective and scalable approach to achieve fiber-laser-level coherence in semiconductor lasers by coupling them to high-Q integrated microresonators [6]. Furthermore, monolithic integration of piezoelectric actuators onto such photonic integrated SIL laser platforms allows fast laser frequency tuning via the stress-optic effect without introducing additional optical losses [5]. State-of-the-art SIL architectures leverage low-loss Si_3N_4 cm-long spiral cavities endowed with aluminum nitride (AlN) piezoelectric actuators, achieving frequency noise below that of commercial fiber lasers, with Hz-level intrinsic linewidths and frequency agility up to 400 kHz of bandwidth, establishing a performance point where ultra-low linewidth and fast, linear frequency tuning coexist on a single monolithic PIC platform. State-of-the-art implementations self-injection locked lasers, however, require precise control of detuning and feedback phase to access and maintain narrow-linewidth operation, necessitating active stabilization schemes that limit robustness and hinder practical deployment. Moreover, the tuning efficiencies achieved in the state of the art (approximately 2.5 MHz/V) remain considerably below the 10–20 MHz/V demonstrated with lower-coherence laser architectures.

We demonstrate a photonic integrated self-injection locked laser with universal narrow-linewidth operation enabled by engineered feedback-phase dispersion, ensuring robust locking across all operating conditions. Efficient and highly linear frequency tuning is achieved using a dis-aggregated actuator design combined with AlScN piezoelectric actuation.

References

[1] C. A. A. Franken, R. Cheng, K. Powell, G. Kyriazidis, V. Rosborough, J. Musolf, M. Shah, D. R. Barton III, G. Hills, L. Johansson, K.-J. Boller, and M. Lončar, "High-Power and Narrow-Linewidth Laser on Thin-Film Lithium Niobate Enabled by Photonic Wire Bonding," arXiv:2407.00269 (2024). https://doi.org/10.48550/arXiv.2407.00269

[2] M.-C. Amann, "Phase Noise Limited Resolution of Coherent LIDAR Using Widely Tunable Laser Diodes," Electron. Lett. 28(18), 1694–1696 (1992). https://doi.org/10.1049/el:19921077

[3] A. Rogers, "Distributed Optical-Fibre Sensing," Meas. Sci. Technol. 10(8), R75–R99 (1999). https://doi.org/10.1088/09570233/10/8/201

[4] G. E. Marti, R. B. Hutson, A. Goban, S. L. Campbell, N. Poli, and J. Ye, "Imaging Optical Frequencies with 100 μHz Precision and 1.1 μm Resolution," Phys. Rev. Lett. 120(10), 103201 (2018). https://doi.org/10.1103/PhysRevLett.120.103201

[5] G. Lihachev, J. Riemensberger, W. Weng, J. Liu, H. Tian, A. Siddharth, V. Snigirev, V. Shadymov, A. Voloshin, R. N. Wang, J. He, S. A. Bhave, and T. J. Kippenberg, "Low-Noise Frequency-Agile Photonic Integrated Lasers for Coherent Ranging," Nat. Commun. 13(1), 3522 (2022). https://doi.org/10.1038/s41467-022-30911-6

[6] M. A. Tran, D. Huang, J. Guo, T. Komljenovic, P. A. Morton, and J. E. Bowers, "Ring-Resonator Based Widely-Tunable Narrow-Linewidth Si/InP Integrated Lasers," IEEE J. Sel. Top. Quantum Electron. 26(2), 1–14 (2020). https://doi.org/10/ghc48t