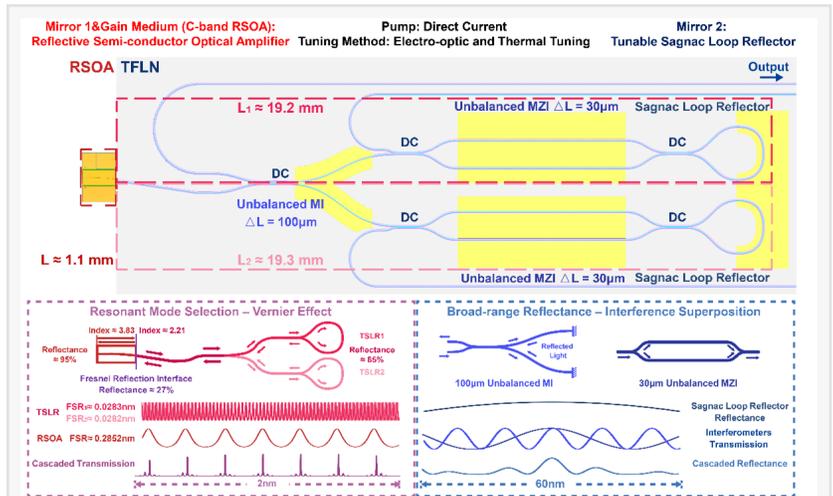


Broadband Narrow-Linewidth Tunable On-Chip Hybrid Integrated Laser

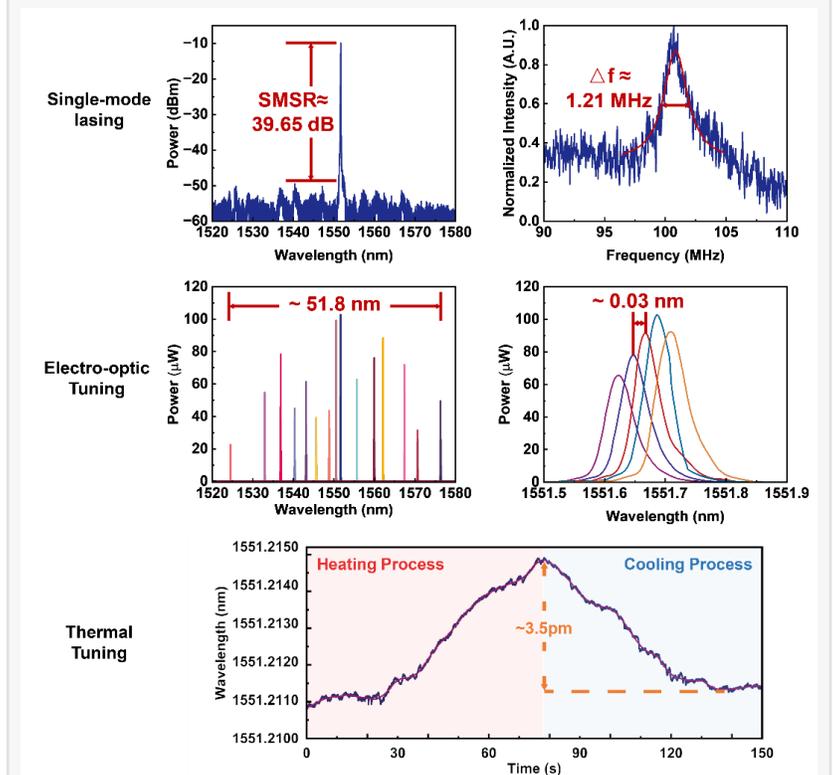
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Tunable lasers are key light sources capable of precisely and rapidly adjusting their output wavelength while maintaining extremely high spectral purity. These lasers serve as core components in cutting-edge fields such as high-speed coherent optical communications, high-precision laser sensing, precision spectroscopy, and quantum technology. Currently, widely used tunable narrow-linewidth lasers commonly suffer from issues such as bulky system size, complex packaging, high cost, and limited electro-optic tuning speed, making it difficult for them to meet the urgent demands of modern optoelectronic systems for miniaturization, integration, and high performance.

In recent years, the rapid development of photonic integrated circuit (PIC) technology has provided a new pathway to overcome these bottlenecks. By integrating optical functional elements onto a chip in the form of waveguides and hybrid-integrating them with semiconductor



Design of a Hybrid Integrated Tunable Semiconductor Laser



Laser Performance

gain chips, compact, low-power, and stable on-chip lasers can be constructed. Among various platforms, thin-film lithium niobate (TFLN) has emerged as a promising integrated photonics platform, attracting significant attention from both academia and industry due to its excellent electro-optic properties (ultra-high electro-optic coefficient, broad transparency window), low optical loss, and compatibility with CMOS fabrication processes. It provides an ideal material foundation for realizing high-speed, broad-spectrum electro-optically tunable on-chip lasers. However, current tunable lasers demonstrated on this platform often face the challenge of balancing tuning range with precision. Therefore, expanding both the wavelength tuning range and the tuning precision of such lasers has become a critical research direction for advancing TFLN-based integrated lasers toward practical applications.

The authors of this article proposed and demonstrated a hybrid integrated C-band high-precision tunable semiconductor laser based on a thin-film lithium niobate external cavity. By ingeniously designing a unique external cavity structure featuring a tunable Sagnac loop reflector, they successfully resolved the long-standing challenge of simultaneously achieving a wide tuning range and high tuning precision.

The core innovation of this research lies in the meticulous construction of a novel external cavity structure based on tunable-reflectivity Sagnac loop reflectors. This design integrates Sagnac loop reflectors with multiple sets of unbalanced interferometers. The Sagnac loop reflectors provide a broadband reflective background, while the unbalanced interferometers, featuring different arm-length differences, generate spectral modulations with distinct periods. Their superposition achieves narrowband filtering across a wide spectral range. The laser is formed by directly butt-coupling a C-band reflective semiconductor optical amplifier (RSOA) with a thin-film lithium niobate external cavity chip. Here, the RSOA provides electrical pumping gain and serves as a highly reflective mirror on one end, while the lithium niobate external cavity chip acts as a tunable mirror on the other end, delivering wavelength-selective feedback. By adjusting the reflection spectrum of the external cavity, wide-range tuning of the output laser wavelength is achieved while maintaining narrow-linewidth characteristics.

Leveraging this innovative design and the excellent electro-optic properties of thin-film lithium niobate, the team successfully developed a laser exhibiting a series of outstanding performance metrics: a central lasing wavelength of 1551.3 nm with a tuning range reaching approximately 51.8 nm; a tuning precision as high as 0.03 nm; while maintaining a narrow linewidth of about 1.21 MHz and a side-mode suppression ratio exceeding 39 dB. Furthermore, the laser can achieve continuous mode-hop-free tuning of approximately 3.5 pm.

Furthermore, the mode competition theory was refined for semiconductor lasers, directly linking it to the quality factor (Q-factor) of the optical microcavity. It was theoretically demonstrated that in miniaturized cavities with a limited number of modes, such as those in on-chip lasers, there is no need for the extremely sharp, high-finesse filters typically employed in conventional lasers to forcibly select a mode. Instead, by creating sufficient threshold differences between modes using filters with gentle spectral transitions, single-mode lasing can be naturally initiated via the

intrinsic "gain clamping" effect of the semiconductor gain medium itself. This theory provides new insights and a theoretical toolkit for the design of on-chip tunable lasers.

Keywords: hybrid integrated laser, high-precision tuning semiconductor laser, thin-film lithium niobate

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Yiran Zhu is a doctoral candidate at the State Key Laboratory of Precision Spectroscopy, East China Normal University, under the supervision of Professor Ya Cheng. The primary research focuses on high-quality optical microcavities based on thin-film lithium niobate and on-chip lasers.

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