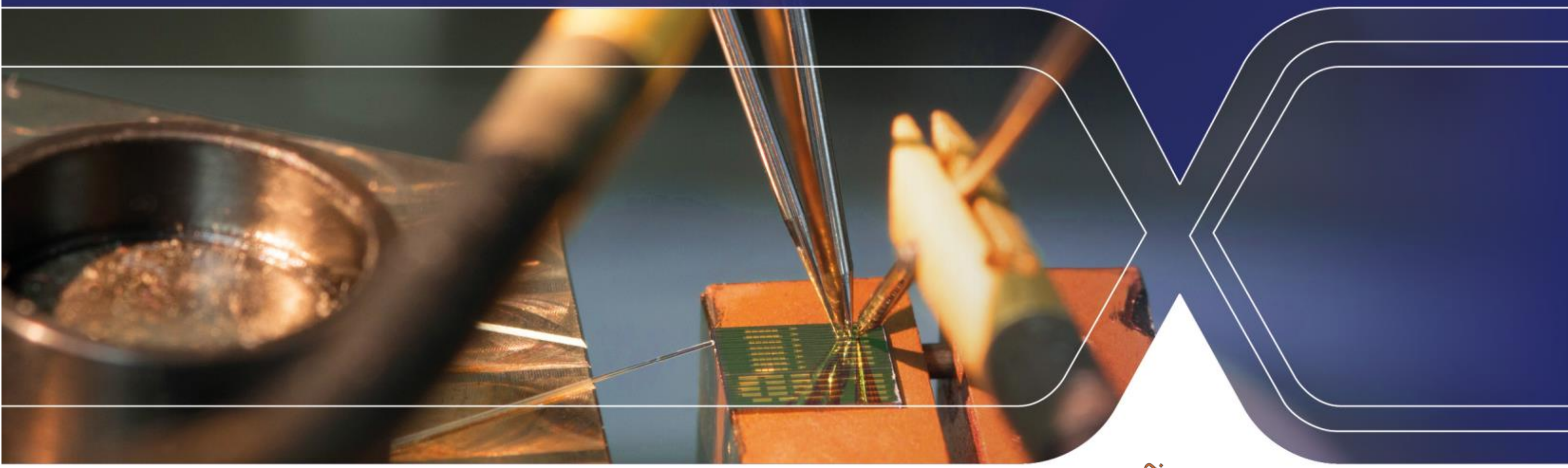

Monolithically integrated tunable lasers

Widely-tunable lasers can find application in a large variety of tasks including sensing, communication technologies and beam steering[1-6]. As a driving market sector, fiber-optic dense wavelength-division-multiplexed (DWDM) networks have revolutionized the data transport cost per bit in the last decade. This technology uses the low-absorption window in glass fibers around 1550 nm (C-band), with state-of-the-art systems supporting up to 192 wavelength channels at 400 Gbit/s capacity and Tbps systems on the horizon[4]. Frequency-modulated continuous-wave (FMCW) lidar is on its way to revolutionize the transport and sensing sector to the same degree, requiring tunable, low-cost laser sources for a competitive market[6]. Integrated indium phosphide (InP) technology can cater to both of these examples with widely-tunable laser sources and additional functions integrated on a single-chip. Promising reduction in size and cost while providing high output powers in the C-band, which remain eye-safe at higher levels than emission at wavelengths shorter than 1400 nm. While single-absorption line spectroscopy and millimeter-wave applications suffice with just a few nanometer tunability, DWDM requires full C-band coverage of about 40-nm wavelength span[4]. Gas sensing and 2D beam steering demand even larger wavelength spans: >50nm[5] for multiple species gas sensing and >100 nm for beam steering angles >30° [6]. Figure 1 shows an overview of monolithically integrated tunable laser technologies on InP, comparing their tuning-ranges to required wavelength coverages by specific applications.

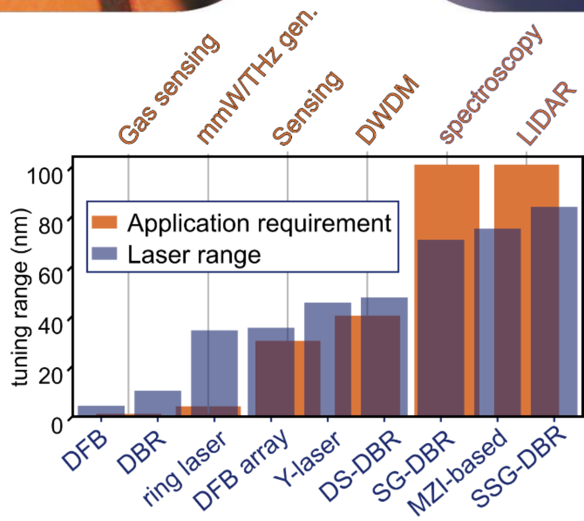

Figure 1: Comparing application required wavelength coverage and tunability of InP laser technologies.

Advantages of photonic integration

While monolithically integrated tunable InP lasers are commercially available as standalone, fiber-coupled modules[10-12], research and industry are further exploiting the InP integration platform by adding more on-chip features like detectors, signal splitters, combiners, filters, electro-absorption and phase modulators, and semiconductor-optical-amplifiers (SOAs). These additional functionalities come at no additional cost, do not significantly increase the fabrication complexity and allow the

[1] Gas Sensing https://doi.org/10.1109/LPT.2019.2958711
[2] mmW / THz generation: http://doi.org/10.1109/JLT.2018.2836298
[3] Sensing: https://www.technobis.com/index.php/themes/fibre-optic-sensing
[4] DWDM: https://www.adva.com/en/products/technology/dwdm
[5] Multi-species Gas Sensing+MZI-based laser: https://doi.org/10.1109/JPHOT.2015.2493722
[6] Light Ranging/LIDAR: https://doi.org/10.1364/OL.42.004091
[7] tunable DFB: https://doi.org/10.1016/B978-012395172-4/50012-7
[8] DBR laser: https://doi.org/10.1109/2944.954126
[9] Ring laser: https://doi.org/10.1109/JLT.2019.2952466
[10] DFB laser array: https://doi.org/10.1109/2944.954126
[11] Y-laser: https://www.finisar.com/communication-components/s7500
[12] DS-DBR: https://www.lumentum.com/en/products/micro-itla-tunable-laser-300-khz
[13] SG-DBR: https://doi.org/10.1117/12.2554541
[14] SSG-DBR: https://doi.org/10.1049/el:19930238

InP Photonic Integrated Circuits (PICs)

Optical chips or PICs can contain tens to hundreds of optical components. While electronic integrated circuits (EICs) consist of transistors, capacitors, and resistors, a PIC consists of, for example, lasers, modulators, photodetectors, and filters, all integrated on a single substrate. Several application fields, such as data- and telecom, sensing, and lidar are already using or are considering the use of PICs for their products. This PIC technology is accessible to users without a cleanroom, through so-called multi-project wafer runs and open access foundries. InP based technology is commercially available through SMART Photonics and Fraunhofer Heinrich-Hertz-Institut. Access is individually coordinated by JePPIX.

elimination of external optical components to reduce the size of a complex optical system. Not only can tunable lasers replace many single-wavelength distributed-feedback (DFB) lasers with one tunable laser, but the integrated functionalities allow for bulky sensing applications and THz-/mmW-generation to be brought to chip-scale levels[2,3].

State-of-the-art technology

The basic components of tunable semiconductor lasers are the laser cavity, the gain section, and a mode-selection filter to ensure single-frequency operation. Using filters, mirrors, and phase-shifting sections, tunability is achieved by appropriately aligning the relative spectra of the tunable filter, gain element and the cavity modes. The DFB laser constitutes probably the most common single-frequency laser, using a periodic structure acting as both a distributed cavity mirror and a mode-selection filter. Tuning of a few nanometers can be achieved thermally[7], but combining multiple sources into one DFB array[10] provides full C-band coverage. The distributed Bragg reflector (DBR) laser uses a Fabry-Perot cavity formed by a partially reflecting front grating and total reflection at the rear grating. Gain and phase control can be included in the cavity to achieve a wavelength tunability of up to 10 nm[8]. This tuning range is vastly improved by varying the grating design of the DBR. The digital supermode (DS) DBR laser[12] combines a broad reflection spectrum of a chirped front grating with the comb-like spectrum of the rear grating to select the lasing mode. The sampled-grating (SG) DBR laser[13] combines two comb-like reflection spectra of gratings with periodically removed elements and the super-structure grating (SSG-) DBR laser[14] uses periodically modulated gratings to achieve the same effect. Laser mode selection makes use of the Vernier effect, filtering all but one selected cavity mode, dictated by the product of the two reflection spectra. This allows a widely tunable output by independently tuning both reflection spectra. All these designs can cover the full C-band, but the SSG-DBR laser currently holds the record of a 83 nm tunable wavelengths range single-mode operation[14]. Alternatives to the grating-based lasers are MZI-based lasers[5], Y-branch lasers[11] and ring-based lasers[9], which show tunability exceeding the C-band range using the Vernier effect as well. Figure 2 shows a total of six MZI-based lasers integrated on one InP chip of just a few square millimeters. Combining just two of these lasers similarly to DFB arrays could enable wave-length tunability exceeding 140 nm on a single chip.

Discuss your application with us

If you are interested in knowing more about the capabilities and use of InP PIC technology contact JePPIX (pilotline@jeppix.eu). The JePPIX Pilot Line provides low entrance-threshold to mature-manufacturing, enabling high-TRL development in a scalable design kit driven process.

	DFB [7]	DBR [8]	Ring [9]	DFB a.[10]	Y-laser[11]	DS-DBR[12]	SG-DBR[13]	MZI-based[5]	SSG-DBR[14]
Tuning range	4 nm	9 nm	34 nm	>35 nm	>35 nm	47 nm	53 nm	74.3 nm	83 nm
SMSR	>40dB	>40dB	>50dB	>45dB	>40 dB	>50dB	>40dB	>30dB	>40dB
Linewidth	<1MHz	<9MHz	110kHz	<160kHz	5MHz	<300kHz	700kHz	363 kHz	<10MHz
Power	<20dBm	>0dBm	>0dBm	13 dBm	13 dBm	>16dBm	9dBm	<5dBm	<10dBm