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Indium phosphide monolithic photonic integrated circuits for gas sensing applications

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In order to extend the scope of potential applications for the generic photonics integration technology platforms [1] it is desired to widen the range of spectral bands covered by such integration technologies. Access to wavelengths in the mid-infrared range at around 2µm would make it particularly attractive for gas sensing applications due to presence of strong absorption lines of many gas species e.g. acetone and ammonia. Therefore, a development of long-wavelength (2 µm) active-passive monolithic integration technology on indium phosphide substrate with use of strained multi-quantum wells (MQW) was undertaken at the COBRA Research Institute [2]. Along with the technology development a novel tunable laser design featuring an asymmetric Mach-Zehnder interferometer (AMZI) based intra-cavity filter suitable for single line gas spectroscopy has been proposed [3]–[5] . The device has been fabricated within a multi-project wafer (MPW) run using such long-wavelength technology as presented in Fig. 1.

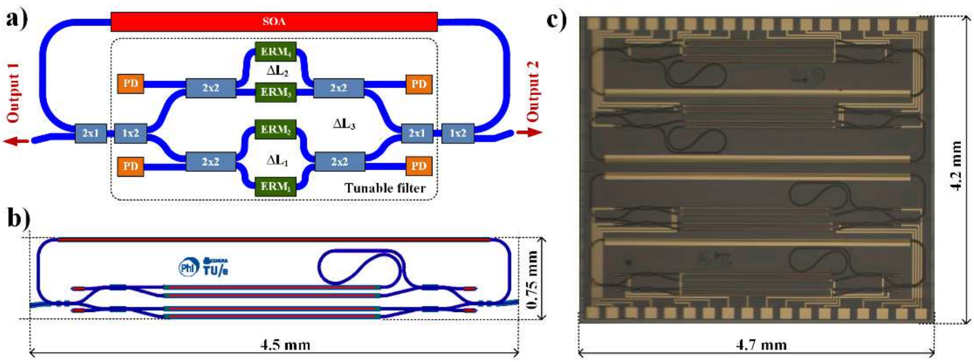

Fig. 1 (a) A diagram of the extended cavity ring laser featuring an intracavity tunable wavelength filter based on nested asymmetric Mach-Zehnder interferometers (dotted box). The photonic integrated circuit (PIC) consists of several basic building blocks connected with passive waveguides (in blue): a semiconductor optical amplifier (SOA), multimode interference couplers (1x2, 2x2 MMI), electro-refractive modulators (ERM) and photodiodes (PD). (b) Mask layout of the laser cavity with a total area of 3.4 mm^2. (c) A microscope picture of a long-wavelength chip including four tunable lasers. The 20 mm^2 PIC was fabricated within a multi-project wafer run.

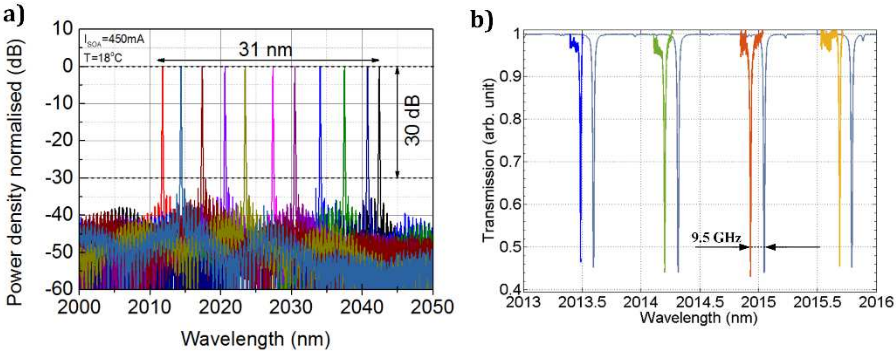

Fig. 2 (a) Optical spectra recorded for a series of sets of reverse voltages applied to the ERMs with the injection current into the SOA and temperature kept constant at I_{SOA}=450 mA and T= 18 °C respectively. (b) Four absorption lines of carbon-dioxide recorded using the long-wavelength PIC laser overlapped (9.5GHz offset) with the simulated absorption spectrum.

The fabricated PIC laser operating at DC current injection and at room temperature features a threshold current density of 3.4kA/cm^2 and delivers around 0.1mW of average output power coupled into the lensed fiber (~ 0.3mW ex-facet assuming a fiber coupling loss of ~5dB). The AMZI filter in a nested configuration allows for a record tuning range of 31 nm at around 2027nm Fig. 2(a). Such tuning bandwidth is achieved by applying a reverse bias voltage to four electro-refractive modulators (ERM) while the current injection into the semiconductor optical amplifier (SOA) section and the temperature of the chip are being held constant. The laser's feasibility for gas spectroscopy was evaluated in a gas spectroscopy experiment using a carbon-dioxide reference cell. Four individual absorption lines were targeted using the voltage controlled ERMs and the lasing wavelength was tuned across each line by scanning the current injected into the SOA section. The four absorption lines are presented in Fig. 2(b) overlapped with the absorption spectrum of carbon-dioxide simulated using the HITRAN database and parameters of the reference gas cell.

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