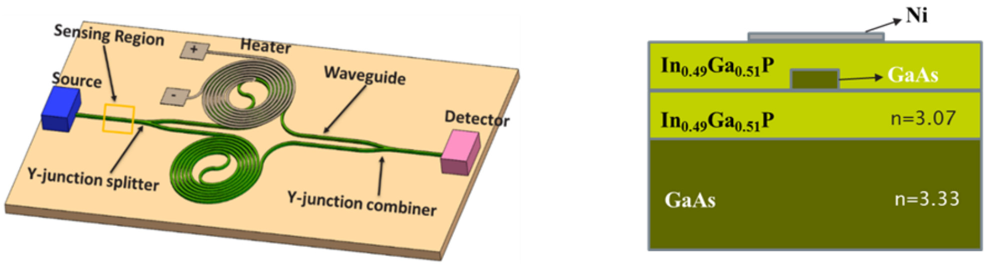
III-V Semiconductor Based Mid-IR Spectrometer on Chip

Ganapathy Senthil Murugan, Vasileios Mourgelas, and James S. Wilkinson
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK

Abstract— Mid-Infrared (MIR) spectroscopy is a powerful technique for biochemical analysis in applications such as point of care diagnostics and pollution monitoring. It provides a plethora of qualitative and quantitative chemical information and can be used for label free analysis due to the inherent selectivity of the MIR spectral region. Commercially available MIR spectrometers are usually bulky and expensive. An ultra-portable and cost-effective/mass-manufacturable platform, suitable for use in low resource settings, has not been demonstrated yet. Most of the examples of miniature MIR spectrometers that can be found in the literature, suffer from many drawbacks with the main one being the material absorption in the MIR fingerprint region in waveguide-based devices. We are interested in exploiting the fingerprint region extending from the mid-wave to the long-wave infrared bands and for this reason we have chosen a III-V semiconductor platform for the waveguide materials (core/cladding) with a transmission window extending from 1 µm to 16 µm. Our platform is based on a waveguide system comprising a simple thermo-optically tunable Mach-Zehnder interferometer (MZI) employing spiral waveguides as shown in Fig. 1(a). The multilayer structure is shown in Fig. 1(b). Both GaAs (core) and InGaP (cladding) offer a strong thermo-optic effect (dn/dT$\sim 2 \times 10^{-4}\,K^{-1}$) and the reported propagation losses of GaAs are of the order of 0.2 dB/cm at a wavelength of 1550 nm. Furthermore, III-V materials have a mature history and can be fabricated using well standardised techniques.

Although our ultimate aim is to fabricate spectrometers operating in the long-wave band for which this platform is most suitable, the first generation proof of principle device was designed and modelled for operation between $\lambda = 3$ and 4 µm with an achievable spectral resolution of 10 cm^{-1}. The modelling results and the theoretical calculations showed a required temperature rise at the waveguide core of around 83 K for a waveguide spiral length of 6 cm. The various optical layer geometries were optimised to provide low absorption/radiation loss (metallic heater/high refractive index substrate), good optical layer quality and rapid thermal response when required. The total optical losses of the platform were estimated to be < 2.5 dB (excluding coupling loss). Depending upon the design of the optical layer structure and the geometry of the heater and the waveguides, the device can be tailored to provide a normal temperature response of a few seconds with a moderate power consumption. In order to achieve very low power consumption, the device should be properly thermally isolated.



(a) (b)

Figure 1: (a) Integrated spectrometer device layout and (b) multilayered waveguide structure.

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