Distributed feedback lasers for gas sensing in the 3.5 µm wavelength range


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BIOGRAPHY

Dr. Marc Fischer: Marc Fischer is divisional director for device fabrication at nanoplus Nanosystems and Technologies GmbH with their clean room facilities in Gerbrunn and Meiningen, Germany. He is responsible for the manufacturing of laterally coupled DFB lasers and related process development. He joined nanoplus in 2002. Here, he also contributed to various national and international research activities on novel laser sources and served e.g. as project manager for the EU project SENSHY focusing on photonic gas sensors for the detection of hydrocarbons.

Marc Fischer was born in Tettnang, Germany in 1972. He graduated in Physics from the State University of New York at Buffalo (USA) and Würzburg University (Germany) in 1997 and 1999, respectively. During his PhD, he worked on the MBE growth of GaInNAs structures and developed EELs and VCSELs in this GaAs based material system for future telecom applications, realizing for example the first GaInNAs/GaAs LD in the 1500 nm wavelength range. In 2003, he received his PhD degree from Würzburg University.

TECHNICAL ABSTRACT

The wavelength range around 3.5 µm is of particular technological and industrial importance since the fundamental absorption bands of many relevant hydrocarbons are located in this range [1]. Two GaSb based approaches to application-grade semiconductor lasing in the 3 - 4 µm wavelength region have been proven especially successful over the past years. These concepts use type-I transitions in quinary AlGaInAsSb barrier confined quantum wells [2] or type-II transitions within a cascade scheme [3], respectively. Tunable laser spectroscopy (TLS) is a versatile and very successful approach making use of such laser sources for high performance trace gas detection. A crucial requirement for TLS is the availability of spectrally monomode emitters. In this talk, we will report on monomode DFB laser sources as well as multi-section devices with extended tuning range in the wavelength range of interest.

We will first present monomode DFB devices based on type-I as well as type-II laser material in the 3.5 µm wavelength range. The gate to ambient temperature spectroscopy with formerly unattainably high precision is pushed open by these new devices [4]. They will have considerable impact especially on industrial applications based on the detection of hydrocarbons in the wavelength range around 3.5 µm. For device fabrication, overgrowth-free processing routes were used, having significant advantages for GaSb based heterostructures, where an overgrowth is extremely hard to achieve due to the reactivity with oxygen. Our approach also allows the characterization of the underlying laser structure for an adjustment of processing parameters like DFB grating periods. Using lateral metal gratings or etched sidewall gratings defined by electron-beam lithography in combination with a ridge waveguide structure, efficient DFB coupling with high yield is obtained. As an example, a type-I DFB laser diode emitting around 3.4 µm, suitable for ethane detection, is shown in Figure 1. The laser has been integrated into a TO5 laser package (including an internal thermoelectric cooler for temperature tuning) and was hermetically sealed using a sapphire window. The spectrum (see inset of Figure 1) shows a side mode suppression ratio around 45 dB at typical operating conditions of 10°C chip temperature and 160 mA operating current. This excellent spectral characteristic permits a very high selectivity in gas sensing. Corresponding L-I curves of the laser in continuous wave (CW) operation up to room temperature are also depicted in Figure 1. With monomode output powers in the milliwatt range, the fabricated lasers are very suitable for use in TLS. Sampling of characteristic absorption lines in such a measurement is performed by DFB wavelength tuning via current modulation with tuning coefficients on the order of 0.04 nm/mA. Additionally to the type-I developments DFB devices based on type-II interband cascade material were also fabricated. Figure 2 shows an example of a DFB...
laser source around 3.5 µm suitable for formaldehyde detection. An etalon trace of the device emission under current tuning is given in the figure. For increasing operating current from 48 to 115 mA, a smooth, mode-hop free wavelength tuning is observed. The corresponding tuning range amounts to around 3 nm (80 GHz).

While the current induced tuning range of a DFB laser is typically limited to a few nanometers (as also found above), a number of applications will benefit from laser devices with an extended tuning range. These include liquid sensing as well as multi-component gas analysis. To enable such applications, monolithic widely tunable devices were also investigated in the discussed wavelength range. Figure 3 depicts the underlying schematic of a fabricated two-section device based on binary superimposed grating structures. Device operation in different monomode channels is obtained by independently injecting two currents into the two laser sections. A corresponding mode map (the emission wavelength is color-coded for the respective combination of currents) is shown in Figure 3. An overall quasi-continuous tuning range of more than 13 nm has been achieved.

**Figure 1:** L-I and V-I curves of a fabricated type-I DFB laser in CW operation at different chip temperatures and spectrum of the laser at 10°C / 160 mA (inset).

**Figure 2:** Etalon trace for variation in operating current between 48-115 mA of a fabricated type-II interband cascade DFB laser emitting at around 3.5 µm for formaldehyde sensing.

**Figure 3:** Schematic design (left) of a two-section laser with binary superimposed gratings and results of spectral characterization (right) of a fabricated widely tunable laser in the 3.4 µm wavelength range. Device characterization was performed under CW operation at a chip temperature of 3°C.


**Keywords:** Semiconductor laser, Distributed Feedback (DFB), tunable laser spectroscopy (TLS), gas sensing, GaSb