Tunable Quantum Cascade Laser based waveguide sensors for mid-infrared spectroscopy

Georg Ramer1, Markus Brandstetter1, Jürgen Kasberger2, Bernhard Lendl1

1 Institute of Chemical Technologies and Analytics, Vienna University of Technology, Getreidemarkt 9/164 AC, 1060 Vienna, Austria
2 Research Center for Non Destructive Testing GmbH (RECENT), Hafenstrasse 47-51, 4020 Linz, Vienna

INTRODUCTION

Probably the two most frequently used techniques in infrared spectroscopy are transmission and ATR measurements. Transmission measurements offer the possibility of large optical interaction lengths and therefore high sensitivity. Furthermore, they are especially suitable for weak absorbers. The ATR technique, on the other hand, offers mechanical robustness and, due to the short interaction lengths of the evanescent field, the possibility to measure highly absorbing samples.

Novel single mode waveguide sensors (WaGS) offer the best of both worlds, robustness and high interaction lengths and sensitivity.[1] However, high interaction lengths also call for a high powered light source. Quantum Cascade Lasers (QCL) can offer this with spectral power densities that are more than four magnitudes higher than for thermal emitters [2]. Furthermore, they are already available with spectral tuning ranges of up to several hundred wavenumbers.

The use of grating couplers to couple light into and out of waveguides, makes angles of incidence that are almost perpendicular to the waveguide possible - a major advantage for the use in plug-in sensors.

SINGLE MODE WAVEGUIDES - THE BETTER ATR CRYSTAL?

High interaction lengths

In WaGS, the evanescent field stretches along the whole length of the waveguide structure, making long interaction lengths possible.

Custom depth of penetration and wavelength

Simulation of the field distribution along a segment of a 0.85 μm SiN4 waveguide. Calculations were performed in CAMFR.

Custom Materials

Simulations of the electric field distribution of the 0th order TE-mode of 6μm infrared radiation in a SiN4 waveguide. Calculations performed in CAMFR.

COUPLING ANGLES

The efficiency of coupling light into the waveguide via a grating coupler depends on the incident angle and the wavelength of the light. The coupling efficiency at a certain angle can easily be determined by placing the waveguide’s grating coupler between laser and detector at that angle.

In contrast to butt-coupling, a grating coupler allows angles of incidence close to 0°. This facilitates the application of waveguide sensors in plug-in sensors. Through the choice of grating material, period and height, the coupling can be fine-tuned to specific angles and wavelengths.

FIRST RESULTS

A tunable External-Cavity QCL (160 cm⁻¹ tunability) served as source for the infrared radiation. By shifting the laser beam vertically, the angle of incidence was set. As detectors, a peltier cooled MCT detector and a pyroelectric detector were tested. To remove signal aberrations caused by the tunable quantum cascade laser, a Fourier-based algorithm was used.

FUTURE DEVELOPMENTS

We could demonstrate basic broadband coupling of a tunable QCL laser source into a mid-IR slab waveguide via grating couplers. Further optimization of the gratings will be done to allow steeper coupling angles and acceptance of a wider wavelength range. Furthermore, changes in waveguide material and shape, offer a wide range of possible improvements. However, based on the results already achieved we are positive, that grating coupled WaGS will see practical application in IR spectroscopy in the near future.


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