SINGLE MODE MID-INFRARED WAVEGUIDE FOR EVANESCENT SENSOR SCHEME IN LIQUIDS

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ABSTRACT

A Si/Ge based, single mode, mid-infrared optical waveguide, is used as an evanescent sensor in liquid matrix. The selectivity is achieved by the use of quantum cascade lasers (QCLs) tuned to the maximum absorption of a given analyte. The cocaine detection in human saliva at 5.81 microns is chosen as a pilot application to demonstrate the technology. Light emitted from the QCL is butt coupled into the Si/Ge waveguide. The waveguide is passing through the detection part of the micro-fluidic sample preparatory/handler, and interacting with the analyte, it is collected and guided into the mid infrared quantum cascade detector QCD.

KEY WORDS: Chemical sensor, Optical waveguide, Mid-infrared, Evanescent field

INTRODUCTION

Sensing Scheme

Biomedical applications of the mid-infrared spectroscopy represent a powerful tool with both high sensitivity and selectivity. In a difference to the majority of the state of the art bio-medical analytic methods, they allow for a low threshold label-free analysis by the means mid-infrared target laser spectroscopy. In addition there is a demand of a portable, real time, or automatic on-line sensing, where the mid infrared laser spectroscopy has potential. The availability of high radiance narrow-band light sources, such as quantum cascade lasers [1]. All organic substances (and many inorganic ones as well) have a strong and specific absorption somewhere in the mid-infrared band (3-25 microns). They correspond to the fundamentally (any hybrid) vibrotational states of the particular molecule. The low detection threshold and the specificity of the mid-infrared laser spectroscopy are given by the possibility of the selective interaction with these states. The traditional mid infrared spectroscopy method, is using a Fourier transform infrared spectrometer (FTIR) in combination with an attenuated total reflection (ATR). Being a bulky instrumentation, it possesses only a low potential for miniaturization and for integration into on-line sensing instruments or portable instruments.

We propose a chemical sensor based on a Si/Ge micro-structured mid-infrared waveguide, in combination with a micro-fluidic scheme performing the preparation and guiding of the liquid sample into the evanescent field of the waveguide. Figure 1 shows the scheme of the device. Light emitted from QCL is coupled into a single mode Germanium core waveguide. A part of the waveguide is embedded into the micro-fuidic channel, to enable the interaction of the evanescent field with the analyte. Cocaine detection in human saliva at 5.81 microns is chosen as a pilot application to demonstrate the technology [2]. Owing to the compact design of the sensing scheme, the light source, the light detector, and the integrated micro-fluidics, will be integrated on the same substrate, constituting a core of a portable device [3].

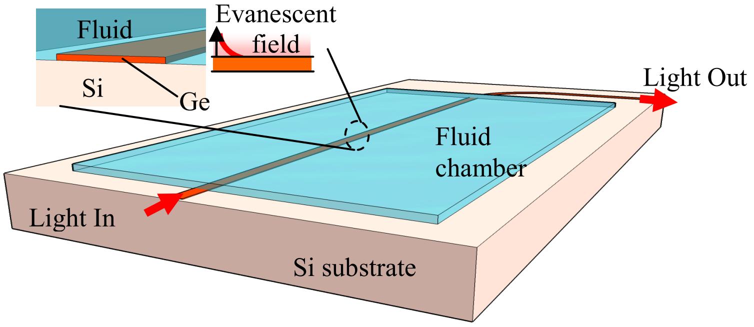

Figure 1: The scheme of the proposed sensor. The light emitted from the QCL is injected into a Si/Ge single mode waveguide. The evanescent field of the mode (about 5% of the injected light) is then interacting with the liquid analyte within the micro-fluidic channel. The light is collected and focused onto a quantum cascade detector.

Mid-infrared Germanium Waveguide

Germanium waveguides are fabricated out of a Germanium layer molecular beam epitaxy (MBE) grown on a Silicon substrate. A standard photolithography process is applied in combination with a reactive ion etching using a CF_4 chemistry. Since Ge and Si are both transparent in a wide mid-infrared range (2 ~ 18 μm), this material system can cover practically the whole mid-infrared range. Owing to this, the sensing scheme can be adapted for sensing of all possible analytes.

Figure 2 shows an SEM photo of a Ge waveguide. The waveguide profile is designed for optimum coupling (matching to the QCL waveguide geometry). The thickness is 1.1 microns and width is 15 microns. The waveguide is then tapered into a narrow 4.1 microns wide single-mode waveguide with a strong evanescent field. A waveguide bend and further elementary structures are designed in order to be able to compose various complex optical structures and schemes.

In Figure 3, the mode profile, simulated with the software CST Microwave-Studio is shown.

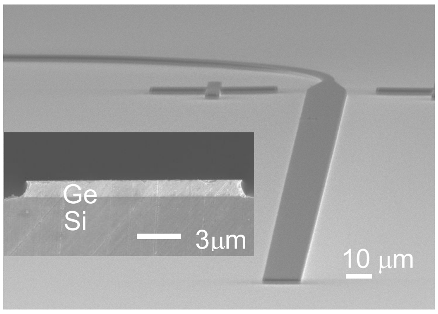

Figure 2: SEM photo of Ge waveguids on a Si substrate – top view and the cross section view (inset).

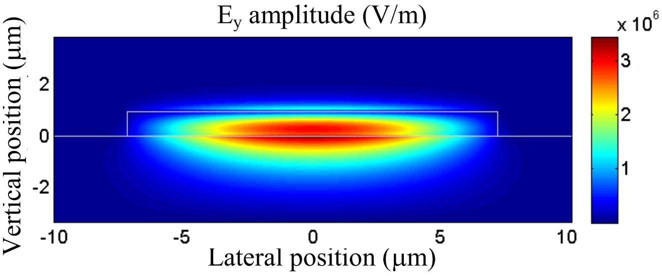

Figure 3: Simulation of the waveguide mode profile in the waveguide.

Optical Characterization

The optical characterization is performed in a butt coupling configuration. As shown in figure 4, a quantum cascade laser is positioned closely behind the waveguide entrance, and the emitted light is coupled into the waveguide in the near field of the laser, simply due to the overlap of the wave functions of the mode in the laser and in the waveguide. The light is passing an L-shaped waveguide (with a single 90° bend) and after exiting the waveguide it is collected by a system of off-axis parabolic mirrors onto a cryogenically cooled Mercury-Cadmium-Telluride (MCT) detector.

Propagation loss and bending loss of the waveguide are measured. The preliminary results show the nominal waveguide loss to be in the range of 5.3 dB/cm.

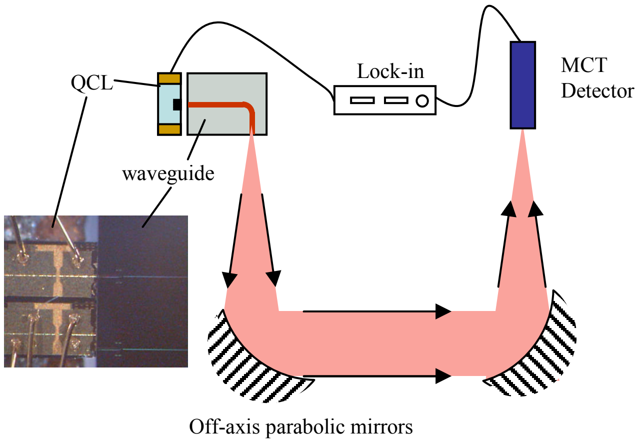

Fig. 4 The setup for optical characterization with a butt-coupling of the waveguide and the quantum cascade laser

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