Mid infrared waveguide spectroscopy for cocaine detection in liquid environments

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Summary

A germanium strip waveguide on a silicon substrate is integrated with a microfluidic chip to detect cocaine in tetrachloroethylene solutions. In the evanescent field of the waveguide, cocaine absorbs the light at 5.8μm, which is emitted from a quantum cascade laser. The lowest measured concentration is 100μg/ml.

Introduction

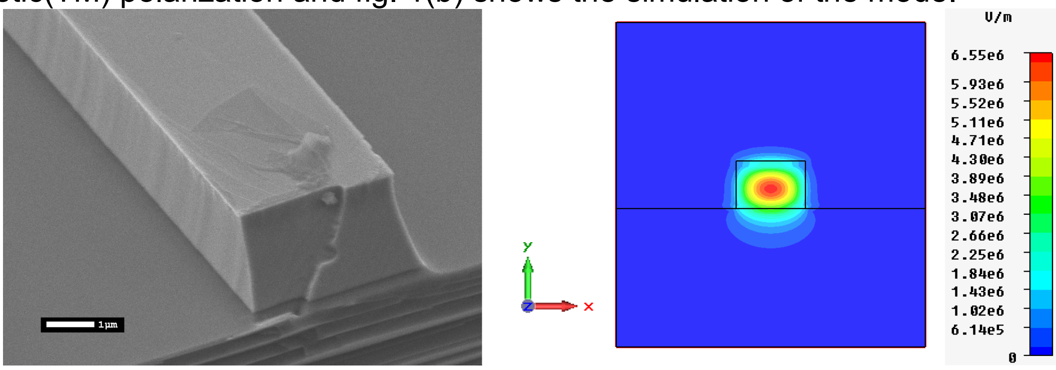
Mid-infrared (mid-IR) spectroscopy is widely used in chemical sensing and chemical identification because of its sensitivity and selectivity. In the liquid phase, ATR-FTIR (attenuated total reflection Fourier transform infrared spectroscopy) can analyze the samples in the evanescent field of total reflections. When the use of mid-IR spectroscopy is often limited in the laboratories due to the size of instruments, the emerging of quantum cascade lasers(QCLs) [1] promotes the development of compact and portable devices [2].

A single mode germanium strip waveguide on a silicon substrate is used here to measure the absorption from analytes in the evanescent field. Because of its small dimensions, the sample size can be reduced. Furthermore, it can be conveniently integrated with a microfluidic chip [3] for sample preparation and handling.

Cocaine detection is a pilot demonstration for this technology. The laser wavelength is selected to be one of cocaine's absorption peaks at 5.8μm [4].

Discussion

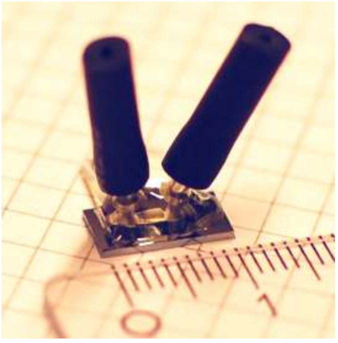
The waveguide is fabricated with a mono-crystalline germanium layer on a silicon substrate. It is low loss due to the low intrinsic absorption of the two materials in the mid-IR. Figure 1(a) shows the cross-section of the waveguide after standard lithography and reactive ion etching. It is designed to be single mode in transverse magnetic(TM) polarization and fig. 1(b) shows the simulation of the mode.

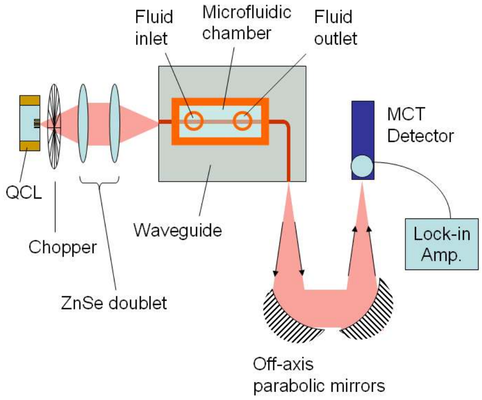


(a) (b)

Fig.1 (a) Scanning electron microscope image of the cross-section of a mono-crystalline germanium waveguide on a silicon substrate: The thickness is 2μm and the width is 2.9μm. (b) simulation of the TM fundamental mode at wavelength of 5.8μm

The waveguide is then bonded with a polymer microfluidic chip [3] and coupled to the QCL and a mercury-cadmium-telluride detector. Figure 2 shows the bonded chip and the measurement setup.





(a) (b)

Fig.2 (a) The waveguide bonded with a micro-fluidic chip: The channel is made from NOA81(Norland Optical adhesives). It is 1mm-wide and 7mm-long where the depth is 50μm. (b) Measurement setup: The waveguide is coupled to a QCL and a detector with lenses and mirrors.

Cocaine is dissolved into tetrachloroethylene, which is transparent in a wide range of mid-IR. The waveguide output intensity is measured when the cocaine concentration changes with time. Figure 3 is a preliminary measurement result and the lowest detected concentration is 100μg/ml, which can be improved by longer waveguides and lower system noise. The integrated microfluidic chip enables the possibilty to build a low-cost and disposable device with portability and a small sample volume.

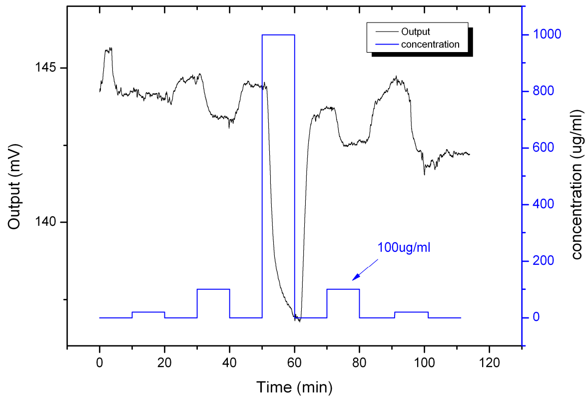


Fig.3 Cocaine measurement with different concentrations in tetrachloroethylene solutions: The lowest measured concentration is 100μg/ml

Conclusion

Mid-IR waveguide spectroscopy is demonstrated by cocaine detection and can be extended to other analytes by tuning the laser wavelength. It has great potential in portable devices for biomedical applications, or health and environmental monitoring.

References

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