Long-wave infrared upconversion spectroscropy

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Objectives

➢ A novel upconversion detection scheme will be investigated for following applications:

❑ Characterization of long-wave quantum cascade laser (QCL) system
- Fast pulse analysis for long-wave QCL

❑ Development of LWIR-upconversion spectroscopy
- Gas sensing for volatile organic compounds (VOCs)
  - Trichloroethylene (TCE)
  - Tetrachloroethylene (PCE)
- Food inspection
- Breath analysis

❑ Investigation of noise-reduction system for upconversion spectroscopy

❑ Investigation of nonlinear crystal for long-wave infrared (LWIR) upconversion
- 13-16 µm long-wave upconversion scheme with $AgGaSe_2$ crystal

Main idea of upconversion technology

➢ The frequency upconversion scheme is used to convert Mid Infrared (MIR) to near Infrared (NIR) in which detection is processed via silicon based camera offers :

✓ High quantum efficiency

✓ Low noise

✓ Cost efficient

✓ Room temperature operation

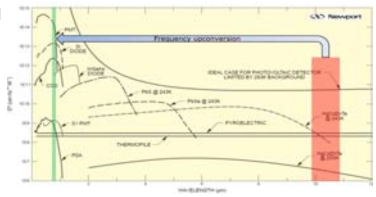

Figure 1. Overview of sensor detectivity

Status

➢ **Characterization of long-wave quantum cascade laser (QCL) via upconversion detection**

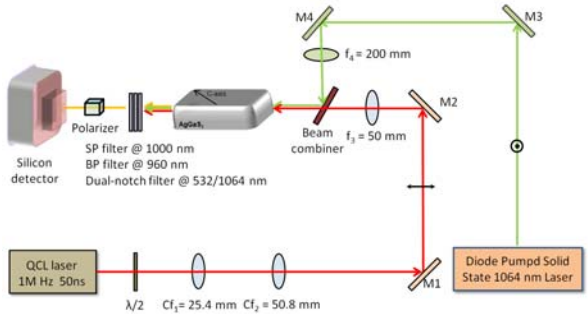

Figure 2(A). Schematic diagram of upconversion system

❑ Frequency conversion
- Energy conservation

$$\frac{1}{\lambda_{IR}} + \frac{1}{\lambda_P} = \frac{1}{\lambda_{UP}}$$

- Momentum conservation

$$\boldsymbol{k}_{IR} + \boldsymbol{k}_P = \boldsymbol{k}_{UP}\,;\ |\boldsymbol{k}_j| = \frac{2\pi}{\lambda_j}\, n(\lambda_j, \theta)$$

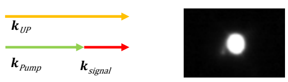

Figure 2(B). Collinear phase matching scheme

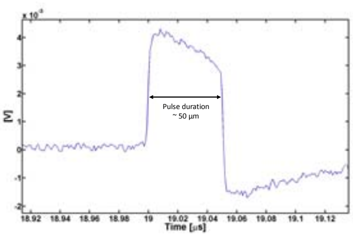

Figure 2(C). Optically measured pulse duration of QCL

➢ **Development of noise-reduction system via upconversion technique**

❑ Signal and reference performs identically to compensate noises generated during measurement by rationing.

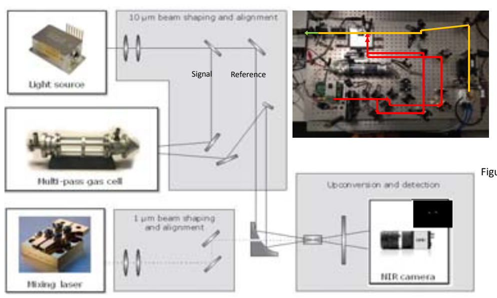

Figure 3(A). Schematic diagram of noise reduction system

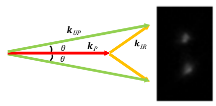

Figure 3(B). Non-collinear phase matching scheme

❑ The correlation between signal and reference presents to what degree the system will be able to compensate noises

❑ The correlation tested by varying power and wavelength of QCL and power of mixing laser shown in Fig.4(A)-(B) presents the amplitude noise and power fluctuations that can be compensated using common mode rejection

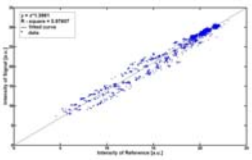

Figure 4(A). Correlation of signal and reference by power and wavelength tuning as seen in (B)

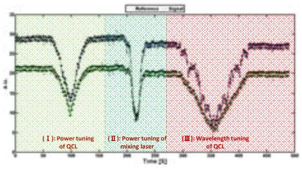

Figure 4(B). Intensity of signal and reference measured via CCD detector

❑ The high R - squares shown in Fig.4(C)-(E) shows the potential for common mode noise reduction.

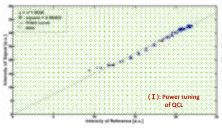

Figure 4(C). Signal / Reference correlation from power variation of the QCL

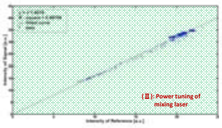

Figure 4(D). Correlation originating from power variations of mixing laser

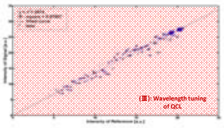

Figure 4(E). Correlation from wavelength tuning of QCL, which also alters the power

Secondments

➢ **Planed organizations to go: Humboldt-Universität zu Berlin (HUB), FOSS, and Rambøll**

❑ HUB (with ESR-10):
- o 1st stay : 23rd – 25th of November in 2016.
- – To learn QCL system and get preliminary results to make plans for following stay
- o Planed 2nd stay : To investigate long-wave infrared QCL above 13 µm wavelength using upconversion technology
- – Joint publication: Investigation of long-wave infrared quantum cascade laser using upconversion technique

❑ FOSS
- Joint publication : Food inspection in long-wave region (9 - 13 µm) using upconversion spectroscopy

❑ Rambøll
- Joint publication : Real time measurement of Trichloroethylene and Tetrachloroethylene components at contaminated sites

Publications accepted and progressed

➢ **Accepted publication:**

❑ "Development and test of optical sensor for real time measurement of volatile organic contaminants in air", Poster Presentation (D3) at 10th international conference on remediation of chlorinated and recalcitrant compounds, Palm Springs, California, USA, 22nd – 26th of May, 2016.

➢ **Progress:**

❑ "Upconversion detection of long-wave infrared radiation from quantum cascade laser ". Authors: Y-P. Tseng, P. Tidemand-Lichtenberg, and C. Pedersen. Year of publication: January, 2017

❑ "Investigation of long-wave infrared quantum cascade laser using upconversion technique". CLEO®/Europe-EQEC , June, 2017 (Joint conference paper)

❑ "High-sensitive gas sensing using quantum cascade laser illumination and upconversion detection". Authors: Y-P. Tseng, P. Tidemand-Lichtenberg, C. Pedersen, and industrial partners. Year of publication: May - June, 2017

❑ **Followings:**
- Food inspection in long-wave region using upconversion spectroscopy (with FOSS)
- Real time measurement of Trichloroethylene (TCE) and tetrachloroethylene (PCE) components at contaminated site (with Rambøll)
- Potential medical application for breath analysis using upconversion detection

ECTS credits obtained

✓ Mid-IR science and technology, 5 ECTS, February, 2016

✓ Noise in electromagnetic and optical systems, 5 ECTS, March – July, 2016

✓ Entrepreneurship in mid-IR technologies, 5 ECTS, August, 2016

✓ Progress : Biomedical Optics, 5 ECTS, December, 2016

✓ Planed : Leadership development for tomorrow's mid-IR technologies and applications, 5 ECTS, 2017