Development of Volume Bragg gratings for the hyperspectral imaging of greenhouse gases

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Introduction

Due to climate change, northern regions are currently undergoing important transformations. Notably, the reinforced **melting of permafrost** in **thermokarst** lakes generates important quantities of **greenhouse gases**. Monitoring these gas outflows precisely would therefore offer a better understanding of the influence that climate has on northern regions.

For that matter, **hyperspectral imaging** is a promising technique as it would allow to **spatially map**, for the first time, the emitted gas fluxes in **real time** in a **hard-to-access** environment like a **thermokarst lake**. More precisely, imaging in the mid-infrared **(3 – 5 µm)** is particularly interesting as these gases have strong unique resonances in this region.

We will therefore develop, with our collaborators at ***Photon etc.,*** the first hyperspectral camera using a **Volume Bragg grating (VBG)** in the mid-infrared, personalized for the detection of gases emitted by thermokarst lakes.

Experimental setup

Volume Bragg grating filtering

- VBGs are glass bulks with a periodic refractive index, therefore acting as effective **spectral filters** with record **tunability** and **selectivity**
- The company *Photon etc.* developed a hyperspectral imaging approach based on the use of VBGs that is now widespread in many applications from the visible to the near-infrared[1]
- **Hyperspectral imaging** combines **spectroscopy** and standard imaging in a single system. It allows to obtain a series of **monochromatic images** of a given object over a large **range of wavelengths**

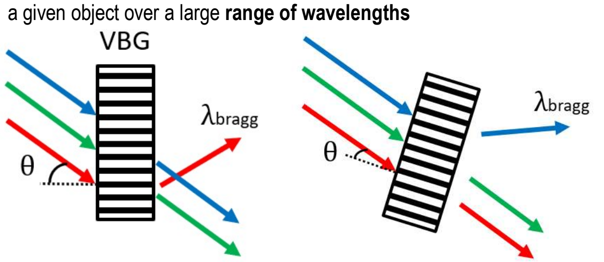

Figure 1. Wavelength selection of the VBG depending on the angle between itself and the incident light .

- The wavelength of the monochromatic image sent to the camera's pixel detectors is chosen by **rotating the VBG** with regards to the incident light
- This approach has **not been used in the mid-infrared yet** due to the strong absorption of the VBGs sold on the market[2]. Therefore, we will apply an innovative method to inscribe the **first mid-IR VBGs**

Gas sensing

- We will use an **active imaging** technique that consists of **shining a laser** on the gas volume above the lake and looking at the absorption resonances in the transmitted spectrum of the pixels

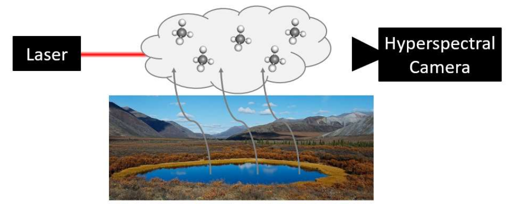

Figure 2. Proposed setup to map the greenhouse gas fluxes above the thermokarst lakes[3]

- A supercontinuum laser with a **broad spectrum** covering the whole **3 – 5 µm range** has been developed
- It allows to **simultaneously detect** several gases
  - H_2O at 3.2 µm
  - CH_4 at 3.2 µm
  - CO_2 at 4.3 µm
  - N_2O at 4.5 µm
- Advantages of active VBG-based hyperspectral imaging
  - ✓ It does **not require light** from the **ambient** environment
  - ✓ The camera is **robust** and not **sensitive to misalignment**
  - ✓ Temperature has little impact on the camera performances
  - ✓ It allows **real-time imaging** without extensive calculations and data storage

Results

- We have already demonstrated the **first VBG** ever **inscribed in a fluoride glass** (transparent up to 7 µm)[4]

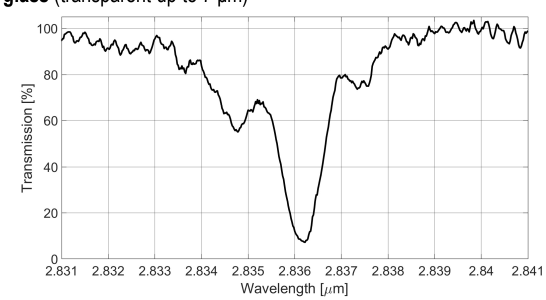

Figure 3. Transmission spectrum of a VBG showcasing a strong diffraction peak at the Bragg wavelength

- Different types of glasses will also be investigated (silica, fluoride and chalcogenide glass)
- By changing the angle between the incoming light and the VBG, we **tuned the selected wavelength over an interval of 250 nm**

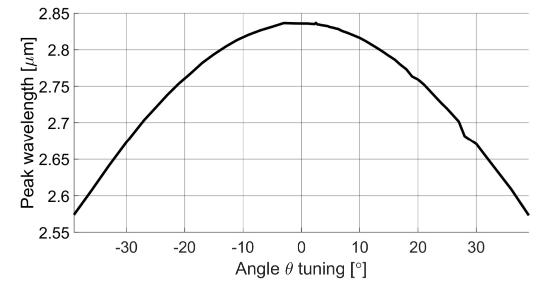

Figure 4. Angular tuning of the VBG's Bragg wavelength

- Further optimization of the VBG inscription setup will allow us to obtain VBGs that cover the whole 3 – 5 µm
- The VBGs are inscribed by focusing highly powerful laser pulses (femtosecond pulses) inside the glass and shaping the incident laser beam (with a phase mask) in a periodic way

Conclusion

- We have demonstrated the inscription of the first VBG obtained inside a mid-IR glass. Despite its very promising performances, we will have to optimize our VBG inscription setup to produce components tailored for the hyperspectral imaging of gases
- We will work with *Photon etc.* to develop such new VBGs and implement them in the **first hyperspectral camera using VBGs in the mid-infrared**
- This system will then be deployed in a northern **thermokarst in the Tasiapik valley** to study the release of greenhouse gases

References

[1] D. Roxbury et al., Scientific Reports 5.1, 1-6 (2015)

[2] O.M. Efimov et al., Applied Optics 38.4, 619-627 (1999)

[3] Image: Keith Williams via Flickr, https://www.flickr.com/photos/keithmwilliams

[4] L. Talbot et al., Optics Letters 45.13, 3626-3629 (2020)

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