

# Very Low Frequency Stokes and Anti-Stokes Raman Spectra Accessible with a Single Multichannel Spectrograph and Volume Bragg Grating Optical Filters

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## INTRODUCTION

Multichannel measurement of Raman bands with frequencies very close to the excitation line has traditionally been possible with the use of triple monochromator systems<sup>1,2</sup>. These systems are very flexible, but they can be complex to use, large, low in throughput, and expensive. We have recently demonstrated the use of a single monochromator Raman system where the Rayleigh filtering elements are made of Volume Bragg Gratings (VBGs); such a system enabled recording of Stokes and anti-Stokes modes with frequencies less than 10 cm<sup>-1</sup>.

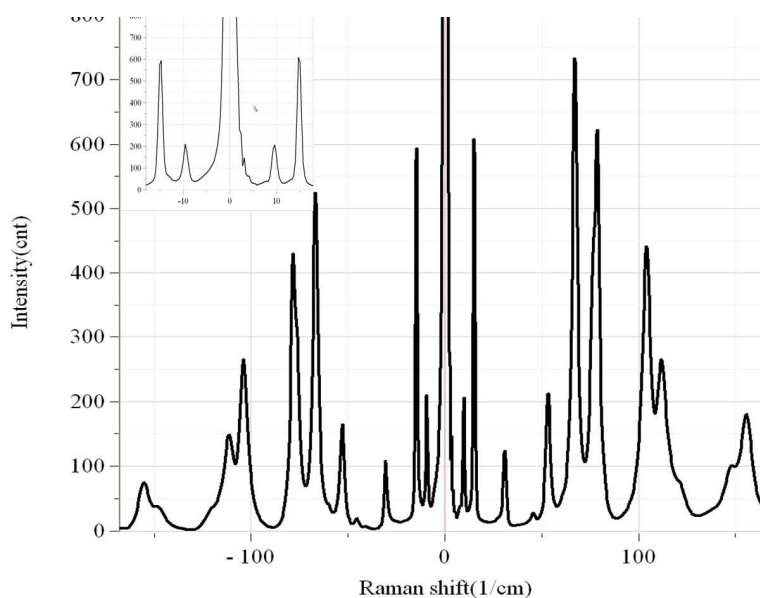
## Results

A red Helium Neon laser (HeNe, 632.8 nm wavelength) was used for the measurements presented. The HeNe laser beam was cleaned from its plasma lines with a BragGrate<sup>TM</sup> Bandpass filter with a linewidth of about 4 cm<sup>-1</sup> (FWHM). The bandpass filter is a reflecting VBG with a diffraction efficiency ~95%, which can be easily angle-tuned to the resonant wavelength of the laser.

Measurements of Raman modes with frequencies below 10 cm<sup>-1</sup> in a single monochromator system were enabled by BragGrate<sup>TM</sup> Notch filters (BNFs). A BNF is a reflecting VBG formed by holographic techniques in bulk photo-thermo-refractive glass<sup>3</sup>. After latent holographic image formation by UV irradiation, the glass substrates are thermally developed, so that the developed filters have high diffraction efficiency and throughput, high laser induced damage threshold (>1 kW/cm<sup>2</sup>), are not susceptible to degradation by humidity, and can operate at temperatures up to 450°C. No organic materials are used in BNF fabrication. Specially developed technology of

high efficiency VBGs allows fabrication of a single 3-4 mm thick notch filter at 632.8 nm with optical density 3-4, and the line width of 5-10  $\text{cm}^{-1}$  at FWHM. At 785 nm, BNFs have optical density of 4-5 and transmission of 90-95%.

Using three BNFs, the Stokes and Anti-Stokes spectra of l-cysteine were easily measured simultaneously well below 10  $\text{cm}^{-1}$  (see Fig.1). The l-cysteine spectrum obtained was very symmetric, taking into account the Boltzmann population of the Stokes and anti-Stokes energy levels involved.



**FIGURE 1.** Spectrum of powdered l-cysteine measured with a LabRamHR and 3 BNFs. The inlay shows a zoom of the very-low frequency region. The Stokes and Anti-Stokes lines at  $9\text{cm}^{-1}$  are clearly defined, and the neon plasma lines are well eliminated with the BraggGrate bandpass filter.

The 632.8 nm BNFs used in the measurements had anti-reflection coatings and each had a transmission in the Raman region greater than 80%. This resulted in a total transmission efficiency for the three filters that exceeded 50 %, which is better than the throughput of the first 2 stages of a triple monochromator system. Furthermore, the transmission of each filter was above 50% over the entire visible range, 450 to 1100 nm, and was without any defined features such as those exhibited by dielectric edge filters which can perturb a spectrum if left uncorrected.

Due to better performance of VBGs in near IR region, the first very low Raman frequency measurements were done at 632.8 and 785 nm, but current work is in progress to implement filters at shorter wavelengths such as 488 and 532 nm.

## REFERENCES

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