Simultaneous Stokes and anti-Stokes Measurements of Raman Signals at 785nm with Volume Holographic Grating (VHG) Filters

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Introduction

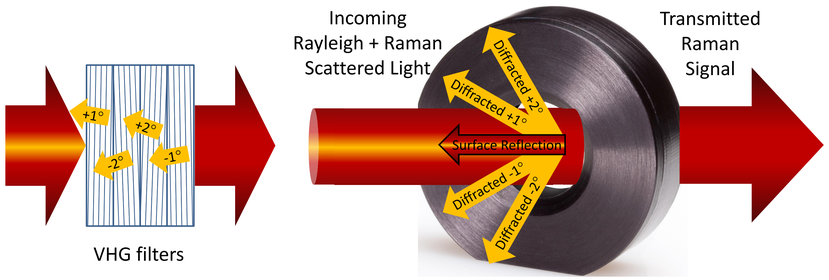
Volume Holographic Grating (VHG) based notch filters have significant advantages over traditional edge filters in their ability to simultaneously measure both Stokes and anti-Stokes Raman signals to within 10cm^{-1} of the excitation wavelength with high throughput.

These characteristics are particularly useful for measurements of:

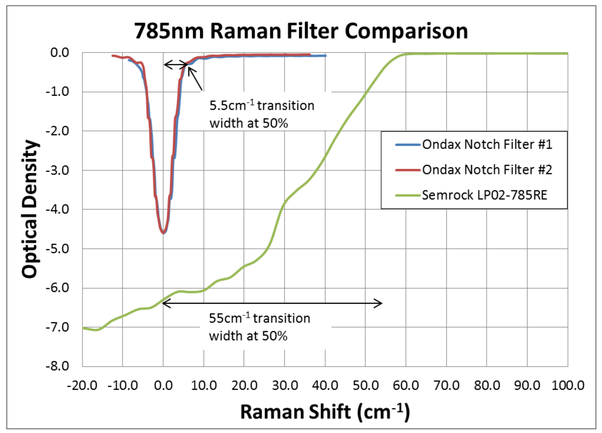
- Folded acoustic modes of multilayer superlattice structures in advanced semiconductor devices
- Vibrations of compounds that contain heavy atoms
- Radial breathing modes (RBM) of single and multi-wall carbon nanotubes
- Relaxation modes of various liquids and solutions
- Rotational modes of gases based on bond length

Previously reported measurements made with VHG filters had been limited to gas or DPSS lasers by imperfect filtering of laser sidebands for diode lasers at 785nm.

Using an 80mW Ondax SureLock™ wavelength stabilized 785nm laser to produce a stable, narrow linewidth source with a Ondax NoiseBlock™ ASE suppression and SureBlock™ ultra narrow-band notch filters to eliminate the broadband ASE light, we were able to produce high quality ultra-low frequency Raman measurements showing clear signals as low as 4cm^{-1}.



The stacked VHG notch filter assembly selectively diffracts only the incoming light within 10cm^{-1} of the excitation line, and transmits the Raman scattered light with extremely high throughput of 90% at 785nm. Each filter comes in a standard 1" ∅ housing with a 9.5mm ∅ opening.



A spectral comparison of the Ondax filters used in this experiment with a low frequency edge filter shows an order of magnitude improvement in transition width with OD 4.5 rejection.

Experimental Setup Used to Make Raman Measurements

Princeton Instruments SpectraPro 2300i imaging spectrograph

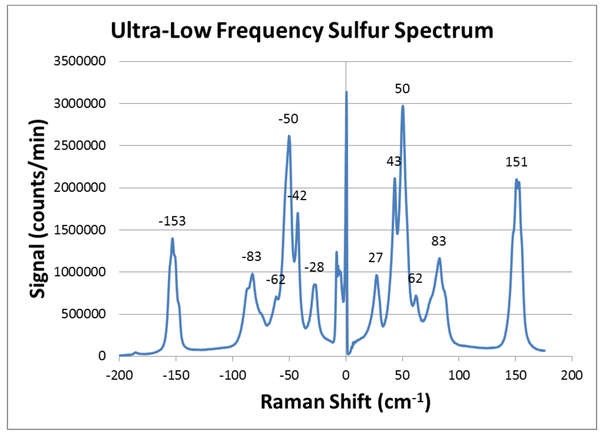
Ondax SureBlock™ Ultra Narrow-Band Notch Filters

Ondax NoiseBlock™ ASE Suppression Filter

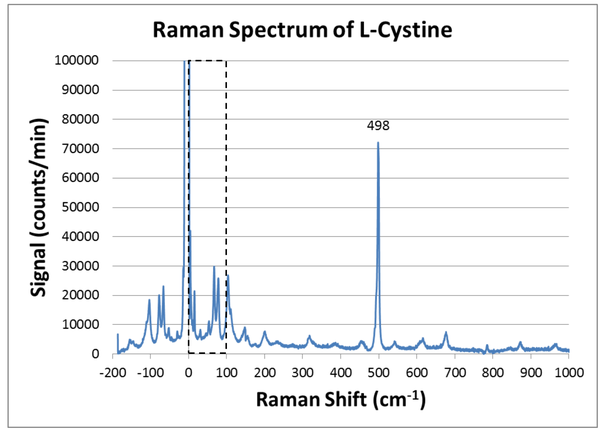
Ondax SureLock™ 785nm, 80mW wavelength stabilized Raman laser

Key Requirements for Ultra-Low Frequency Raman Measurements

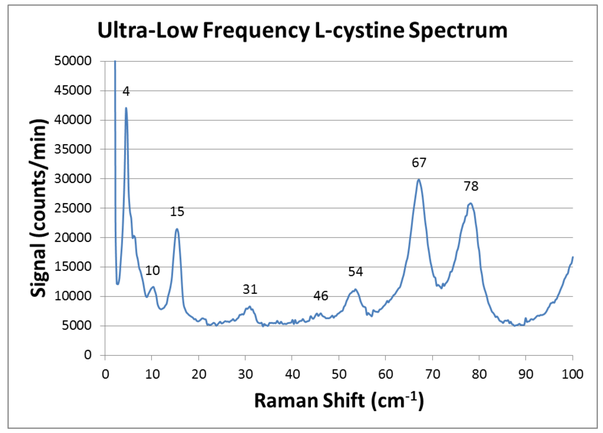
- Spectrometer with High Resolution Grating - >1500 lines/mm for best performance
- Ultra-Narrow Band Notch Filters – Block excitation light, transmit signals >10cm^{-1}
- ASE Suppression Filter – Suppress ASE in diode lasers
  - — Suppress nearby parasitic modes of gas/solid state lasers
- Wavelength Stabilized Laser – VHG stabilized diode laser or gas/solid-state laser



Five well defined peaks below 100cm^{-1} are simultaneously observed for both Stokes and anti-Stokes signals. The Rayleigh suppression capability of the notch filters is clearly evident, reducing the signal to a level that is comparable to the surrounding Raman scattered signals.



L-Cystine exhibits numerous peaks below 100cm^{-1} that are comparable to the strong disulfide bond (S-S) at ~500cm^{-1}.



The ultra-low frequency region (<100cm^{-1}) of L-Cystine shows 4 strong peaks as low as 4cm^{-1} and 3 weaker peaks. The large number of strong peaks make material identification much easier by requiring a smaller calibration range and shorter integration times.

Conclusion

The first reported measurements of ultra-low frequency Stokes and anti-Stokes Raman spectra with VHG filters at 785nm show clear strong signals as low as 4cm^{-1} from the excitation wavelength.

The results are comparable to triple-stage spectrometers but have much higher throughput at a fraction of the size and cost, using only a single stage Princeton Instruments imaging spectrograph, an Ondax 785nm VHG wavelength stabilized laser, and well matched ASE and ultra-narrow band notch filters.

This new capability enables compact solutions for the measurement of a variety of important materials.

Ondax SureBlock™ ultra-narrow band notch filters and NoiseBlock™ ASE suppression filters are currently available for all Raman wavelengths from 400nm to >2000nm.

Ondax SureLock™ wavelength stabilized lasers are currently available at common Raman wavelengths of 405nm, 640nm, 658nm, 690nm, 780.25nm, 785nm, 808nm and 830nm.

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