Low-Frequency Raman Spectroscopy – Enabling Affordable Access to the Terahertz Regime

James Carriere and Frank Havermeyer
Ondax, Inc: Booth #48
SCIX/FACSS: 10/3/2012
Low-frequency Raman scattering probes the same energy range as Terahertz spectrometers

- $10 \text{cm}^{-1} – 100 \text{cm}^{-1} \Rightarrow 300 \text{GHz} – 3 \text{THz}$

<table>
<thead>
<tr>
<th></th>
<th>Low-frequency Raman</th>
<th>Terahertz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>Economical</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>Easy to use</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>Real-time data</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>No special sample preparation required</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>Large penetration depth</td>
<td>✗</td>
<td>✔</td>
</tr>
</tbody>
</table>
How do Raman and THz Spectroscopy Work?

Molecular Energy Level Diagrams

**Rayleigh Scatter**
- **Virtual State**: N
- **Elastic scatter**: excitation and scattered photons have the same energy
- **hv**: Absorption

**Stokes Scatter**
- **Virtual State**: N
- **Inelastic scatter**: molecule absorbs energy from photon and emits lower energy photon
- **hv** and **h(ν−Δν)**

**anti-Stokes Scatter**
- **Virtual State**: N
- **Inelastic scatter**: molecule absorbs energy from photon and emits higher energy photon
- **hv** and **h(ν+Δν)**

**THz Absorption**
- **Virtual State**: N
- **Absorption**: photon absorbed by molecule, increasing the energy state
- **h(Δν)**
**Spectral Range & Resolution**

**Terahertz:**
- Frequency is scanned over the spectral range
- Systems limited to 10s of GHz up to ~6 THz (~1cm\(^{-1}\) – 200cm\(^{-1}\))
- Resolution determined by step size

**Low-frequency Raman:**
- Entire spectral range is measured with a CCD camera
- Can measure both Stokes and anti-Stokes from <10cm\(^{-1}\) to >5000cm\(^{-1}\) (300GHz – 150THz)
- Resolution is determined by number of camera pixels and size of spectrometer
Scan Time & SNR

Terahertz:
- Each measurement is for a single frequency
- Scan time determined by number of data points and integration time

Low-frequency Raman:
- SNR is based on:
  - total integration time
  - laser power at the sample
  - sample scattering probability

Typical THz measurement:
- 15 GHz spectral resolution
- 2000 points
- 1 sec per point
  - 30 minutes scan time, 3 THz range
  - SNR ~100

Typical Low-frequency Raman measurement:
- <1 cm⁻¹ spectral resolution
- 1024-2048 pixels
- 1-10 sec integration time
  - 10 second scan time, 650 cm⁻¹ range
  - SNR ~10-100
Experimental Setup

Andor Technology Shamrock 500 Imaging Spectrograph with 1800 lines/mm Diffraction Grating

Newton or iDus CCD Camera

Ondax SureBlock™ Ultra Narrow-Band Notch Filters

Ondax NoiseBlock™ 90/10 Beamsplitter Filter

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

Ondax NoiseBlock™ ASE Suppression Filter

Sample

Combined OD 9 performance from a system the size of a sheet of paper

www.ondax.com
Raman Measurements with VHG Notch Filters

Cascaded VHG filters
Transmit Raman signal
Block Rayleigh scatter

Each Filter has
Optical Density >4

10X narrower bandwidth
than thin film filters
Simultaneous Stokes and anti-Stokes measurements

Rayleigh/Raman Ratio = 3.4%

Strong Raman signal is an order of magnitude improvement over multi-stage systems!
L-Cystine Spectrum – 532nm

Clearly resolved signals < 10cm\(^{-1}\)

Raman Shift (cm\(^{-1}\)/THz)

L-Cystine

anti-Stokes

Stokes

Raman Signal (a.u.)
Carbamazepine


Data taken with an Andor SR303i system at 532nm, equipped with Ondax notch filters
1,1,4,4-Tetraphenyl-1,3-butadiene

Samples courtesy of Prof. Alberto Girlando, University of Genoa

Data taken with a Renishaw InVia system at 514nm, equipped with Ondax notch filters.
Common Pharma Products with Low-frequency Signatures

- Many common pharmaceuticals exhibit strong low-frequency Raman signatures.

Data taken with a PI 2300i system at 785nm, equipped with Ondax notch filters.
- Commonly used excipient
- Spectrum similar to certain high explosives
- THz absorption peaks at 540 GHz, 1.2 THz, 1.38 THz
- Equivalent weak Raman peaks at 18 cm\(^{-1}\), 40 cm\(^{-1}\), 46 cm\(^{-1}\)

Data taken with an Andor SR303i system at 532 nm, equipped with Ondax notch filters
Caffeine Hydrate

- Commonly used excipient
- Weak low frequency Raman signals

Data taken with an Andor SR303i system at 532nm, equipped with Ondax notch filters


- Stokes/anti-Stokes signal ratio can be used to measure in-situ temperatures

Data taken with an Andor SR303i system at 532nm, equipped with Ondax notch filters
Ondax XLF-CLM Live Demo

Carbamazepine – Form III
Conclusions

• Demonstrated an economical solution to making low-frequency Raman measurements
• Simple and easy to use
• Real time measurements
• Enables discrimination between different polymorphic compounds
• Viable alternative to Terahertz spectrometers
Acknowledgements

• Andor
• Princeton Instruments
• Renishaw
• Laser Quantum
Thank You!

- Come see Ondax’s Live demo of our new XLF-CLM Raman System in Booth #48