Index of Refraction of Solid *para*-Hydrogen

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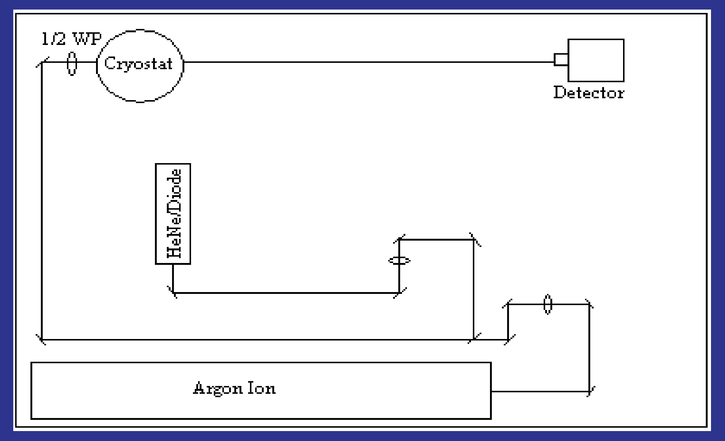
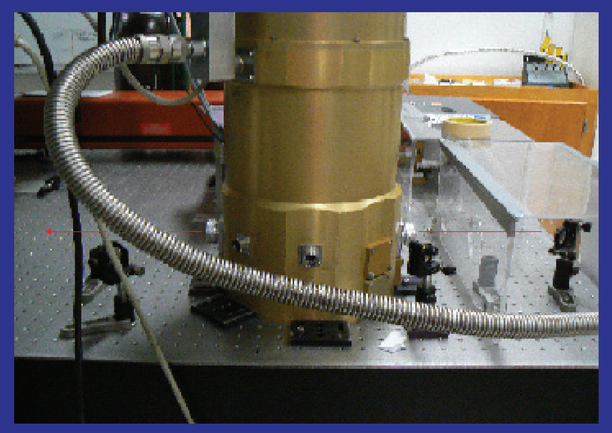
EXPERIMENT

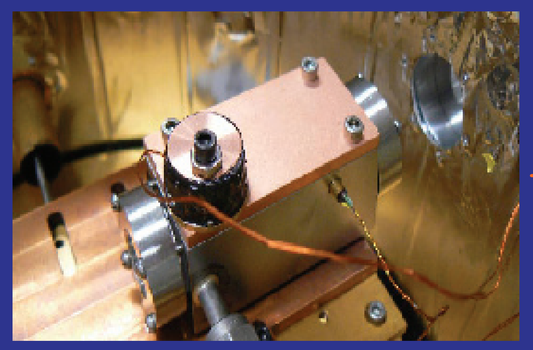


- ~99.9% pure *para*-hydrogen produced using *para*-hydrogen converter[2]
- Three light sources to measure the index of refraction:
  - Argon Ion (476, 496, 514 nm)
  - Helium Neon (633 nm)
  - Diode Laser (950 nm)

- Crystal growth from crystallization of liquid through the triple point (13.8 K)
- Optical windows of the cryostat allow light to pass through the crystal
- Conditions studied:
  - Temperature (density)
  - Wavelength of light
  - Angle of polarization



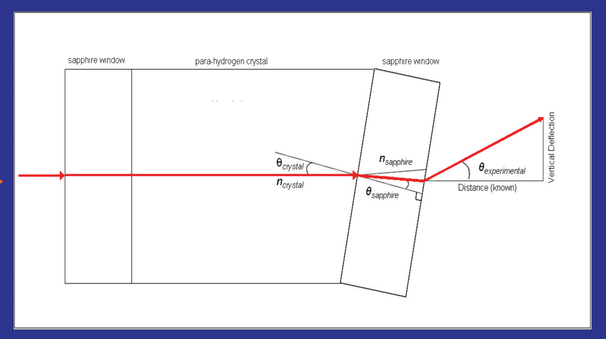
HYDROGEN CRYSTAL CELL



- Cell is designed to reach 4.3 K, using liquid He, with minimal heat loss
- Indium gaskets to seal the windows
- Copper pin on top of cell to initiate crystal growth
- Exit window tilted intentionally to produce a vertical deflection as light exits the cell

DERIVING THE INDEX OF REFRACTION

- Back reflection of windows are used to determine the angle of cell with respect to the table and angle of tilted window
- Vertical deflection as light passes through the crystal experimentally determined
- Using Snell's Law and the trigonometry of the cell, we can relate the refractive index to the vertical deflection

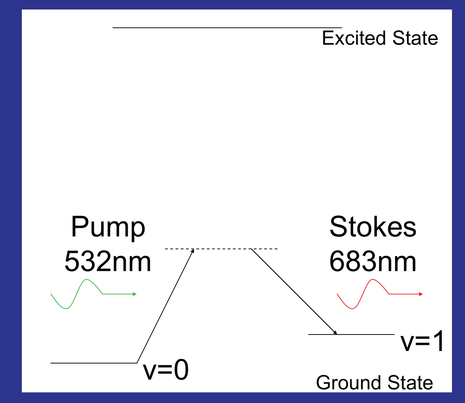


Snell's Law: $n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2$

$$\sin^{-1}\left[\frac{n_v}{n_c}\times\sin\left(90-\theta_p\right)\right]=\sin^{-1}\left[\frac{n_v}{n_c}\times\sin\left[\sin^{-1}\left[\frac{n_a}{n_v}\times\sin\theta_6\right]+90-\theta_a\right]\right]+\theta_a-\theta_p$$

MOTIVATION

- The mid-infrared spectral region (4.4 -11 μm) is important for the study of characteristic vibrations of molecules in interstellar space. Commercially available continuous wave (cw) light sources of mid-infrared region are limited and include numerous gaps.
- Hydrogen gas has effectively been used to produce light from Stimulated Raman Scattering (SRS)[1]. The use of SRS through solid hydrogen offers the ability to produce light at 4.4 – 8 μm with a gain of ~7000 times greater than hydrogen gas
- We are planning to create a cw-Raman laser using solid *para*-hydrogen. It is important to know the basic optical property of refractive index for solid *para*-hydrogen prior to using it as the lasing medium



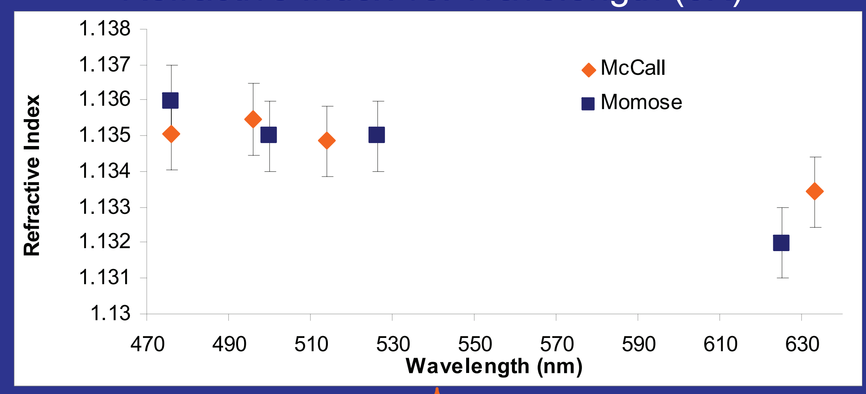
Energy levels in H_2 for cw-Raman laser. Note that the virtual level (dashed line) is associated with first electronic excited level[1].

RESULTS

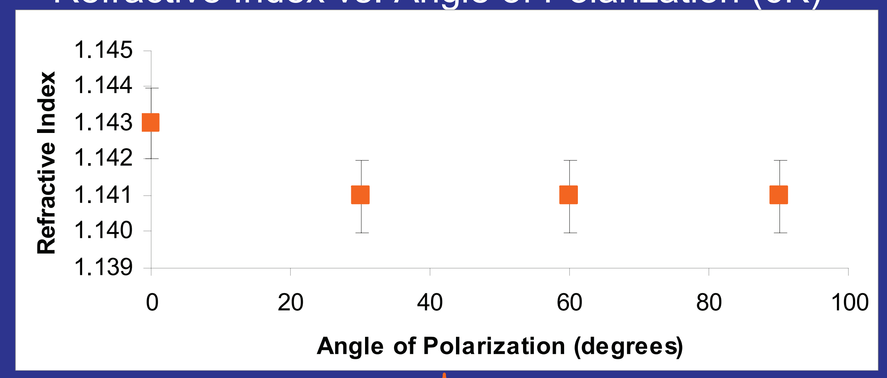
IMPROVEMENTS

- Added radiation baffles inside cryostat windows to reduce heat from room light
- Increased surface contact by adding indium foil as a spacer
- Improved heat switch mechanism

Refractive Index vs. Wavelength (6K)



Refractive Index vs. Angle of Polarization (6K)



- No significant change in refractive index with linear polarization of IR light

- Refractive Index ~ 1.135
- General trend suggests a small decrease in the refractive index with higher wavelengths of light
- Data consistent with previous lab work by Momose and co-workers

FUTURE WORK

- Determine temperature dependence of refractive index

1. J. K. Brasseur, K. S. Repasky, J. L. Carlsten, *Optics Letters*, **23**, 367, (1998).
2. B. Tom, S. Bhasker, Y. Miyamoto, T. Momose, B. McCall, *Rev. Sci. Instrum.* **80**, 16108 (2009).