NIST

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Wavelength References for Optical Fiber Communications

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NIST

Bandwidth Mining

Wavelength Division Multiplexing (WDM)

multiple channels of different wavelengths in the 1500 nm region (send more information down existing fiber)

use erbium-doped fiber amplifiers
all optical amplification; preserves wavelength

early systems: ~ 1 nm (~ 100 GHz) channel spacing

closer spacing starting

will likely expand into other wavelength regions

Wavelength Calibration

Need wavelength standards in the 1500 nm region to:

- *evaluate WDM optical components & set channels*
- *calibrate fiber Bragg grating sensor systems*

Current industry calibration needs

0.01 - 0.0001 nm accuracy

single point calibration & linearity measurement

NIST Approach:

- *Develop high accuracy wavelength standards for NIST internal calibration*
- *Develop moderate accuracy transfer standards to help industry calibrate instrumentation*

Recipe for a Wavelength Standard

Atomic or molecular absorption lines

fundamental resonances

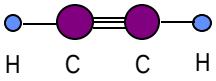
very stable under changing environmental conditions

Good references in the 1500 nm region:

acetylene
hydrogen cyanide
rubidium
noble gas emission lines (neon, krypton, xenon)

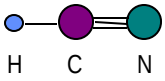
Transfer Standards
Molecular Absorption References

acetylene



Vibrational combination band
$\nu_1 + \nu_3$

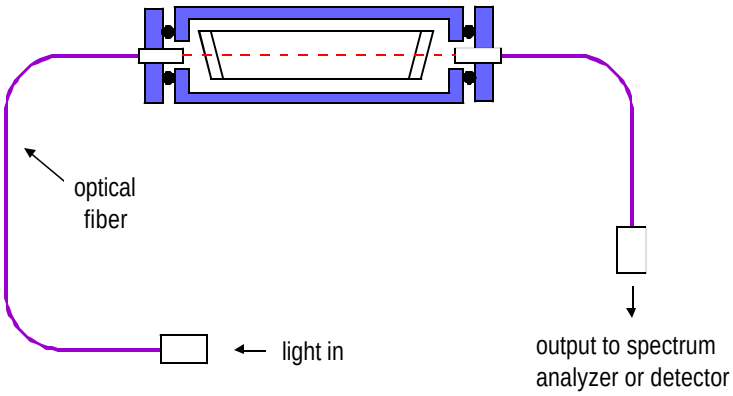
Hydrogen cyanide



Vibrational overtone band
$2\nu_3$

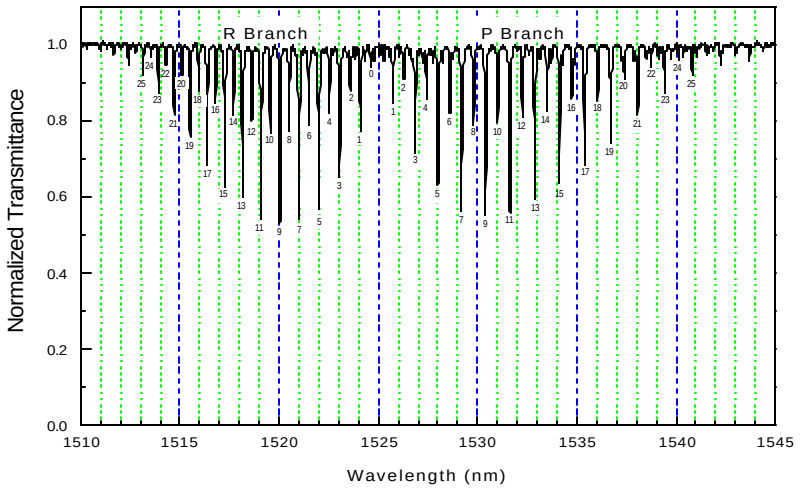
Both mainly H— C stretching vibration + rotational substructure

Acetylene
NIST Standard Reference Material 2517



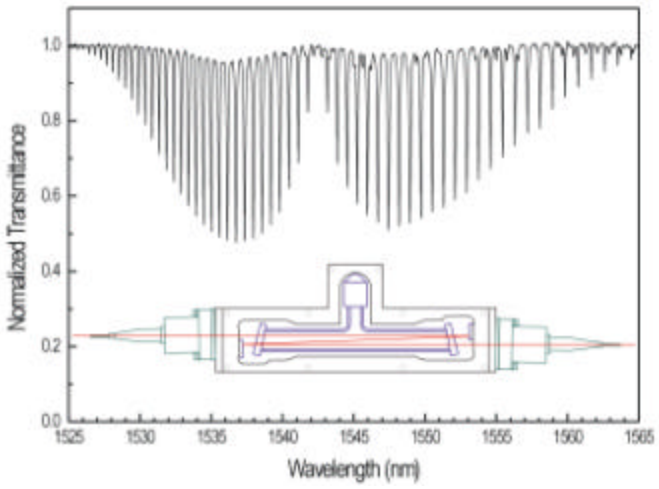
NIST Standard Reference Material 2517

Absorption of LED light by acetylene ($^{12}C_2H_2$)



NIST Standard Reference Material 2519

Absorption of LED light by hydrogen cyanide ($H^{13}C^{14}N$)



Wavelength SRMs

Characteristics of current SRMs:

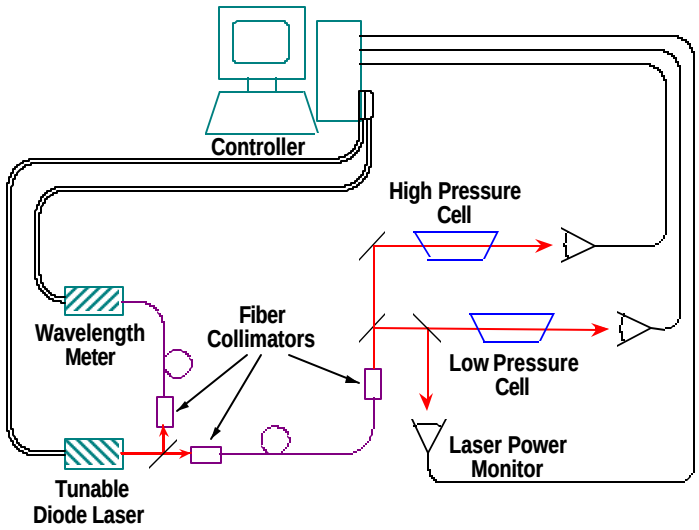
- *2 units cover 1510 – 1565 nm*
- *linewidths ~ 20 – 100 pm*
  - acetylene pressure: 27 kPa (200 Torr)
  - hydrogen cyanide pressure: 13 kPa (100 Torr)
- *line center accuracy certified with 0.6 pm uncertainty*
  - includes pressure shift

Have received requests for higher resolution and accuracy

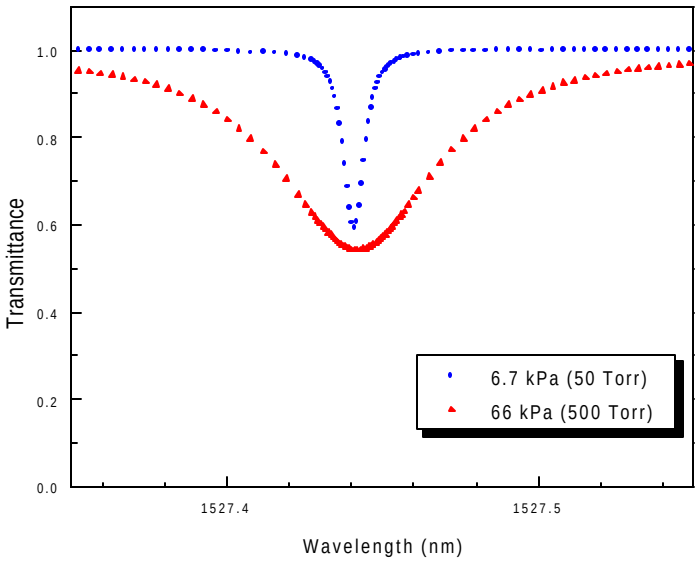
Developing high resolution wavelength reference SRM

- *acetylene $^{12}C_2H_2$*
- *narrow linewidth*
- *line center uncertainty near 0.1 pm » 12 MHz*
  - need higher-accuracy measurement of pressure shift

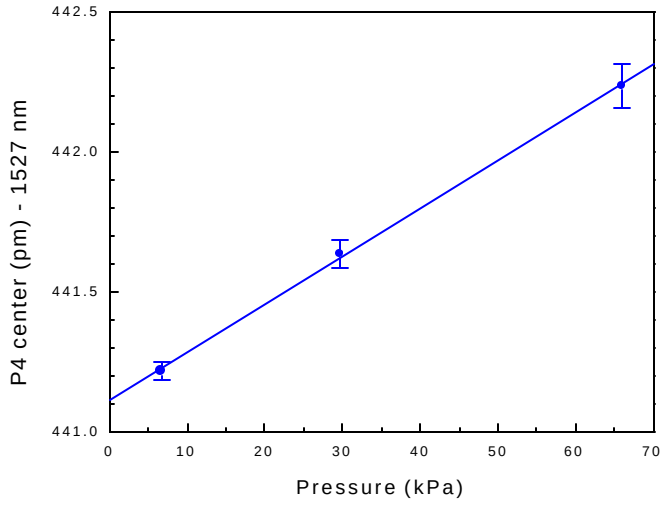
Pressure Shift Measurement Apparatus



Pressure Shift Measurement



Acetylene Pressure Shift – Line P4



P4 shift = + 0.017(2) pm/kPa [0.0023 pm/Torr or –0.29(3) MHz/Torr]

Pressure Shift Results

Measured shift for 15 acetylene lines

+0.008 pm/kPa < $\mathcal{D}n$ < +0.043 pm/kPa

typically +0.017 pm/kPa (= 2.3×10^{-3} pm/Torr = –0.29 MHz/Torr)

For proposed 7 kPa (50 Torr) high-resolution SRM:

- most lines shifted by about 0.1 pm
- largest shift 0.3 pm
- linewidths would be about 6 pm (750 MHz)

Other Shift Mechanisms

Temperature

Modifies pressure shift (changes collision frequency)

mean velocity $\propto \sqrt{T}$; T in Kelvin

Effect small:

8% change of pressure shift with 50° C temperature increase

Magnetic Fields

Magnetic moment very small (electrons paired)

~ 1/1000 that of atoms ⇒ Zeeman splitting negligible

≤ ~ 1 MHz @ 0.1 T (1000 G)

Electric Fields

No permanent electric dipole moment (symmetry)

⇒ ordinary Stark effects absent

AC Stark effect small at moderate pressure ($I_s \sim 10^8$ W/cm^2)

High Accuracy Wavelength Standards

Needed for NIST internal calibration

Frequency-doubled 1560 nm light

1560 nm diode laser ‡ fiber amp ‡ PPLN crystal

output at 780 nm » 5 μW

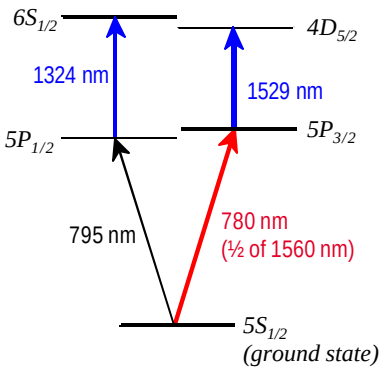
Conducted saturated absorption spectroscopy of rubidium; stabilized laser

very narrow lines

checked wavelength meter

verified 1 x 10^{-7} accuracy (0.16 pm)

Rubidium Spectrum

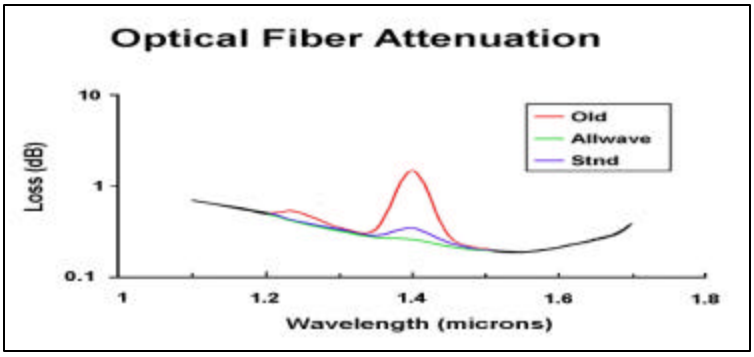


Future Work

Wavelength division multiplexing expanding into other I regions

Current guess: longer λ first (1565 -1620 nm region)

1300 nm region soon after that? 1400 nm region?



Future Work

Want references with uncomplicated spectra and strong lines (ideally)

Possible References:

1300 nm region

methane (CH_4)	*weak absorption, slightly complex spectrum*
hydrogen fluoride (HF)	*good spectrum but eats practically everything*

1400 nm region: *hydroxide (OH)*

1560-1620 nm region

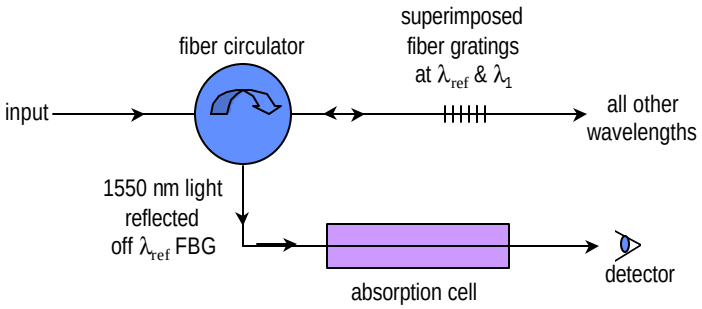
carbon monoxide (CO)	*weak absorption, good spectrum*
hydrogen iodide (HI)	*good spectrum but some instability*

Artifact References? (wavelength-selective device)

Can drift with temperature, strain, pressure changes, ...

Working on an actively-stabilized artifact reference

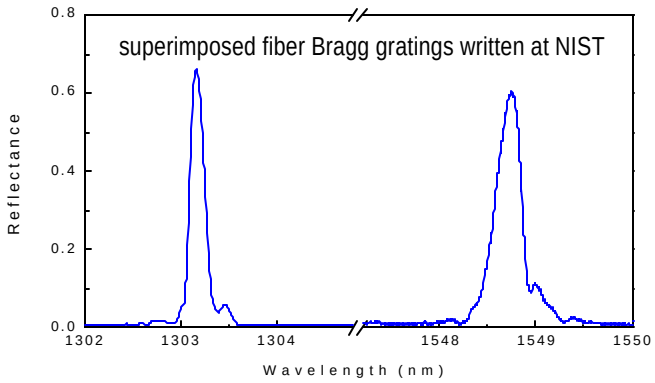
Hybrid Fiber Grating Artifact Reference



Grating at λ_{ref} stabilized to absolute molecular reference near 1550 nm,
λ_1 FBG at different wavelength – gratings sample same temperature and strain

Example:

Hybrid Wavelength Reference



Demonstrated principle

- *Stabilized 1549 nm grating*
- *Obtained good stability for 1300 nm grating (few pm)*
- *Expect < 1 pm uncertainty possible*

Filed provisional patent, looking for technology transfer opportunities

Conclusions

Current WDM C band wavelength calibration

- *2 SRMs available to for calibration between 1510-1565 nm*
  0.6 pm uncertainty; single point or linearity calibration
- *High resolution SRM will be available in 2000*
  narrower lines, uncertainty near 0.1 pm

WDM L band (1565 to ~1620 nm)

- *SRM under development*

Other Regions

- *1300-1500 nm*
- *Other? 980 nm?*