Combination Gas Cells for 900nm to >2 microns

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Abstract *Gas cells provide subpicometer accuracy absolute wavelength calibration but typically a narrow wavelength range. We give results of gas cells with combinations of gases that cover hundreds of nanometers in a single device*

Introduction

Accurate wavelength calibration is essential for many applications in fiber optics. Newer WDM systems based narrow frequency grids can require an accuracy of one or two picometers or even better. These systems are today utilizing the S and L wavelength bands in addition to the more traditional C band. Other new applications have also taken advantage of the technologies developed for fiber optic communactions in diverse industries. Some examples are sensing systems that can detect the temperature, pressure and other parameters often in the harsh environments and detection systems for chemical and biological materials. These application areas can have especially severe wavelength accuracy requirements very often subpicometer and in addition cover a very broad wavelength region.

There are many means to produce wavelength references in two broad categories, those based on fundamental physical atomic or molecular energy levels and those based on optical artifacts such as etalons or fiber Bragg gratings. Artifact based references are convenient in that they can provide calibration at arbitrary wavelengths but they suffer from large sensitivity to environment and can have aging drifts as well. Even with stabilization artifact references typically have considerably lower accuracy then fundamental references [1].

Wavelength references based on vibrational/ rotational molecular absorption spectra are particularly well suited to this wavelength region. Environmental effects are very small with almost no effects due to electric or magnetic fields and very low temperature drift. For example, over a 50 degC temperature change the line centers of a 50 Torr acetylene cell will shift by <1Mhz [2]. As the probe beam passes through the gas cell the light experiences absorption at specific wavelengths dependent on the energy levels of the molecule. Molecular absorption lines have a linewidth determined by Dopplar and collision (pressure) broadening.

Approach

Molecular absorption cells are available from several vendors and offer excellent accuracy at low cost. These absorption cells have been promoted by NIST as primary references in the WDM wavelength region. NIST has four SRMs available using acetylene, hydrogen cyanide, and C12 and C13 carbon monoxide [3]. These SRMs together cover the wavelength range from 1510nm to 1630nm. To extend this wavelength range other gases are available that offer absorption lines from 850nm to >2 microns [4,5] and are summarized in Table 1.

The absorption strength of the species varies by several orders of magnitude but all gases mentioned in the table achieve usable absorption levels with a path length of <0.8 meter which can be provided in a practical low cost package. Most of these gases can be housed in conventional glass envelopes but hydrogen flouride requires special handling as this gas attacks glass. We have found it possible to house HF in a cell where only copper, silver, and sapphire contacts the gas and achieve long life [6].

Each of the gases mentioned in the table covers a limited wavelength range but some cover multiple bands based on transitions between different vibrational states. There are two means of achieving a wide wavelength range in a gas cell, one by cascading gas cells of various species and the other by combining several species in a single gas cell. Cascading cells has the disadvantages of transmission losses, bulk, and high cost. Combining gases is attractive but mutual pressure shift can alter the position of the gas line peaks. This pressure shift effect is well known in gas cells and is proportional to pressure but is typically <<1pm. It should also be emphasized that the pressure shift does not constitute a source of error, that is, all cells made with the same pressure exhibit the same pressure shift. As the pressure of the gas is increased from zero the absorption depth will increase until the pressure broadening becomes comparable to the Dopplar broadening of the line (about 4pm). As the pressure is increased above this level the absorption depth saturates and the line just become broader due to collision broadening. For applications where the system resolution is poor such as in optical spectrum analyzers it is advantageous to use a relatively high pressure. For high resolution systems such as tunable lasers it is generally useful to use a lower pressure to minimize absorption width. We have looked at a number of gas mixtures to achieve a wide wavelength range while maintaining the accuracy of fundamental references.

Table 1:

Species	Wavelength Range
HF	867nm-909nm 1257nm-1340nm
$^{12}C_2H_2$	1510nm-1540nm
H_2O	895nm-983nm 1100nm-1210nm 1320nm-1500nm
^{12}CO	1560nm-1595nm
^{13}CO	1595nm-1633nm
$H^{12}CN$	1523nm-1560nm
$H^{13}CN$	1528nm-1565nm
$^{12}CH_4$	1314nm-1345nm 1637nm-1697nm
HCl	1185nm-1239nm 1718nm-1871nm
$^{12}CO_2$	1431nm-1443nm 1570nm-1610nm
HBr	1940nm-2070nm

Combination Gas Cells

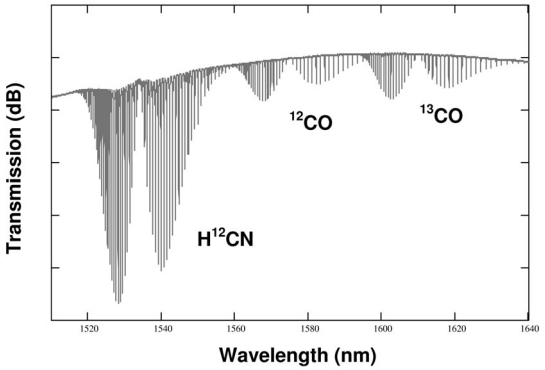
Criteria for gas combinations are that the gases be chemically compatible, that the lines cover the wavelength range, and they do not show too much interference. We have investigated several combination gas cells to cover various wavelength ranges. Cells with HCN or HCl were found to be incompatible with water vapor due to the formation of the acid. The combination investigated covering the widest range was one with four gases and consists of C12 (carbon 12) acetylene + C12 carbon monoxide + C13 carbon monoxide + water vapor. Demonstration cells were fabricated in a glass envelope of overall length of 16cm. The windows were constructed of glass with a broadband AR coating and with a slight wedge of about 0.1 degrees. The wedge essentially eliminates the small residual etalon caused by the finite reflectivity of the window surfaces. The tube was evacuated to about 10 microns and the tube was filled with the gases (>99% purity). The partial pressure of the constituents was 150 Torr for both isotopes of carbon monoxide, 10 Torr for the water vapor, and 1 Torr for the acetylene. The pressures were chosen to allow for relatively equal absorption depth for the lines of all four constituents and to minimize the pressure shift while maximizing the absorption depth. The absorption tube was then placed in an aluminum housing fitted with single mode fiber collimators and mirrors to result in five passes through the cell for an overall path length of 80cm. Both input and output fiber was SMF28. Overall size of the finished device is 18cm by 3.75cm by 2.2cm. This cell exhibits lines with minimal gapped regions from 1320nm to 1633nm so is a true S+C+L gas cell. The largest gap is from 1540nm to 1560nm. Absorption depths for the CO lines was about 0.4dB and for the water and acetylene lines about 1dB. Residual interferences fringes of the cells spectral response was <0.02dB and the cells throughput was >50%.

Cells were also fabricated for C+L performance only with the combination of C12 HCN + C12 CO +C13 CO. In this case the pressures chosen were 150 Torr for both CO isotopes and 10 Torr for the HCN. The cell exhibited essentially no gaps and covers from 1523nm to 1633nm. Absorption depth was 0.4dB for the CO lines and 1 dB for the HCN lines. Again the residual interference artifacts were <0.02dB and the throughput >50%.

Conclusions and Error Analysis

The low pressure line positions for the molecules investigated is generally known to an absolute accuracy of better then 0.1pm. Potential sources of error include the flatness of the spectral response of the cell, the influence of nearby lines on the line position determination, and the mutual pressure shift of different species on one another [9]. All these effects will be mitigated by the use of low pressure in the cells. The spectral ripple gives a maximum uncertainty of 0.1pm in the devices tested. To investigate other sources we simultaneously scan the combination gas cells along with low pressure single component devices in a component tester. This allow us to measure the influence of weak nearby lines and pressure shift as well as the dependance on the measurement algorithm. What we find is that the pressure shift of combination cells follow a similar pattern to that of single component devices but of a smaller magnitude, typically 50%-80%. The maximum pressure shift of the combination cells was 1pm but the reproducability was much better then this, on the order of 0.1pm.

We find it possible to achieve the supurb accuracy of gas cells while maintaining a wide wavelength range.



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