

Moderate-Accuracy Wavelength Standards for Optical Communications

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INTRODUCTION

Wavelength standards in the 1.3 μm and 1.5 μm regions are important for proposed optical communication schemes involving wavelength and frequency division multiplexing. Such systems will increase the information-carrying capacity of a fiber by simultaneously transmitting many different wavelengths. The first systems that will utilize this type of multiplexing will probably have channel separations on the order of 1 nm (≈ 130 GHz). To define each channel and prevent channel overlap, a moderate-accuracy wavelength reference (accuracy of about 0.01 nm, or 7 parts in 10^6) will be needed for each channel. Such references could also be used to calibrate optical spectrum analyzers in these wavelength regions. Wavelength references with higher accuracy will be required for systems with smaller channel spacing.

We have designed an apparatus for moderate-accuracy wavelength standards which uses molecular absorption lines as references. For absolute wavelength standards, a stable, reproducible reference is necessary. Natural resonances of atoms or molecules are ideal, since their wavelengths are not subject to large variations due to environmental changes such as temperature or pressure. Unfortunately, atomic and molecular reference lines in the 1.3 μm and 1.5 μm regions are not common; atomic transitions initiate from excited states, and molecular lines are weak overtone or combination bands.

We probe molecular resonances by illuminating a gaseous sample of molecules with light from an LED and observe the characteristic absorption lines using an optical spectrum analyzer. The system is simple and compact, and provides a series of reference lines in the 1.5 μm region. We are presently working on a similar approach for the 1.3 μm region.

1.5 μm APPARATUS

Our 1.5 μm wavelength reference apparatus is based on the absorption of light by the acetylene molecule. Of the molecular absorbers identified to date, acetylene has the strongest lines in this region. The $\nu_1 + \nu_3$ vibrational-rotational band of the $^{12}\text{C}_2\text{H}_2$ acetylene molecule has a clean spectrum containing approximately 40 clearly distinguishable lines with

spacings of about 0.5 nm between 1.51 μm and 1.54 μm .¹ A similar spectrum shifted about 8 nm toward longer wavelengths can be obtained from $^{13}\text{C}_2\text{H}_2$.² If additional lines are required, the $^{12}\text{C}^{13}\text{CH}_2$ spectrum³ could also be used.

A schematic diagram of the apparatus is shown in Fig. 1. Light from a fiber-pigtailed 1550 nm edge-emitting LED is collimated and passed through a sealed absorption cell containing $^{12}\text{C}_2\text{H}_2$ acetylene gas. The transmitted light is coupled into an optical fiber and is then observed on a diffraction-grating optical spectrum analyzer. The acetylene absorption lines appear as dips on the 70 nm wide LED emission spectrum. Figure 2 shows a scan over the acetylene absorption spectrum using this apparatus. The absorption lines are labeled according to the molecule's rotational-vibrational structure. The vacuum wavelengths of these lines, given in Table 1, have been measured to an accuracy of ± 0.001 nm.³

The system was designed to be rugged, compact, and stable. With the exception of the path through the acetylene cell, the LED light was guided in single-mode fiber. Coupling of the light into and out of the acetylene cell was accomplished using fibers which were fused to graded refractive index (GRIN) rod lenses. The first lens produced a collimated beam of light which passed through the 5 cm long acetylene cell and was coupled into the output fiber by a second GRIN lens. The acetylene cell was secured in an aluminum frame, and the GRIN lenses were held in aluminum plates which were rigidly locked to the cell frame after alignment. A simple electronic circuit using 5 VDC supplies and resistance networks supplied current for the LED and its thermoelectric cooler. The cell was constructed out of glass tubing with windows fused onto the ends and a small tube on the side for filling. It was first evacuated and then filled to a pressure of 4×10^4 Pa (300 Torr).

Figure 3 shows a scan over part of the acetylene spectrum on an expanded scale. The linewidths of the absorption lines are limited by the 0.1 nm instrumental resolution. The line centers can be easily determined to an accuracy of 0.01 nm. Sakai, Sudo, and Ikegami² have studied the effect of temperature and acetylene pressure on the center wavelengths of the acetylene absorption lines. They concluded that the temperature sensitivity is less than 100 kHz/K and the pressure sensitivity is less than 1.5 kHz/Pa. This sensitivity is very small compared with the desired accuracy of 0.01 nm (~ 1.3 GHz).

1.3 μm APPARATUS

We are presently investigating the use of methane (CH_4) as a reference for the 1.3 μm region. The $\nu_2 + 2\nu_3$ band, centered at 1.33 μm , is very weak and requires a longer absorption path. We have constructed an apparatus which is very similar to that described in the previous section with the substitution of a 15 cm long absorption cell. With a methane pressure of 4×10^4 Pa, we observed an absorption of 15% on the 1.331 μm Q branch line⁴ of this band. Other molecular candidates for references in the 1.3 μm region are ammonia and hydrogen fluoride.

CONCLUSIONS

We have constructed a simple apparatus for producing a series of reference lines in the $1.5 \mu\text{m}$ region. We are investigating a similar approach for the $1.3 \mu\text{m}$ region. These LED/molecular absorber systems provide wavelength references with accuracies of 0.01 nm , which is sufficient for wavelength division multiplexed optical communication systems with channel spacings of about 1 nm .

REFERENCES

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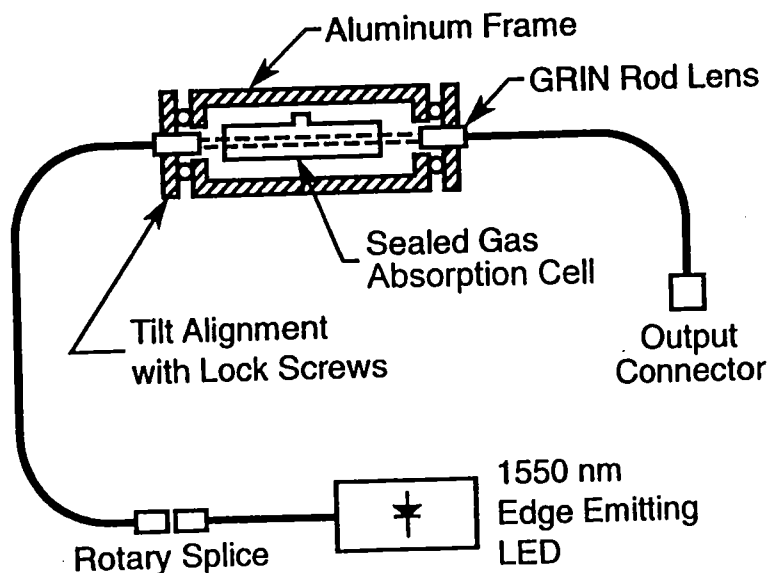


FIGURE 1 Schematic diagram of the $1.5 \mu\text{m}$ wavelength reference apparatus.

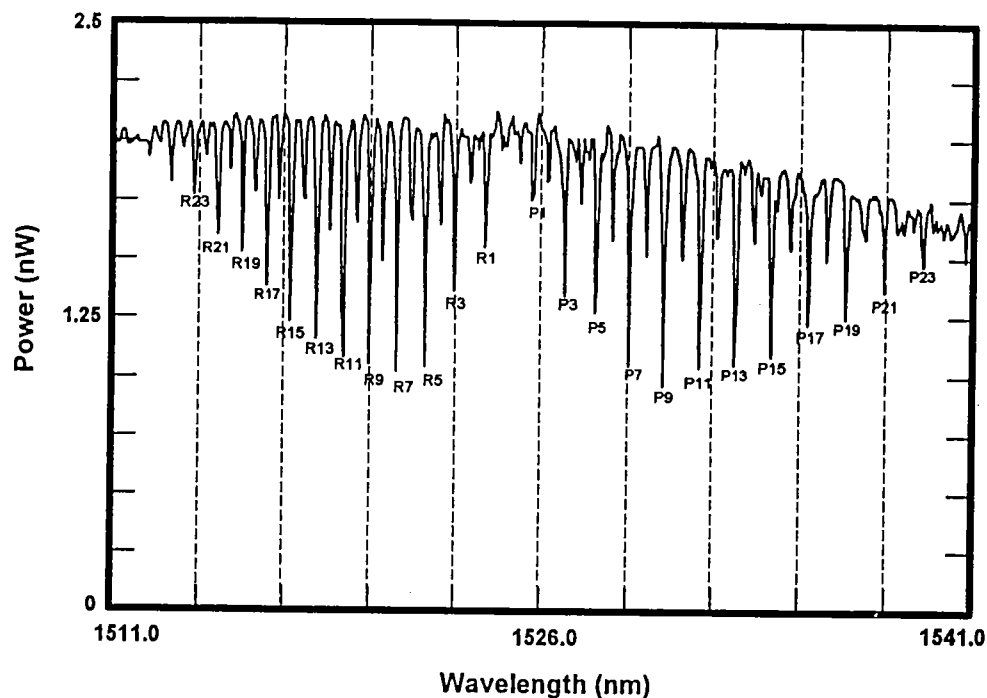


FIGURE 2 Scan over the acetylene $\nu_1 + \nu_3$ absorption band with a resolution of 0.1 nm. Wavelengths for the labeled lines are given in Table 1. The intermediate lines (R₂₂, R₂₀, ...) are also accurately measured.

Line	λ_{vac} (nm)	Line	λ_{vac} (nm)
R23	1513.97	P1	1525.76
R21	1514.78	P3	1526.87
R19	1515.59	P5	1528.01
R17	1516.44	P7	1529.18
R15	1517.31	P9	1530.37
R13	1518.22	P11	1531.59
R11	1519.14	P13	1532.83
R9	1520.08	P15	1534.10
R7	1521.06	P17	1535.39
R5	1522.06	P19	1536.71
R3	1523.09	P21	1538.06
R1	1524.14	P23	1539.43

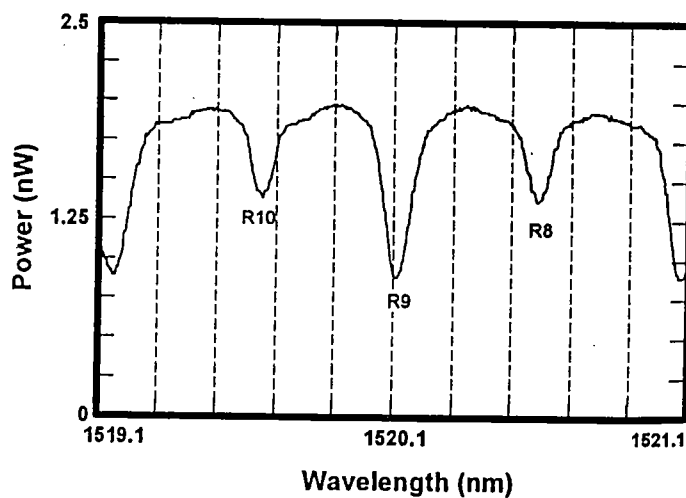


FIGURE 3 Scan in the vicinity of R9 (0.1 nm resolution).