

Multiple wavelength reference based on interleaved, sampled fiber gratings and molecular absorption*

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Abstract: We present a wavelength calibration reference based on sampled fiber gratings stabilized to a molecular absorption line. Such a hybrid reference can provide multiple stable calibration peaks over a wide range of wavelengths.

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1. Introduction

Wavelength calibration references are needed in a variety of wavelength regions to calibrate wavelength-measuring instruments such as optical spectrum analyzers (OSAs). Molecular absorption lines can provide very stable and accurate calibration points, but convenient references are not available in all wavelength regions. Artifacts, on the other hand, can provide references at arbitrary wavelengths, but can also suffer from large sensitivity to temperature, strain, and pressure. We have developed a hybrid multiple-wavelength reference that incorporates the wavelength flexibility of artifact references and the stability of fundamental molecular absorption references. A series of customized wavelength reflection peaks are generated by writing interleaved, sampled fiber Bragg gratings. One of the reflection peaks is actively stabilized to a molecular absorption line, which results in the stabilization of the entire ensemble of peaks. We are using this approach to produce wavelength references in the 850, 1300, and 1550 nm regions. Since this approach provides many calibrated reflection peaks in each region, the reference can also be used to measure scan linearity within each region.

2. The gratings

Interleaved, sampled fiber Bragg gratings (ISFBGs) consist of two sampled fiber Bragg gratings (SFBGs) that are interleaved so that both gratings are contained in the same length of fiber but their inscribed sections are offset from each other. Each SFBG is a uniform grating with an on-off amplitude modulation of the refractive-index inscription so that the resulting fiber grating has a regular pattern of short inscribed regions separated by non-inscribed regions. The resulting reflection spectrum is a series of regularly spaced peaks under a broad central envelope with small side lobes. Interleaving two SFBGs gives this spectrum in two wavelength regions. Figure 1 shows the reflection spectrum for a 1300/1550 ISFBG.

We made the 1300/1550 ISFBGs with a phase-mask-based method [1]. A brief description follows and more details can be found in Ref. 1. The grating was written using a cw, 244 nm laser beam focused vertically to a line

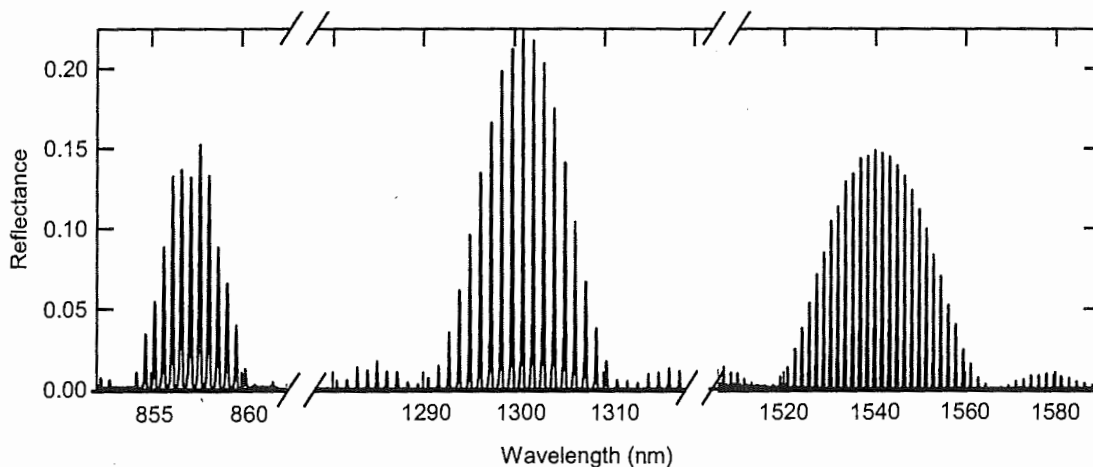


Fig. 1. Reflection spectra for ISFBGs. The 1300 nm and 1550 nm lines are from a single 1300/1550 ISFBG. The 850 nm lines are from a separate 850/1550 ISFBG.

focus through the back of a phase mask and onto a ~ 1 cm length of fiber. The H_2 -loaded, singlemode standard communication fiber was in near contact with the phase mask's front face. Opaque metal strips that plate the front face of the phase mask provided the sampling by blocking off sections of the UV beam. One SFBG was written at a time using the appropriate sampled phase mask for the wavelength region desired. The fiber was shifted before writing the second SFBG so that the new grating was written in the previously unexposed region. Figure 1 shows the reflection spectrum for a typical ISFBG that we make. The on-off periodicity, Λ_{MOD} , was $500 \mu\text{m}$, and the length of the individual inscribed regions, D_{ON} , was $50 \mu\text{m}$ for the 1300 nm grating and $30 \mu\text{m}$ for the 1550 nm grating. These parameters determine the line spacing, broad envelope widths, and individual peak widths [1] which were $1.2(1.6) \text{ nm}$, $10(20) \text{ nm}$, and $110(120) \text{ pm}$, respectively, for the $1300(1550) \text{ nm}$ region. The spectrum has more than $20(25)$ lines suitable for references in the $1300(1550) \text{ nm}$ region.

We used an interferometer-based method to make an 850 nm SFBG, extending the wavelength range of gratings for wavelength standards. Although the interferometer is more difficult to align than a phase mask, the interferometer approach has the advantage that a broad range of wavelengths can be written by adjusting the angles of the interferometer. We used fiber that was singlemode at 850 nm for this grating. Singlemode fiber provides a clean set of peaks that can be identified by relative amplitude and fit without worry about contamination by secondary peaks of varying amplitude, which would occur in multimode fiber. In the interferometer, two beams were focused vertically to a 1 cm long line focus where they intersect and form the interference pattern for writing the grating. To produce the on-off modulation of the grating, a shadow mask was added. We used a commercial metal mask ($\sim 100 \mu\text{m}$ thick) that had been photochemically machined with $\sim 200 \mu\text{m}$ wide grooves, spaced $500 \mu\text{m}$ apart. This mask was held in contact with the fiber. Given the mask thickness and the angle between the interfering beams (35° for 850 nm), the length of the individual interference sections, D_{ON} , was only about $30 \mu\text{m}$. After the 850 nm SFBG was written, we interleaved a 1550 nm SFBG using the phase mask method described above. Figure 1 shows the reflection spectrum for the 850 nm region of the ISFBG. The 1550 nm region is similar to the spectrum shown. The lines in the 850 nm spectrum were 90 pm wide and spaced by 0.5 nm . At least twelve of these lines are suitable for references.

3. The 1300/1550 wavelength reference for OSA calibration

Figure 2 shows the basic components of the fiber-optics-based wavelength reference. This reference is based on the ideas presented in Ref. 2. Here we use a system with two phase locked loops so the fiber grating's spectrum is not dithered. Also, this reference uses ISFBGs, so there are many lines available in each wavelength region. A 1550 nm DFB diode laser is frequency modulated and locked to a HCN absorption line [3]. This is done by using standard phase-locked-loop techniques and feeding back to the laser's temperature to keep the laser at the absorption maximum. Once the 1550 nm laser is locked to the HCN absorption line the fiber grating is locked to the 1550 nm laser. Another beam from the 1550 nm laser is split off and sent to the grating. The laser light reflected off the grating is detected with the grating signal photodiode. Again, standard phase-locked-loop techniques are used, and feedback to the grating temperature controller keeps the grating at its reflection maximum.

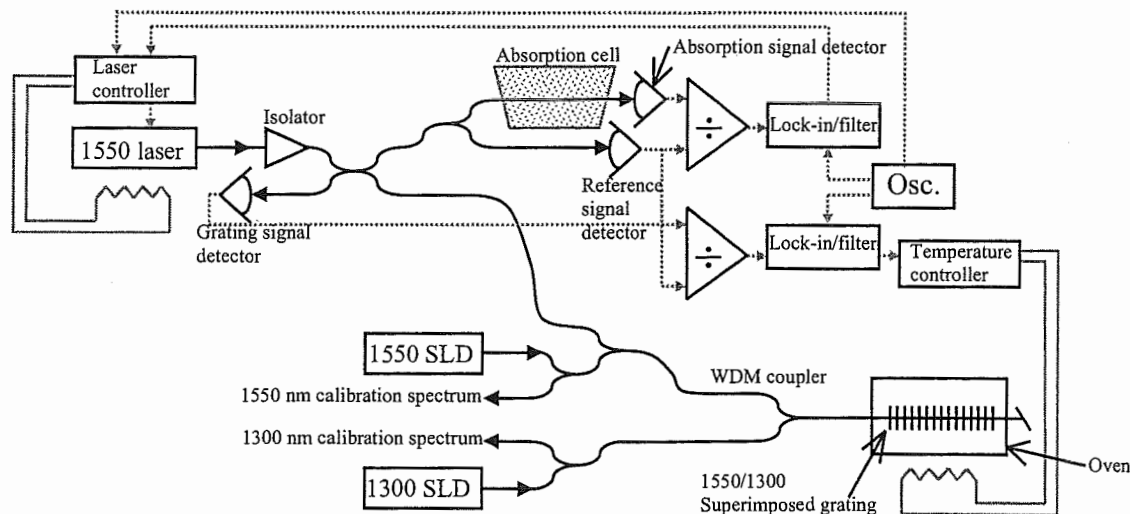


Fig. 2. Basic components of the hybrid wavelength reference.

The user accesses the multiple stabilized peaks of the fiber grating by way of the 1300 nm and 1550 nm calibration spectrum ports. Two superluminescent diodes (SLD), one centered at about 1300 nm, and one centered at about 1550 nm, serve as broadband light sources to illuminate the fiber grating. Light from the SLDs that is resonant with the fiber grating is reflected and aimed back to the calibration spectrum ports. We have measured the center wavelengths for each reflected peak, and can therefore use the reference to calibrate the wavelength and scan linearity of an OSA in both wavelength regions.

4. Results and conclusions

We imitated harsh environmental conditions by straining the fiber grating and then checking the response of the system. The fiber grating was held between two fiber chucks, one on a micrometer, in order to apply a calibrated strain to the fiber. With the system locked, it compensated for a change in strain, $\Delta\epsilon$, with a change in the temperature of the grating, ΔT , so that the Bragg wavelength, λ_B , remained unchanged.

$$\Delta\lambda_B = (C_T\Delta T + C_\epsilon\Delta\epsilon)\lambda_B = 0 \quad (1)$$

Here C_T is the grating's temperature coefficient and C_ϵ is the grating's strain coefficient. The temperature change that compensates the 1550 grating for the added strain must also be very close to the correct amount to cancel the strain-induced change at 1300 nm. Previous measurements of the strain and temperature coefficients at both 1300 nm and 1550 nm indicated that this was the case [2]. We tested this directly by locking up the system and looking for shifts in the Bragg wavelength at 1300 nm as we strained the fiber. The center wavelength of one of the 1300 nm peaks was monitored by scanning it with a laser. We measured the Bragg wavelength for different strains, spanning 200 $\mu\epsilon$, and found that the Bragg wavelength changed by $< 2 \times 10^{-3}$ pm/ $\mu\epsilon$. Of course, this amount of strain is an extreme test. Without compensation the grating's Bragg wavelength would shift by more than 200 pm for a strain change of 200 $\mu\epsilon$. The stabilized system, however, changed its temperature by about 20° C and the shift in the grating's Bragg wavelength was less than 0.4 pm.

A polarization dependent wavelength (PDW) shift of the grating can affect the accuracy of the wavelength reference. If the Bragg wavelength depends on the input polarization then the calibration spectra can shift as the polarization changes. We measured the PDW of our gratings with a separate experiment [4] and selected fiber that resulted in low PDW gratings. Our measured values for PDW were typically 1 to 2 pm in both wavelength regions for the selected fiber. Since we presently have no control over the polarization in the device we believe that PDW is our current limitation to the accuracy of the wavelength reference. We checked the wavelength reference by inserting a tunable 1300 nm diode laser in place of one of the superluminescent diodes. The light reflected off the grating was detected at the 1300 nm calibration spectrum port as the laser was scanned over a peak with the system locked. The variation in the center wavelength of the peak over a day was typically under 1 pm. We have monitored the same fiber for over 70 days, checking it about once a week. The maximum deviation between measurements over this time was 3.5 pm.

We have described a hybrid wavelength reference that provides multiple calibrated reflection peaks in the 1300 nm and 1550 nm regions. This approach can be extended to any wavelength region that can be guided in singlemode optical fiber. Toward this goal, we have written a sampled grating in the 850 nm region using a flexible interferometer setup, and have interleaved this with a 1550 nm grating. Although the system described is intended for calibration of an OSA, the approach could be used for tunable laser calibration by substituting the user's tunable laser for one of the SLDs.

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