In the Lecture

Thomas E. Briggs and Scott T. Sanders*
Department of Mechanical Engineering, University of Wisconsin–Madison, Madison, WI 53706; *ssanders@engr.wisc.edu

Optical techniques for measuring material properties are becoming increasingly popular, and as a result many graduate engineering courses on the subject are evolving. Our experimental methods course includes topics ranging from basic signal processing to the proper use of thermocouples to advanced optical techniques such as laser-induced fluorescence. In the pure sciences, courses involving spectroscopy are continuing to develop. Many of the above courses, like ours, are lecture-based. In such courses it can be very instructive to spend a portion of the class time on a streamlined experiment rather than simply lecturing on the material.

Modern telecommunications equipment is particularly well-suited to making streamlined demonstrations such as the one discussed below. Thus, topics that were once too complicated to demonstrate without a dedicated laboratory section to a course can now be made accessible to students. Of course, in laboratory versions of these courses, experiments similar to the one presented here can also offer a highly efficient learning experience.

Fiber-pigtailed broadband light sources are becoming available over a range of wavelengths. For instance, superluminescent diodes with ~40 nm fwhm (full width at half-maximum) and greater than 1 mW optical power are now available throughout most of the 600–1700 nm range. Furthermore, white-light sources spanning extremely broad wavelength ranges, for example, 350–2200 nm (I), are beginning to emerge. Optical spectrum analyzers (OSAs) that span a range of 350–1750 nm are readily available. The above colors can be fiber-coupled in standard silica fiber, at least for short distances (0.3 dB/m attenuation typical at the extremes of 350 and 2200 nm). Coupled with a gas cell or a liquid or solid sample, there are numerous experiments that can be imagined within the above wavelength range.

The experiments are generally simple to set up and conduct. Video output from the OSA enables real-time data to be projected in class. Several parameters of interest may be explored within a typical lecture. The data obtained from this demonstration can then be provided to the students in digital form to be processed to obtain useful engineering results, such as an unknown pressure of the gas in the cell. This process provides a valuable learning experience to the students that would not ordinarily be available to them. They not only see a typical experimental setup and how it is run, but they work with actual data with all of the resulting challenges; this gives them a head start on learning how to deal with their own research data as they progress through their academic and professional careers.

Materials and Equipment

- Fiber-pigtailed superluminescent diode (1550-nm center wavelength, 40-nm spectral width)
- Agilent 8614OB optical spectrum analyzer
- Aluminum test cell with wedged glass windows (Figure 1)
- Corning SMF-28 single-mode fiber patchcords
- Acetylene and nitrogen gases
- Pressure gauge
- Fiber collimation packages
- Kinematic mounts

Procedure

The procedure is available in the Supplemental Material.

Hazards

For safety purposes the test cell was located in an unoccupied room across the hall from the lecture room, with the optical fiber between the cell and the OSA strung above the hall. The students were encouraged to observe the setup in small groups after the lecture to see how it was assembled. The fiber-coupled equipment makes many of the safety issues trivial. The high-intensity light remains confined to ei-

Figure 1. Test cell for spectroscopy experiment.
ther the fiber or test cell at all times. The fiber also allows the pressurized cell and the required compressed gas bottles to be located in a remote space so that the students will not be in danger from any mishaps.

Should the equipment need to be located in the room with the students (such as for a laboratory exercise rather than a lecture demonstration), basic laboratory safety practices should be observed. Again, given the fiber coupling for the light path, there is no danger from the light source. Installing a pressure relief valve to prevent overpressurization of the test cell is advisable, particularly if students would be running the experiment. At a minimum, cell preparation should be performed in a well-ventilated laboratory to prevent acetylene buildup in the room. Once the cell has been charged with acetylene it may be moved to an unvented room for performing the experiment. If the experiment will be moved much, the use of small gas bottles rather than the standard size is also advisable to minimize the danger from the compressed gas supply.

Results and Discussion

The measured spectrum from the OSA can be downloaded from the instrument and plotted as in Figure 2. As can be seen, both captured curves show the dips expected at the absorption wavelengths of acetylene.

To reduce the transmission spectrum as shown in Figure 2 to an absorption spectrum, a curve is constructed to simulate what the OSA would have recorded if no acetylene were present. This “baseline” curve is constructed by spline fitting the data through points where the absorption due to acetylene is known to be small. This “simulated baseline” is generally more reliable than an actual measurement of the OSA baseline due to experimental variations. The absorption spectrum is computed using

$$\text{absorbance} = -\ln \left( \frac{I(\lambda)}{I_0(\lambda)} \right) \quad (1)$$

where $I(\lambda)$ is the transmitted light intensity and $I_0(\lambda)$ is the incident light intensity, both as function of wavelength.

The resulting absorption spectrum is plotted for a low and high pressure case as shown in Figure 3. Note that the primary x-axis has been converted to optical frequency from wavelength. This is the common unit that is used in spectroscopy, and having the students work in this unfamiliar unit in an assignment should enable them to more readily interpret results in the literature.

The students used the absorption data to look at a number of parameters in the test, such as partial pressure of the acetylene, the relative areas of the P- and R-branches of the spectrum, the Doppler and collisional widths of acetylene, and finally the total pressure of the gas at the high pressure condition.

The students were led through these analytical steps by a combination of guidance in the homework assignment, articles on acetylene spectroscopy (2, 3), and excerpts from texts discussing spectroscopy (4) and molecular dynamics (5). This breadth of outside information also fit with the assignment goal of leading the students through a realistic exercise where
the information must be sought out rather than made available prior to beginning the work.

The assignment included a variety of analytical techniques, including: curve fitting, numerical integration, quantitative calculation of spectral parameters, simple modeling of spectral data, and design of future experiments. Again, this wide range of techniques provided a solid introduction to research methods for the students in the class who are new to their graduate careers. For the more experienced students the assignment still provided opportunities to look more closely at a research area that may be far from their own research.

An alternate approach for this demonstration and assignment would be to use a premixed C_2H_2/N_2 gas supply so that the concentration of acetylene in the cell remained constant as the pressure was increased. Also, the effect of temperature on the spectra could be investigated (using dry ice as a means to cool the cell during a lecture period, for example). Finally, for situations where adequate venting is available, CO could be used as the absorbing gas. This would allow direct comparison with the spectra produced by HITRAN (6). Students could then interact with an important spectroscopic software package and potentially use HITRAN to improve their inference of gas properties such as temperature and pressure.

Conclusions

This assignment has been tested in the experimental methods course with around 25 students. Early feedback gathered from the students indicates that the demonstration was an effective teaching tool. We are currently exploring other demonstrations that may be incorporated into lectures.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. CTS-0238633. Additionally, Chris Hagen, Amanda Pertzborn, and Drew Caswell provided assistance in setting up the demonstration and analyzing the data for this article.

Supplemental Material

The experimental procedure and questions for the students are available in this issue of JCE Online.

Notes


Literature Cited