Rapid Field Testing of Low-Emittance Coated Glazings for Product Verification

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ABSTRACT

This paper analyzes prospects for developing a test device suitable for field verification of the types of low-emittance (low-e) coatings present on high-performance window products. Test devices are currently available that can simply detect the presence of low-e coatings and can measure other important characteristics of high-performance windows such as the thickness of glazing layers or the gap in dual glazings. However, no devices have yet been developed that can measure gas concentrations or distinguish among types of coatings. This paper presents two optical methods for verification of low-e coatings. The first method uses a portable, fiber-optic spectrometer to characterize spectral reflectances from 650 nm to 1,100 nm for selected surfaces within an insulated glazing unit (IGU). The second method uses an infrared-light-emitting diode and a phototransistor to evaluate the aggregate normal reflectance of an IGU at 940 nm. Both methods measure reflectance in the near (solar) infrared spectrum and are useful for distinguishing between regular and spectrally selective low-e coatings. The infrared-diode/phototransistor method appears promising for use in a low-cost, hand-held field test device.

INTRODUCTION

Energy-efficient window glazings sold today often employ new technologies that are not discernible to the human eye. Although a national labeling system now provides a fair, accurate, and credible basis for determining the thermal properties of window systems, no field procedures currently exist to verify that a specific product actually incorporates the advanced technologies that are indicated on its label. Nondestructive field test procedures would help to (1) ensure that the right labels end up on the right products, (2) ensure that products contain the intended components, (3) determine performance levels after temporary labels are removed, and (4) determine whether energy performance deteriorates with time (from loss of gas fills or degradation of coatings). Such verifications could enhance consumer confidence that energy-efficient technologies will deliver the performance they promise.

An ideal field-test kit for high-performance windows would consist of a small number of low-cost, easy-to-use, hand-held devices that could quickly and easily characterize the important attributes of high-performance glazings. In addition to low-e coatings, these attributes include the thickness of glazing layers and the presence or concentration of insulating gas fills between glazing layers. Field test devices for measuring glazing thickness are already commercially available (EDTMI 1997). A number of approaches have been explored for verifying gas fills, but no device or procedure is likely to be available as a hand-held device in the foreseeable future (Elmahady and Yusaf 1995; Gross and Fricke 1997). Although low-e coatings are difficult to discern with the human eye, an experienced person with good vision can identify the location and type of low-e coatings by viewing the pattern and coloring of reflections from a small flashlight or a lit match. This technique is not a quantitative measurement and lacks the certainty afforded by a test device. Although a commercially available device can be used to determine whether or not a low-e coating is present in a window unit, there are problems with its accuracy, and no measurement device yet exists that can distinguish among types of low-e coatings. The authors have proposed two optical measuring techniques that could be used to determine the type of low-e coating present on a high-performance window unit. One technique uses a portable fiber-optic spectrometer, and the other uses an infrared-light-emitting diode and a phototransistor. Both techniques measure reflectance in the near (solar)

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infrared spectrum. The latter technique shows promise for use in a hand-held field test device.

METHODS FOR TESTING LOW-EMITTANCE COATINGS

The insulated glazing unit (IGU) is the main component of a high-performance window product. Although the window's frame and edge-of-glass components can significantly affect performance, the glazing component has major implications for building energy use. However, the IGU's attributes, particularly the presence and type of low-emittance (low-e) coatings, are difficult to assess by simple visual inspection. There are two main types of low-e coatings: regular and spectrally selective. Regular low-e coatings boost the thermal resistance of a glazing unit by reflecting long-wave infrared radiation (wavelength > 3 μm). Spectrally selective low-e coatings also reflect long-wave radiation but are tailored to reflect solar infrared radiation as well, in order to reduce unwanted heat gain through the window unit. Distinguishing between regular and spectrally selective coatings is important because the type of coating used has a large impact on energy use during the heating or cooling seasons. Figure 1 shows reflectance vs. wavelength for selected clear, regular, and spectrally selective low-e glazings, as presented by the Window 4.1 computer program. The results were obtained using the appropriate spectral data files (Arasteh et al. 1993) (files available from http://windows.lbl.gov). The data represented in Figure 1 are for total reflectance at normal incidence for one glazing layer with the coating on the back side. Data for the three glazing types are plotted only for wavelengths from 650 nm to 1,100 nm, the near infrared spectrum, which can be measured using inexpensive, silicon-based detectors.

Although substantial efforts are made to measure spectral optical properties of glazing components in the laboratory, real products are not measured in the field. An electronic product is available that can detect the presence of low-e (EDTMI

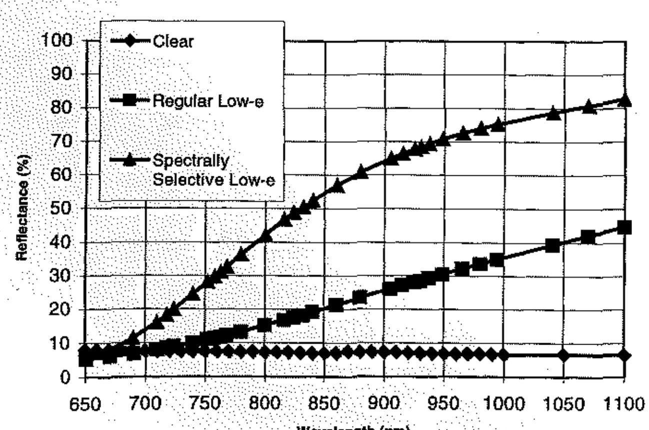

Figure 1 *Normal total reflectance in near infrared for selected clear, regular low-e, and spectrally selective low-e coatings: Window 4.1 spectral data.*

1997). This device, which works on the principle of a metal detector, senses the presence of an electrically conductive layer; low-e coatings contain conductive materials. The small, hand-held device is placed against the glazing (away from the edge) and indicates four possible configurations: clear glazing, coating on near pane, coating on far pane, or coating in contact with the detector. It transmits a 5 kHz electronic signal. Electrically conductive materials present in the window unit reflect the transmitted 5 kHz, which is then detected by analyzing oscillating circuitry. The reflected signal is stronger when the conductive coating is closer, enabling the device to distinguish among different coating positions. There have been problems with the accuracy of this device, especially when used by unskilled operators. The metal detection technology used in the device may be responsible for erroneous reading. These erroneous readings result when the detector is operated too close to other conductive materials such as metal spacers and framing materials. Other common problems stem from using the device on IGUs with gap thicknesses in excess of 13 mm and glass layers in excess of 3.2 mm. Unfortunately, many glazings have such characteristics. If it is operated correctly, the device appears to be well suited to measuring the presence of a low-e coating on the near glazing layer of an IGU. The unit is unable to distinguish between regular or spectrally selective low-e coatings. It will also show false positive readings for metallic films that are used to reduce transmission but are not actually low-e coatings.

In an effort to develop a hand-held device that can be easily used in the field to distinguish among types of low-e coatings, the authors have developed two optical measuring techniques to determine the type of low-emittance coating present on a window product. The first technique uses a portable, fiber-optic spectrometer, and the second uses a simple infrared-light-emitting diode and phototransistor. Both techniques measure glazing reflectance in the near, or solar, infrared spectrum.

Portable Fiber-Optic Spectrometer

Setup. Figure 2 diagrams the setup for a portable spectrometer that can be used to measure glazing products in the field. The spectrometer is a commercial product built onto a plug-in computer data acquisition card that was installed in the bus of a portable computer (OOI 1997). The spectrometer's diffraction grating is set up to direct light of wavelengths 650 nm to 1,100 nm onto a silicon detector array with 1,024 elements. Light that has been collected by a collimating lens is directed to the card by a fiber-optic cable. The light source is a tungsten halogen bulb specially configured to feed light into a second fiber-optic cable. A long-pass IR filter (that permits radiation longer than 600 nm to pass) is used at the light source to eliminate lower wavelength light. The presence of the filter will help to avoid second-order diffraction that can cause erroneous measurements. A second collimating lens on the light source fiber-optic is used to focus the source light beam onto the window specimen.

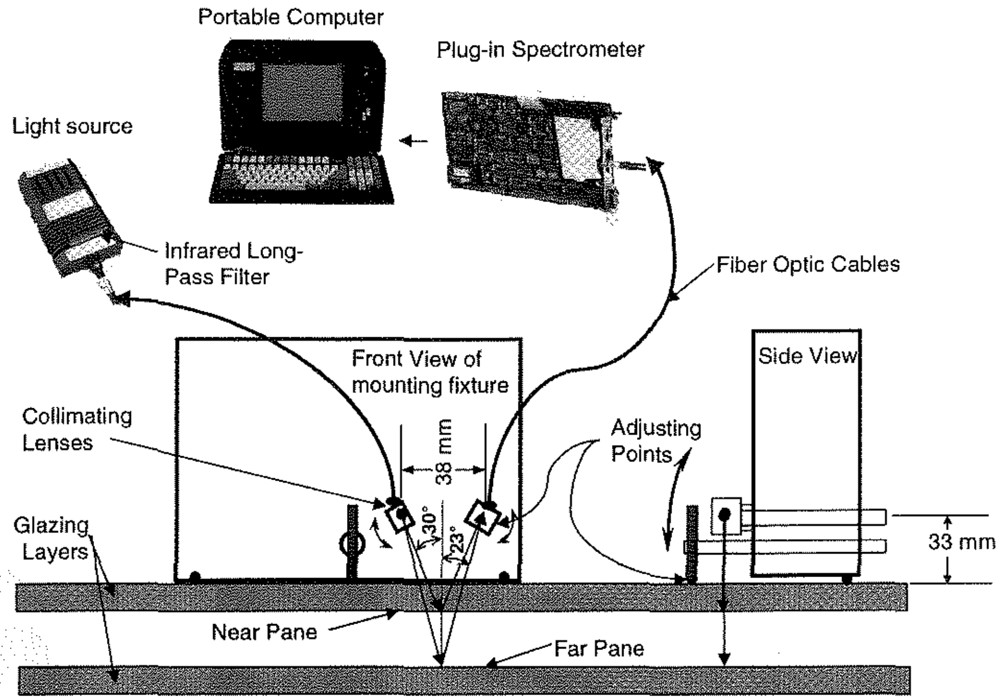

Figure 2 *Experimental setup for portable fiber-optic spectrometer.*

We designed an aluminum optics mounting fixture to align the detector and light source collimating lenses on the IGU in a controlled and repeatable fashion. Although transmission measurements could also be made, this setup is for reflectance measurements because it is helpful in the field to require access to only one side of the glazing. The optics must be constantly realigned because of variations in glazing and gas-layer thickness as well as deflections (bending) of glazings resulting from internal and external pressure differences. The angles of the fiber-optic collimating lenses must be tuned to focus the measurement on the desired surface. These angles are the same for both the detector and light source and were about 30° from normal for measurements on the inner surface of the near pane and about 23° from normal for the far pane. The detector and light source lenses are held in the same plane, but because of glazing deflections, the mounting fixture has an adjusting point that allows rotating the measurement plane relative to the glazing surface. The lens angle and fixture rotation were adjusted by hand while the spectrometer output was monitored in order to maximize the spectrometer response level for each measurement.

To obtain reflectance data, it is necessary to reference the spectrometer measurements to the characteristics of the light source and to correct for (dark) noise in the detector system. The spectrometer operates by counting detection events over a period of time from a charge-coupled device (CCD) array. These raw spectrometer counts are converted to reflectance values by dividing the levels measured for the specimen by the levels measured for just the light source. However, first a measurement is taken with the light source turned off and stored as a dark level that is subtracted from subsequent measurements. In order to measure the level of the light source in a reflectance configuration, it is necessary to use a reference mirror since the light source cannot be viewed directly. A custom IGU was fabricated that has a 2 in. area of gold on each pane. The gold coating was vacuum deposited onto normal clear window glass. Gold makes a good selection for a reference mirror because it has high specular reflectance and flat spectral response. Figure 3 shows the raw spectrometer measurements of the gold coating on both panes, which were typical of the reference data used to quantify the light source.

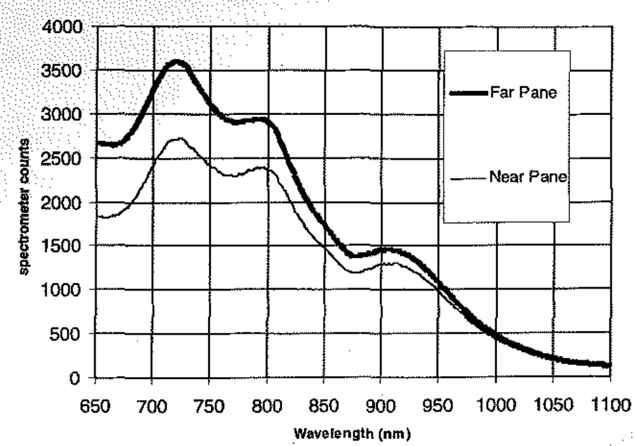

Figure 3 *Gold coating spectrometer measurements used for referencing the light source.*

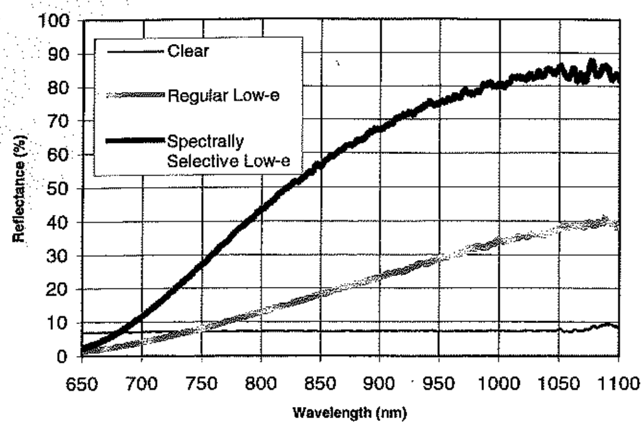

Figure 4 *Near pane measurements with portable fiber-optic spectrometer.*

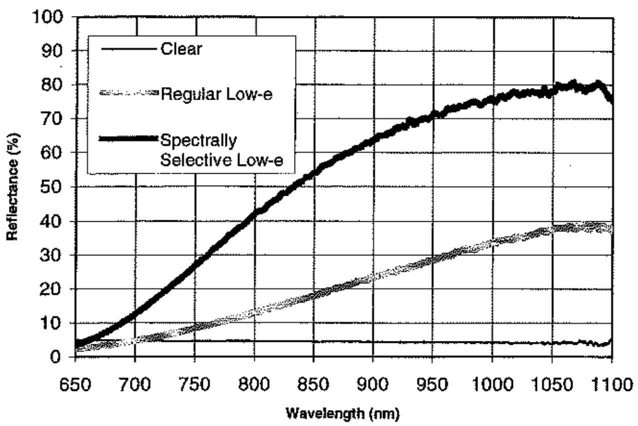

Figure 5 *Far pane measurements with portable fiber-optic spectrometer.*

Laboratory Results. The portable fiber-optic spectrometer was used in the laboratory to measure a number of sample IGUs. Results are shown in Figures 4 and 5 for three specimens representing the main kinds of IGUs. Figure 4 data, taken by turning the same glazings over, were taken with the spectrometer aligned on the inner surface of the near pane. The data in Figure 5 were measurements of the far pane. For coatings on each pane, near or far, a reference light level was gathered using the reference IGU with a gold coating placed on the same pane.

Field Test Exercise. A preliminary configuration of the portable spectrometer system was taken to three occupied residences in a blind exercise to determine how effective the system would be at identifying products in the field. The field test sites, located in the San Francisco Bay area, were selected and coordinated by consultants working for the local utility company. All three houses had retrofit windows installed by the same contractor, who works for the utility company's incentive programs for energy-efficient buildings. The spectrometer operators did not know what types of glazings were supposed to be in the windows. The configuration of the spectrometer system at the time of the tests differed from the setup shown in Figure 2 in that the infrared long-pass filter was not used and the rotation adjusting point had not yet been added to the mounting fixture.

The results of the field exercise are summarized in Table 1. Windows that had spectrally selective coatings were evaluated at both Home 1 and at Home 2. While the window at Home 1 was correctly identified, the window at Home 2 was not. At Home 3, two clear windows and three spectrally selective windows were evaluated and correctly identified. The spectrally selective windows in Home 3 were measured while under full sunlight without any obvious effect on the spectrometer operation.

Infrared LED/Phototransistor Pair

A low-cost hand-held device for field testing low-e coatings could be developed using an infrared-light-emitting diode (IR-LED) paired with an appropriate phototransistor. Similar simple optoelectronic devices are commonly used as optical switches in communications and motion detection equipment. Figure 6 shows the spectral distribution of light emitted by a typical IR-LED as relative intensity vs. wavelength. This IR-LEDs spectrum includes a range useful for characterizing differences between clear and regular or spectrally selective low-e coatings (compare the spectrum of Figure 6 to that of Figure 1).

TABLE 1
Summary of Field Test Exercise Results

Home	Product's Specified Coating	Quantity Tested	Portable Spectrometer Field Test Results			
			Access	Surface Measured	Test Conclusion	Results
1	Spectrally Selective	1	Exterior	Near	Spectrally Selective	Correct
2	Spectrally Selective	1	Interior	Far	Regular Low-E	Incorrect
3	Clear	2	Interior	Far	Clear	Correct
3	Spectrally Selective	3	Interior	Far	Spectrally Selective	Correct

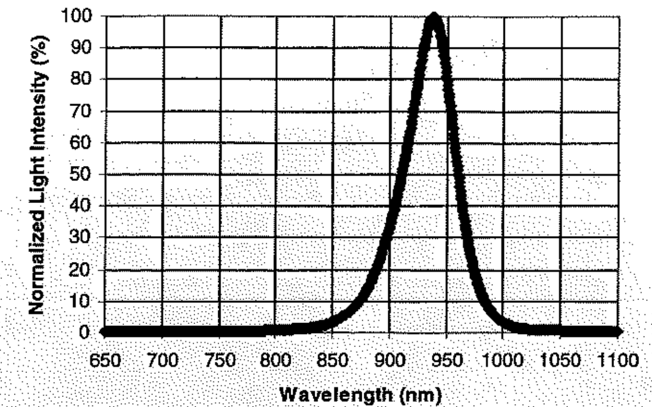

Figure 6 *Spectrum of infrared-light-emitting diode.*

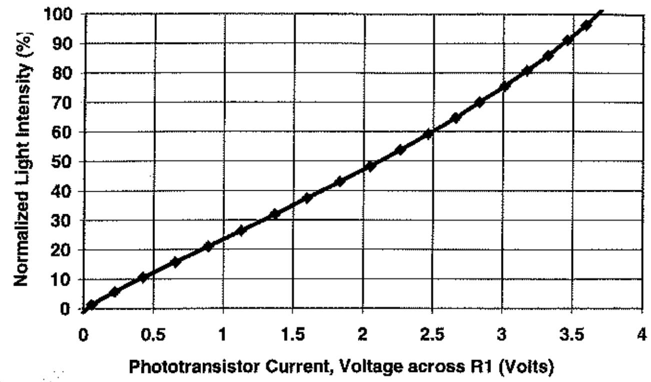

Figure 8 *Detector response to intensity of infrared light.*

Setup. The experimental setup diagrammed in Figure 7 was used to demonstrate the use of the IR-LED/phototransistor pair. In this setup, the light emitted by the IR-LED shines into the glazing and the phototransistor senses the light that is reflected back out of the glazing.

The amount of light that hits the phototransistor determines the amount of electrical current that it permits to pass. This current is measured as voltage across a resistor (R_1, see Figure 7). The IR-LED is not focused or collimated, but the angle of incidence is roughly normal. This setup does not allow isolating the measurements on either near or far pane surfaces but simply views the aggregate normal reflectance. The electronic circuit is diagrammed in Figure 7. This circuit has been tuned by selecting a resistor that provides a nearly linear response for the measured voltage vs. light levels reaching the phototransistor.

Preliminary experiments were performed to characterize the response of the phototransistor detector. In measuring glazings, we would like to know the percentage of light being reflected, which requires understanding the relationship between the light intensity and the measured voltage. In the preliminary experiments, a separate setup characterized the intensity of the IR-LED for varying levels of electrical power using both the spectrometer and a light meter. Then the setup shown in Figure 7 was placed on a highly reflective front surface mirror. The electrical power to the IR-LED was varied using a separate power supply, and the phototransistor voltage was recorded. The results of the detector characterization are shown in Figure 8. A simple (second order) polynomial equation was developed using recorded data for detector voltage and light intensity in order to correlate voltage readings with infrared reflectance.

Results. Results of the IR-LED/phototransistor were gathered for three types of glazings plus the gold-coated refer-

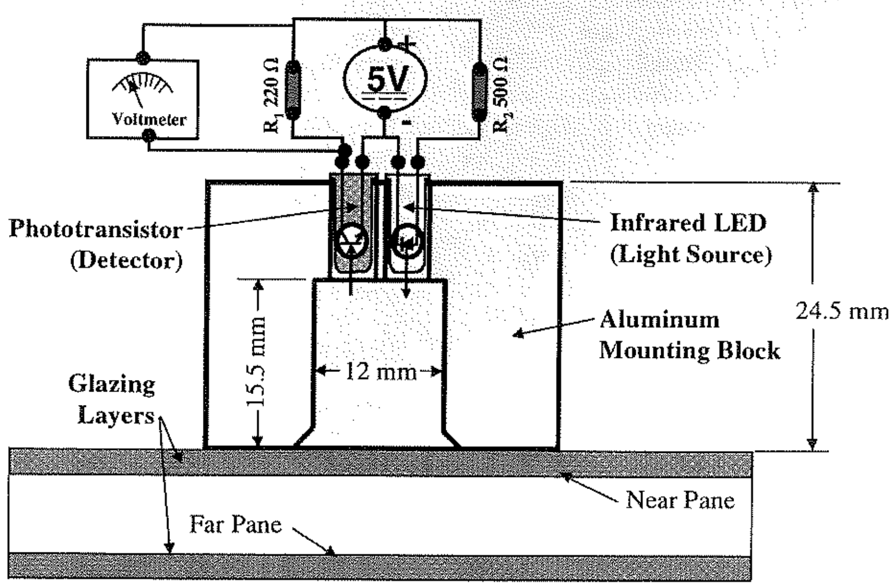

Figure 7 *Test setup for IR-LED/phototransistor pair.*

TABLE 2
Result of IR-LED/Phototransistor

Specimen (Dual Glazing)	Coating Location (Pane)	Voltage Reading (VoltsDC)	Reflected Light Relative to Gold Coating on Near Pane
Gold Coating	Near	3.065	100%
	Far	2.155	65.5%
Regular Low-E	Near	0.920	28.1%
	Far	0.793	24.4%
Spectrally Selective Low-E	Near	2.064	62.5%
	Far	1.557	46.8%
Clear/Clear	N/A	0.397	12.3%

ence glazing mentioned above. Results for measurements of various glazings are shown in Table 2. The voltage readings were first correlated to light intensity and then normalized with respect to the reference IGU with gold coating on the near pane.

DISCUSSION

The authors have developed two techniques useful for distinguishing among types of low-e coatings. The first technique uses a portable fiber-optic spectrometer that has been demonstrated to distinguish between the types of low-e coating that may be used in an IGU. The spectral data in Figures 4 and 5 are very similar to the expected data shown in Figure 1 and clearly show differences between clear, regular low-e, and spectrally selective low-e. The portable spectrometer was manageable in a field testing situation when used by a skilled operator. An erroneous reading at one home in our field exercise was caused by incorrect alignment of the optics when the spectrometer was focused on the surface of the far pane. This error caused a downward shift in the reflectance spectrum, which made the higher reflectance, spectrally selective coating appear to be regular low-e. This error highlights the main problem in using the current spectrometer configuration. Using the current configuration involves frequent operator judgement in aligning the optics to allow focusing on different glazing surfaces and compensating for deflected IGUs and various glass thickness. The spectrometer system is probably too complex to be used by a typical building inspector but is appropriate for research situations. Such a system could be a useful tool for developing a simpler system and may be effective for research on the durability and variability of optical properties in real products. However, no hand-held test device based on a spectrometer has been developed at this time. A hand-held device with spectrometer that connects to a notebook computer could be developed in a short period of time. A stepper-motor-driven translating mounting fixture could alleviate the operator judgment problems with tuning. With considerable effort, a self-contained hand-held unit with specially configured microprocessor-controlled electronics could also be developed to provide simplified results. However, the author's second technique for identifying low-e coatings shows much more promise for use in a simple hand-held device.

Results of Table 2 show that this optical technique, using an IR-LED and a phototransistor, can distinguish between the performance levels of regular and spectrally selective low-e coatings at 940 nm. The results showed reflectance values of about 12% for clear glazing, 24% to 28% for regular low-e, and 47% to 62% for spectrally selective low-e. The optoelectronic components are well suited to be the basis for a battery-powered, hand-held tester useful for field verification. While the 940 nm wavelength used by the IR-LED is useful for distinguishing between these two types of coatings, additional wavelength regions would need to be measured in order to accurately identify products in certain situations. For example, composition tints or simple reflective coatings might show reflectances similar to low-e coatings over this narrow band of wavelengths. For this reason, it is likely that a versatile test device would need to add one or more additional LEDs of different wavelengths to enable accurately identifying spectrally selective coatings. A test device could use a visible spectrum LED (operating at say 600 nm) to enable comparing the reflectance levels in the near infrared region to that of the visible region in order to better distinguish between different types of glazings. Other refinements to the experimental setup are needed, including the addition of a referencing technique to account for varying light output of the IR-LED and a means for simple presentation of the test results.

CONCLUSIONS

1. Optical techniques that measure in the near-infrared can detect and distinguish between different types of low-emittance coatings on window products.
2. A hand-held test device based on an infrared-light-emitting diode and phototransistors is feasible and could be developed to aid field tests for product verification.

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