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2013 OIC Measurement Problem
Contest Entry by Sandia National Laboratories

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Measurement Procedure

Since it is not possible to directly measure reflectance at normal angle (0^o) of incidence (AOI), we measured the reflectance at the lowest AOI that is common to our instruments, in order to acquire data that approaches the reflectance at normal incidence. This lowest AOI is 8^o and we acquired reflectance measurements at this AOI in both S and P polarization (Spol and Ppol). We also acquired reflectance data at 45^o AOI in Spol and Ppol. The two different instruments that we used to acquire these measurements are described briefly below.

- We utilized a Perkin –Elmer Lambda 950 spectrophotometer equipped with the Universal Reflectance Accessory to acquire the reflectivity measurements at 8^o and 45^o AOI in Spol and Ppol over the 400 nm – 700 nm wavelength range. The minimum AOI at which this instrument can measure reflectivities is 8^o. Spol and Ppol were achieved using a Glan-Thomson polarizer. Measurements were acquired over the wavelength range from 400-700 nm in 1 nm intervals.
- We utilized Sandia's custom-built large optics reflectometer to acquire reflectivity measurements at 8^o and 45^o AOIs in S and P polarization at 527 nm to compare with the reflectivity data acquired from the Lambda 950 at that wavelength. This instrument can measure reflectivity down to a minimum AOI of 3.5^o but we used it at 8^o AOI in order to compare its results with those of the Lambda 950 spectrophotometer. For each AOI and polarization, we took detector readings of the reflected signal at one-second intervals over 2-minute windows of time.

Sample Treatment

We prepared the sample for the reflectance measurements by roughening the back of the sample with 260-grit sandpaper, and then painted that surface with black spray paint, in order to eliminate back-surface reflections and their effects on the measurements.

Data Analysis

- Lambda 950 Measurements: For each AOI (8^o and 45^o) and for each polarization, four spectral scans were taken. This provided four reflectance data points per wavelength in both Spol and Ppol. At each wavelength, we calculated the average and standard deviation of the four reflectivity data values. This determined the average measured reflectivity in 1n wavelength intervals from 400 nm to 700 nm. Our data indicates that at 8^o AOI, the reflectances for both Spol and Ppol are very similar, with a small deviation between them as expected; one reflectance slightly above and the other slightly below the reflectivity at normal incidence. Because of this similarity, at this point, we averaged the 8^o AOI, S and P polarization data together to approximate the reflectance at 0^o AOI.
- Large Optics Reflectometer Measurements at 527 nm: We performed a 2-minute scan at 1-second intervals for each AOI (8^o and 45^o) and for each polarization. We took the average and standard deviation of each 2-minute scan to determine the average reflectivity at each AOI and polarization setting. We compared these results to the Lambda 950 results. These measurements have a higher accuracy than the Lambda 950 measurements. Therefore, we determined the offset between the reflectometer and spectrophotometer measurements at 527 nm, and then applied this offset to all of the spectrophotometer data.

Measurement Uncertainty

The uncertainties for each AOI are the following. They account for the standard deviations of the reflectometer data and the spectrophotometer data, as described above.

- 8^o AOI: +/- .0022236% (this corresponds to P-pol, which has higher uncertainty than S-pol)
- 45^o AOI, S-pol: +/- .0019881%
- 45^o AOI, P-pol: +/- .0098303%

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