University of California, San Diego

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# Visible Light Coefficient Measurements for Tokamak Wall Tiles

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The coefficients for visible light reflection off a graphite wall tile from DIII-D and off a molybdenum wall tile from Alcator C-mod were measured. The measurements were performed using a small mercury lamp mounted at a fixed incidence angle $q_i$ relative to the wall tile normal direction, with both mounted on a calibrated turntable. Light from the lamp was focused at a very small incident cone ($Dq_i$ = 1.50°) onto the wall tile surface. Light reflected from the surface was collected into a small acceptance cone ($Dq_r$ = 0.5°) and focused onto the entrance slit of a visible spectrometer. By varying the angle of the entire turntable, the variation of the reflected light distribution with reflection angle $q_r$ was obtained. By varying the spectrometer grating setting to look at different mercury lines, the variation of reflection coefficient with wavelength was obtained.

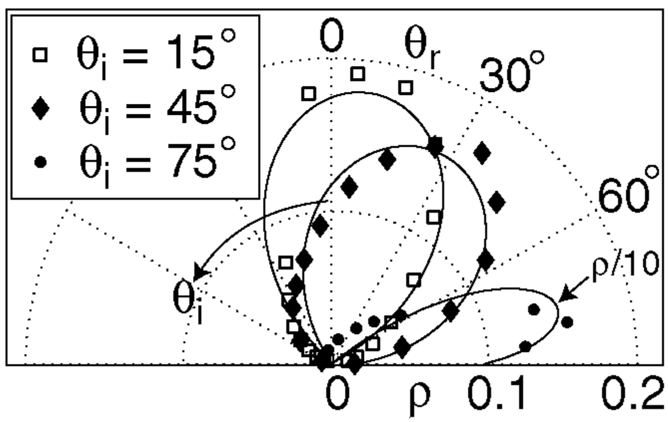


Fig. 1. Measured normalized reflectivity $r$ for graphite as a function of reflection angle $q_r$ for three different incident light angles $q_i$ at wavelength λ = 5456 Å. The solid curves are fits to the data of the form $r = r_o cos\left(\frac{q_r - q_o}{k}\right)$.

The points in Fig.1 show the measured normalized reflectivity for the graphite tile at wavelength λ = 5456 Å as a function of reflection angle $q_r$. The normalized reflectivity is defined as the reflected intensity per unit solid angle $\partial I_r / \partial\Omega$ normalized by the incident light intensity $I_i$:

$$r \equiv \frac{\partial I_r / \partial\Omega}{I_i} \quad . \qquad (1)$$

Three different incident light angles $q_i$ are shown; the data for $q_i$ = 75° is plotted divided by 10 for clarity. The data shown is for a constant unit surface area $dA$. In the setup used here, the spectrometer-diagnosed spot size is small compared with the lamp image on the tile, and therefore the measured illuminated surface area increases like 1/cos$q_r$. The measured $r$ is multiplied by cos$q_r$ to remove this effect.

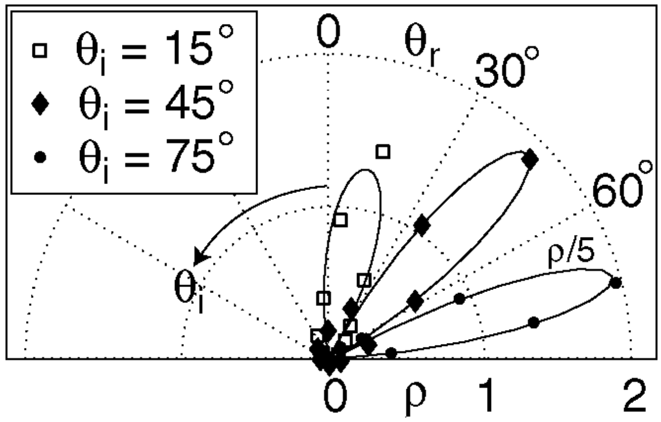


Fig. 2. Measured normalized reflectivity $r$ for molybdenum as a function of reflection angle $q_r$ for three different incident light angles $q_i$ at wavelength λ = 5456 Å. The solid curves are fits to the data of the form $r = r_o cos\left(\frac{q_r - q_o}{k}\right)$.

Similarly, Fig. 2 shows the reflectivity $r$ measured for the molybdenum wall tile for three different angles of attack at λ = 5456 Å. In both Fig. 1 and Fig. 2, the solid curves are fits to the data of the form $r = r_o cos\left(\frac{q_r - q_o}{k}\right)$; it can be seen that this simple functional form fits the data reasonable well. The width of the reflection lobe is thus $Dq = kp/2$. The total reflection coefficient $R$ can then be obtained by assuming that the reflection lobe is symmetric about the axis $q_r = q_o$ and integrating over all solid angles:

$$R = \frac{I_r}{I_i} = \int r\, d\Omega = \begin{cases} 2pkr_o\left(\frac{sin(kp/2) - k}{1 - k^2}\right) & , k \neq 1 \\ pkr_o & , k = 1 \end{cases} \quad . \qquad (2)$$

Note that the reflection coefficient is defined here as the ratio of intensities, not the ratio of electric fields, as is often used in theory discussions. The measured total reflection coefficient $R$, the reflection lobe width $Dq$, and the central angle of the reflection lobe $q_o$ are plotted as a function of wavelength for graphite in Fig. 3. The solid lines are smooth fits to the data. The solid diamonds, solid circles, and open squares are taken using the mercury lamp.

The open diamonds are taken using a PISCES-A deuterium discharge on a carbon target as a light source. The reflection coefficient at $q_i = q_r = 45°$ was measured for $D_\alpha$ (6560 Å), $D_\beta$ (4860 Å), $D_\gamma$ (4340 Å), and the CD band head (4298 Å). For these measurements, the variation with reflection angle could not be obtained, so the lobe width $Dq$ measured from nearby lines using the mercury lamp was used to obtain the total reflection coefficient *R*. It can be seen the reflection coefficients obtained using plasma light agree reasonable well with the mercury lamp results.

Similar data taken for molybdenum is plotted in Fig. 4. In this case, reflection from the CD band was not measured.

Also shown in Fig. 3 and Fig. 4 are scattering data taken at $q_i$ = 45° and 75° using a He-Ne laser (λ = 6328 Å). In these measurements, the laser spot was aimed near the edge of the tile and a large photodiode was mounted at the tile edge to measure the reflected light. The acceptance angle of the photodiode was about 150°, which is large compared with the lobe widths seen in Fig. 3 and Fig. 4, so we expect these measurements to give a reasonably good estimate of the total reflection coefficient *R* when normalized by the beam power. Two different polarizations are shown: *s* (with the laser polarized perpendicular to the surface), and *p* (with the laser polarized parallel to the surface). The *s* polarization reflection was found to be 6 % larger than the *p* in the case of graphite ($q_i$ = 45°), 2 % larger in the case of graphite ($q_i$ = 75°), 4 % larger than in the case of moly ($q_i$ = 45°), and 19 % larger in the case of molybdenum ($q_i$ = 75°). A negligible difference (5 % or less) was seen in the total reflection between the plasma-exposed (front) tile surfaces and the clean, unexposed back tile surfaces using the laser reflection measurement technique.

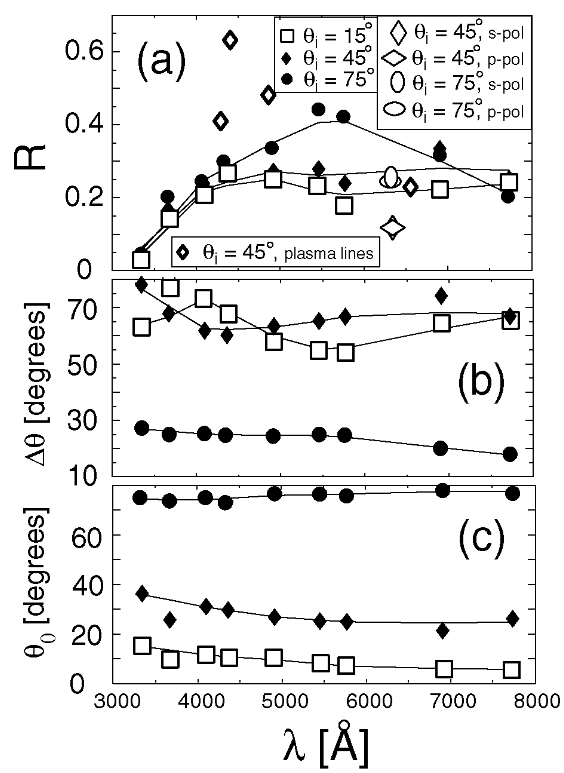


Fig. 3. (a) total reflection coefficient *R*, (b) lobe width *Dq*, and (c) lobe angle $q_o$ as a function of wavelength λ for graphite. Data marked "plasma lines" was taken using Dα, Dβ, Dγ, and CD

plasma emission as a light source; data marked “s-pol” or “p-pol” was taken using a He-Ne laser as a light source; and all other data was taken using mercury lines from a lamp as a light source.

| | $\theta_i = 15°$ | | | $\theta_i = 45°$ | | | $\theta_i = 75°$ | | |
|---|---|---|---|---|---|---|---|---|---|
| λ [Å] | Δθ | $\theta_o$ | R | Δθ | $\theta_o$ | R | Δθ | $\theta_o$ | R |
| 3341 | 63.0 | 15.0 | 0.021 | 78.5 | 35.9 | 0.037 | 27.4 | 74.6 | 0.038 |
| 3674 | 79.8 | 9.8 | 0.163 | 67.8 | 25.6 | 0.183 | 25.2 | 73.5 | 0.196 |
| 4098 | 73.8 | 11.6 | 0.206 | 61.9 | 30.7 | 0.203 | 25.2 | 74.9 | 0.238 |
| 4358 | 68.4 | 10.4 | 0.262 | 60.3 | 30.0 | 0.271 | 25.0 | 73.4 | 0.301 |
| 4916 | 58.5 | 10.0 | 0.252 | 63.4 | 26.4 | 0.270 | 24.3 | 76.5 | 0.336 |
| 5456 | 54.9 | 7.9 | 0.238 | 64.8 | 25.2 | 0.278 | 25.2 | 76.5 | 0.441 |
| 5770 | 54.0 | 6.8 | 0.180 | 66.8 | 25.4 | 0.242 | 24.3 | 76.0 | 0.422 |
| 6908 | 64.8 | 5.2 | 0.224 | 74.4 | 21.5 | 0.336 | 19.8 | 78.7 | 0.315 |
| 7729 | 65.7 | 6.1 | 0.238 | 66.1 | 26.0 | 0.252 | 18.0 | 77.0 | 0.203 |

Table 1. Fitting coefficients for graphite reflection.

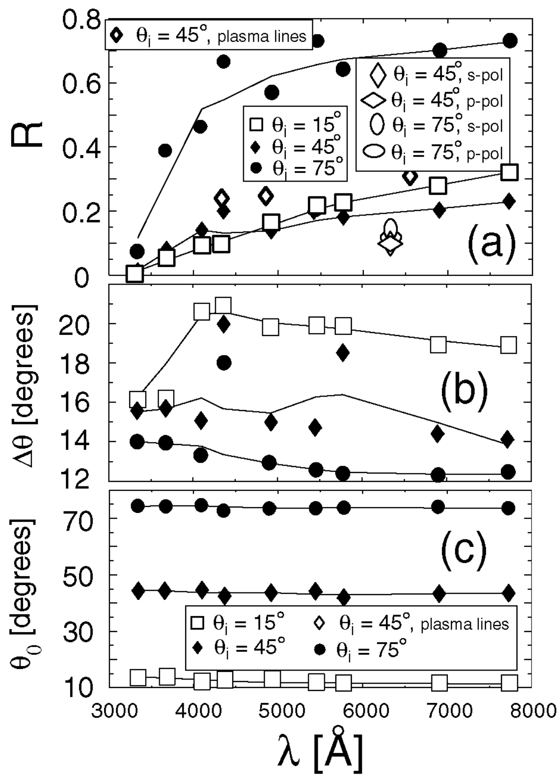


Fig. 3. (a) total reflection coefficient *R*, (b) lobe width *Dq*, and (c) lobe angle $q_o$ as a function of wavelength λ for molydenum. Data marked “plasma lines” was taken using Dα, Dβ, Dγ, and CD

plasma emission as a light source; data marked "s-pol" or "p-pol" was taken using a He-Ne laser as a light source; and all other data was taken using mercury lines from a lamp as a light source.

| | $\theta_i = 15°$ | | | $\theta_i = 45°$ | | | $\theta_i = 75°$ | | |
|---|---|---|---|---|---|---|---|---|---|
| $\lambda$ [Å] | $\Delta\theta$ | $\theta_o$ | R | $\Delta\theta$ | $\theta_o$ | R | $\Delta\theta$ | $\theta_o$ | R |
| 3341 | 16.2 | 13.8 | 0.0084 | 15.6 | 44.6 | 0.0133 | 14.0 | 74.3 | 0.070 |
| 3674 | 16.1 | 13.6 | 0.0518 | 15.7 | 44.2 | 0.078 | 13.9 | 74.5 | 0.393 |
| 4098 | 20.6 | 11.9 | 0.0938 | 15.0 | 44.5 | 0.140 | 13.3 | 74.5 | 0.464 |
| 4358 | 20.9 | 12.3 | 0.098 | 20.0 | 42.3 | 0.199 | 18.0 | 72.5 | 0.665 |
| 4916 | 19.8 | 11.6 | 0.154 | 15.0 | 43.9 | 0.138 | 12.9 | 73.7 | 0.565 |
| 5456 | 19.9 | 11.7 | 0.217 | 14.7 | 43.9 | 0.193 | 12.6 | 73.7 | 0.735 |
| 5770 | 19.8 | 11.7 | 0.228 | 18.5 | 41.7 | 0.182 | 12.4 | 73.8 | 0.640 |
| 6908 | 18.9 | 11.3 | 0.280 | 14.4 | 43.7 | 0.203 | 12.2 | 73.8 | 0.700 |
| 7729 | 18.9 | 11.4 | 0.322 | 14.1 | 43.4 | 0.231 | 12.4 | 73.6 | 0.730 |

Table 2. Fitting coefficients for molybdenum reflection.