Measurement of Optical Absorption in Dielectric Reflectors

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Abstract. The absorption of optical coatings can be measured by the method described with an accuracy of 0.001%. The radiation absorbed by the optical coating causes a change in the temperature of the coating and the substrate. The temperature change is measured by means of a thin-film resistance thermometer deposited on the substrate. The method was tested for laser reflectors at 1060 nm with a laser as a light source.

Index Headings: Absorption – Dielectric coatings

In laser optics, reflectors with dielectric coatings are used. These reflectors have the advantage of low absorption. For some applications in the laser field, in particular for high-power lasers, it is of interest to know the absolute value of the absorption of dielectric reflectors. Neglecting the effect of scattering, a rough estimate of the absorption can be made by use of the relation

\[ A = 1 - r - t. \]  

(1)

where \( W \) is the incident radiation intensity. The temperature difference \( \Delta T \) is determined by the increase \( \Delta R \) in the electrical resistance \( R \) of the gold layer:

\[ \Delta T = \frac{\Delta R}{\alpha \cdot R}. \]  

(3)

\( \alpha \) is the thermal coefficient of the resistance. From relations (2) and (3), the determination of the absorption appears quite simple. However, the temperature \( \Delta T \) of the resistance thermometer is also influenced by the current \( I \) in the thermometer circuit, and this has to be taken into consideration. The temperature \( T_e \) due to the current in the resistance is given by the relation

\[ G(T_e - T_0) = RI^2 = P \]  

(4)

where \( T_0 \) is the ambient temperature. The radiation intensity \( W \) incident on the reflector causes the temperature to rise:

\[ T = T_e + \Delta T. \]  

The temperature as a function of time is given by the following differential equation:

\[ C \frac{d \Delta T}{dt} + G \cdot \Delta T = W \cdot A + \frac{dP}{dT} \cdot \Delta T \]  

(5)

where \( C \) is the thermal capacity of the reflector. With the introduction of an "effective thermal con-
ductance" [1] \( G_e = G - \frac{dP}{dT} \) the solution of (5) is
\[
\Delta T = \frac{W \cdot A}{G_e} \left( 1 - e^{-\frac{G_e}{C \cdot t}} \right).
\]

For the arrangement shown in Fig. 1 the change in \( P \) with temperature is
\[
\frac{dP}{dT} = \alpha \cdot R \frac{dP}{dR} = \alpha \cdot R \cdot T^2 \cdot \frac{R - R_{th}}{R + R_{th}}
\]
\[
= \alpha \cdot G(T - T_0) \frac{R - R_{th}}{R + R_{th}}.
\]
For \( R > R_{th} \) the current can be considered constant; hence the change in temperature can be calculated directly from the change in voltage \( \Delta U_m \) across the resistor \( R \):
\[
\Delta T = \frac{\Delta U_m}{\alpha \cdot U_m}.
\]

The absorption \( A \) can now be determined from the measured values by the relation
\[
A = \frac{G_e}{W} \cdot \Delta U_m.
\]

For precise measurement of the small amount of absorption expected for dielectric coatings, a high light intensity is necessary. This is achieved by the use of a laser. In addition, the sample must be well insulated in order to keep down the thermal conductance.

The set-up is shown in Fig. 2. The measurements were made under vacuum in order to avoid heat losses. The influence of scattered light was eliminated by a screen. Quartz plates about 2.5 cm in diameter and about 1 mm thick were used as substrates. The thermometer resistance was deposited on the substrate as a thin ring of gold in order to ensure good thermal contact. The dielectric reflector was deposited on the substrate within the ring of the resistance thermometer (Fig. 3). A calculation of the temperature distribution on the sample showed that the difference between the measured temperature and the average temperature on the dielectric reflector is less than 2.5%. The temperature coefficient \( \alpha \) of the thin gold film differs from the coefficient of the solid material [2]. Therefore the coefficient \( \alpha \) is determined experimentally for each gold film. The accuracy in the determination of the absorption is \( \pm 0.001\% \) (absolute error). The accuracy can be improved by reducing the thermal conductance of the substrate, by a better control of the ambient temperature \( (\Delta T_{amb} < 0.1^\circ C) \), and by the use of a more powerful laser.