What are reflection losses and how can they be minimized?

Reflection occurs at an interface between two media of differing refractive indices. Each reflection splits the incoming beam into a transmitted and reflected component. Typically, it is the transmitted component that is of further interest. In these cases, the reflected component is the unwanted byproduct and the light lost to the reflection only subtracts from the overall light available to the measuring process.

An example is a gas transmission cell. The gas is contained inside the cell during the measurement. The light is brought into the cell through an optically transparent window. A window has two interfaces, both reducing the intensity of the transmitted light. The light is generally incident perpendicular to the window, and for the perpendicular incidence, the intensity loss per surface is:

$$R = \left(\frac{n-1}{n+1}\right)^2 \quad (1)$$

where n is the refractive index of the window material and the refractive index of air as well as the sample is assumed to be one. The expression for the transmittance of a window is:

$$T = \frac{1-R}{1+R} \quad (2)$$

The reason the transmittance is not simply 1-2R is that the light reflected back from the second interface is re-reflected forward by the first interface. For a typical case of a cell with two KBr windows (n=1.5), the loss of light is approximately 20%.

In a liquid cell, the situation is somewhat different. First, the sample refractive index is no longer essentially one. Thus the cell contains two window-air interfaces and two window-sample interfaces. The reflectance at window air interfaces is still controlled by (1). The window-sample reflectance is:

$$R = \left(\frac{n-n_s}{n+n_s}\right)^2 \quad (3)$$

where n_s is the refractive index of the sample.

With liquid samples in IR, the cell pathlength is very short. Multiple reflections through the cell interfere and yield so called interference fringes in the transmitted light spectrum. These fringes have period:

$$\Delta = \frac{1}{2n_s d} \quad (4)$$

where d is the cell pathlength and n_s is the refractive index of sample. Since these fringes originate from the multiple reflections on window-sample interfaces, one method of reducing their effect is to match refractive index of windows to that of the sample. In that case, according to (3), the reflectivity of the interface vanishes and so do fringes.

The other issue is one of reducing the reflection losses due to the windows. Coating the interface with a transparent film can modify the reflectance of an interface. The exact results depend on the refractive index and thickness of the coating. A single layer coating with a material with refractive index roughly square root of the refractive index of the window inhibits reflection at a particular set of wavelengths. The wavelengths of vanishing reflectance can be fine tuned by the choice of the thickness of the coating. By combining a number of films of different refractive indices and thicknesses, the reflectance could be minimized in a broader spectral range. Broadband anti-reflection (BBAR) coatings effective over almost the entire IR range have been developed.