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Measurements of Optical Loss in Transparent Solids
using a Novel Spectrometer Based on Optical Cavity Decay

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ABSTRACT

Recent advances in High Average Power (HAP) solid state lasers and the development of new concept lasers with the potential of ultra-high average power output have put increasing demands on the transparency of optical window materials. To gain a better understanding of the current status of window materials and to direct research towards more nearly transparent materials, we have constructed an optical characterization facility with the purpose of making quantitative optical loss measurements in the sensitivity range of 10^{-3} to 10^{-6} cm^{-1} .

The cornerstone of this facility is a scanning optical lossmeter in which loss is determined by comparing the decay time of an optical cavity with and without a transparent solid present. The lossmeter has been successfully applied to measurements of the optical loss of witness samples of highly transparent fused silica. A description of the lossmeter and a compilation of preliminary loss measurements are presented here.

1. Introduction

Research on High Average Power (HAP) lasers places significant constraints on the optical quality of laser components. At Lawrence Livermore National Laboratory (LLNL), researchers often use predictive models to judge performance before constructing high power laser systems. The accuracy of these predictions is very dependent on knowledge of the various loss components. Of current high interest is window material for HAP lasers. Loss measurements are required to predict beam-induced damage to the windows, and possible phase-front distortion to the beam caused by non-uniform laser heating of the optics.

Since any phase distortion will have to be corrected throughout the optical system, lower absorption minimizes the complexity of the system. Consequently, to monitor window materials and improvements thereof, loss measurements must be routinely made at 10^{-5} cm^{-1} and better. In this paper we present results of loss measurements on highly transparent fused silica, and discuss in detail the principal technique for these measurements, the infrared (IR) scanning cavity lossmeter.

2. Theory

For transparent optic characterization we routinely employ three complimentary loss measuring techniques or instruments; laser calorimetry, an optical scattering sphere, and a scanning cavity lossmeter. Calorimetry measures absorption loss by monitoring the temperature rise of a thermally isolated sample under laser irradiation.² The scattering sphere measures surface and bulk scatter of the sample by integrating total scatter over a nearly 4π steradian surface area.³ The scanning cavity lossmeter performs wavelength dependent total loss measurements on highly transparent samples by a cavity ringdown technique. Use of the latter technique in the near infrared is a new approach that has given us an important tool in determining the optical quality of laser components. It achieves the goal of bulk loss measurements sensitive to less than 10^{-5} cm^{-1} and is described in more detail below.

2.1 Ringdown Loss Measurement Theory

Figure 1. Schematic diagram of resonant cavity.

In routine operation, a short laser pulse is introduced on axis to a precisely aligned resonant cavity (see figure 1). If the coherence length of the pulse is short compared to the cavity length, a sizeable fraction of the pulse energy is established as cavity radiation. This energy (I_0) decays as it is dissipated by the various cavity loss mechanisms. The decay is exponential and can be represented by:

$$I(t) = I_0 e^{-t/\tau} \quad (1)$$

where τ is the empty cavity lifetime (or ringdown time).

If T is the transmission of each cavity mirror and L is the loss incurred by the pulse on a single pass of the cavity, then the intensity remaining in the cavity after a single round trip is given by:

$$I(t = \text{round trip}) = I_0 e^{-L} (1-T) e^{-L} (1-T) \quad (2)$$

where $I_0 e^{-L}$ is the intensity remaining after a single pass through the cavity and $(1-R)$ is the mirror reflection coefficient. Since T is very small ($\sim 10^{-4}$) equation 2 can be written as:

$$I(t = \text{round trip}) = I_0 e^{-2(T+L)}. \quad (3)$$

The time required for a round trip is simply $2d/c$, where d is the cavity length and c is the speed of sound in the cavity. By relating equation 3 to equation 1 (evaluated at $t = 2d/c$) we obtain an expression that relates ringdown time to total cavity loss:

$$(T + L) = d/c\tau. \quad (4)$$

Consequently, with knowledge of d and c (corrected for index if a sample is present) the cavity total loss is readily determined from a measurement of ringdown time τ .

2.2. Ringdown Lossmeter Description

The IR cavity lossmeter is shown schematically in Figure 2. The system consists of a driver laser, a tunable probe laser and a Raman scattering cell. The driver laser is a JK Model 750 HyperVAG that has nominal output energy of 850 mJ at 1064 nm with a 10 Hz repetition rate and 10 ns pulse width. The driver output is frequency doubled with an angle-tuned KD*P crystal and injected into a dye laser. The dye laser is Lumonics Model HD-300 which is configured as an oscillator-amplifier. The output of the dye laser is nominally 15-25 mJ with a 10 ns pulse width and 0.17 cm^{-1} linewidth. For tunable operation in the near IR, the dye laser output is focused into a 1 m long stimulated Raman scattering (SRS) cell containing hydrogen gas at 200 psi. The first or second Stokes output, which is selected by a suitable transmission filter, provides continuous tunability to 2000 nm. The output of the SRS cell is then aligned coaxial with, and transverse mode-matched to, the optical cavity. Wavelength selection and scanning is controlled by computer through an interface to the dye laser scan control unit.

Figure 2. Schematic diagram of IR scanning lossmeter.

The optical cavity consists of two nearly identical, highly reflective mirrors with a transmission of approximately 10^{-4} at 1064 nm, radius of curvature of 6 m, and a separation, d, of 40 cm.

The decay rate of the radiation within the cavity is measured by monitoring the intensity of transmitted light through the exit mirror with a photomultiplier tube (PMT). A waveform digitizer registers the decay and the $1/e$ lifetime is calculated with a curve fitting routine.

The decay curve of a typical cavity ringdown is shown in Figure 3. The computer uses the calculated τ to obtain the total cavity or roundtrip loss. In practice, the loss due to the sample alone is obtained by subtracting the empty cavity losses from the loss measured when a sample is present.

Figure 3. Typical ringdown trace with computer loss calculation displayed above.

3. Results & Discussion

Because of the low absorption properties of fused silica and its commercial availability in large aperture, we have thoroughly studied it as a laser window candidate. Commercially available fused silica glass was obtained from Corning Glass Co. (Corning, NY), Corning 7940, and Heraeus Optical Co. (West Conshohocken, PA), Infrasil II, Suprasil I and Suprasil M1. Five witness samples were obtained of each fused silica glass material, with each witness representing different manufacture lots. Samples were cut to 1 cm diameter cylinders, 2 cm in length. All samples were simultaneously polished to laser quality or better. Opposing faces were held parallel to 10 sec of arc or less.

Total loss (scattering plus absorption) was determined by the cavity lossmeter at wavelengths 1064 nm and 1600 nm. Absorption loss was determined by calorimetry at 1064 nm only.

Table 1. Compilation of loss measurements on fused silica.

Sample	Loss (ppm/cm)		
	Lossmeter (1600 nm)	Lossmeter (1064 nm)	Calorimeter (1064 nm)
Corning 7940			
A1	150	89	31
B1	150	86	34
C1	158	105	45
D1	167	78	39
E1	163	85	37
Heraeus Infracel II			
A1	462	980	785
B1	55	85	61
C1	192	220	87
D1	106	154	100
E1	56	50	40
Heraeus Suprasil 1			
A1	200	27	14
B1	218	47	18
C1	212	48	14
D1	202	27.5	12
E1	209	31	15.5
Heraeus Suprasil M1			
A1	7	10.5	3.5
B1	9	11.5	1.4
C1	4.5	10.5	2.8
D1	5	11.5	3.3
E1	6	11	3.9

Loss measurements on the fused silica glass are summarized in table 1 above. Results at 1064 nm shows decreasing losses with a decrease in the water content of the sample. Suprasil M1 was the most transparent sample measured with absorption losses comparable to values measure by others.³ Infracel II showed the greatest variability in loss, probably due to the fact that it is a natural quartz product.

4. Conclusions

A new concept loss measuring technique has been developed and successfully applied to studies of high power laser window materials. The window materials, prepared from witness samples of vendor supplied stock, had total loss coefficients of 10^{-3} to 10^{-5} cm⁻¹ measured at 1.06 μ m. Absorption loss was determined to be as low as 3×10^{-6} for high quality fused silica. Samples prepared from natural materials had higher loss and greater sample to sample variability than those prepared from synthetic stock.

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6. References

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