SLAC-PUB-17470

DIRC Note # 140

July 15, 2001

Internal Group Note

Measurement of EPOTEK-301-2 Optical Glue Refraction Index and a Reflectivity from EPOTEK-301-2/Fused Silica Interface.

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Abstract

To my surprise, the refraction index of EPOTEK-301-2 glue is not that well known in the DIRC wavelength region. Ref.1 used information from the Epoxy Technology Company. In the mean time I have learned that this information is based on the liquid glue sample. No data exists for the cured epoxy; the company representative "guessed" that the cured EPOTE-301-2 glue may have the refraction index as much as 0.03 higher, which is a quite substantial amount. I decided to resolve this puzzle by measuring the refraction index of solid EPOTEK-301-2 glue by casting it into a prism form. The measurement was performed at four laser wavelengths. The paper also presents a direct measurement of the reflectivity from the interface of the glue and fused silica at 442nm as a function of incident angle, and finds a slight disagreement with the Fresnel theory, if one uses the newly measured refraction index. Both measurements presented in this paper are important input for the photon background study presented in the Ref. 2.

1. Introduction

After I wrote the DIRC Note 129, I was surprised to find out that the refraction index of the EPOTE-301-2 optical glue quoted in the Epotek Co. data sheet corresponds to glue in a liquid form. They use a commercial spectrometer with a liquid cell, and as a result it is convenient for them to do it this way. More disturbing thing was that the manufacturer told us that the refraction index of the solid glue may be higher compared to liquid by as much as 0.03. The Epotek Co. is quoting the refraction index at one wavelength (a sodium line at 589.3 nm). The company provided the data of another customer (not named) covering a wavelength range between 1000 and 5000nm. It was not clear to them if this particular data was obtained with glue in liquid or solid form. In absence of more complete information at that time, I simply made a linear interpolation between the refraction index values corresponding to 589.3 and 1000nm in Ref. 1.

To solve this confusion, I have decided to measure the refraction in the DIRC wavelength region. The measurement of the refraction index is considered a simple task until one has to do it. I decided to try to cast the glue in a form of a wedge with an angle of about 10^{o}. The major systematic errors are the knowledge of the wedge, incident and deflection angles. The measurement was done at four different laser wavelengths: 325, 442, 543 and 633nm (at 266nm the glue is not transparent any longer). I believe I succeeded to measure the refraction index with an error of about ± 0.005, which is better than I was expecting when I started.

I have also decided to measure the reflection coefficient of the EPOTEK-301-2/Fused Silica interface directly. In principle, one could simply use the refraction index of glue and fused silica, and calculate the Fresnel reflection. That is, if one is convinced that the Fresnel theory fully describes the problem. Various effects could spoil this assumption. For example, non-ideal fused silica bar polish, or lack of adhesion of the glue to the fused silica surface, etc. In fact, I do find a discrepancy between the theory and the measurement at larger incident angles.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-76SF00515.

2. Measurement of the refraction index of EPOTE-301-2 glue.

Figure 1 shows the principle of the measurement of the refraction index. Table 1 shows various distances, typical contributions to various errors and the final values of the refraction index. The wedge angle was measured on the coordinate measuring machine at the QC shop at SLAC, and therefore its error represents a negligible contribution compared to all other errors in the problem. The largest contributing error was due to error in the incident angle. The error in the deflection angle is smaller because the imaging screen was ~3 meters away, which provided a sufficient lever arm. The wavelength was chosen by a selection of one of four lasers. I could not use the 266nm wavelength because the EPOTEK-301-2 glue is not transparent below ~300nm. I have not see any systematic variation in the result when different spots on the wedge were chosen, i.e., the result does not depend on the thickness of the glue, which would indicate problems of curing larger bulk of the glue. Figure 2 shows the results of the measurements together with polynomial fit. Figure 3 shows a comparison of my measurement with other data. One can see that my measurements with the solid glue (open squares) are in agreement, within errors, with the Epotek Co. ‘s measurement at 596.3nm using liquid glue. Figure 4 compares the refraction index of fused silica, water and EPOTE-301-2 glue.

Once the refraction index of EPOTEK-301-2 glue and fused silica are known, one can use the Fresnel theory to calculate the reflection coefficient as a function of wavelength and incident angle. Figure 5 shows this calculation as a function of incident angle at 442 nm wavelength for TE and TM polarization modes, and Fig. 6 shows it as a function of wavelength for 0^o incident angle. One can see that up to ~350nm there is no large reflection from the glue/fused silica interface. The reflectivity goes up with the wavelength.

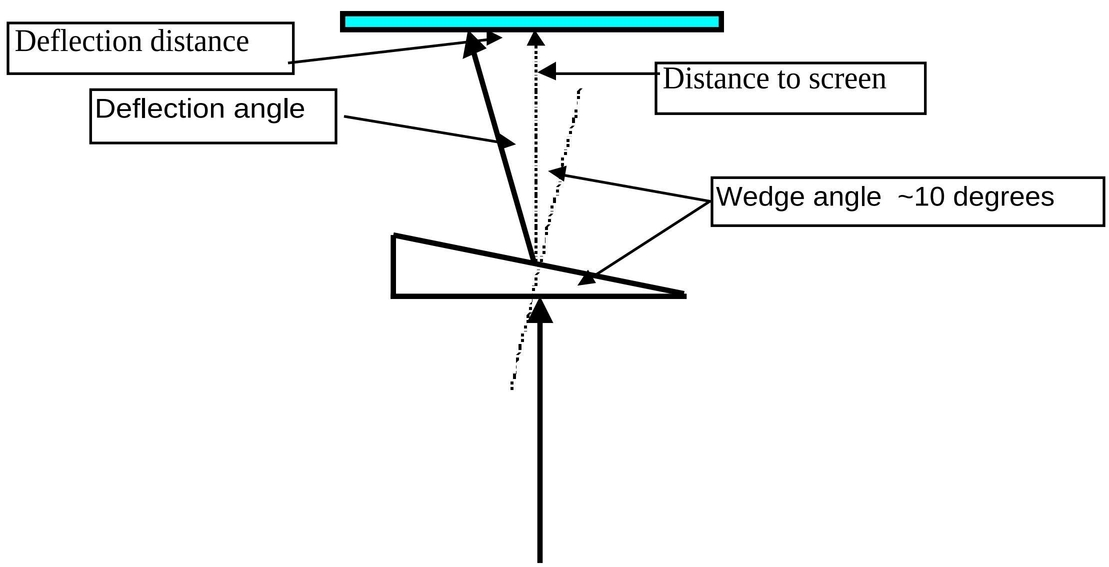

Fig. 1 – Schematic description of geometry of a setup used to measure of the refraction index of the cured EPOTEK-301-2 optical glue.

Table 1 – Various measured parameters in my test necessary to estimate the refraction index and its error

EPOTEK-301-2

Wedge angle:	10.0816	deg

<--- Note: Measured in the QC department at SLAC using the coordinate machine

Wavelength [nm]	Color	Deflection Dist. [mm]	Defl. Dist. error [mm]	Distance to screen [mm]	Dist. To screen error [mm]	Defl. angle [deg]	Error (Defl. Angle)	Error (Inc. angle)	Error (wedge angle)	Total Error [deg]	Refr. Index	Total Error (refr. Index)
325	UV	325.4375	1	2844.8	1.5	6.526114	0.02014053	0.0490378	0.0005	0.0530151	1.6327712	0.00528583
442	blue	300.0375	1	2844.8	1.5	6.020656	0.02014053	0.0490378	0.0005	0.0530151	1.5844143	0.00528583
543	green	292.1	1	2844.8	1.5	5.862504	0.02014053	0.0490378	0.0005	0.0530151	1.5692584	0.00528583
633	red	287.3375	1	2844.8	1.5	5.767569	0.02014053	0.0490378	0.0005	0.0530151	1.560155	0.00528583

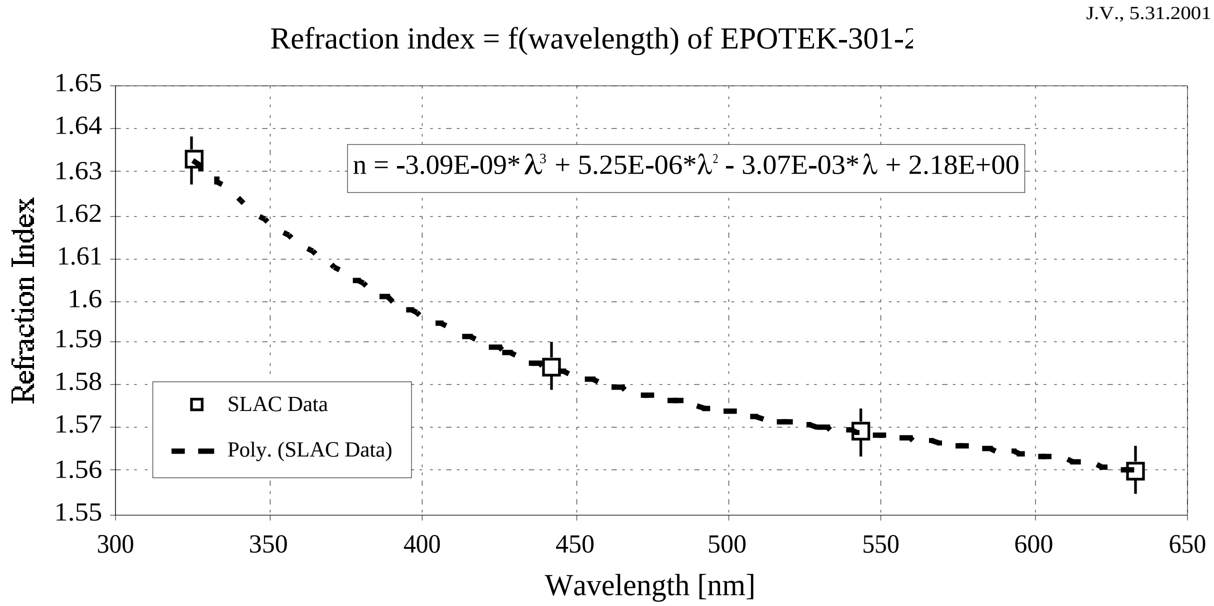

Fig. 2 – Measurement of the refraction index of the EPOTEK-301-2 optical glue used to glue the DIRC fused silica bars together. The wavelength region covers the DIRC bandwidth. The graph also shows the polynomial fit to data.

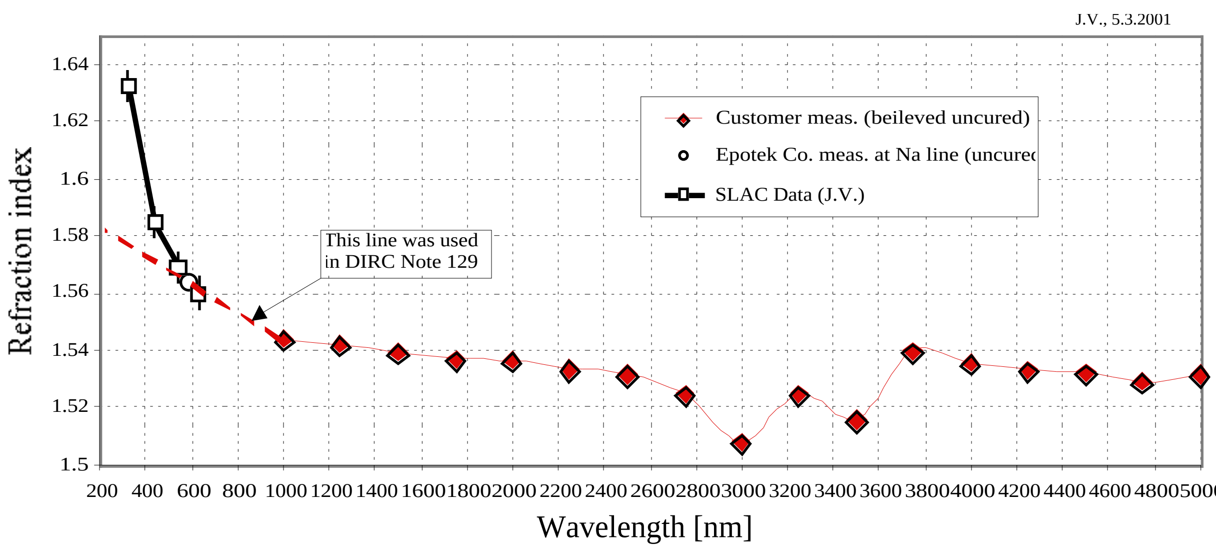

Fig. 3 – Overall match of my measurement (open squares) to that of Epotek Co. (596.3nm; open circle) and the other “unnamed” source (1000-5000nm; diamonds). It turns out that my measurement if solid EPOTE-301-2 glue is consistent with the Epotek Co.’s measurement of the wet glue. However, it is clear that the previous “straight line” extrapolation is underestimating the value of the refraction index considerably below ~400nm.

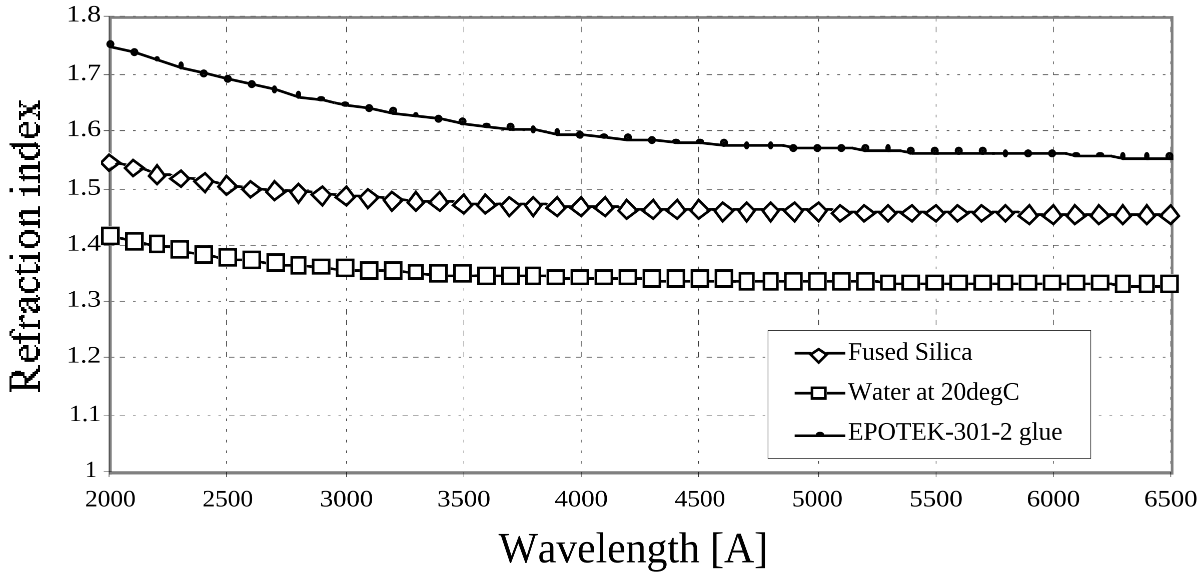

Fig. 4 – Refraction index of fused silica[1], water[2] and EPOTEK-301-2 optical glue[3] used to glue DIRC bars together.

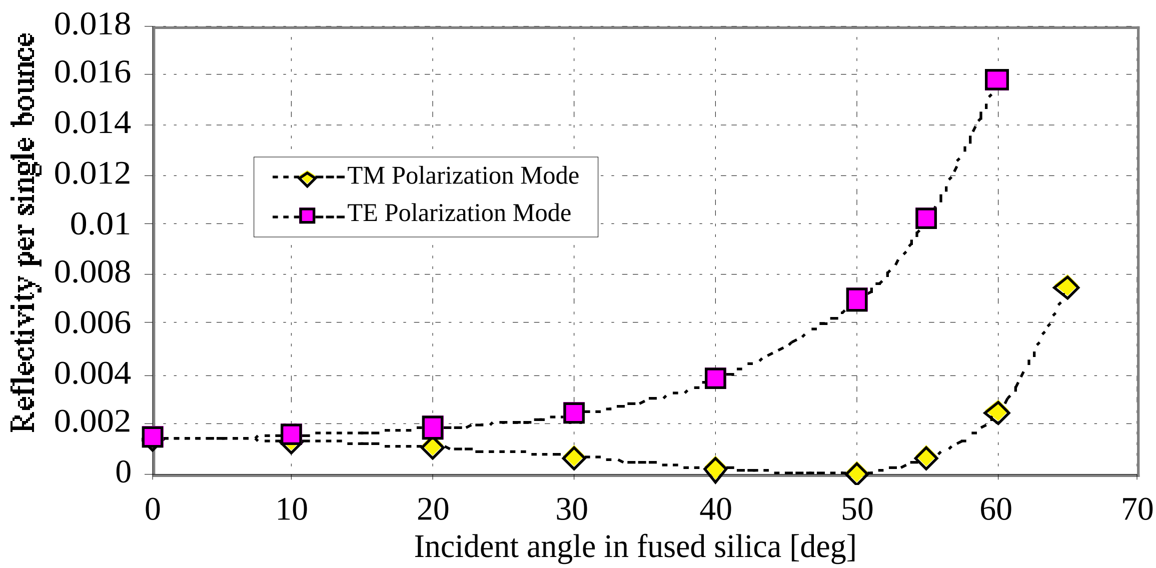

Fig. 5 – Fresnel reflectivity per single bounce from the EPOTEK-301-2 glue / fused silica interface for TE and TM photon polarization modes (calculated at 442 nm). The calculation is based on the knowledge of the refraction index only.

[1] This parameterization of the quartz refraction index comes from the Melles-Griot Company's catalog.
[2] The refraction index data come from N.I. Koshkin, M.G. Shirkevich, Handbook of Elementary Physics, 1982.
[3] Fit to the refraction index data presented in this paper is shown in Fig. 2.

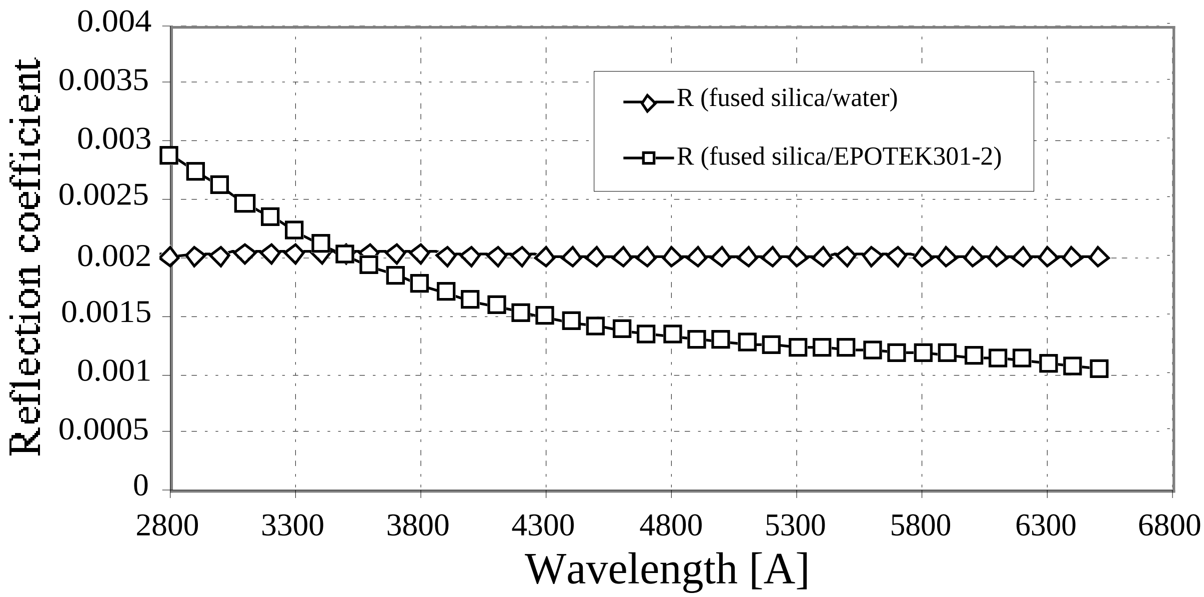

Fig. 6 – Calculated Fresnel reflectivity per single boundary at incident angle of 0º for two typical interfaces used in DIRC. The calculation is based on the measurement of the refraction index shown in Fig.2. One can see that the EPOTEK-301-2 glue/fused silica interface begins to be reflective at long wavelengths. On the other hand, the interface of fused silica & water is rather non-chromatic.

2.4. A direct measurement of the EPOTEK-301-2 glue/Fused Silica interface reflectivity as a function of incident angle in a TE mode.

Figure 7 shows a principle of the relative measurement of the reflectivity coefficient on the EPOTEK-301-2 glue and the fused silica interface as a function of angle of incidence. The measurement is relative one. It compares the transmission through two specially prepared samples: (a) one sample is made of two identical fused silica coupons glued together with 0.001" thick EPOTEK-301-2 glue, using identical procedure as for the DIRC bars, and (b) the second sample is an identical single fused silica coupon without any glue. Both samples are mounted on a rotating table capable of setting the incident angle identical for both samples. For each chosen angle of incidence one measures a relative transmission through two samples, which are selected without changing the angle of incidence. I assume that the coupons have identical surfaces and therefore the Fresnel correction on the front and rear surfaces cancels out in ratio. Furthermore, it is assumed that the losses in coupon's volume are also identical. What remains then are transmission losses in two glue/fused silica interfaces.

Figure 8 shows the raw transmission measurement using the test setup described in Fig. 7. The transmission involves crossing two fused silica/EPOTE-301-2 glue interfaces. Based on this measurement one can then calculate the reflectivity per single interface of fused silica and EPOTE-301-2 glue. Figure 9 shows the resulting reflectivity per single glue/fused silica boundary at 442nm in TE polarization mode. The 442nm blue laser is vertically polarized (500:1). The data were normalized at 0º incident angle using the Fresnel reflectivity calculation, which used the refraction index of EPOTE-301-2 glue and fused silica shown in Fig. 4. Figure 9 shows that the measurement disagrees with the Fresnel theory for angles above 20º. It is not clear why. A possible explanation is that the fused silica coupons used for glue sample and for the reference are not identical, or the glue does not adhere to the fused silica surface, or there is a slight subsurface damage in these coupons. Figures 10 and 11 show the polynomial fit to either all data, or just data set #1 and #2. It is interesting to point out that the Ref. 2 explains the data only if the reflectivity from fused silica/EPOTEK-301-2 glue is also increased relatively to the Fresnel theory only.

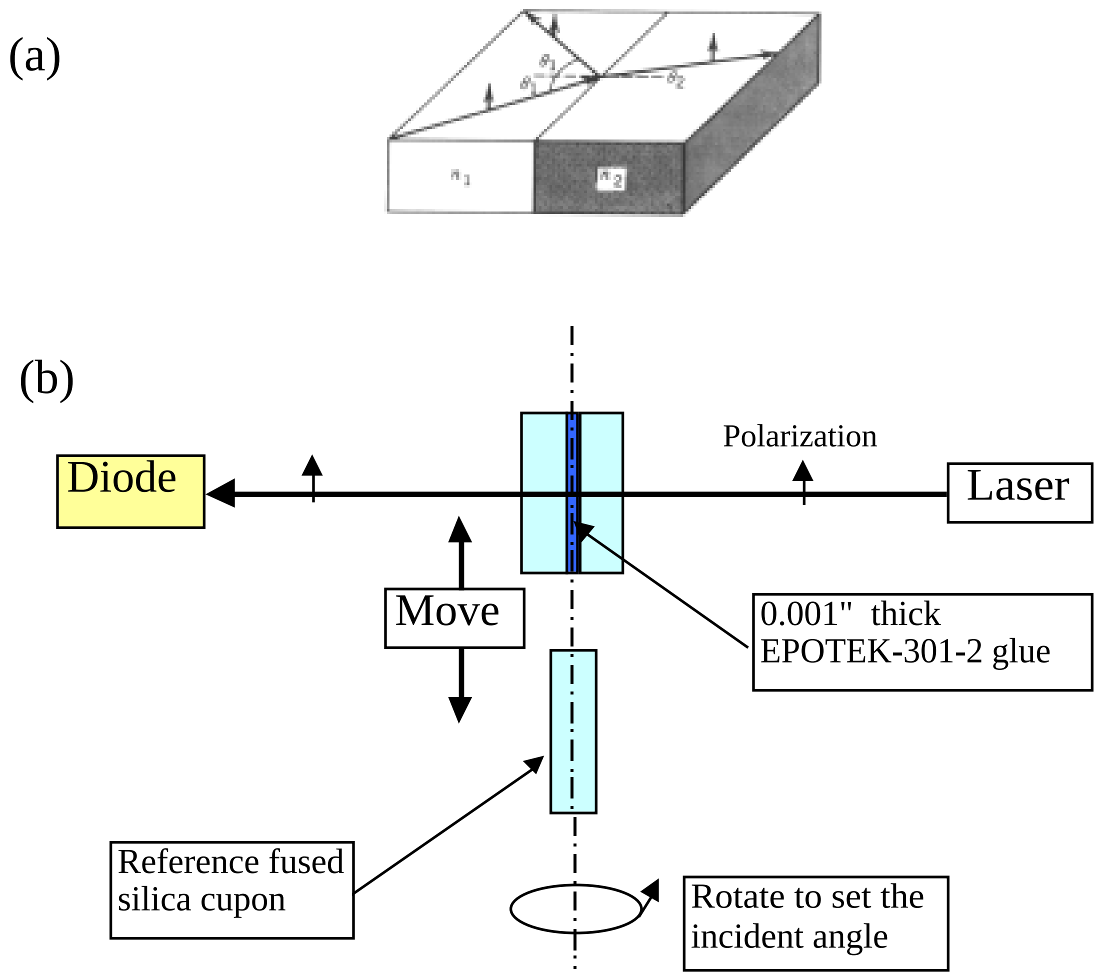

Fig. 7 – (a) Reflectivity for TE polarization mode (n_2 = n(EPOTEK-301-2 glue) > n_1 = n(Fused silica)). (b) Schematic description of the relative measurement of the reflectivity of the EPOTEK-301-2 glue. The fused silica coupon is used as a reference.

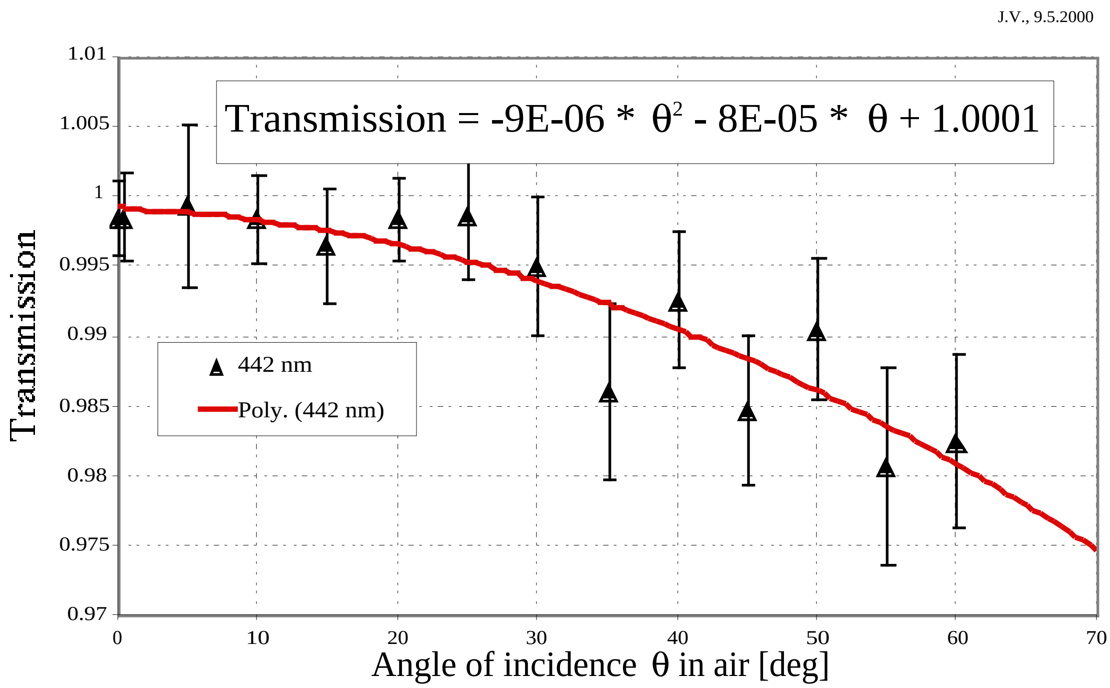

Fig. 8 – Relative transmission through the fused silica/glue sample as a function of incident angle in air.

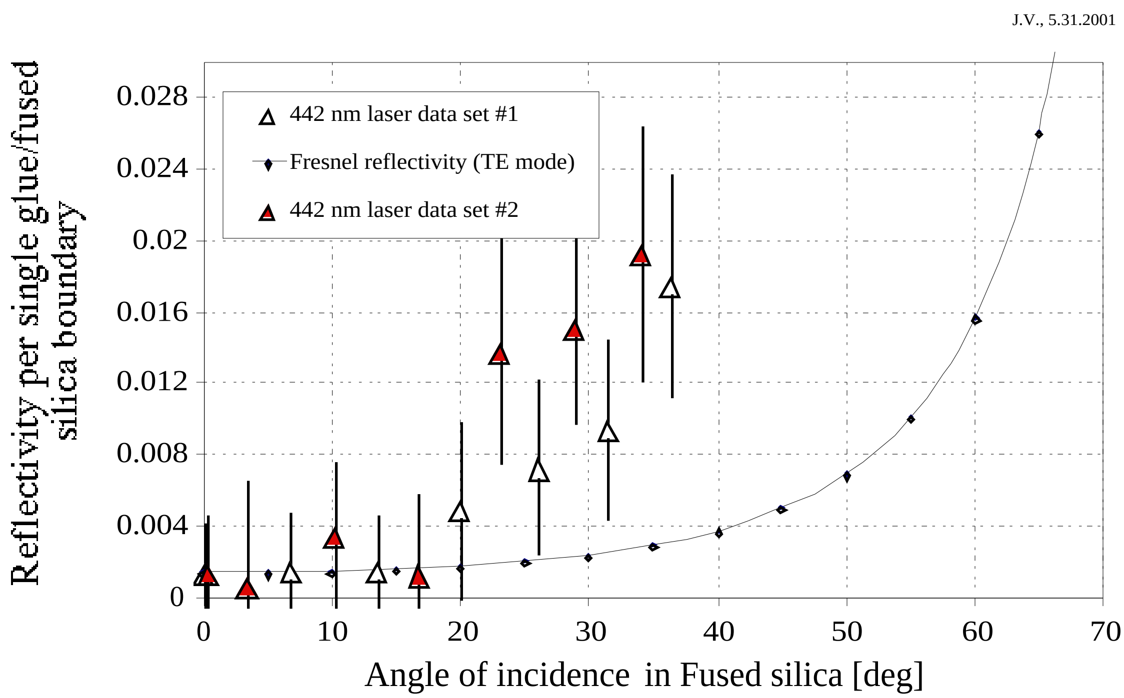

Fig. 9 – Comparison of measured (two different data sets) and calculated reflectivity at 442 nm using the Fresnel theory for the TE polarization mode assuming the refraction index shown in Fig. 2.

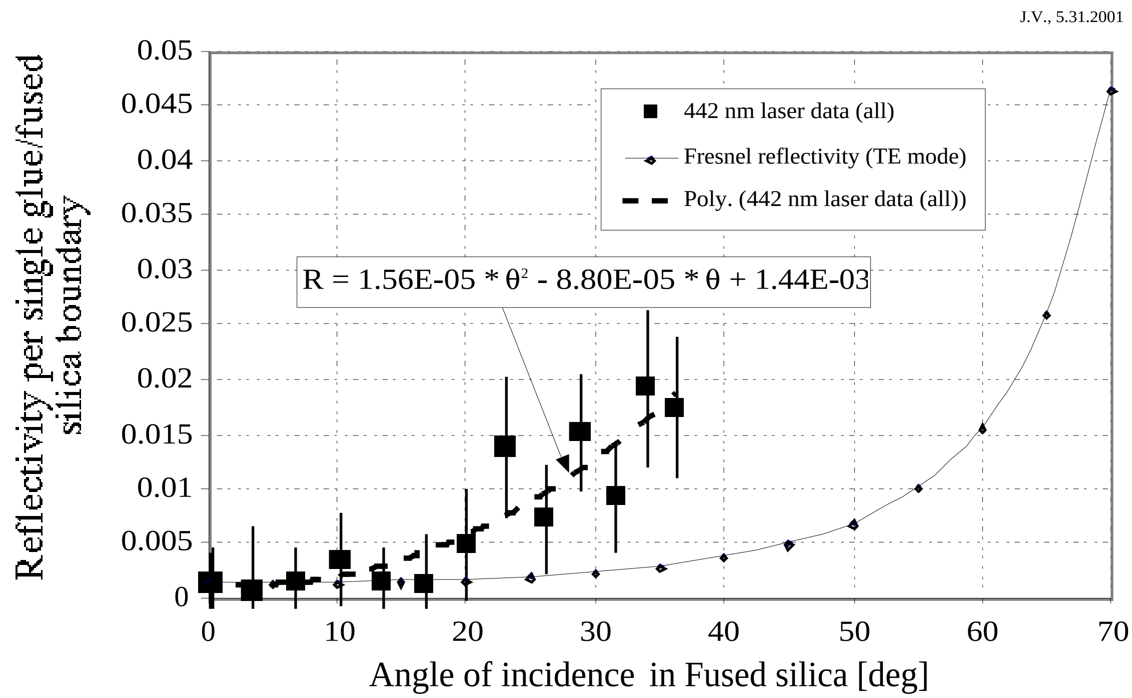

Fig. 10 – Fit all combined data sets shown in Fig. 7. The fitted curve clearly does not agree with the Fresnel theory at 442 nm for the TE polarization mode and assuming the refraction index shown in Fig. 2.

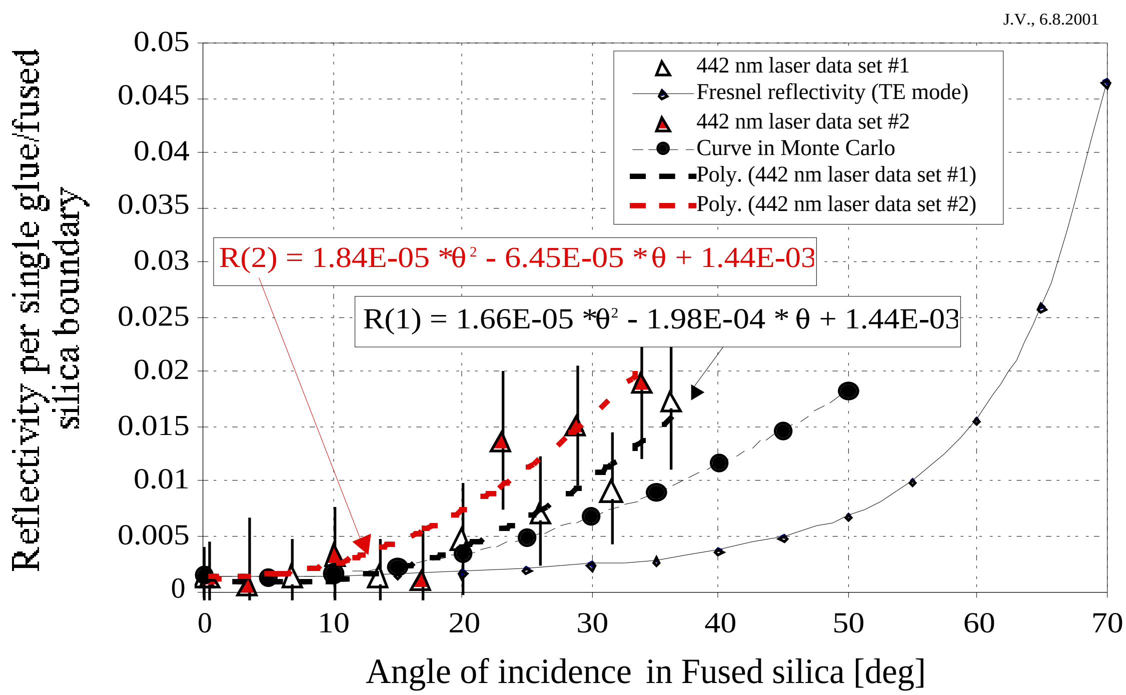

Fig. 11 – Fit two different data sets shown in Fig. 7 separately to indicate a measure of systematic error present in this measurement. Figure also shows the Fresnel theory (small black circles) calculated at 442 nm for the TE polarization mode and assuming the refraction index shown in Fig. 2, and also a reflectivity curve needed to explain the photon background data of Ref. 2 using the Monte Carlo program (large black circles). Clearly, the first measurement of the reflectivity is rather consistent with what the simulation requires.

Conclusions

The paper presents a measurement of the refraction index of EPOTEK-301-2 in the solid form at four different wavelengths between 325 and 633nm. This information represents the last major missing piece in the knowledge of optical behavior of the major DIRC optical components. It turns out that this measurement is consistent with the data provided by the Epotek Technology Co., which are based on the EPOTEK-301-2 glue in the liquid form. This somewhat contradicts the information from the company, which indicated that a larger discrepancy between liquid and solid glue is to be expected.

The paper also presents a direct measurement of the reflectivity per single boundary of fused silica and EPOTE-301-2 glue. This result is compared to the Fresnel theory, which is calculated using the above mentioned glue refraction index. It is found that the measured reflectivity is larger than that expected from the Fresnel theory.

The result of this note is the important input into Ref. 2, which is attempting to explain the photon background observed in the DIRC bars. Ref. 2 found two major contributions to this background: (a) the primary particle induced delta rays producing the Cherenkov light, and (b) the primary particle induced Cherenkov ring photons reflecting from the glue/fused silica interfaces. It turns out that the direct measurement of the reflectivity of the glue/fused silica interface is consistent with the curve obtained from tuning of the Monte Carlo program needed to explain the bar photon background [2].

Acknowledgements

I would like to thank Matt McCulloch for preparing the EPOTEK-301-2 glue wedge sample and Bob Reif for preparing the fused silica/EPOTEK-301-2 coupon.

References

[1] J. Va'vra, DIRC Note #129, April 12, 2000.
[2] K. Yarritu, S. Spanier and J. Va'vra, DIRC Note #141, August 22, 2001.