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Apparent Depth-Imaging Analysis for Refractive Index Measurement

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***Abstract*—In this work we present a simple optical method, to measure the refractive index of thin glass by means of the images produced by a travelling microscope in the apparent depth experimental setup. The imaging analysis technique is based on comparison between captured images as the travelling microscope moved vertically upward. This approach may overcome the problem arises in identifying the best focused images when using naked eye. With the assist of high resolution CCD and available imaging software the imaging analysis can be affectively accomplished.**

Keywords—Apparent depth; imaging analysis; refractive index

I. INTRODUCTION

The basic optical property of most glass in which permitting light to transmit through it is the refractive index (*n*). There are various techniques which can be employed in the determining its value in glasses which can be found in many texts on optical properties [1-3]. In general the *n* is defined as the ratio of the velocity of light in a vacuum to the velocity of light in the medium which it travels through it. A well-known way which *n* can be measured directly is the application of Snell's law as in the refraction of light inside a dielectric material such as glass with refractive index *n*. This famous law called Snell's law of refraction is given as:

$$n = \sin\theta_1/\sin\theta_2 \qquad (1)$$

where $\theta_1$and θ_2 are the angle of incidence and refracting beam which striking the glass surface respectively. In this study the refractive index of the glass samples were measured in bulk form for selected 'host' samples.

II. EXPERIMENTAL

A. *Apparent depth method*

The measurement of glass *n* was done through a technique called 'apparent depth' method. An object in a higher refractive medium will be look more closer than it was when it been seen from a relatively lower refractive index. The medium with high refractive index n which in this case the glass sample with thickness d can be known by the setup shown as in Fig. 1. A travelling microscope M is focused on a small thin object and the reading is recorded as M1. Then the glass is put on top of the object. At this condition the object is seen at a certain depth which

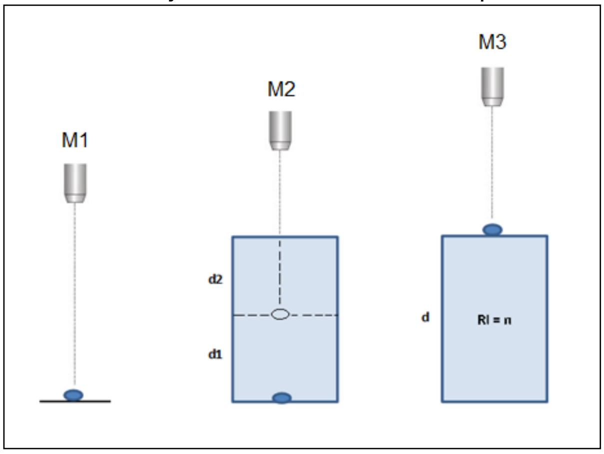

Fig.1. Measurement of glass refractive index (n) through an 'apparent depth' method

called the apparent depth d2. The image of the object is brought into focus again by moving up the microscope at reading M2. Finally the object is put on the top of the glass and using the same procedure the new reading is recorded as M3.

The refractive index *n* is given by the ratio of the real depth or glass thickness d to its apparent depth d' and are well established elsewhere discussing this matter [4]. Considering the above procedure:

$$n = d / d'$$
$$n = d / d2$$
$$n = d / (d - d1)$$
$$n = (M3-M1) / [(M3-M1) - (M2- M1)] \qquad (2)$$

B. *Instrumentation*

The setup of this measurement is shown as in Fig. 2. The travelling microscope comes with two verniers, both having reading of the accuracy ±0.01 mm. Since the imaging procedure involved is quite tedious job and required patient and concentration a high resolution portable handheld microcope-ProScope HR2™ with USB 2.0 interface was attached on the eyepiece of the travelling microscope. The imaging analysis was run via a license imaging software program-Image Comparer 3.8 Build 711 (Copyright©

2002-2011 Bolide Software).This software is having capability in finding and differentiate similar as well as

fully identical images. Its program algorithm works in such a way that different resolution, color number and compression level does not affect the comparison accuracy.

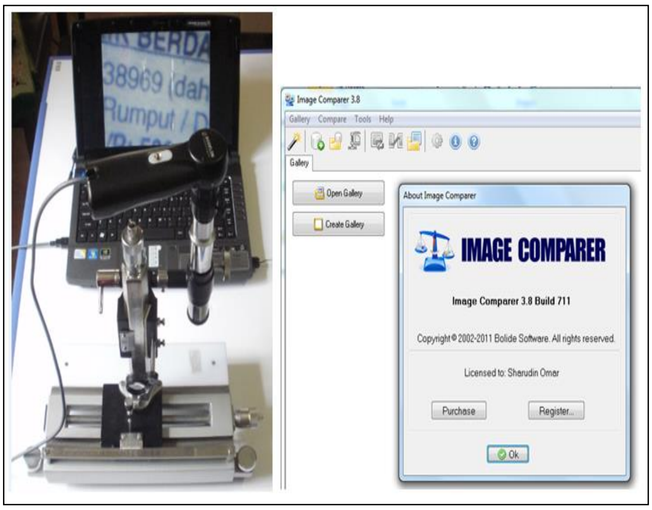

Fig. 2. The refractive index imaging analysis via Image Comparer 3.8 Build 711 (Copyright© 2002-2011 Bolide Software)

The imaging analysis adopted in this study is based on comparison between captured images as the travelling microscope moved vertically upward. This approach may overcome the problem arises in identifying the best focused images when using naked eye. It is due to thin samples and the images that seen were almost similar and difficult to differentiate between one to another. With the assist of high resolution CCD (Charge-Coupled Device) camera and available imaging software the imaging analysis can be effectively accomplished.

The refractive index n for a given glass as in equation (2) is related to its thickness d. Thus if both quantities are known it is possible to determine the apparent depth d' position of an object inside the glass as in Fig. 1. Since the refractive indices for glasses may ranges from n = 1.5 for silicate glass to as high n = 2.2 for lead and bismuth glasses [5-7], we are be able to calculate the d' values for any given glass thickness d. As guidance a reference table which consists of tabulated d' values for any possible range of thicknesses versus the refractive indices can be generated (Table 1). As we can see for a given thickness d the d' values decrease as refractive indices increases. In other word the object image is become closer to the top surface of the glass. It is also to note that the differences between successive d' values is very small. This is one of the reasons why such imaging technique is preferred. By knowing the range of d' for a specific thickness d the images of the object were captured as the travelling microscope is moved vertically upward. All the captured images were analyzed with Image Comparer and the cumulative number of better image pairing at each respective d' position was recorded.

TABLE 1. REFERENCE TABLE OF TABULATED D' VALUES FOR ANY POSSIBLE RANGE OF THICKNESSES VERSUS THE REFRACTIVE INDICES

Apparent depth(mm) d' = d/n Table											
	refractive index n										
thickness d/mm	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
2.00	1.33	1.25	1.18	1.11	1.05	1.00	0.95	0.91	0.87	0.83	0.80
2.10	1.40	1.31	1.24	1.17	1.11	1.05	1.00	0.95	0.91	0.88	0.84
2.20	1.47	1.38	1.29	1.22	1.16	1.10	1.05	1.00	0.96	0.92	0.88
2.30	1.53	1.44	1.35	1.28	1.21	1.15	1.10	1.05	1.00	0.96	0.92
2.40	1.60	1.50	1.41	1.33	1.26	1.20	1.14	1.09	1.04	1.00	0.96
2.50	1.67	1.56	1.47	1.39	1.32	1.25	1.19	1.14	1.09	1.04	1.00
2.60	1.73	1.63	1.53	1.44	1.37	1.30	1.24	1.18	1.13	1.08	1.04
2.70	1.80	1.69	1.59	1.50	1.42	1.35	1.29	1.23	1.17	1.13	1.08
2.80	1.87	1.75	1.65	1.56	1.47	1.40	1.33	1.27	1.22	1.17	1.12
2.90	1.93	1.81	1.71	1.61	1.53	1.45	1.38	1.32	1.26	1.21	1.16
3.00	2.00	1.88	1.76	1.67	1.58	1.50	1.43	1.36	1.30	1.25	1.20
3.10	2.07	1.94	1.82	1.72	1.63	1.55	1.48	1.41	1.35	1.29	1.24
3.20	2.13	2.00	1.88	1.78	1.68	1.60	1.52	1.45	1.39	1.33	1.28
3.30	2.20	2.06	1.94	1.83	1.74	1.65	1.57	1.50	1.43	1.38	1.32
3.40	2.27	2.13	2.00	1.89	1.79	1.70	1.62	1.55	1.48	1.42	1.36
3.50	2.33	2.19	2.06	1.94	1.84	1.75	1.67	1.59	1.52	1.46	1.40
3.60	2.40	2.25	2.12	2.00	1.89	1.80	1.71	1.64	1.57	1.50	1.44
3.70	2.47	2.31	2.18	2.06	1.95	1.85	1.76	1.68	1.61	1.54	1.48
3.80	2.53	2.38	2.24	2.11	2.00	1.90	1.81	1.73	1.65	1.58	1.52
3.90	2.60	2.44	2.29	2.17	2.05	1.95	1.86	1.77	1.70	1.63	1.56
4.00	2.67	2.50	2.35	2.22	2.11	2.00	1.90	1.82	1.74	1.67	1.60

III. RESULTS AND DISCUSSIONS

The refractive index calculation technique and analysis for selected host glass samples performed by apparent depth method are assisted with an imaging analysis approach. The captured images are compared in pair and the best images between two images are identified. The process repeated until all images completely compared by the imaging software. The total or cumulative number of best image pairing (CNB Image Pairing) at respective travelling microscope (TM) vernier positions for both 'without glass' and 'glass on logo' for known reference glass (Corning glass) is given in Table 2 below. As shown a total of 10 and 21 pairs of images can be compared for five and seven captured images for 'without glass' and 'glass on logo' measurements respectively (for N images: total pairing=∑(N-n), n=1,2,..,N). A graphical analysis was performed via licensed OriginPro 8.5.1 software for refractive index calculation. A Gaussian fitting with statistical error analysis was also presented in this work as shown in Fig. 3. Fig. 4 is the selected captured images for the reference glass-Corning glass.

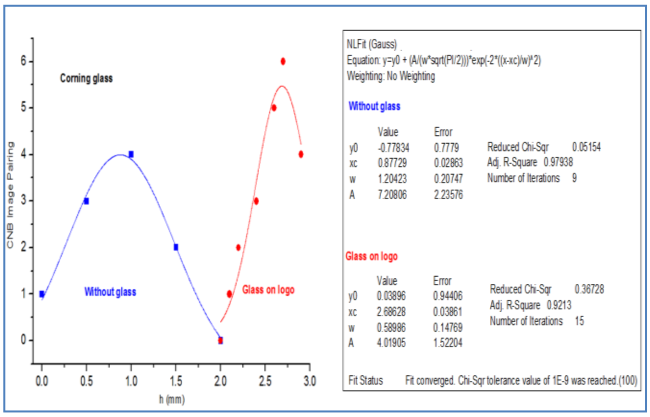

Fig. 3. The refractive index imaging analysis via Image Comparer 3.8 Build 711 (Copyright© 2002-2011 Bolide Software)

TABLE 2. THE CUMULATIVE NUMBER (CNB) OF BEST IMAGE PAIRING AT RESPECTIVE TRAVELLING MICROSCOPE (TM) VERNIER POSITIONS FOR CORNING GLASS

Without glass			
TM vernier position ±0.01 mm	h(mm) ±0.01 mm	Image ID G	CNB Image Pairing
5.00	0.00	1	1
5.50	0.50	2	3
6.00	1.00	3	4
6.50	1.50	4	2
7.00	2.00	5	0
		Total pairs =	10

Glass on logo			
TM vernier position ±0.01 mm	h(mm) ±0.01 mm	Image ID G	CNB Image Pairing
7.00	2	6	0
7.10	2.1	7	1
7.20	2.2	8	2
7.40	2.4	9	3
7.60	2.6	10	5
7.70	2.7	11	6
7.90	2.9	12	4
		Total pairs =	21

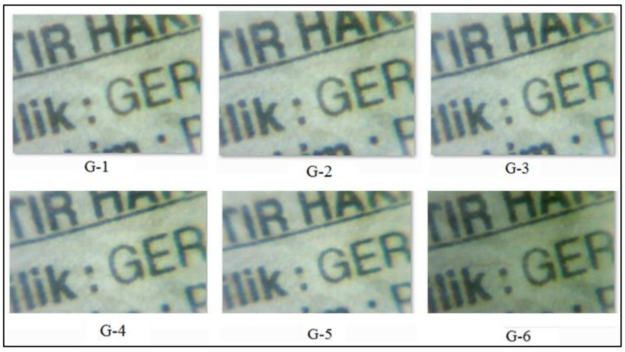

Fig. 4. Captured images comparison for Corning glass (out of 12 images)

Table 3 summarizes the refractive index analysis for Corning glass which mentioned in Fig. 3. The calculated refractive index standard error lies below 5%. The measured refractive index for Corning glass (Soda Lime Glass-0215 Corning Glass Slide) is almost in good agreement with the standard value of n=1.515 [8]. Such small deviation from standard value is understood due to statistical analysis adopted in this technique where the images are compared with respect to vernier positions where brightness of the light was kept consistent at all times to ensure consistency in the produced images.

TABLE 3. SUMMARY OF THE REFRACTIVE INDEX ANALYSIS FOR CORNING GLASS SLIDE (REFERING FIG. 3)

Glass	Thickness/d ± 0.01 mm	Gaussian Peak Position/ X_c	
		Without Glass/Xc1 mm	Glass on logo/Xc2 mm
Corning	5.00	0.87729 ± 0.02863	2.68628 ± 0.03861

Height $H=(X_{c2}-X_{c1})$ mm	ΔH mm	Apparent depth d'=(d-H) mm	Δd' mm	Refractive Index n=d/d'	Δn
1.80899	0.04807	3.19101	0.04910	1.567	0.02431

IV. CONCLUSIONS

The refractive index of glass was successfully measured via apparent depth technique assisted by imaging analysis approach for Corning glass slide. Our method has obtained refractive index which is approximately similar and within 5% standard deviation errors value.

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