A Way to Determine Light Diffusion Factor

Aurelian Ovidius Trufasu
Universitatea Politehnica Bucuresti/ Facultatea de Inginerie Mecanica si Mecatronica, Str. Splaiul Independentei 313, Sector 6, Bucuresti
a_trufasu@yahoo.com

Abstract

The paper is focused on a way of determining the light diffusion factor for organic glass with high end optical properties; the way is in between classical and dynamic light scattering providing results of samples related to a reference called etalon, made from the same material with different 3D dimensions.

Keywords
Light diffusion factor, light scattering.

Introduction

Light diffusion is the scattering of direct light by making it pass through a non-transparent material or by bouncing it off a semi-reflective surface. Two different light scattering methodologies can be used to characterize material transparency for organic glass:

- "classical" light scattering (also known as "static" or "Rayleigh" scattering or MALS) provides a direct measure of molecular mass. It is therefore very useful for determining whether the native state of a protein is a monomer or a higher oligomer, and for measuring the masses of aggregates or other non-native species. It also can be used for measuring the stoichiometry of complexes between different proteins.

- "dynamic" light scattering (DLS), which is also known as "photon correlation spectroscopy" (PCS) or "quasi-elastic light scattering" (QELS), uses the scattered light to measure the rate of diffusion of the protein particles. This motion data is conventionally processed to derive a size distribution for the sample, where the size is given by the "Stokes radius" or "hydrodynamic radius" of the protein particle. This hydrodynamic size depends on both mass and shape (conformation). Dynamic scattering is particularly good at sensing the presence of very small amounts of aggregated protein (<0.01% by weight) and studying samples containing a very large range of masses. It can be quite valuable for comparing stability of different formulations, including real-time monitoring of changes at elevated temperatures.

Experimental procedure

To determine total diffusion factor on measuring equipment it was necessary to manufacture many reference samples according with raw materials of finished products. Samples are shaped as optical organic glass prism with at least 2 fine polished surfaces, less macro pitches which can be seen with a 10x magnifier and a limited number of micro pitches.

The samples manufacturing is based on fine polishing completed with a few special operations for blocking the second surface to gain parallel surfaces less 30°.

Diffusion factor determination needs the equipment to be completed with:

- The laser, placed inside of apparatus to limit or eliminate accidental touch during measuring;
- Laser guiding, made by a periscope system made from 2 assemble: mirrors and mounts;
- Chopper, placed in front of mounts and after it is placed a half mirror;
- Detecting assemble, placed on reflected optical trace.

The equipment is driven by dedicated software with special features:
- Communication with amplifier lock-in SR512;
- Communication with Physic instrumented bench;

The software permits:
- Proportional signals measuring sample with diffuse light;
- Changing samples position and determining the output;

- Measuring of monitoring signal of incident radiation power variation;
- Tension monitoring for photomultiplier detector.

![Figure 1 Optical scheme for measuring device](image)

**Table 1 Measuring outputs for neutral filters**

<table>
<thead>
<tr>
<th>Spectrophotometer</th>
<th>Equipment</th>
<th>Calculated value</th>
<th>Average error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.0525</td>
<td>9.5</td>
<td>5.26</td>
</tr>
<tr>
<td>12</td>
<td>0.063</td>
<td>11.5</td>
<td>4.34</td>
</tr>
<tr>
<td>14</td>
<td>0.0735</td>
<td>13.8</td>
<td>1.44</td>
</tr>
<tr>
<td>18</td>
<td>0.0945</td>
<td>17.12</td>
<td>5.14</td>
</tr>
<tr>
<td>20</td>
<td>0.105</td>
<td>19.55</td>
<td>2.30</td>
</tr>
<tr>
<td>22</td>
<td>0.1155</td>
<td>20.23</td>
<td>8.74</td>
</tr>
<tr>
<td>24</td>
<td>0.126</td>
<td>22.75</td>
<td>5.49</td>
</tr>
<tr>
<td>26</td>
<td>0.1365</td>
<td>24.72</td>
<td>5.17</td>
</tr>
<tr>
<td>28</td>
<td>0.147</td>
<td>26.65</td>
<td>5.06</td>
</tr>
<tr>
<td>36</td>
<td>0.189</td>
<td>34.29</td>
<td>4.98</td>
</tr>
<tr>
<td>50</td>
<td>0.252</td>
<td>45.64</td>
<td>5.17</td>
</tr>
</tbody>
</table>

The optical scheme for device presented in figure 1, has the following legend; the device use comparing etalons opaque seated on transparent background or transparent on opaque background.

The measuring surface diffusion factor equipment is made from functional blocks which are:

1) Microscope, with core components: illumination system and condenser L₁; polarizer Z₁; collimator objective L₂; splitter B; ¼ λ prism Q₁ and Q₂; referential R₁, R₂...Rₙ; viewing objective L₃; analyzer Z₂; sample positioning assembly, to introduce the sample in measuring field and positioning sample in it -M; pinholes P₁, P₂, P₃; retro-reflecting system R’;

2) Image acquisition system CCD camera;
3) IBM PC computer to get the video information and display test and etalon images and equalizes the contrast of those two images; at the same time it can automatically select the width of existing defect by memorizing the data from etalon graphic.

4) Dedicated software;

5) Frame grabber.

Figure 2 Picture of measuring device

The experiments

The equipment testing starts with setting signal linearity and calibration of measuring unit. This testing was made based on the outputs of signal variation inputs. For that reason it was used a set of neutral filters measured by Beckman spectrometer. First, the sample was placed on radiation wave after that filters. Synthetically, the results are presented in table 1 and chart 1.

Calculated value for transmission factor from table 1 was determined by interpolation knowing that measured value for 50% transmission was 252 mV. The average error was gain by dividing the difference of values measured though two methods by reference values (get with spectrophotometer Beckman).

Measuring surface micro pitch

Measuring micro pitches was done on special apparatus AVA designed to measure micrometers defects; it is compatible with ISO 10110-7 Annex E, SR ISO 10110-7 Annex E.
The irregularities of all kind change the direction of light and the presence of them can be highlighted by:
- Either diffused light, or;
- Absorbed light.

Etalon comparing is done in the same way no matter what route it is choose. In both situations the images contrast is analyzed.

This is the main way of working for the device, where irregularities image visibility, in special condition (lighted field) can be measured and compared with no lighted line image with a known width (or a point image with a known diameter). Thus, any irregularities with widths between [1-40] µm can be quantified in terms of defined parameters as line equivalent width (LEW) or any point with diameters between [4-100] µm in terms of spot equivalent diameter (SED).

Following the experiments a measuring irregularities method was done for any kind of micrometers irregularities present on plane optical surfaces working in light transmission. LEW and SED are photometric parameters, not geometrics, the whole light quantity extracted by irregularities is the only exception, then LEW come geometric width and SED is geometric diameter.

Light comes from a lamp 6V-24W and is focused on pinhole P<sub>1</sub> placed in focal point L<sub>2</sub>. Light after trespassing polarizer Z<sub>1</sub> comes to beam splitter B as a parallel beam. The beam splitter generates two beams – reflected and transmitted (the reflected beam comes to probe and the transmitted beam comes to reference direction). Between beam splitter and probe is placed ¼λ plane (which is rotating to maximize the intensity of beams focused on TV camera).

*On reference channel:* the reflected light from reference plate is turned back, trespass ¼λ plane Q<sub>2</sub> and come to beam splitter where is reflected and image formed by L<sub>3</sub> is focused on TV camera after trespassing analyzer Z<sub>2</sub>.

*On probe channel:* after reflection on tested probe the light is turned back to B point (after trespass Q<sub>1</sub>) and is transmitted following the same route as reference channel.

Any irregularities placed on T and a pinhole on R are positioned as their images to be focused one by one and their images contrast is seen as dark lines in light field correlated with light quantity shaded by them from original light beam which trespass probe and reference channel.

The light intensities on those two channels have to be equal is the first condition to measure correctly, because the measuring is based on ration of two visibilities of compared irregularities:

\[
\frac{t_1}{t_2} = \frac{tg^2 \theta_1}{tg^2 \theta_2}
\]

The device is used by totaling Z<sub>1</sub> thus the exposure to be alternatively on TV camera, both beams and adjusting angular setting of Z<sub>2</sub> to reduce to zero difference between reference and tested images.

The polarizer Z<sub>2</sub> can be stopped in this moment and set carefully as angular position (θ), the position where tested and reference images have maximum contrast.

\[
\frac{t}{r} = tg^2 \theta
\]

Where t and r are lost quantities of light because of tested and reference irregularities. The angular setting of polarizer is done in terms of width of opaque line for transmission or free hole on reflected light, in reflexion, setting done on initial time.

The graph is designed with θ values determined by equivalent width of lines or points (LEV or SED). θ value read for a tested probe are pleced on graph where can be read the width of equivalent line.

Malus law–dependance of light intensity polarized by analyzer-polarizer system orientation:

\[
O_o = OM \cos \alpha; L^{-1}A \cos^2 \alpha; O_e = OM \sin \alpha; L=B \sin^2 \alpha; J = A+B
\]

Probe:

\[
B \sin^2 \theta + A (1-t) \cos^2 \theta;
\]

Intensity on TV camera;

Reference:

\[
A \cos^2 \theta + B (1-r) \sin^2 \theta;
\]

\[
B \sin^2 \theta + A (1-t) \cos^2 \theta = A \cos^2 \theta + B (1-r) \sin^2 \theta;
\]

\[
B \sin^2 \theta + A \cos^2 \theta - A \cos^2 \theta = A \cos^2 \theta + B \sin^2 \theta - B \sin^2 \theta;
\]

\[
A \cos^2 \theta = B r \sin^2 \theta;
\]

\[
\frac{t}{r} = tg^2 \theta;
\]
Where $\theta$ is the angle between polarizer plan of light which leave the polarizer and optical axis.

![Etalon reticule Type B](image1)

Figure 3 Etalon reticule Type B, (Grade Nr. 0,040-0,004) PRECISION OPTIC GmbH.

Clicking on the right side of mouse can design two squares a red one and green one over test image and over etalon grid (as following images). From upper bar of instruments can be selected command “Monitoring 2”. A window with both squares images and a window with “Monitorizare Scr.&Dig.” appears with options: “medium” and “contrast”; to equalize the light intensity on both channels is used option “medium” and to equalize contrast is used option “contrast”.

<table>
<thead>
<tr>
<th>Grid type</th>
<th>Line width (µm)</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque lines on transparent background</td>
<td>30</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td>43.6</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td>76.2</td>
<td>24.7</td>
</tr>
<tr>
<td>Transparent lines on opaque background</td>
<td>36.6</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>54.2</td>
<td>51.5</td>
</tr>
</tbody>
</table>

Table 2 Line width versus angle

![Line width - angle dependency](image2)

Chart 2 Line width - angle dependency

**Conclusion**

Irregularities and diffusion are in linear dependency, as it’s proved above, by significant experiments. So, determining presence, dimension and irregularities number and proportion on certain surface we can figure how much they act against incident light, what is level of diffusion and what we expect to improve making surfaces with better shape and quality.

**References**

[4] [http://www.tpub.com/neets/trv/106-5.htm](http://www.tpub.com/neets/trv/106-5.htm);