The Stray Light Absorption and Anti-photobleaching Capacity of Matting Materials on Optical System

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Abstract: Eliminating stray light is a very important item in optimizing optical systems. The typical method is to use matting materials to coat onto the optomechanical component. However, the material will deteriorate or bleaching after being exposed to long periods of time and high UV energy. The performance of the optical system will be therefore affected. In this study, the anti-photobleaching capacity of matting materials on various substrates was discussed. A high intensity UV source was used to radiate the samples for long time. The changes of the morphology and relative reflectance of sample were observed and analysed. Also, a 355 nm pulsed laser was used to perform the surface modification on samples. An improvement of the matting performance was expected. This study succeeded in establishing a comparing procedure, which enabled the characteristic comparison between the various experimental conditions. This study provides a useful database for the development of matting material technology.

1 INTRODUCTION

Optical systems are widely used in various fields such as imaging, illumination, and spectral detection. The modules of its extension are very versatile and closely related to people's modern life. In the development process of various consumer and professional-grade optical systems, the specifications focused on are often different. Therefore, it should be optimized for the demand during the optical design. For example, cameras require high-quality resolution, light sources require uniform light field distribution, display systems require high collimation, and so on. However, all optical systems always have the same requirement, that is, less stray light. (Cheng, 2018) (Buisset, 2015) (Williams, 2018). The reason is that these undesired beams often interfere with the original ideal optical system. Typical examples are camera produces ghost and illumination becomes uneven. They result in a significant drop in optical quality. Sources of stray light often come from the edges of optical systems with limited dimensions or the imperfect lens quality. The beam is constantly reflected in the system and deviates from the optical path that was originally expected. This problem can be overcome by the anti-reflective film coated on the lens surfaces and the matting materials processed on the optomechanical component (Patterson, 2003) (Benjamin, 1962). The anti-reflection coatings were a common and mature technology, we notice that the matting process on the optomechanical surface is a topic worth studying. Generally, it is not difficult to achieve high-quality stray light elimination under a low-brightness optical system, but a high radiation optical system (such as an photo lithographer) requires a much higher level of extinction capability. In addition, the matting material also needs to have excellent anti-bleaching properties in order to make the optical system have a long service life.

In figure 1, the stray ray distribution of the lens edge, stop and barrel inner wall of the lithography light source system by the optical simulation software was analyzed. The simulation model was traced by ten million samples. It can be seen from the figure that since the illuminating light source cannot be perfectly spatially symmetrical, the irradiated intensity of the lens edge will be uneven. If the edge of each lens provides a slight contribution to the intensity difference, the entire system will be affected by a non-negligible noise. This represents a need for matting at the edge of the lens. For the vicinity of Stop, since the energy is

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concentrated in the middle of the hole, the beam that has not been successfully passed will expose the edge of the hole to form a donut-like shape. This part of the energy is very high (red area). Therefore, even though the surface of the Stop has been matted, it is still prone to failure due to photo bleaching effect. Finally, the matte treatment of the inner wall of the lens barrel is inevitable because of it always encounter a mount of stray lights. In general low-brightness optical systems, most of them are treated with black fluffs or black paint. This is not the case in high-brightness systems, which the scorched fluffs might contaminate the lens surface. High-brightness optical systems often use complex surface modification process, and require good anti-photobleaching capacity.

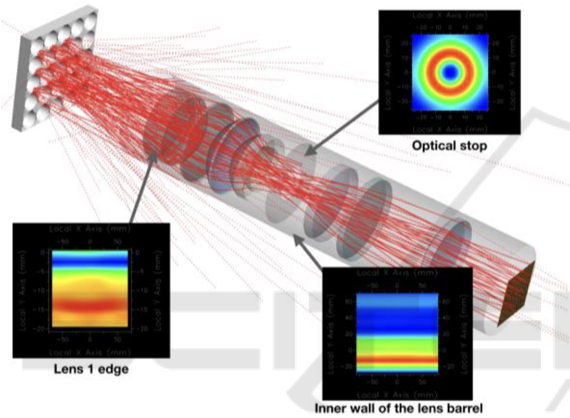
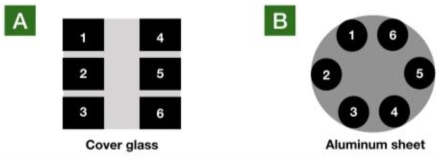


Figure 1: Optical intensity distribution of stray light on the lens edge, stop and inner wall of lens barrel.

In general, the matting treatment on the surface of the object is divided into two types, one is coating of the light absorbing material, and the other is surface modification to form a scattering structure. A wide variety of light absorbing materials was formulated for the wavelength match. Some people created the coating with high melting point and high absorbance characteristics (Suzanna, 2015) (Draggoo, 1986) (Jürgen, 2008). The advantages of these kinds of coating are easily manufacturing and low cost. The disadvantages of them are that the absorbances usually lower than 90% and easy to increase the optical element temperature. The other people design the diffuser structure on the optomechanical surface to reduce the effects of stray ray (Amemiya, 2015) (Mohammad, 2018). A rough and irregular structure was obtained by destroying the flatness of the material surface. The specular reflection behaviour will be converted into diffuse behaviour, meaning that the directionality of the light beam will be attenuated by optical scattering. The advantage of this method is that the extinction effect is good, but the processing cost is high and has the risk to damage the optomechanical accuracy. Surely, the really best way is to combine the two to achieve a balance between performance and cost. In this study, a self-made high-intensity UV source was used to radiate several kinds of matting materials. The matting materials were coated onto the glass and metal substrate, and the light exposure time was over 8 days. By analysing the changes of the surface structures and relative reflectance, the anti-photobleaching capacity could be estimated. In addition, we also try to directly surface-modify these materials by a UV pulse laser. A novel method was proposed to increase the matting performance with the advantages of simple, fast processing and low-cost. We believe that this study provides a useful database for matting processing technology.

2 EXPERIMENTAL SETUP AND SAMPLE PREPARTION

In order to avoid the deterioration of the optical quality caused by the stray light generated at the "inner wall of the optical tube" and the "edge of the lens", a proper design of the matting treatment is necessary. There are two typical matting treatments, one is surface modification and the other is black painting. The former is to manufacture a high-rough surface to achieve a large amount of optical scattering, that is, to achieve the extinction by means of optical diffusion (Diffuse). The effect is very obvious, but has the disadvantage of high processing costs. The latter achieves extinction by using an absorbing material for the wavelength, which is performance acceptable and inexpensive, but has the disadvantage of easily accumulating energy to cause deterioration of the material. In this paper, we prepared six types of materials as experimental samples, and were coated on the two types of substrates. The material information are shown in Figure 2, where numbers 1~3 are pure matting materials, and numbers 4~6 are materials mixed in different proportions. The material types, characteristics and proportions are also shown in Figure 2. There are two types of substrates, matte glass and aluminium metal, which are used to simulate the "edge of the lens" and the "inner wall of the optical tube" respectively. The materials was applied to the substrate in the same manner, and the position was as shown in the top of Figure 2. The entire sample has a size of about 10 mm, and the six materials are sustained the similar luminance values during the optical exposure experiment. When various materials are applied to the substrate, they will form a slightly rough surface due to cohesive force, but the contribution of the extinction mainly comes from the light absorbing ability of the material. In the second experiment, a pulsed laser was used to try to form a highly scattering surface structure on the matting materials.



Sample No.	Matting material	Characteristic	Percentage
1	Chinese black ink (Carbon particles & Water)	Water-based	100%
2	Matting material (Black paint & Acrylic Resin)	Oil-based	100%
3	Black acrylic paint : Black 2.0	Dilutable with water	100%
4	Black ink + Black acrylic paint	Mixed in different proportions	1:1
5	Black ink + Black acrylic paint		2:1
6	Black ink + Black acrylic paint		1:2

Figure 2: Configuration diagram of the matting material and substrate type.

Figure 3 shows the experimental setup. The light source is a high brightness LED array with a wavelength of 365 nm. Arranging 25 LEDs in a square shape makes the illumination more uniform. The 100mm * 100mm panel size provides a stable and a large exposure environment. The samples prepared in Figure 2 are placed in the middle of the projected range. Before performing the exposure experiment, the stability of the light source was verified. As shown in the lower figure in Figure 3, the linear characterises and intensity did not change or drift after gradually increasing the electric power and starting in ten minutes. This plot was measured when the distance between the sample and the sensor is 30 cm. The extinction material experiment was performed for 192 hours, that is, the samples were exposed to continuous high-intensity ultraviolet light for 8 days. Each sample receives an illumination value of approximately 100mW / cm2 and the distance between the sample and the light source is about 10 mm. Subsequently, the surface degradation of the material was observed by confocal optical microscopy to analyse and estimate the anti-photobleaching capacity of the material. The confocal microscope used in this study has an axial resolution of up to 1 μm. Further, in order to make the matting material have both optical absorption and structural scattering characteristics, this study also uses 355 nm pulsed lasers to perform a surface modification to achieve a better matting performance. This approach allows for faster and lower cost surface processing and also can directly improve the quality of the optical system.

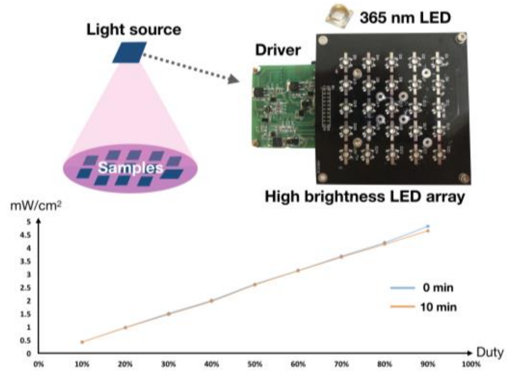


Figure 3: Experimental setup and light source stability test for anti-photobleaching experiment.

3 RESULTS AND DISCUSSION

To understand the change of the matting material with time under the exposure of high-intensity ultraviolet light, an optical confocal microscope was used to obtain the roughness of the surface of the sample. The surface morphology of the 12 samples (two kinds of substrates) were measured after each day of light exposure. The samples were illuminated for a total of 8 days, so a total of 96 sets of data were obtained after the end of the experiment. Figure 4 and Figure 5 show the morphologies of the sample surface before and after light exposure (8 days). The symbol A indicates the use of a glass substrate, and No. 1 to 6 individually represents the matting material shown in figure 3. The measurement results show that different materials have different particle and pore distributions. The surface of the sample A1 is fine-grained after light exposure, and therefore it leads to an increase of the reflected light. The morphology changes of sample A2 and A4 are not significant. The sample A3 has a tendency to increase the particles on surface, and A5 and A6 have significantly less particles. Obviously, the surface changes of various materials after light exposure are different.

The surface roughness of the sample determines the characteristics of light extinction. In general, the higher the roughness, the better the matting performance. In the experiment, root mean square (RMS) roughness of each sample surface was measured and analysed, as shown in figure 6. The horizontal axis is the number of exposure days, and the vertical axis is the measured RMS roughness value. Since the sample would still be slightly uneven in each area during the fabrication process, the change in sample roughness over time should be represented by a trend line. The β value indicates the slope of the trend line. We assume that the change is nearly linear. It can be found that the surface of the sample A1 has a significantly flattened appearance, and thus its matting efficiency is lowered. This is consistent with the results in Figure 4. The surface morphology of sample A2 is almost unaffected by the high intensity light exposure, and therefore can be considered as a matting material with the most anti-photobleaching characteristics. Although the sample A3 slowly increase the roughness, it was not obvious. The samples mixed in different proportions can theoretically adjust the desired effect. The sample A5 has a higher contribution of water-based black ink, so its trend line is similar to the sample A1. However, it become flatten because it is affected by the influence of the sample A3. The sample A6 was flatter than A5 because the contribution of the sample A3 is increased. The most appropriate proportion may be A4 because its flatness is closest to A2 and ignore the influence of light exposure. It means that the sample A4 also has the good anti-photobleaching capacity.

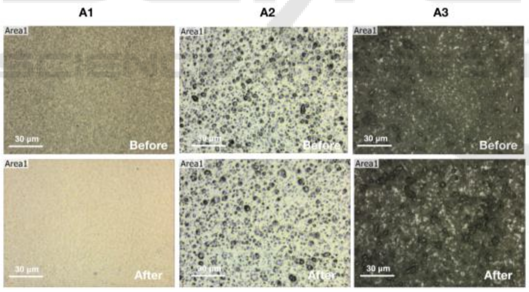


Figure 4: The morphology changes of the matting materials (#1~3) on glass substrate after high intensity light exposure.

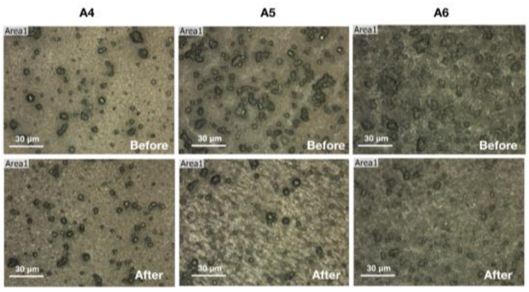


Figure 5: The morphology changes of the matting materials (#4~6) on glass substrate after high intensity light exposure.

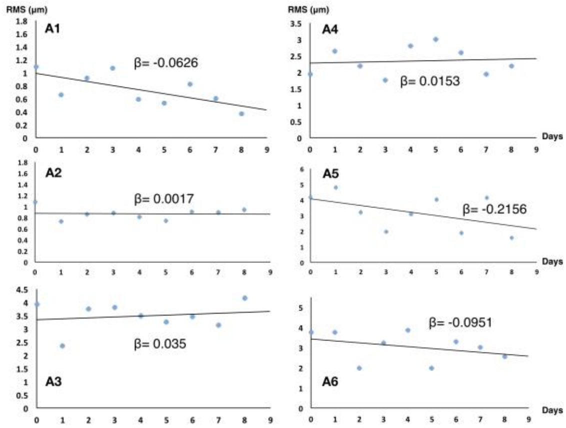


Figure 6: The roughness of different matting materials on glass substrate varies with exposure time.

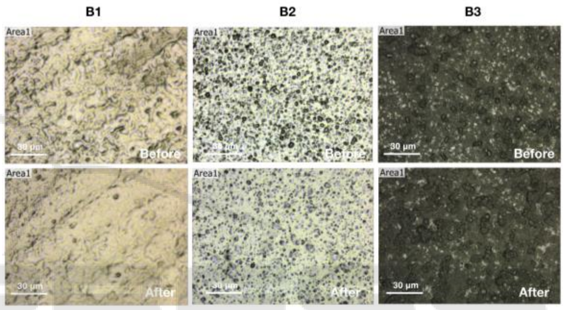


Figure 7: The morphology changes of the matting materials (#1~3) on metal substrate after high intensity light exposure.

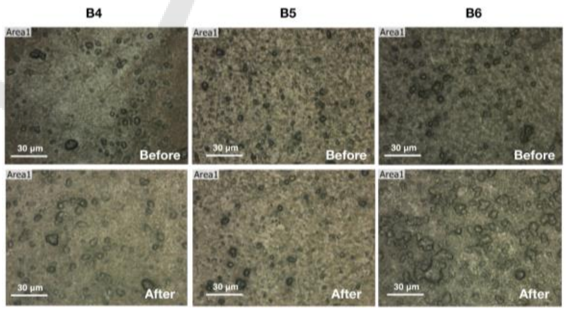


Figure 8: The morphology changes of the matting materials (#4~6) on metal substrate after high intensity light exposure.

Figure 7 and Figure 8 show the morphologies of the sample surface before and after light exposure (8 days). The symbol B indicates the use of a metal substrate (aluminium), and No. 1 to 6 individually represents the matting material shown in figure 3. The measurement results show that different materials have different particle and pore distributions. The surface distribution of sample B1 has lower frequency structures after light exposure. The morphology changes of sample B2 are still not significant. The samples B3 and B6 show an increased phenomenon on surface roughness. The surface change of sample B4 and B5 cannot be judged by image observation, thus software was used to perform the surface structural analysis. The metal substrates have a higher capacity of heat dissipation, so it will benefit the anti-bleaching performance of the matting materials.

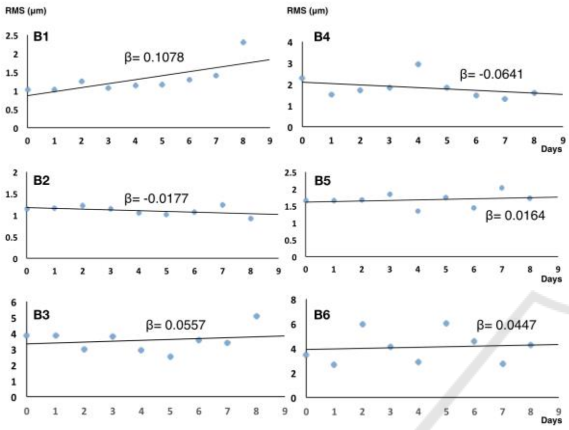


Figure 9: The roughness of different matting materials on metal substrate varies with exposure time.

Figure 9 shows the roughness of different matting materials on metal substrate varies with exposure time. The surface of the sample B1 was gradually roughened, which was completely opposite to the case of the A1. This means that the stability of the water-based black ink is not very good. The sample B2 is still unaffected by the light exposure and is the most stable material for anti-photobleaching. Although sample B3 slowly increase the roughness, it wasn't obvious. The result was completely consistent with sample A3. The results also show that the morphologies of the sample B4, B5 and B6 are only slightly affected by the water-based black ink. Their characteristics are very similar to those of the B3. That is, the increase and decrease in roughness are not significant. The experimental results show that the matting materials on the metal substrate have good anti-photobleaching capacity, except for the water-based black ink. Therefore, experimentally, it is necessary to perform a longer light exposure or higher light intensity to see an obvious difference in the anti-photobleaching capacity of the matting material on the metal substrate.

The matting materials in this experiment all have good optical absorption characteristics, but the scattering efficiency contribution of their surface roughness is not actually significant. Then a 355 nm pulsed laser was used to perform a surface modification on them. The matting ability was expected to be further increased. The experimental results show two typical effects : First type is that the surface modification of the sample generates a highly scattering surface structure. The second type is that the surface modification forms a photo bleaching effect. Figures 10 and 11 show the experimental results of surface modification performed lasers on samples A1 and A3. Zone 1, 2 and 3 in Fig. 10 and 11 represent the morphology and brightness of the sample processed by the laser power of 3W, 1W and 0.5W, respectively. The brightness change of the zones in image demonstrates that different matting materials under laser processing have two type results : Some materials can increase their extinction by laser modification, while the others only have the opposite effect. It means that the laser surface modification do not necessarily increase the performance of the matting materials.

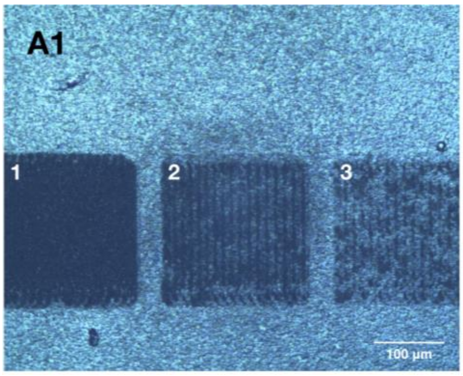


Figure 10: Laser surface modification of the A1 matting material.

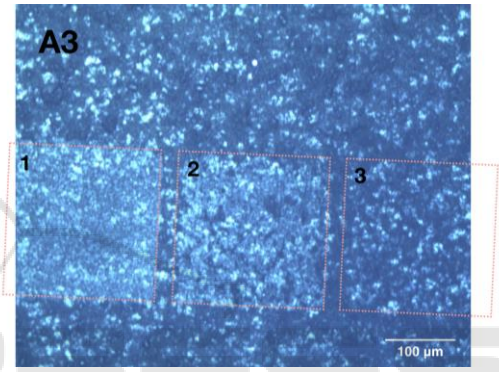


Figure 11: Laser surface modification of the A3 matting material.

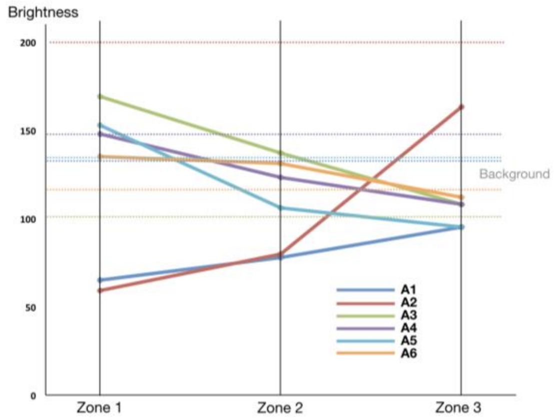


Figure 12: Reflected brightness change of the different matting materials after laser surface modification.

Figure 12 shows the reflected brightness change of the different matting materials after laser surface modification. The horizontal axis is the surface modification area under different laser powers. The smaller the zone number, the greater the power. The vertical axis is the relative brightness value. The values are obtained by averaging the brightness in the processing area. The dotted lines represent the original brightness values of the matting samples. They are relative reflectance before laser processing. The experimental results show that both samples A1 and A2 become darker after laser treatment. Conversely, the samples A3~6 become brighter. The sample A2 has not only been demonstrated its ability to resist photobleaching in previous experiments, but also it has significantly increased its light extinction capacity after laser surface modification. We can therefore believe that it is the highest quality matting material among these materials. This study proposes a procedure for testing and analysing the matting material quality. The performance of the materials in optical absorption and anti-photobleaching could be accordingly determined.

4 CONCLUSIONS

This study succeeded in developing a simple, rapid and relative accurate method for the quality estimation of the matting materials on glass and metal substrate. A high intensity UV light source with a wavelength of 365 nm was used to irradiate the prepared matting materials for 8 days. With the optical observation of experimental results, many samples have the reflectance and morphology changes. Roughness and brightness analysis allows us to understand the anti-bleaching capacity of the samples. The experimental results shows that the oil-based matting paints and 1:1 mixed materials are the most stable materials that have good anti-photobleaching characteristic. A UV pulsed laser was further used to try to improve the matting performance of the materials. However, only some materials can benefit from it. The other materials have become less effective. This study procedure is compatible with the other matting materials and can be applied to various optical systems. This study provides a useful database for optical matting and anti-photobleaching technology.

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