Investigation of Novel Diffuser Films for 2D Light-Distribution Control

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ABSTRACT

We synthesized high transmissive films that had 2-dimensional light distribution patterns such as square and hexagon. With the materials which showed 1-dimensional anisotropic diffusion if cured with a tube-type UV light source, arrays of UV-LEDs produced films of 2-dimensional distribution patterns corresponding to the symmetries of the light source arrays.

1. INTRODUCTION

Recently the request for energy saving demands a high efficiency on illuminations and display devices. Light diffusing films have indispensable roles in those usages and the most desirable characteristics of the films are high total light transmittance and optimized light distribution. Light diffuser films with specific distribution patterns are called "light control films" and are making outstanding progress in reducing the loss of light power.

A particular demand on illumination/lighting with multiple LEDs is the uniformity of the light distribution. Since LEDs have a characteristic that obeys Lambert's Cosine Law, simple overlaps of them require a good amount of distance from the light sources to achieve uniformity.

To date, many anisotropic light diffusers have been introduced as light control films. Among those films, an attractive characteristic is the specific dependency on incident light angles, which shows diffusive or transparent characteristics according to the angles.

We have succeeded in realizing 2-dimensional light distribution control on our novel diffuser films. The realized 2-dimensional patterns were square and hexagon in addition to line (anisotropic, 1-dimensional) and circle (isotropic, 0-dimensional). Their light efficiency was over 80% in total light transmittance. Their performance is sufficiently applicable to diffusers in lighting for uniform illumination and to projector screens for uniform luminance. In this paper we introduce the method of production and the obtained characteristics.

2. EXPERIMENT

Our diffuser was synthesized by UV polymerization of acrylates. In order to make small size films, monomer mixtures were enclosed in cells of 0.5 mm thick silicone rubber frames with their tops and bottoms covered with PET films or glasses. The cells were kept at 70 °C while being irradiated with 5 to 50 μW cm^{-2} UV until the completion of curing (Figure 1). As the UV light sources, a tube-type lamp and LEDs of UV-B were used. The UV-LEDs had a bullet shape of 5 mm diameter and a narrow directivity as shown in Figure 2.

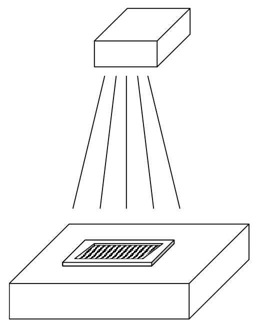


Fig. 1 A UV-irradiation system for polymerization

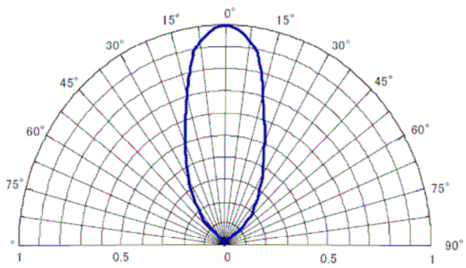


Fig. 2 Directivity of UV-LED

The images of the light distribution patterns of the resulted films were captured with a digital camera. A LASER was used as the incident light and the transmitted light was projected onto a white paper at 50 mm distance from the films under test. The images of the sectional planes of the films were taken by the normal viewing of KEYENCE's LASER microscope VK-9700. The total light transmittance was measured by MURAKAMI COLOR RESEARCH LABORATORY's hazemeter HM-150.

3. RESULTS AND DISSCUSSION

With the UV-B irradiation, light diffuser films were formed by the induced radical polymerization.

3.1 1-Dimensional Diffusion

The films irradiated with the light from a tube-type UV lamp showed over 80% total light transmittance and anisotropic light diffusing characteristic with which the film acted as a diffuser against the incident light parallel to the film's normal direction and became transparent to the inclined incident light. A structure of layers at 2 to 5 μm pitch was observed on the sectional planes of the film as shown in Figure 3. This observation agreed with the past reports [1, 2, 3].

3.2 0-Dimensional Diffusion

With the same materials but irradiated with a point light source, a cylindrical micro structure in the film was reported in the past succeeding study [4]. With our material complex, the synthesized film did not show a clear structure, however, a same result was obtained, in which the incident light from the normal direction was diffused to a circular shape and the inclined incident light was diffused to a crescent shape (Figure 4).

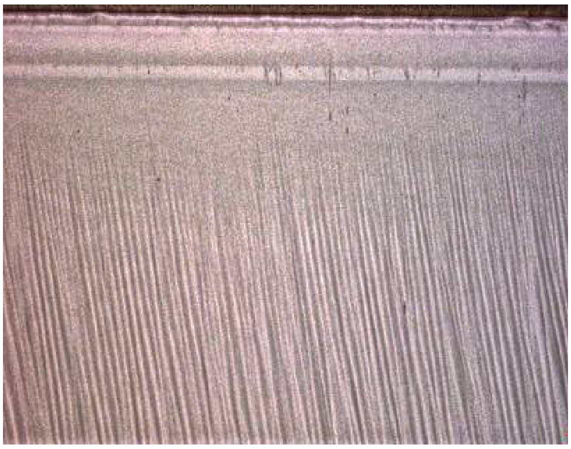
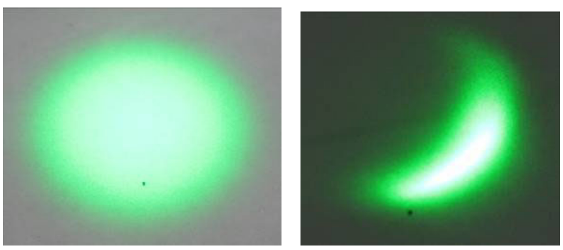


Fig. 3 A photo of sectional view of anisotropic diffuser film



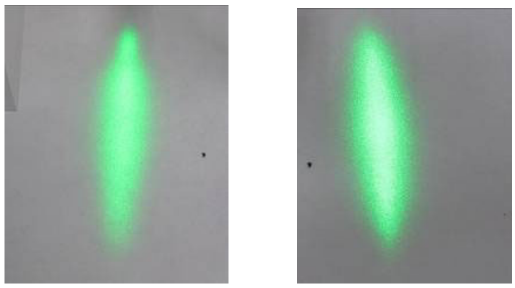
(a) (b)

Fig. 4 Photos of the distributions of diffused light with the films polymerized by a single UV-LED
Directions of the incident LASER light:
normal(a) and inclined(b)

3.3 Necessity for The Control of UV Light Directions to An Irradiated Point

Although those previous studies established the production of 1-dimensional(anisotropic) and 0-dimensional(isotropic) diffuser films, 2-dimensional light distribution control has not been realized yet.

Aiming at the control of 2-dimensionl light diffusion, at first we noticed the fact that the distribution patterns of the diffused light were same to the shapes of the UV light sources of irradiation. A spherical lamp as a point UV light source produced a circular distribution pattern and a tube-type lamp as a liner UV light source produced a linear pattern. Therefore, a straightforward induction from this fact was that a film with a square-shaped diffusion pattern could be made with a square-shaped UV light source. A trial with a uniform square UV light source produced by a ground glass was performed but resulted in failure. The resulted film had no haze but was transparent in any direction. We clarified the reason, that was, the randomness of the UV light directions produced by the ground glass caused the transparency.



(a) (b)

Fig. 5 Distributions of the synthesized anisotropic diffuser films
UV light source: an array of linearly aligned UV-LEDs(a) and a tube-type lamp(b)

Since the transparency was produced if a point of film was irradiated with non-directional UV light, we thought that the directions of UV light to a point must be within a critical angular range. Then we adopted directional UV-LEDs as the UV light source and made arrays of them. In order to verify the assumption, we performed an experiment to check whether a linear array of UV-LEDs would work as a tube-type UV lamp. An array of linearly aligned 10 UV-LEDs at 10 mm pitch was used. The distance from the UV light source array to the irradiated cells must be large enough to make sufficient overlaps of UV lights between LEDs in order to emulate a tube-type lamp. On the other hand, if the distance was too large, the power of UV irradiation came short for polymerization. Under an effective condition, anisotropic diffuser film was successfully synthesized. The obtained distribution pattern of diffused light is shown in Figure

5(a) and the pattern by a tube-type UV lamp in Figure 5(b). Those resembled each other and it showed that linearly aligned LEDs worked as a tube-type lamp in the polymerization process.

3.4 2-Dimensional Diffusion

The results indicated that (i) a single point UV light source produced a circular diffusion pattern (Figure 6(b)), (ii) an array of linearly aligned point UV light sources would produce a pattern of connected circles (Figure 6(c)), and (iii) if the overlaps of the circles would be sufficient, the array would produce a linear anisotropic diffusion by a continuous irradiation along the alignment just like a tube-type lamp (Figure 6(a)).

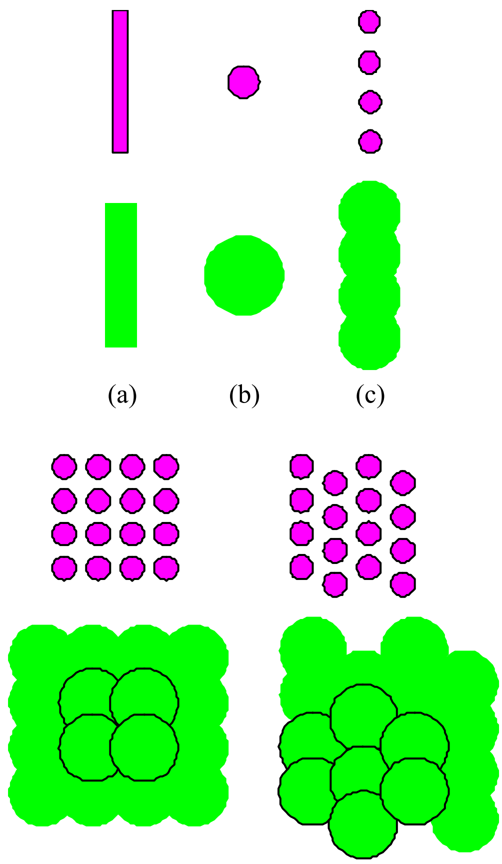
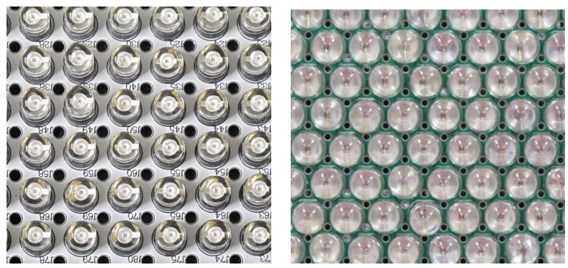


Fig. 6 Strategies for 2-dimentional light distribution control
The upper pictures: arrangements of UV light sources, the lower pictures: the resulted and expected diffusion patterns corresponding to the uppers.

A strategy for 2-dimensional light distribution control was deduced from the above consideration. Since a diffusion circle corresponded to a single UV-LED and a sufficient overlap of the individual irradiation produced the continuity of the diffusion circles which corresponded to the envelope of the original circles, it was expected that an array of square layout of UV-LEDs would produce a rounded square shape diffusion pattern as shown in Figure 6(d). A verification experiment was performed using an array of 10x10 square-disposed UV-LEDs with 10 mm pitches as shown in Figure 7(a). A resulted distribution pattern of the diffused light with the film made by this curing is shown in Figure 8(a). The distribution showed a near square shape as expected. This result supports the strategy.

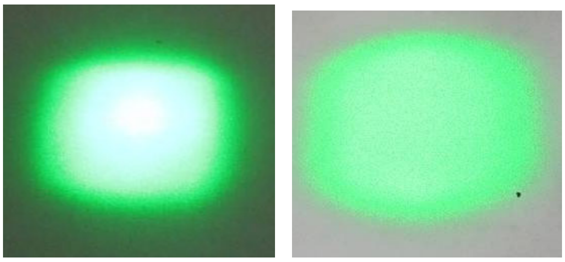
3.5 2-Dimensional Diffusion: Hexagon

For further verification, an array of delta-disposed UV-LEDs shown in Figure 6(e) was examined. With the arrangement of connected equilateral triangles, hexagonal symmetry with a center point was deduced as shown in Figure 7(b). The expected distribution pattern from the symmetry was a rounded hexagonal shape. A resulted distribution pattern with the film polymerized by the array is shown in Figure 8(b). Though the photo looks like a circle, comparison with the photo of the distribution pattern made by a single UV-LED (Figure 4(a)) indicates that the distribution is actually a rounded hexagonal shape as shown in Figure 6(e).



(a) (b)

Fig.7 Photos of 2-dimensionally disposed UV-LEDs
Square layout(a) and delta layout(b)



(a) (b)

Fig. 8 Photos of the distributions of diffused light with the films polymerized by 2-dimensionally disposed UV-LEDs
Arrangements of UV-LEDs: square layout(a) and delta layout(b)

4. CONCLUSION

We synthesized novel light diffuser films by polymerization of acrylates. An anisotropic diffuser film was made by linearly aligned UV-LEDs instead of a tube-type UV lamp. Arrays of square and hexagonal disposed UV-LEDs produced 2-dimensional light diffusion patterns of square and hexagon shapes. These results of 2-dimentional distributions support our strategy to control the diffusion patterns by the arrangement of UV light sources.

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