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Design and Fabrication of Wide-Viewing-Angle Ambient Light Rejection Front Projection Screen

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ABSTRACT

The image quality of reflective type displays is decreased by ambient light. This paper proposed a screen that composed of a micro-lens film with printed black ink stripes and a matte-white-reflection layer to reduce the influence of ambient light in the front projection system. The ambient light was guided to light absorptive black ink by micro-lens and thus enhance the contract ratio of the image in the bright environment. A proposed screen performed a better than 6.5 times improvement in image contrast ratio without sacrificing viewing angle compared to a matte-white screen under ambient light condition was demonstrated. The proposed projection screen works well in short-to-standard throw projectors and good for home or public applications.

1 Introduction

The projection display system has always been a great solution for the big screen display occasion. However, the display performance is limited by the ambient light because of the projection screen gets reflected light in the open air and thus increase the darkest level. Therefore, the contrast ratio of the display in light ambience environment is often less than 10:1 and suffers low image qualities phenomenon [1]-[2].

The ambient light rejecting techniques regarding different projection distances are different. For the ultra-short-throw projection, popular commercial ambient light rejection screens utilize Fresnel-Lens technology, black and white prism technology, or the combination of these two to absorb and block the ambient light rays, and directionally reflect projection light from under or above the screen towards the front of the screen [3]–[4]. As for ambient light rejection screens for standard or long throw application, one method to remove ambient light is utilize light sorption louver structure and reflective layers [5]. The image contract ratio can be improved, however, these ambient light rejection screens are still suffer from issues such as gain loss, limited viewing angles, high manufacturing cost, etc.

In this paper, an optical imaging film based on micro-optics for short-to-standard throw projection is proposed. The screen is composed of a micro-lens array on transparent PET (polycarbonate) film with printed black ink strips corresponding to ambient light focal point, and a diffusion base film for projection light reflection, as shown in Fig.1. Because the ambient light is usually come from larger angle than projector light (defined as normal incident of micro-lens array is 0 deg), i.e., projector light and ambient light is more like on-axis and off-axis to the lens, respectively. The micro-lens on top of screen focused the out coming ambient light to its focal point and then absorbed by pre-printed black ink. Further, the black ink position is assigned to the focal point of ambient light maximum ambient light absorption.

Based above assumption, radius of 130um, pitch of 150um, and substrate of 100um micro-lens film parameters were prepared for further projection properties examination.

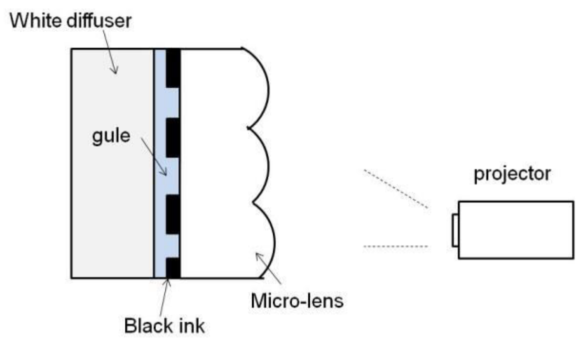


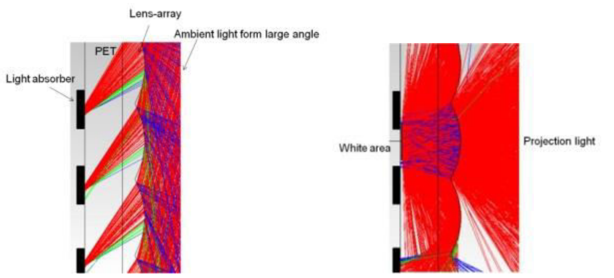
Fig.1 The schematic diagram of proposed ambient light rejection screen for short to standard throw projector. The film is composed of a micro-lens on PET substrate with black ink strips on back side, and laminated with a white diffuser base film.

2. Experimet

An optical model was built for examining the ambient light absorption efficiency as shown in Fig. 2. From the viewpoint of micro-lens, the ambient light was considered as parallel light from different angles, i.e. form 90~ 45 deg to the micro-lens normal surface. The ink absorber was assigned in the focal point of the ambient light position.

The periodic 1-dimension line type light absorber area of 60% duty to the micro-lens pitch was chosen as shown in Fig. 2 (a). The ambient light, comes from 90~45 deg, absorption efficiency was increased from 60% (matte -white diffuser with periodic absorber only) to around 95% because of the ambient light was focused on light absorber area. Micro-lens with periodic light absorber (black ink stripes) is potentially enhanced the ambient light absorption ratio.

The 60% area of white diffusion film was filled with absorber, thus only 40% area left for projector light reflection. For the projector light, micro-lens focus light onto the non-absorber area and then the diffused light collected by the micro-lens again to the viewer and thus enhanced the projection light brightness, as shown in Fig. 2 (b).



(a) (b)

Fig.2 Optical modeling of the proposed screen. (a) micro-lens focus the ambient to periodic line light absorber (i.e. black ink), and (b) the projector light focused to diffuse area and re-collected by the micro-lens to viewer.

The micro-lens film was fabricated by the following steps. First, the micro-lens pattern mold was prepared by diamond turning on a cupper roller. Second, the UV (ultra-violet) embossing on PET film process was adopted for micro-lens pattern replication. The process is promising for large size micro-lens film manufacturing. The optical microscope top view photo of the micro-lens film is show in Fig. 3. Third, after the micro-lens film is manufactured, the screen printing process was adopted for black ink printing on the back side of the micro-lens film. Finally, the micro-lens film with black-ink stripes on back was laminated by adhesive with a 100um matte-white PET film to become a proposed ambient light rejection screen.

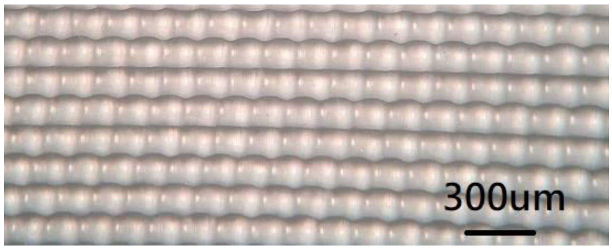


Fig. 3 The top view of micro-lens film taken by optical microscope. The micro-lens film was prepared by diamond turning mold and UV embossing process.

An A4 size sample was prepared for further projection properties evaluation. It appears dark grey in a bright indoor office environment of about 300 Lux lighting environment, as shown in Fig. 4.

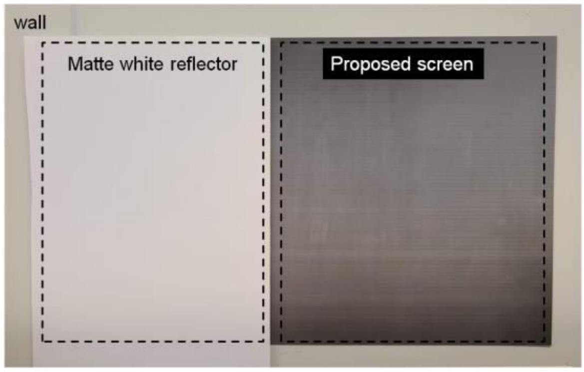


Fig. 4 The proposed screen (right side) appears dark grey in the bright indoor lighting office by comparing with matte-white screen (left side). The proposed screens appear dark grey since the ambient light is rejected.

3 Result and Discussion

In the dark, in the absence of ambient light, on-screen image contrast is maximized and equal to the projector contrast. But viewing in a fully darkened, or even a low-light setting is often not desirable. When the ambient light level is non-zero, it reflects from the screen into the viewing area. On-screen image contrast drops quickly as the ambient light level increases, as illustrated in Eq(1)[1].

On-screen image contrast is given by “light in white areas” divided by “light in black areas

$$= \frac{\text{Projector L255} + \text{ambient light brightness}}{\text{Projector L0} + \text{ambient light brigness}}$$

….Eq (1)

(where projector L255 and L0 are maximum and minimum projection brightness, respectively.)

A BenQ MH550 projector and a Topcon SR3 were adopted as light source and reflection brightness gauge for laboratory on-screen image contract estimation. Under a around 300 lux top lighting laboratory condition, the direct-front-view brightness of the matte-white screen and the proposed screen was 20.2 nits and 3.5 nits, respectively, as projected L0 signal; while 320 nits and 364 nits, respectively, as projected L255 signal. The calculated contract ratio of the proposed screen increased 6.5 times to the matte-white screen.

The center optical gain, defined as ratio of brightness of proposed screen to the matte-white screen, of 1.1 is observed. Further, the optical gain decreased slightly with viewing angle, as show in Fig. 5, which is good for public application. The illustrate qualitatively the visual perception of the improvement in contrast on a split-screen composed of the matte-white screens and the proposed screen is shown in Fig. 6. The images on the propose screen showed distinctively better contrast, darker black level and more vivid colors than the images on the matte-white screen in different angels.

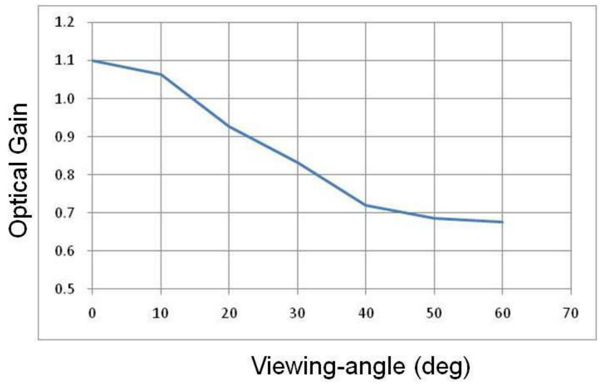


Fig. 5 The optical gain of viewing angle.

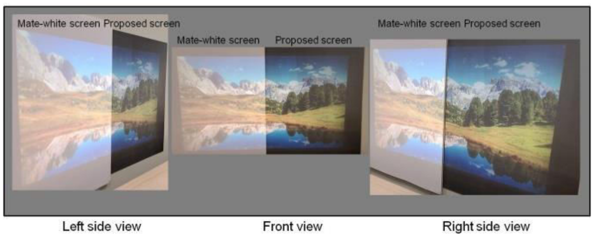


Fig. 6 Visual perception of the matte-white screen and the proposed screen in the bright environment taken from left, center, and right viewing angle.

4 Summary and Conclusion

In conclusion, a front projection screen consisted with micro-lens array, black ink strips, and white diffuser was developed that has ambient-light rejection capability and have achieved a 6.5 times improvement in center contrast over a matte-white screen. Besides image contrast improvement, the large viewing angle with good contract image and high brightness. The proposed screen is good for both home theater and public applications by using short to standard throw projectors.

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