Research on Improving Display Effect of Micro-lens 3D Printing

Linyi Chen and Guangxue Chen(✉)

State Key Laboratory of Pulp and Paper Engineering, South China University of Technology, Guangzhou, People's Republic of China
chengx@scut.edu.cn

Abstract. Micro-lens 3D printing technology, which can achieve naked-eye 3D effect in 360° perspective without any special observation equipment or skills, has gradually become a research hotspot in the field of 3D printing and display. However, there are many problems in micro-lens 3D printing, such as low resolution of 3D micro-image reproduction, image distortion. The process flow of micro-lens 3D printing technology were studied and analyzed in this paper from 3 aspects: micro-lens 3D micro-image design, micro-lens 3D optical film preparation by nano-imprint technology, and micro-lens 3D printing process control. The result showed that the problems which often exist in micro-lens 3D printing, such as low reproduction clarity and image distortion were effectively solved, which significantly improve the imaging and display effect of micro-lens 3D printing.

Keywords: 3D printing · Micro-lens array · Naked-eye 3D effect

1 Introduction

The emergence of 3D printing technology makes the display mode of printed graphics gradually change from 2D to 3D, which significantly improves the information display level, interestingness and anti-counterfeiting performance of printing and packaging products, and greatly increases the visual impact, sensory experience and added value of products. Lenticular lens 3D printing technology has the comparative advantages of larger imaging depth and better stereoscopic effect, but has the fatal defect of limited viewing angle, that is, naked eye 3D effect can only be achieved in the horizontal direction of lenticular lens arrangement instead of the vertical direction. Therefore, micro-lens 3D printing technology, which can achieve naked eye 3D effect in 360° full perspective (free viewing perspective with both horizontal and vertical parallax) without any special observation equipment or skill, has gradually replaced the lenticular lens 3D printing technology and become a research hotspot in academia and industry.

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1.1 Micro-lens Array and Its Research Status in 3D Printing

In recent years, a series of studies have been carried out on the fabrication technology, imaging characteristics and 3D printing and display of micro-lens arrays at home and abroad [1].

Wei [2] proposed a method for fabrication of micro-lens arrays using soft lithograph, which combined the traditional thermal reflow technology with the imprinting technology to fabricate micro-lens arrays. This method avoided the problem that the image effect was affected by the color interference of photoresist alone. Zhao [3] fabricated the micro-lens array with hexagonal aperture and buried in a glass substrate using photolithography and ion-exchange techniques, which enhanced the optical properties of plane micro-lens arrays by parameter optimization. The optical properties and imaging characteristics of the single plane micro-lens arrays and double plane micro-lens arrays were theoretically analyzed. Aymerich et al. [4] presented a laser based technique combined with the Talbot effect for micro-structuring surfaces, which was similar to the thermal reflow technology. The micro-cylindrical masks were fabricated by laser and then annealed to obtain micro-lens arrays. Nieto et al. [5] proposed a hybrid technique for fabricating micron scale micro-lens arrays on soda-lime glass substrates composed by a direct-laser write and a post thermal treatment. And the shape change of the micro-lens at different temperatures was characterized.

From the related research status at home and abroad, we can see that the research on micro-lens arrays focuses on the fabrication technology and imaging characteristics of micro-lens arrays. However, the research on micro-lens arrays in 3D printing is rare. Huang [6] studied the application of micro-lens arrays in stereo printing from the perspective of anti-counterfeiting, and analyzed the stereo printing process of micro-lens arrays. 540-line honeycomb micro-lens arrays anti-counterfeiting film was fabricated by roll-to-roll printing, but the 3D imaging display of honeycomb micro-lens arrays anti-counterfeiting film by printing was not achieved. Li [7] analyzed the imaging mechanism of micro-lens 3D printing, and improved the way of making the 3D image manuscript. The hemispherical micro-lens 3D printing sample based on UV offset printing was successfully fabricated. However, there were some existing problems such as low resolution and image distortion of 3D micrographics reproduction.

1.2 Proposal of Research Topic

The poor imaging and display effect of micro-lens 3D printing is generally caused by the matching of micro-lens array and 3D micrographics, the quality of micro-lens 3D printing materials and the process control of micro-lens 3D printing. Therefore, how to design 3D micrographics to match well with micro-lens arrays, how to fabricate high-quality micro-lens 3D printing materials, how to adjust the adaptability between micro-lens 3D printing materials, printing process and printing equipment, so as to improve the display effect of micro-lens 3D printing is a meaningful and valuable research topic. The process flow of micro-lens 3D printing technology were studied and analyzed in detail below from 3 aspects: how to design 3D micrographics combined with micro-lens array, how to fabricate micro-lens 3D optical films by nano-imprinting technology, and how to control micro-lens 3D printing technology process.

2 Research on Technological Process of Micro-Lens 3D Printing

2.1 Design of 3D Micrographics Combined with Micro-Lens Array

3D micrographics effect is a new periodic Moire pattern generated by the superposition of two arrays with similar periodicity and the double superposition of the visual depth of field effect of micro-lens, resulting in periodically magnified stereo depth of field pattern.

If a group of events or phenomena recur in the same order, the time or space interval to complete the group of events or phenomena is called period, which is expressed by "T". In acoustics, the interference of two sound waves with similar but different frequencies yields a frequency difference between the original two sound waves, which is called difference frequency. The period of 3D micrographics is, in short, the minimum distance between two opposing patterns in the generated periodic 3D micrographics.

As shown in Fig. 1, assuming that the period of sound wave 1 is $T1$, the frequency is $f1$, the period of sound wave 2 is $T2$, the frequency is $f2$, and the intervening period of two sound waves is T and the frequency is f, then:

$$T = \frac{1}{f}; f = f1 - f2 = \frac{1}{T1} - \frac{1}{T2}$$

As a result, it can be concluded that:

$$T = \frac{T_1 * T_2}{|T_1 - T_2|}$$

According to the periodic formula, the closer $T1$ and $T2$ are, the larger the magnification of the 3D pattern of the micro-lens is. In particular, when $T1 = T2$, it's meaningless for mathematics, but meaningful for physical description.

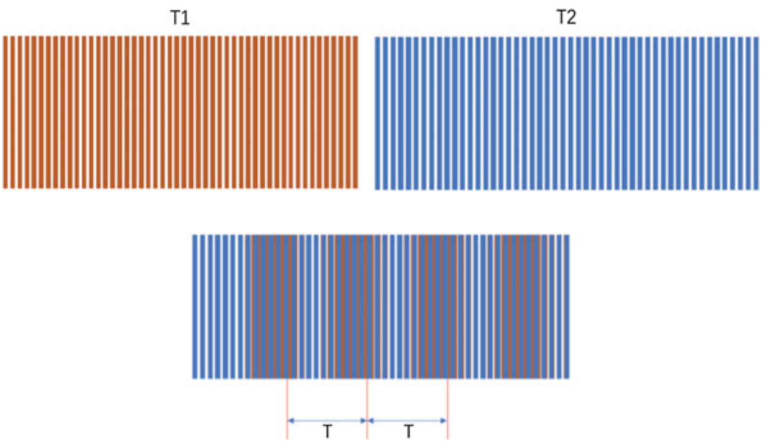

Fig. 1. Two sound wave and interference effects with different periods ($T1$, $T2$)

At this time, the period of the final 3D pattern is ∞, so we can not see the enlarged 3D pattern theoretically. However, due to the inevitable errors in the manufacturing process, we can finally see the enlarged 3D pattern.

We know that once the micro-lens 3D film is produced, the spacing distance between every two adjacent lenses has been fixed. Then how to control the cycle of designed 3D pattern in the design process to ensure that the design effect is consistent with the actual printing effect?

Taking micro-lens sheet with 0.4 mm thick as an example, the spacing distance between every two adjacent lenses of the sheet is $T1 = 0.18$ mm, the diameter of every lens is 0.13 mm, and the spacing distance between every two designed elements of 3D pattern is $T2$. Assuming that the distance T of the final 3D pattern is 5 mm, according to the periodic formula of the micro-lens 3D pattern:

$$T = \frac{T_1 * T_2}{|T_1 - T_2|}$$

There are two values of the spacing between every two elements of the designed 3D pattern according to the above formula: $T2 = 0.174$ mm, the visual effect of 3D pattern is sinking. Or when $T2 = 0.184$ mm, the visual effect of the 3D pattern is floating. That is, when the element spacing of the designed 3D pattern is $T2 < T1$, the visual effect of the 3D pattern is sinking; when the element spacing of the designed 3D pattern is $T2 > T1$, the visual effect of the 3D pattern is floating.

As shown in Fig. 2 below, there are mainly three kinds of lens arrays for micro-lens 3D films, namely 45° orthogonal arrangement, honeycomb arrangement 1 and honeycomb arrangement 2.

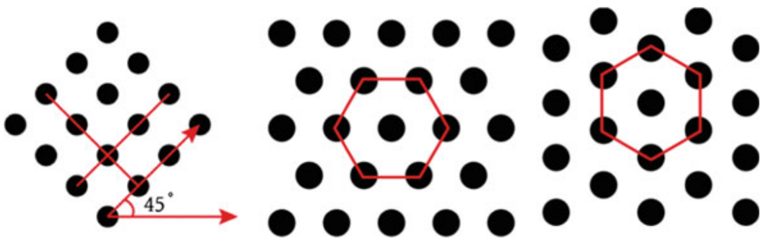

Fig. 2. Three common arrangement modes of micro-lens arrays

Taking a single channel, 45° orthogonal arrangement (0.4 mm micro-lens sheet) micro-lens 3D pattern as an example (we can know from the front discussed, the lens arrangement spacing of micro-lens sheet with 0.4 mm thick $T1 = 0.18$ mm, the spacing of every two designed 3D pattern elements $T2 = 0.178$ mm), the method of using Adobe Illustrator to design 3D micrographics for making printing plate and nano-precision optical mould was discussed in detail as follows. It mainly includes the following eight steps, which are shown in Fig. 3a, b, c, d, e correspondingly.

Step 1, determine the minimum repetitive unit (Fig. 3a).
Step 2, establish a minimum repetitive cell box, $a = 0.178 * \sqrt{2} = 0.252$ (Fig. 3b).
Step 3, the micro-lens 3D pattern elements are set to be in the center of the minimum repetitive unit block diagram.
Step 4, the micro-lens 3D pattern elements are copied and translated to the vertex of the minimum repetitive cell box (Fig. 3c).
Step 5, the path finder is used to cut the redundant parts and establish the minimum repetitive unit.
Step 6, drag the minimum repetitive unit into the color plate and rename it.
Step 7, establish filling area according to designed size (Fig. 3d).
Step 8, select the area to be filled and fill it with the smallest unit in the color plate (Fig. 3e).

After the above eight steps, the design of 3D micrographics for printing plate and nano-precision optical mould is completed.

Note: The edge length of the minimum repetitive cell frame and the arrangement spacing of the designed micrographics element $T2$ should satisfy $a = 2 * T2 = 1.414 * T2$. The calculation results are accurate to 3 decimal places.

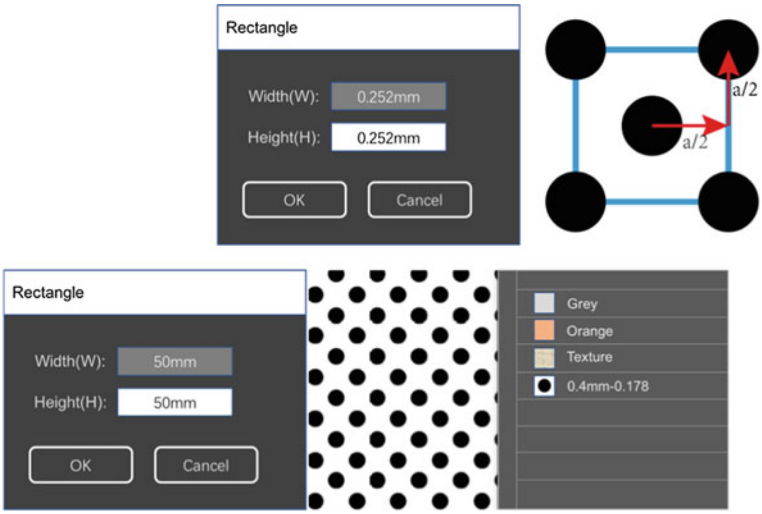

Fig. 3. The process of designing 3D micrographics in Adobe Illustrator (From left to right, from top to bottom, (**a**)–(**e**) successively)

2.2 Fabrication of Micro-lens 3D Optical Film

The micro-lens 3D optical films in this paper are fabricated by the 3D optical film fabrication machine based on nano-imprinting technology.

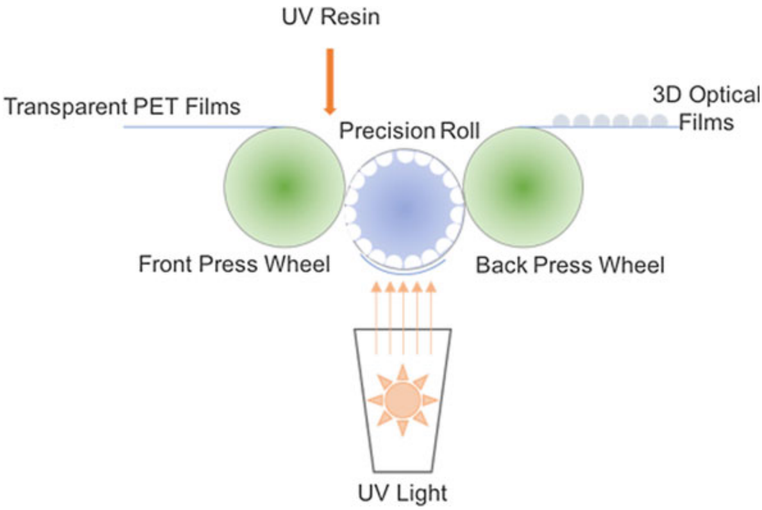

Fig. 4. Principle diagram of micro-lens 3D optical film fabrication machine

The film-made mechanism of micro-lens 3D optical film fabrication machine is as follows: UV resin flows into the micro-lens groove on the surface of nano-optical mould. The excess resin is extruded from the groove by pressing the front wheel. The surface of nano-optical mould and PET film are closely fitted with each other. The resin in the groove is solidified on the surface of PET film through UV lamp irradiation. The PET films with cured resin are peeled off from nano-optical mould after the back pressing wheel. The formed micro-lens layer is firmly attached to the surface of PET to form a transparent 3D optical film. The principle diagram of micro-lens 3D optical film fabrication machine is shown in Fig. 4.

The micro-lens 3D optical film fabrication machine can realize the development and manufacture of 3D optical films with 38–188 µm thick (the thickness of the micro-lens 3D optical film corresponds to the technical parameters of the precision optical mould. For instance, if micro-lens 3D optical film with 50 µm thick is expected, the precise optical mould with the corresponding parameters is needed).

The micro-lenses of 0.05 mm film are arranged by honeycomb (regular hexagonal arrangement), the distance between every two adjacent lenses is 0.046 mm, and the diameter of every lens is 0.03 mm. The micro-lenses of 0.075 mm film are arranged by honeycomb (regular hexagonal arrangement), the distance between every two adjacent lenses is 0.1 mm, the diameter of every lens is 0.08 mm. The micro-lenses of 0.4 mm sheet are arranged by orthogonal arrays, the distance between every two adjacent lenses is 0.18 mm, and the diameter of every lens is 0.13 mm. The micro-lenses of 0.3 mm sheet are arranged by honeycomb (regular hexagonal arrangement), and the distance between every two adjacent lenses is 0.12 mm, and the diameter of every lens is 0.08 mm.

2.3 Process Control of Micro-lens 3D Printing Technology

The process control of micro-lens 3D printing is crucial for the imaging and display effect of micro-lens 3D printing products. Usually, there are two printing methods for micro-lens 3D optical films: one is on the back of micro-lens 3D optical films, the other is on the double sides of micro-lens 3D optical films. However, the printing units of the UV offset press used are all 7 colors, including C, M, Y, K, 3D micrographics, white ink and wear-resistant OP varnish.

Technology process diagram of micro-lens 3D printing is shown in Fig. 5.

For back printing, the printing color sequence is: C, M, Y, K four-color printing for surface graphics, 3D micrographics, white ink, wear-resistant OP varnish.

For double-sided printing, the printing sequence is as follows: firstly, 3D micrographics, white ink and wear-resistant OP varnish are printed on the back of the micro-lens 3D optical films; secondly, C, M, Y, K four-color surface graphics and wear-resistant OP varnish are printed on the front of the micro-lens 3D optical films.

We have done a lot of research and testing on the micro-lens 3D printing process and found that:

On the one hand, unlike ordinary plane printing, micro-lens 3D printing requires very high resolution of CTP plate. Usually, in order to obtain clear naked eye 3D effect, the resolution of CTP plate should not be lower than 4000 *DPI*.

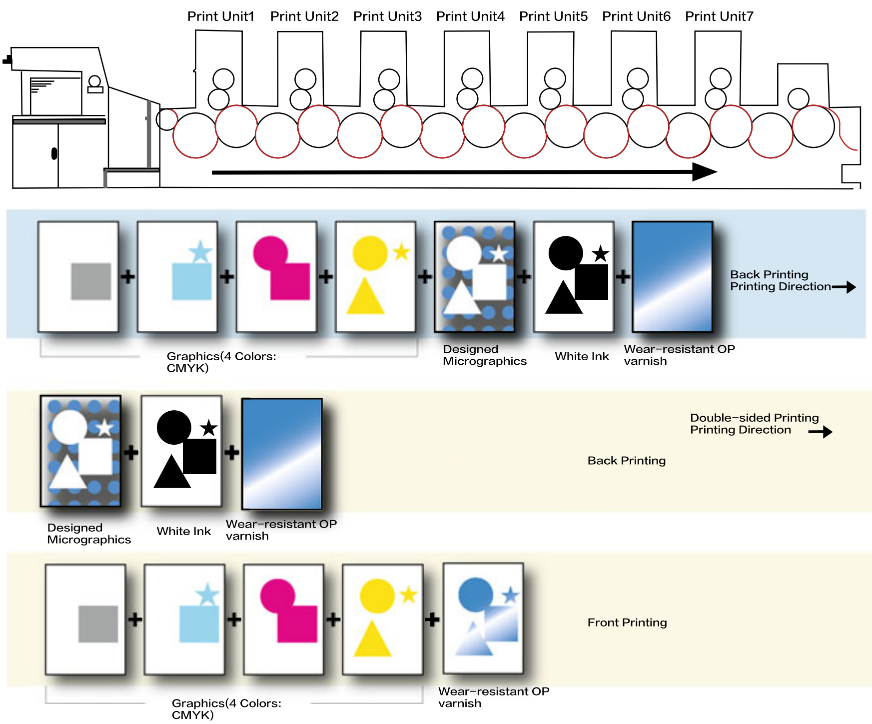

Fig. 5. Technology process diagram of micro-lens 3D printing

On the other hand, like ordinary plane printing, in the process of micro-lens 3D printing, we need to flexibly adjust the corresponding printing speed, printing pressure and other production parameters according to the thickness and surface adhesion of micro-lens 3D optical films, so as to reach the best matching condition between micro-lens 3D printing materials, printing process and printing equipment, thus to achieve 3D printing effect beyond expectation.

3 Results and Discussion

Through the research on how to design 3D micrographics in Illustrator, how to fabricate micro-lens 3D optical films with nano-scale based on nano-imprint technology, how to set printing color sequence and printing parameters to realize the process control of micro-lens 3D printing process, we have successfully solved the existing problems on poor imaging and display effect in micro-lens 3D printing, for instance, low reproduction clarity of 3D micrographics, image deformation, etc. The research results related to micro-lens 3D printing have been successfully applied to packaging products in ICT, tobacco, alcohol, food, cosmetics and other fields, and have been recognized by customers and favored by the market. Figure 6 shows Structural diagram of micro-lens 3D printing product.

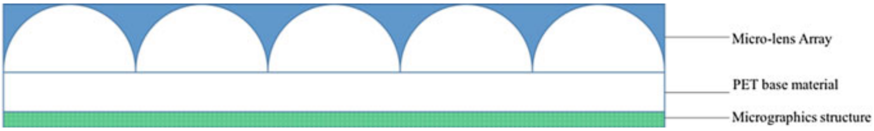

Fig. 6. Structural diagram of micro-lens 3D printing product

4 Conclusions

In this paper, the technological process of micro-lens 3D printing was studied and analyzed from 3 aspects: the design of 3D micrographics, the fabrication of micro-lens 3D optical films based on nano-imprint technology and the process control of micro-lens 3D printing process. The problems, for instance, low resolution of micro-lens 3D printing and image distortion, were effectively solved. And the imaging and display effect of micro-lens 3D printing were improved. Related research achievements have specific reference significance for the technical research and product development in the field of micro-lens 3D printing.

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