

Fabrication of concentric light guiding plate with SiO₂ reflective film

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ABSTRACT

A backlight unit (BLU) of TFT-LCD is composed of a light source, a light guiding plate (LGP), prism sheets, diffusive sheets and a reflective sheet. The LGP is a very important component in backlight panel (BLP). Generally, Polymethyl methacrylate (PMMA) material is chosen to make the LGP by using injection molding technique. In this research, Microelectromechanical Systems (MEMS) and hot-embossing technology are applied to fabricate the integrated LGP with the microstructures of double-sides and a reflective film. The new BLU will be only one integrated LGP without any other optical components, which are a reflective sheet, a diffusive sheet, and a prism sheet in BLU, and it can save the space and the fabrication cost. In future, the integrated LGP could make the display thinner and brighter for LCD application.

Keywords: Microelectromechanical Systems, optical components, light guiding plate, backlight panel

1. INTRODUCTION

Liquid crystal display (LCD) is used to present high uniform luminance as well as thinness, low weight, low electric energy consumption, as such, has been widely used in monitors of notebook, LCD-TV, laptop computer, and many portable information devices, such as cell phones and personal digital assistants, etc. Liquid crystal does not emit light, so a backlight source is used to make a viewable image on LCD. The cold cathode fluorescent lamp (CCFL) is chosen as the light source of the backlight unit (BLU) behind the LCD panel. A backlight system is composed of CCFL, light guiding plate (LGP), prism sheets, diffusive sheets and a reflective sheet as shown in Fig. 1. For instance, the reflective sheet can reflect the light from the light source toward the top of BLU, and increase the luminance of BLU. The light from the light source is placed on the side of the LGP and reflected and refracted the light from the LGP. The diffusive sheets are used to make the light uniformly. The prism sheets can collect the diffusive light and make the light emit in a direction perpendicular to the top surface of BLU. Recently, in order to satisfy the market requirements for cell phones and display panels by lots of companies, it is more and more necessary to improve the BLU and make it thinner, lighter, and brighter by many researchers. For this purpose, different types of BLUs have been reported, which replaced the diffusive dots of LGP and the diffusive sheet with a modification on the BLU [1, 2, 3]. Lin et al [4] have presented a combined process of silicon anisotropic etching and hot-embossing technologies to make the pyramid arrays for BEF applications of BLU. Feng et al [5] have proposed an integrated LGP based on microstructures by using polymethylmethacrylate (PMMA) material, which can be designed to control the illuminative angle. Chien et al [6] have approved a guiding light panel constructed on v-cut structures of double sides by using Microelectromechanical Systems (MEMS) technique for LGP of BLU application. The luminous angle of the traditional LGP is difficult to control, so we proposed an integrated LGP, which can combine the functions for three types of optical components. All of double-side microstructures and the film of enhanced reflection are constructed on the integrated LGP. The micro-prism structure and the micro-pyramid structure of the integrated LGP are considered to alter the direction of the light rays and to make the light emit in a direction perpendicular to the top surface of the integrated LGP. The film of enhanced reflection at bottom of the micro-prism structure can guide the revised light rays from reflective sheet to the micro-pyramid structure. Because the CCFL light source in BLU is not a green product, a white LED is used to be the light source of the integrated LGP and then the optical luminance of the integrated LGP is measured by the optical luminance meter in black room. The size of 1.8 inch of the integrated LGP is designed and fabricated in this research such as for mobile phone panels.

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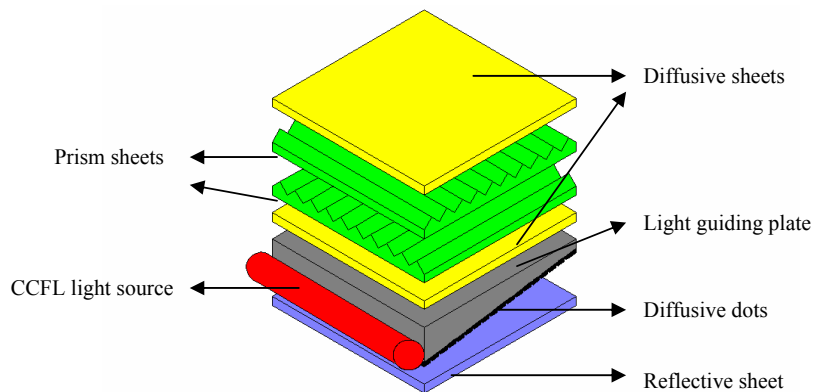


Fig. 1. 3-D structure of traditional backlight unit

2. DESIGN CONCEPT

The conventional edge-light type of the backlight unit (BLU) is consisted of a transparent PMMA light guiding plate (LGP) with printed diffusive dots and some optics-controlling devices. The light rays from the source are directed in the edge of the LGP and are guided inside it constructed on the principle of total internal reflection, as shown in Fig. 2. The optical elements, such as the printed diffusive dots and mirrors are necessary at bottom of the LGP, which can couple the light rays out of the plate. A traditional LGP that is not designed to control the luminous angle can not make the light emit in a direction perpendicular to the top surface of the LGP, as shown in Fig. 3, so it is indispensable to adopt some optical components including diffusive sheets, prism sheets and reflective sheet to convert the light rays direction into the front direction (see Fig. 4).

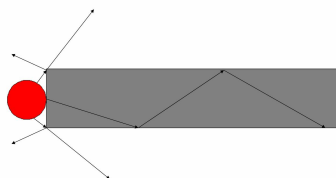


Fig. 2. Guiding light situation of LGP

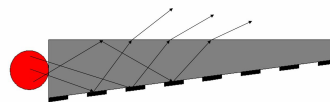


Fig. 3. Guiding light situation of LGP with diffusive dots

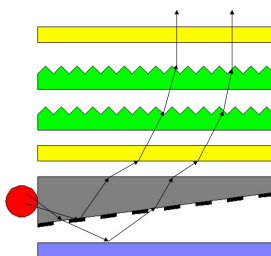


Fig. 4. Guiding light situation of backlight unit

2.1 Design principle and conception of the integrated LGP

Snell's law is applied to calculate the new light direction. If the light is guided to a less dense medium such as from PMMA material to air, either refraction or total reflection may occur, as shown in Fig. 5. The critical angle for total reflection is expressed as

$$\theta_{cri} = \sin^{-1}(\sin \frac{\pi}{2})(\frac{n_{fra}}{n_i}) \quad (1)$$

where n_i and n_{fra} are the refraction indexes of at the incident light (i) and at the refraction light (fra). When the incident angle of light is smaller than the critical angle of light, refraction occurs. The refractive angle for refraction is represented as

$$\theta_{fra} = \sin^{-1}(\sin \theta_i)(\frac{n_i}{n_{fra}}) \quad (2)$$

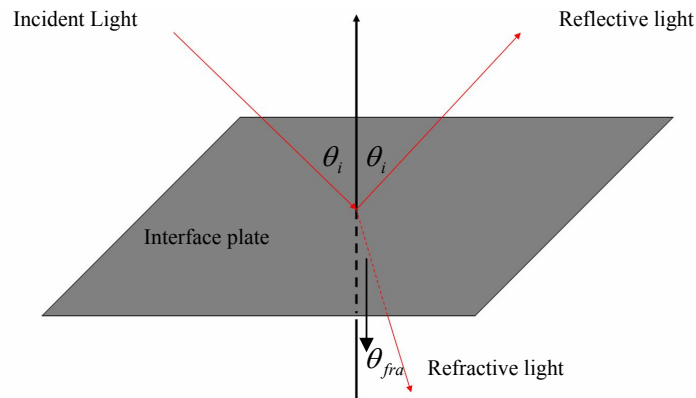


Fig. 5. Schematic diagram of optical terms defined in this research

In order to modify the traditional backlight unit (BLU) and remove these optical components, it is necessary to design an integrated LGP, which can combine their functions into a single guiding light device. Usually, a reflective sheet is placed at the bottom of an LGP and it guides the back leakage light into the LGP in backlight unit (BLU) (see Fig. 6), but the reflective sheet is not used for the LGP to control the illuminative angle; therefore, we proposed an integrated LGP with the double-side microstructures and the film of enhanced reflection (such as SiO_2), which is coated on bottom surface of microstructure. The incident light is reflected by the micro-prism structure and then the transmitted light is guided to the top of micro-pyramid. The micro-pyramid structure, which can make the light emit in a direction perpendicular to the front of LCD- panel. The SiO_2 thin-film is spun on the bottom surface of the LGP, which diminish the refractive angle and light traveling distance to avoid the light lose, as shown in Fig. 7.

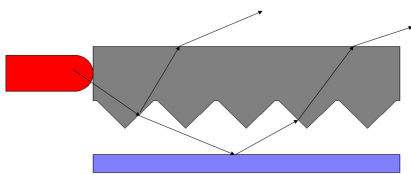


Fig. 6. Guiding light situation of general LGP

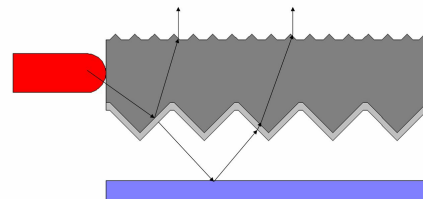


Fig. 7. Guiding light situation of integrated LGP

2.2 The characterization of silicon and material choice for the fabrication of integrated LGP

Bulk silicon etching technologies, used to selectively remove silicon substrates, have been applied in fabrication of microstructure, precision optical component and fiber communication. Anisotropic etchants are used to etch much faster in one direction than in another, exposing the slowest etching over time. Those delineated here slow down markedly at

the (111)-oriented planes of silicon, relative to their etch rates for other planes. Depending upon the crystal orientation chosen, the (111)-oriented planes are generally either at 54.74° to the surface of silicon wafer (for (100)-oriented silicon), as illustrated in Fig. 8.

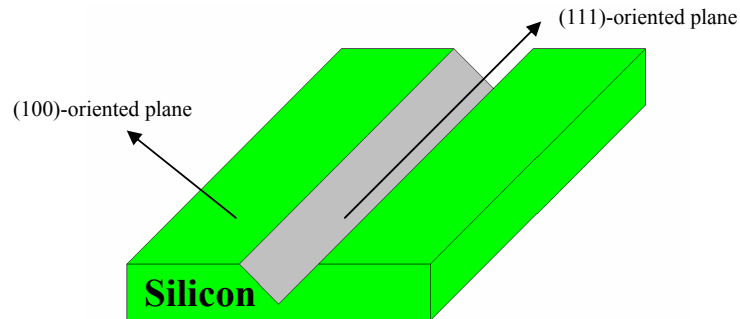


Fig. 8. The schematic diagram of etching characterization of silicon

Anisotropic microstructure of silicon is used to define the shape of the integrated LGP with double-side guiding light elements in this research. Our designed LGP is made of PMMA with a refractive index of 1.5 and its bottom is convex micro-prism structures, which are the same shape and density. Micro-pyramid structures at top surface, which has the shape and density.

2.3 Design dimension of guiding light element and its distribution

The widths of the micro-prism structures are designed 50 μm with depth of 35.3 μm . The area of the each pyramid is $50 \times 50 \mu\text{m}^2$ at the top. Generally, there are three LED light sources for the LGP of cell phone. In order to use only one LED and to make the light which is distributed uniformly, the concentric circle distribution of micro-prisms, pyramid arrays and SiO_2 thin-film are applied to make the integrated LGP. The design positions of the micro structures are along the circle trajectory, as shown in Fig. 9. The concentric circle distribution of prism structures and pyramid arrays are represented as:

$$T = r \theta \quad (3)$$

where T is the trajectory of circle. r is the distance from the light sources to the micro-prism and micro-pyramid structures. θ is the distributed varies of the micro structures with the trajectory angle.

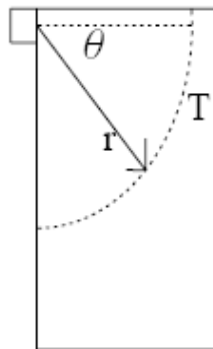


Fig. 9. Schematic diagram of concentric circle trajectory of guiding light element

3. EXPERIMENT

A fabrication process, which combines Microelectromechanical Systems (MEMS) and plastic molding technologies have been developed to make a guiding light panel. The P-type (100) silicon was utilized to be the microstructure mould by using the anisotropic etching technique, and then the silicon mould and the PMMA material were passed through the hot-embossing process. Finally, the film of enhanced reflection was deposited on the bottom of PMMA material, and the concentric integrated LGP was completed.

3.1 The manufacturing methods of mold of prism and pyramid

The silicon micromachining process used only one mask. First, Si_3N_4 was grown on the top of the P-type (100)-oriented silicon wafer, as illustrated Fig. 10(a). It was passed through the lithography process by using a standard UV light exposure and then the patterns on the mask were transferred onto the photo-resist (S1813) on top surface of the P-type (100)-oriented silicon wafer, as illustrated in Fig. 10(b). The resisted silicon nitride layer was then removed by using dry etching process, as shown in Fig. 10(c). The acetone solution was used to strip the photo-resist (S1813), as shown in Fig. 10(d). The anisotropic etching process, which followed so as to define the shape of the silicon wafer [7]. The silicon material was removed such that the prism microstructure was on the top of the silicon wafer, as shown in Fig. 10(e). Finally, the nitride was removed and then the prism mold was completed, as shown in Fig. 10(f) and Fig. 11. The manufacturing method of the micro-pyramid mold was same as the prism mold. The first, the S1813 photo-resist was spun on the (100)-oriented silicon wafer with nitride (Si_3N_4). After that, the pattern was defined through lithography process. Dry etching process was utilized to remove the nitride layer. After the unexposed-PR was stripped, anisotropic etching process was applied to make the pyramid mold and then the pyramid mould was completed, as shown in Fig. 12.

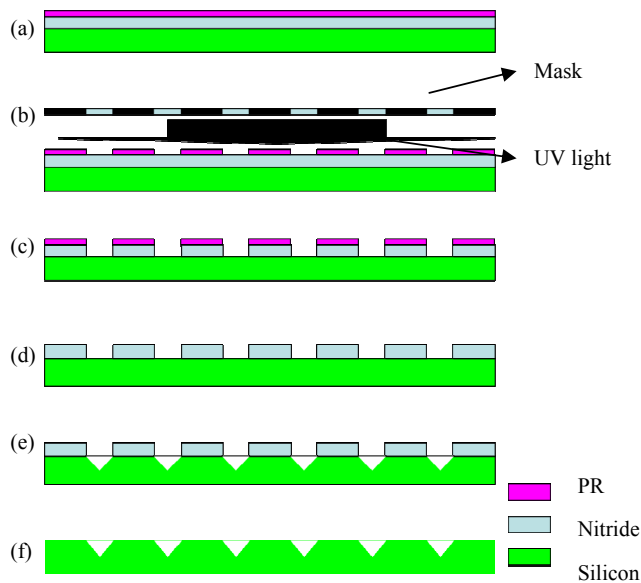


Fig. 10. Schematic diagram of manufacturing methods of prism and pyramid

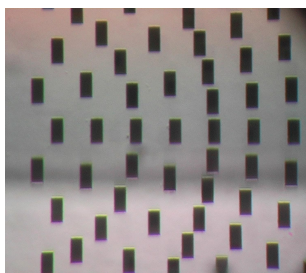


Fig. 11. A microphotography of prism mold

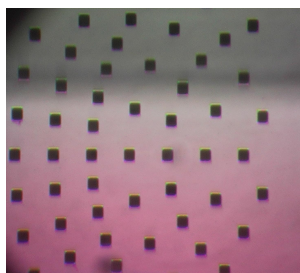


Fig. 12. A microphotography of pyramid mold

3.2 The manufacturing methods of concentric integrated LGP

PMMA material was chosen to make the guiding light component by using hot-embossing process (see Fig. 13). PMMA was deformed through the silicon mould with the molding temperature up to 120°C and the clamping force of the 0.335 kgw/mm^2 . To hold the clamping force during cooling could avoid the shrinkage of the microstructure and then the guiding light component was completed. The $0.1\mu\text{m}$ of thickness of SiO_2 material was deposited on the bottom surface of the guiding light component, to be as the thin-film of the enhanced reflection by using deposited system, and then the integrated LGP is completed, as shown in Figure 14.

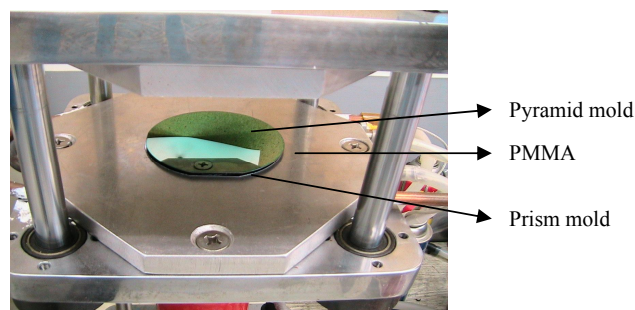


Fig. 13. Hot-embossing process

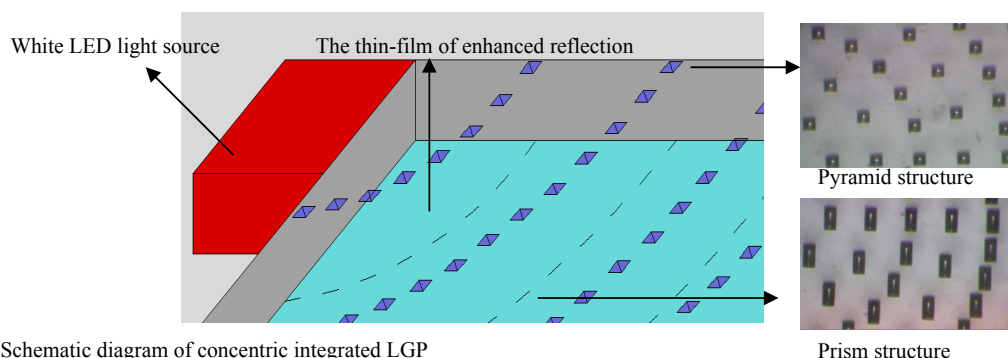


Fig. 14. Schematic diagram of concentric integrated LGP

4. RESULTS AND DISCUSSION

Fig. 15 shows the set up of the experiment of illumination. In black box, the integrated LGP with the white LED light source were placed on the optical plate and then the illumination meter is used to measure the illumination of the integrated LGP. The nine test positions on the concentric integrated LGP are chosen to be measured the illumination with $1\text{ X }1\text{ cm}^2$, as illustrated in Fig. 16.

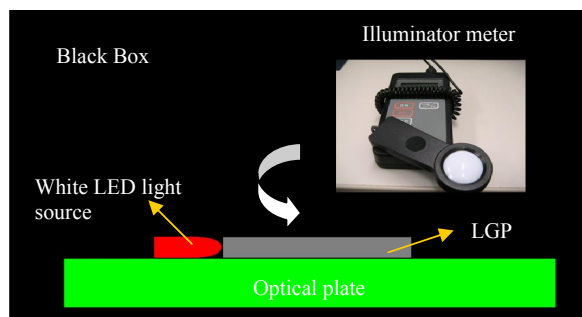


Fig. 15. Schematic diagram of optical lamination set up

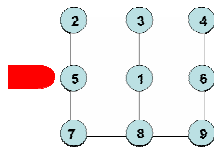


Fig. 16. Illustration of measured method of integrated LGP

Three different types of the LGPs are measured and discussed in this research. The uniformity of illumination is calculated by equation 4 as follows:

$$U = \frac{I_{\min}}{I_{\max}} \quad (4)$$

where $I_{\max}$ and $I_{\min}$ are the maximum illumination and minimum illumination of the concentric integrated LGP, and U is the uniformity of the illumination of the concentric integrated LGP.

First type of the LGP is the single-side concentric LGP and Fig. 17(a) shows the tested illumination data. The maximum illumination is 276.5 lux and the minimum illumination is 214.7 lux; therefore, the uniformity of illumination is 77.6 %. Second type of the LGP is the double-side concentric LGP and Fig. 17(b) shows the tested illumination data. The maximum illumination is 368.1 lux and the minimum illumination is 295.4 lux; therefore, the uniformity of illumination is 80.2 %. Third type of the LGP is concentric integrated LGP and Fig. 17(c) shows the tested illumination data. The maximum illumination is 385.1 lux and the minimum illumination is 320.1 lux; therefore, the uniformity of illumination is 83.1 %. From the above measured results, the uniformity of the concentric integrated LGP is demonstrated better than other types of LGPs. The relationship of the illuminative uniformity of different LGPs is shown in Fig. 18. Xiao [8] reported that the illumination uniformity of v-grooved LGP of BLU is 75% and the illumination uniformity of traditional LGP of BLU is 85%. Thus, the concentric integrated LGP provided the lots of functions of optical components and its uniformity was achieved a standard of general LGP of BLU. An integrated LGP combining three kinds of functions of optical components and it has been demonstrated by using MEMS and hot-embossing techniques successfully in this research.

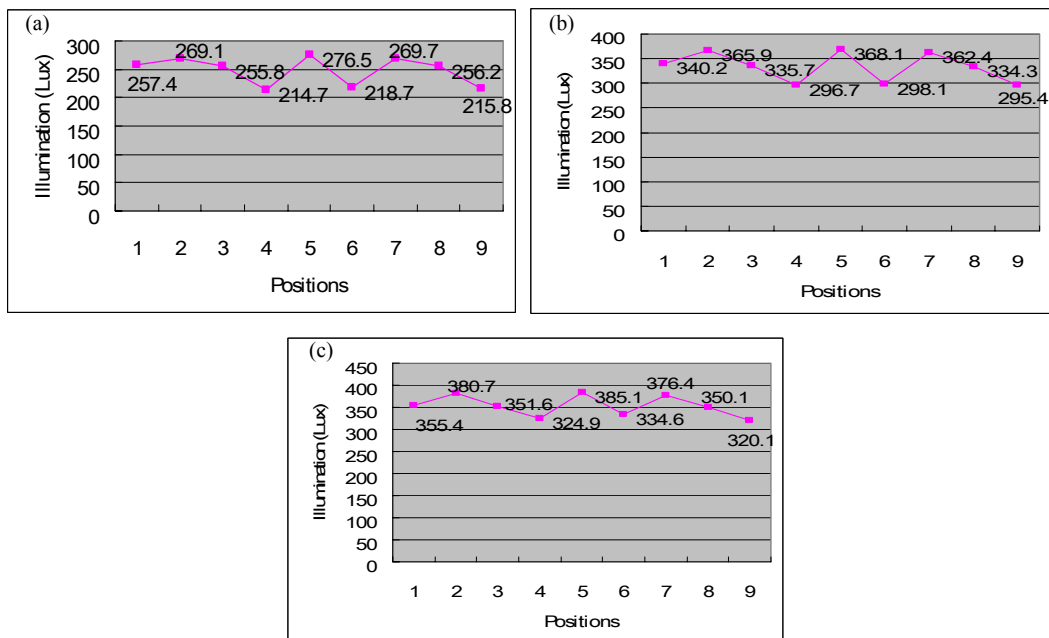


Fig. 17. Illustration of test results for three types of LGPs (a) Concentric LGP (single), (b) Concentric LGP (double-side), (c) Concentric integrated LGP.

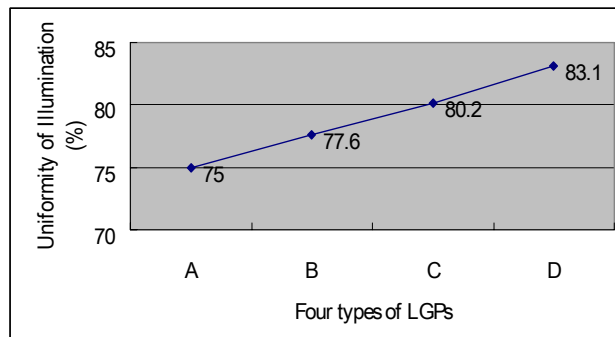


Fig. 18. Illustration of illuminative uniformity for four types of LGPs, (a) A standard general v-grooved LGP, (b) Concentric LGP (single-side), (c) Concentric LGP (double-side), (d) Concentric integrated LGP.

5. CONCLUSIONS

Microelectromechanical Systems and hot embossing techniques are applied to make the concentric integrated LGP with the pyramid arrays, the micro-prisms and the film of enhanced reflection successfully. The experimental result shows that the integrated LGP is demonstrated successfully of guide light function and the its 83.1% of illuminative uniformity of integrated LGP is better than other LGPs. The integrated LGP is integrative with other optical components in one structure, so the process cost and the space of the BLU are saved. In the future, the integrated LGP could make displays thinner and brighter for thin-film LCD applications.

6. ACKNOWLEDGEMENTS

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