Light Guide Film for Mobile Phone

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Recently, thin LGF that illuminates mobile phone keys uniformly has been attracting attention. We have succeeded in developing and commercializing it. Base films with high optical transparency and flexibility and ink that diffuses light effectively and possesses high durability are used for LGFs. We established the important technologies of optical simulation and evaluation of brightness. We report the development of these fundamental technologies and introduce the variations of products developed on the basis of the technology.

1. Introduction

LEDs emitting light at the top are used for lighting the keys of mobile phones. However, in this structure, LEDs cannot be placed below each key, which leads to the problem of light uniformity. If many LEDs are used to improve the uniformity, both the cost and battery drain speed increase. Hence, inorganic EL films were used instead of LEDs. However, due to the problems of decrease in brightness due to humidity, need for DC/AC converter, and generation of audible noise, the use of inorganic films was not widespread. We have succeeded in developing thin LGFs for lighting keys uniformly with less number of LEDs. A thin LGF consists of a base film and light diffusion ink printed on the base film. The base film is required to possess high transparency and flexibility so as not to worsen the tactile feeling, while diffusion ink is required to diffuse the light effectively and prevent damage by knocking. Moreover, technologies are needed for fine dot printing, simulation of lighting, and evaluations of the lighting. We will explain these developments in the following sections.

2. Structure of LGF

Figure 1 shows the mechanism of lighting by thin LGF. The light from an LED goes through the 0.2 mm thickness film and diffuses in the printed area. Diffused light goes out from the film and lights the keys. Thus, following items are needed to light the keys effectively.

- Base film with low absorbance and diffusion of light
- Diffusion ink of low absorbance and effective diffusion of light
- Optical design and simulation to light the keys uniformly

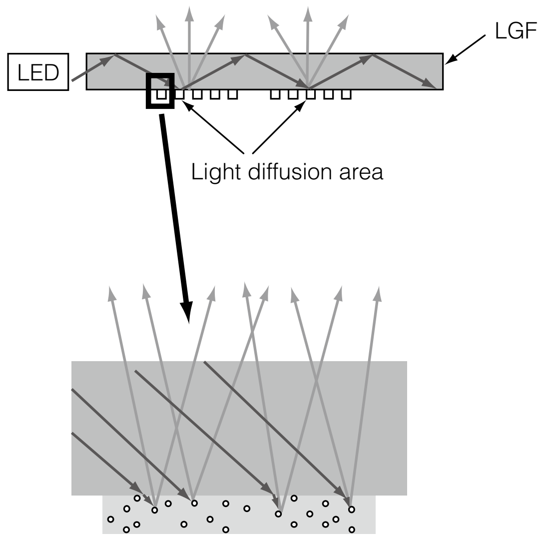

Fig. 1. The mechanism of thin LGF.

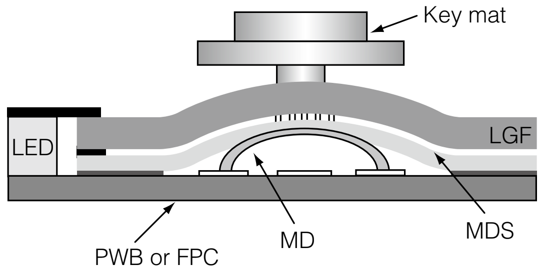

Fig. 2. Cross section of LGF assemble product.

Figure 2 shows a cross-sectional view of LGF products. The LGF is sandwiched between a MDS and the key mat. The LGF requires the following items.

- Retention of the tactile feeling
- High durability for the numbers of knocking

3. Development of a base film

Base film requires the following characteristics.

- Small absorbance and diffusion of light in the visible

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Panel 1. Abbreviations, Acronyms, and Terms.

LGF—Light Guide Film
LED—Light-emitting Diode
DC/AC—Direct Current/Altenating Current
MDS—Metal Dome Sheet (Metal Dome with Adhesive Film)
PET—Polyethylene Terephthalate

region
- High durability for mobile phone application
- Mechanical flexibility to minimize the bad influence on tactile feeling

3.1 Light transmission spectrum

Figure 3 shows the light transmission spectrum of various base films. We made an evaluation system to measure their spectrums. The film thickness is 0.2 mm and the length is 50 mm. The transparency of light emitted from LED, incident from the edge of the film, was measured by integrating sphere and the spectrophotometer. It means that this measurement result is affected not only by the absorption and diffusion in the film but also by the diffusion at the surface and edge of the film. The transmittance of the light through each film was over 90% when measured on the backside of the film of 0.2 mm thickness by shining the light on the surface. When the transmittance of the light through the film of 50 mm in length was measured along the direction of the length, the ratio significantly decreased. Especially, the transmittance of PET film decreased noticeably because the light diffused at the edge of the film.

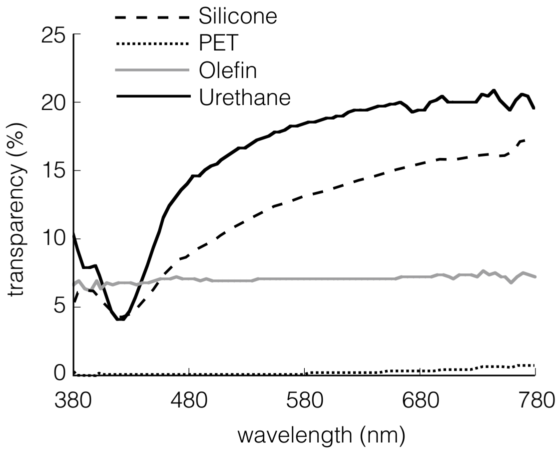


Fig. 3. Transparency of each material.

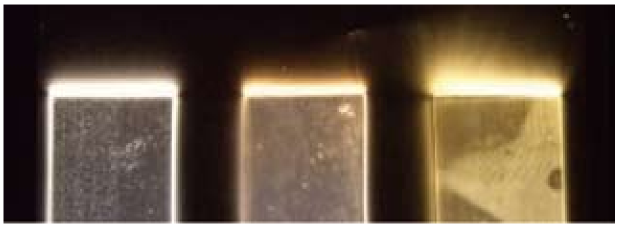


Fig. 4. Color change of each material after heat & humid test.

3.2 Heat and humidity test result

Figure 4 shows the outgoing light after a 1000 hour heat and humidity test. The test was carried out under the conditions of 85°C and 90% humidity. Some films turned yellow because damaged polymers caused increased absorbance at a wavelength of about 400 nm. In contrast, our base film demonstrated high durability to withstand heat and humidity and the outgoing light remained white.

3.3 Tactile feeling

It is possible for an LGF to make the tactile feeling of keys worse because the LGF is sandwiched between the MDS and the key mat. The tactile feeling is expressed as the click ratio, which is calculated from the following formula.

(Click ratio) $=100 \times (P1 - P2)/P1$

P1 and P2 are described in load stroke curve (Fig. 5) and we measured these values by the system of Fig. 6.

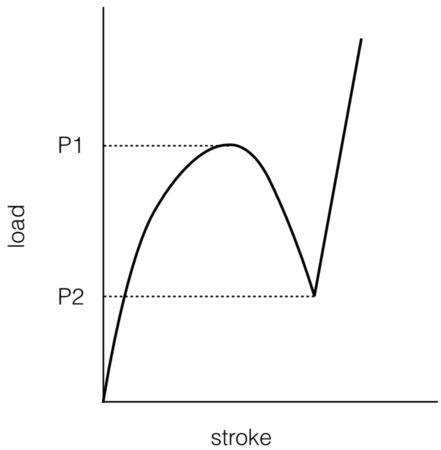


Fig. 5. Typical load stroke curve.

The result is shown in Table 1. While the click ratio of the MDS itself was 46%, it decreased merely to 26% when a hard LGF was put on the MDS. On the other hand, the click ratio was 41% when our elastomeric LGF was put on the MDS, slightly lower than the result of the MDS itself. Generally, click ratio is measured using an actuator of 1-2 mm diameter. The harder the LGF materials, the wider the area on the MDS

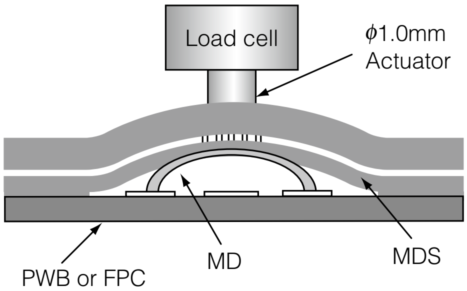
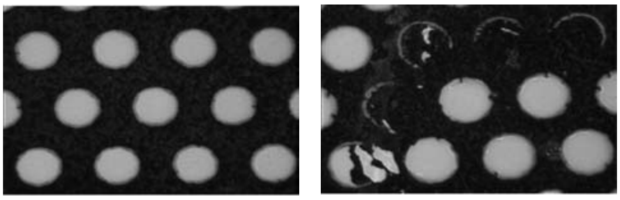


Fig. 6. Tactile feeling measurement system.

Table 1. Load stroke data for each material.

Material	MDS	Soft LGF	Hard LGF
Click ratio (%)	46	41	26



(a) Non damaged (b) Damaged

Fig. 7. Peeling ink after knocking test.

to which load is applied is, and the greater the decrease in the click ratio.

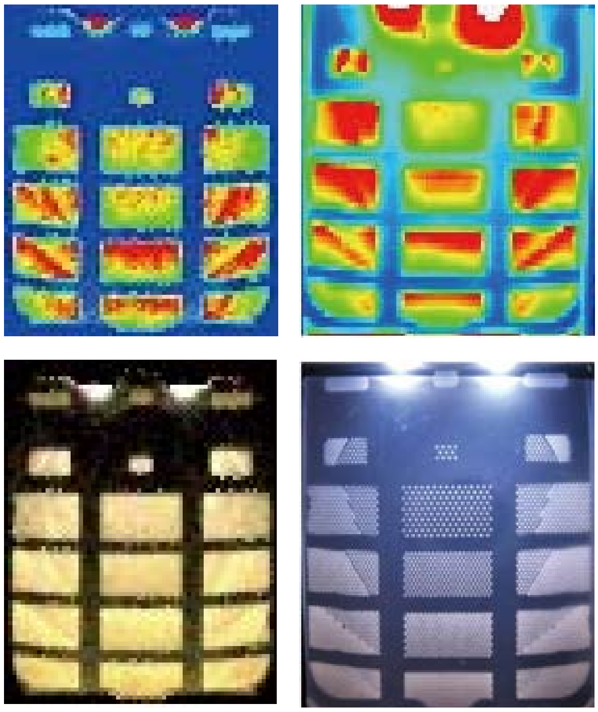
Thus, our base film has high transparency, high flexibility that prevents the tactile feeling from getting worse, and high durability against knocking.

4. Development of light diffusion ink

LGF diffusion area is required to diffuse the light with high efficiency to let out the light from the film. Special diffusion ink is printed on our LGF to achieve highly efficient diffusion. This ink consists of a binder and filler whose refractive index and transparency are optimized. As the diffusion ink printed area is knocked repeatedly, the ink should have high durability to withstand knocking. The damaged ink is shown in Fig. 7(b). If the ink is damaged or peeled off the film, its lighting characteristics worsen. The binder of our diffusion ink is made from special urethane with high durability to withstand knocking. In addition, by pretreating the film, we have succeeded in developing the highly durable light diffusion pattern enduring 1 million knocks. There is no damage as shown in Fig. 7(a) and no change in the performance of light diffusion even after frequent knocking.

5. Optical simulation

The denser the printed area , the more is the light diffused in an upward direction in the lighting area of an LGF. Accordingly, the luminance of the LGF increases with a rise in the density of the printed area.



Simulation Actual lighting

Fig. 8. Luminance of simulation and actual lighting.

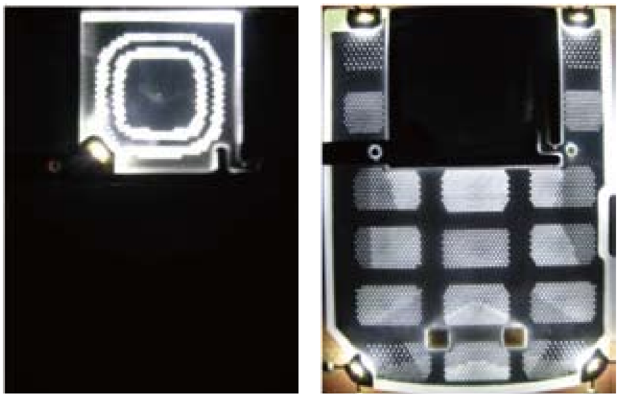


Fig. 9. Segmentation LGF.

Thus, we evaluated the correlation between the density of the printed area and the luminance. We made printing dot samples of different diameters, that is, different densities of the printed area. We measured the luminance with a two-dimension luminance measurement machine made by Konica Minolta. We confirmed that the bigger the dot diameter, the higher the luminance.

We performed an optical simulation to light all the keys uniformly on the basis of the result of the transparency of the film and the correlation between the density of the printed area and the luminance. As Fig. 8 shows, the simulation results coincide with the actual LGF lighting. For the luminance of each key, the maximum and minimum luminance remained within 20% of the mean value. The uniformity of the lumi-

Fig. 10. Multi color LGF.

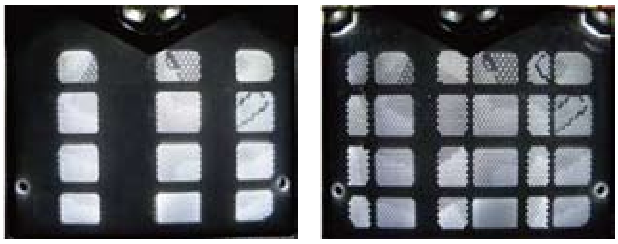


Fig. 11. Multi layer LGF.

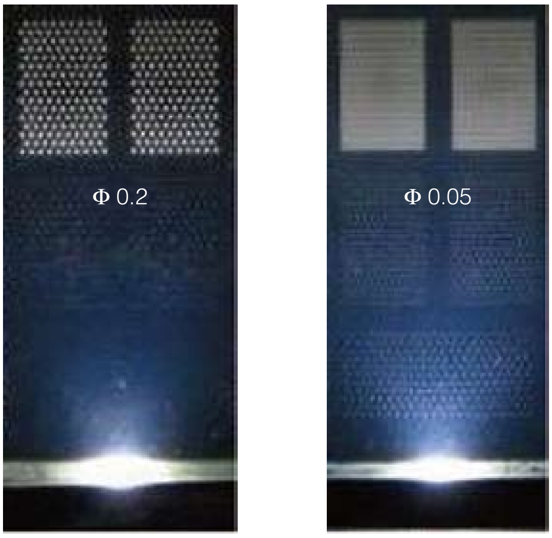


Fig. 12. Fine dot LGF.

nance satisfies the requirement of the mobile phone.

6. Applications being developed

6.1 Segmentation lighting LGF

By blocking the light propagating in the film with the gasket, light segmentation can be realized. We made an LGF sample that can light navigation key independently. This sample is made by the following procedure. First, a slit was made in the film. Second, the film was laminated with an MDS. Third, a gasket was inserted in the slit area. We measured the luminance of this sample and observed that 99% of light

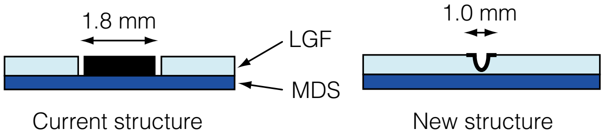


Fig. 13. Cross section of each segment width.

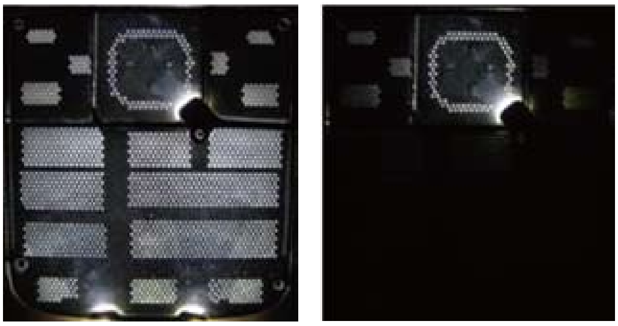


Fig. 14. Fine segment LGF.

Table 2. Specification of Fujikura LGF/MDS product.

Item	Test conditions and specifications
Knocking	After 8 N × 1,000,000 cycles Dot will not peel off
Heat and humid	After 85 °C, 85 % × 1000 hours Transparency decrease by under 20% from original one
MD click ratio	Over 35 %
Luminance uniformity	Min / max = over 60 %
Film hardness	90~96 (JIS A)
Film thickness	0.125, 0.15, 0.2 mm
Dot diameter	Min 0.2 mm (0.05 mm under development)
Segment width	Min 1.8 mm (1.0 mm under development)
Dot color	White, red, blue, yellow, green
LED/LGF distance	0.35 ± 0.2 mm

was blocked. We verified that segmented lighting was achieved. The sample is shown in Fig. 9.

6.2 Multicolor lighting LGF

Regarding normal LGFs, they are lit by diffusing white color lights with light diffusion ink. We can make multi color light with the ink that absorbs the light with specific wavelength as shown in Fig.10.

6.3 Multi layer LGF

By stacking several LGFs, different areas can be lit selectively. Figure 11 shows that numbers and characters on the keys emit the light selectively.

6.4 Fine dot LGF

Regarding the current LGF, the minimum dot diameter is 0.2 mm and this dot size is visible. With a key mat with high transmittance, dots can be seen even through the key mat. That is why we are developing an LGF with invisible dots with a diameter of 0.05 mm or less. The dots are made by gravure offset printing instead of screen-printing. Figure 12 shows the LGF with fine dots.

6.5 Fine segment LGF

We explained the LGF segment method in Section 6.1. One of the disadvantages of this method is the wide area of the borders. To overcome the disadvantage, we are developing new segmentation method shown in Fig. 13. In this method, first, grooves are made, and, second, black ink is printed on these grooves. We can decrease the light block width by about 50% by this method. Figure 14 shows the actual lighting. Light blocking ratio is over 80 % by this new method and it is enough for actual mobile phones.

7. Conclusion

We developed two key materials for LGFs. One is a base film that is superior in transparency, durability, and flexibility. Second is light diffusion ink that is superior in light diffusion performance and durability. Moreover, we established the optical design of the LGF, optical simulation, and luminance measurement method. We have commercialized the LGF for mobile phone key lighting. Table 2 shows the specifications and characteristics of LGFs. We are developing a variety of lighting technologies such as light segmentation, multicolor lighting, and fine dot printing. LGF technology can be applied not only to mobile phones but also to other kinds of digital equipment.