24-2: 470 x 235ppi poly-Si TFT LCD for High-Resolution 2D and 3D Autostereoscopic Display

Shin-ichi UEHARA, Naoyasu IKEDA[1], Nobuaki TAKANASHI, Masao IRIGUCHI[2], Mitsuhiro SUGIMOTO[1], Tadahiro MATSUZAKI and Hideki ASADA

SOG Research Laboratories, NEC Corporation

1120, Shimokuzawa, Sagamihara, Kanagawa 229-1198, Japan

Phone: +81-42-771-0689 e-mail: s-uehara@ak.jp.nec.com

Abstract

We have developed a 470 x 235ppi poly-Si TFT LCD with a novel pixel arrangement, called HDDP (Horizontally Double-Density Pixels), for high-resolution 2D and 3D autostereoscopic display. 3D image quality is especially high in a lenticular-lens-equipped 3D mode because both horizontal resolution and vertical resolution are high, and because these resolutions are equal. 3D and 2D images can be displayed simultaneously in the same picture. In addition, 3D images can be displayed anywhere and 2D characters can be made to appear at different depths with perfect legibility. No switching of 2D/3D modes is necessary, and the design's thin and uncomplicated structure makes it especially suitable for mobile terminals.

1. Introduction

A variety of 3D displays not requiring special glasses have been recently developed for entertainment, medical, design, and other applications. Although they seem to hold promise for use as next-generation displays, a number of design problems remain. 3D image quality suffers, for example, from low resolution (e.g., 52ppi [1], 83ppi [2] and 166ppi [3]), lower than the resolution of the ordinary 2D displays currently used on commercial mobile phones (see Fig. 1).

We have responded to this problem by developing 470 x 235ppi poly-Si TFT LCD with a novel pixel arrangement called HDDP for high-resolution 2D and 3D autostereoscopic display. 3D image quality is especially high in a lenticular-lens-equipped 3D mode because both horizontal resolution and vertical resolution are high, and because these resolutions are equal. 3D and 2D images can be displayed simultaneously in the same picture. In addition, 3D images can be displayed anywhere and 2D characters can be made to appear at different depths with perfect legibility. No switching of 2D/3D modes is necessary, and the design's thin and uncomplicated structure makes it especially suitable for mobile terminals.

[1]Present Affiliation: NEC LCD Technologies, Ltd.
[2]Present Affiliation: System Devices Research Laboratories

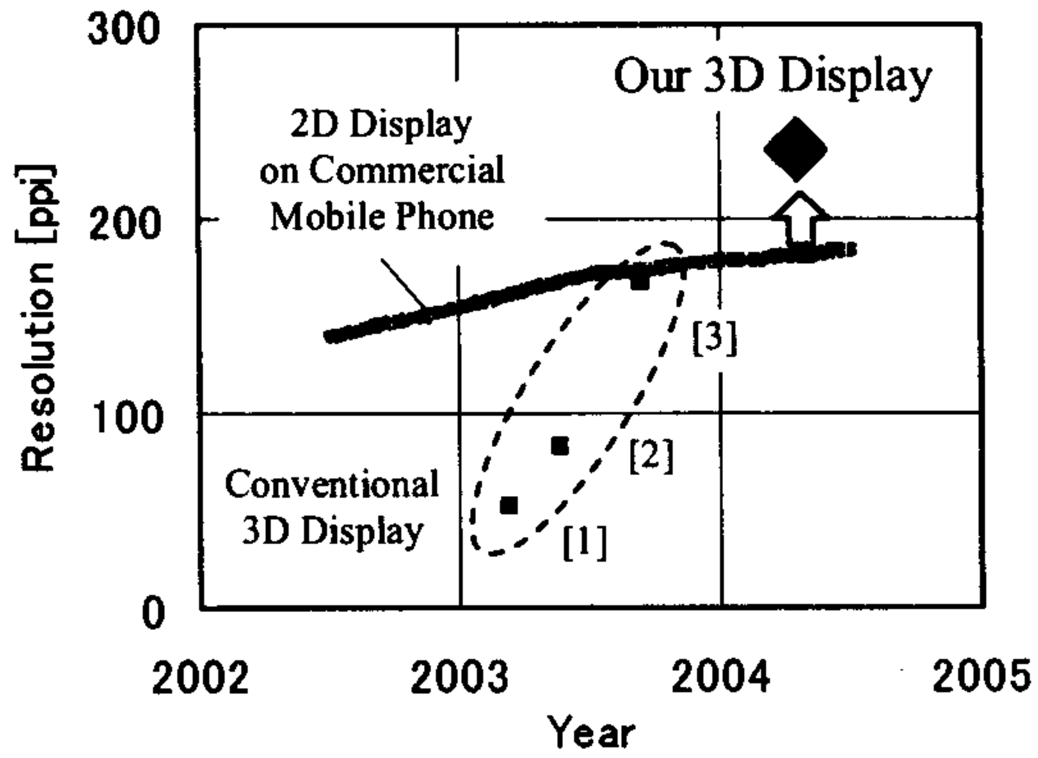


Figure 1. Trends in Display Resolution

2. HDDP Arrangement

2.1 Principle

In a conventional LCD, each pixel (containing three dots: red, green, and blue) is a square. For use in a 3D display, one pixel must be assigned to the left eye and another to the right eye. Each set of left-eye-right-eye pixels, then, will form a rectangle in which the length of the horizontal is twice that of the vertical. This means that horizontal resolution will only be half that of the vertical, which severely limits 3D picture quality. Further, when 2D characters are displayed, this arrangement may result in constituent elements of certain characters being missing, thus causing those characters to be illegible.

In response to this situation, we have developed an LCD with the HDDP arrangement which incorporates rectangular pixels whose width is half that of their height. In the HDDP arrangement, the horizontal pixel density is twice that of the vertical. As a result, each left-eye-right-eye set of pixels forms a square, and in a lenticular-lens-equipped 3D mode, horizontal resolution will equal that of the vertical (see Fig. 2).

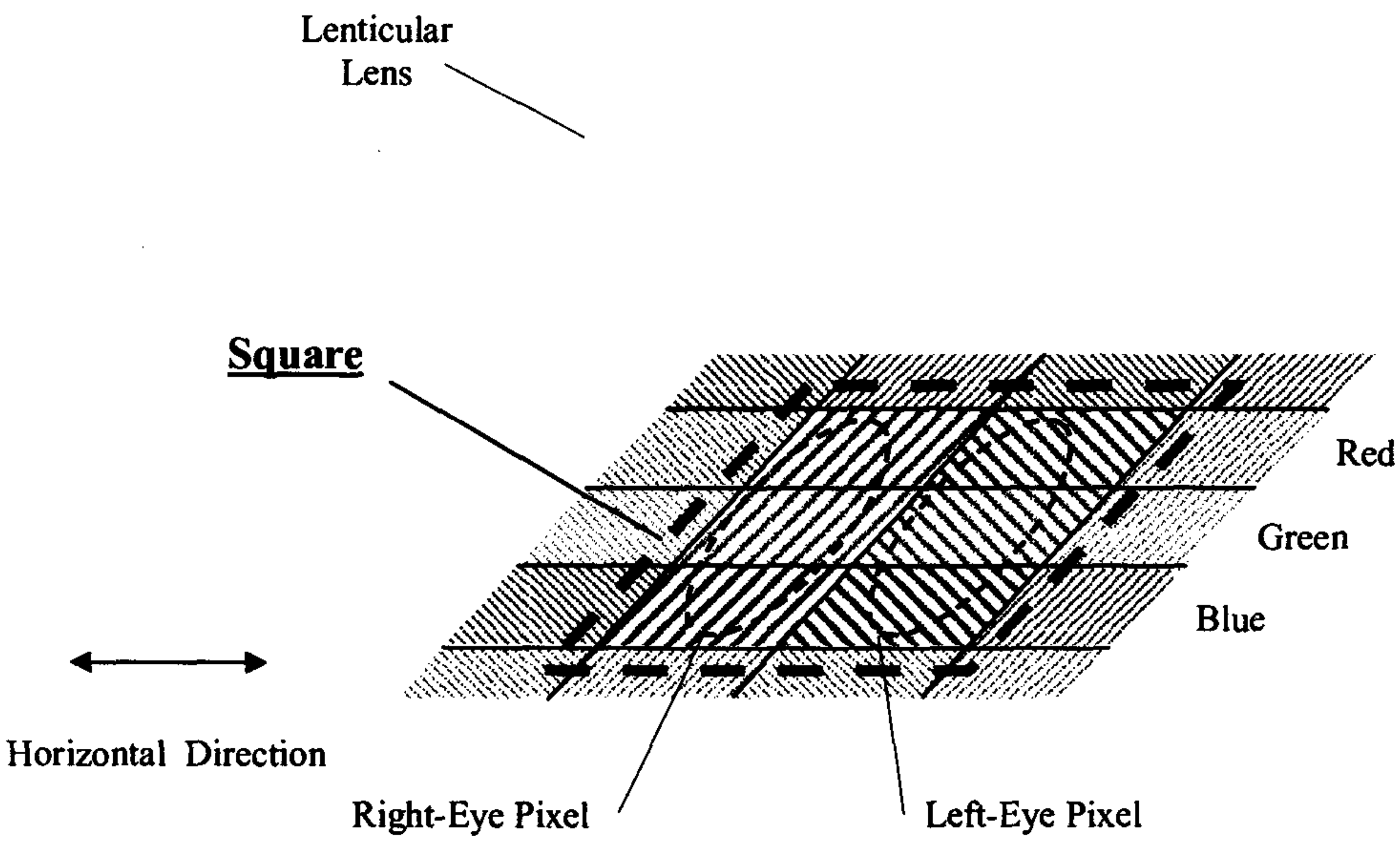
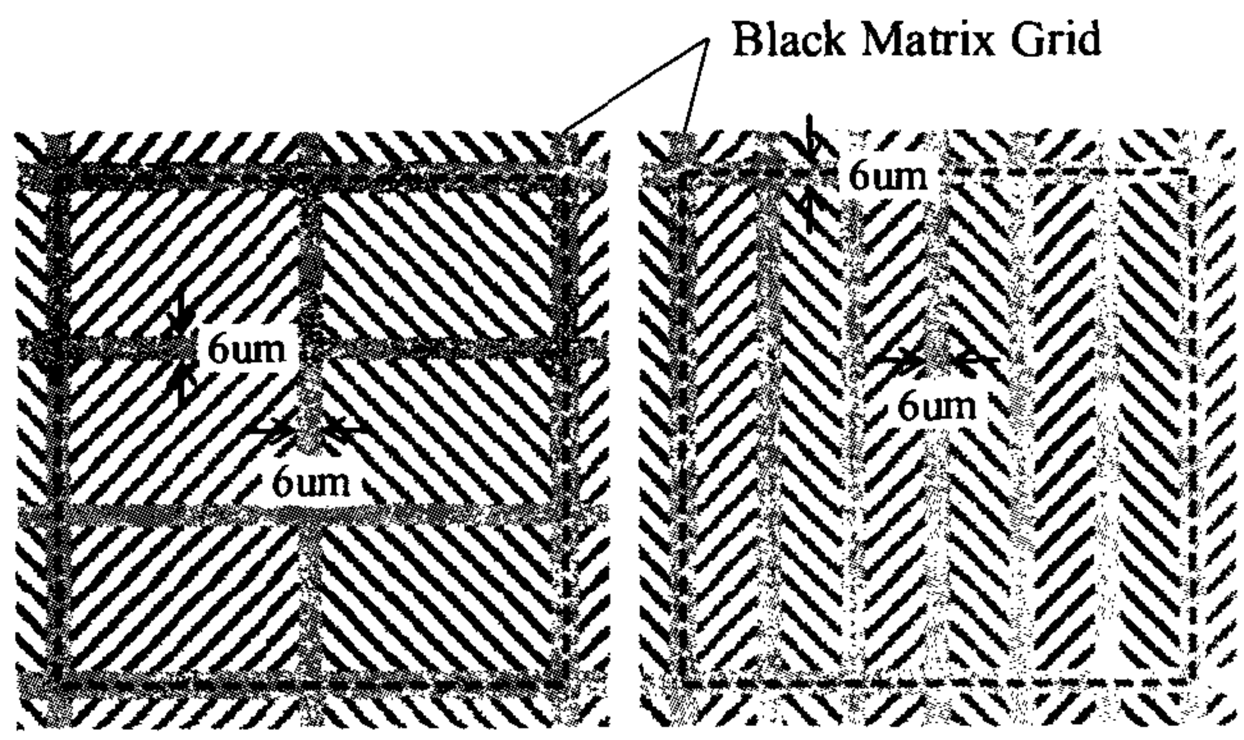


Figure 2. HDDP Arrangement
Right-eye pixel and left-eye pixel combine to form a *square*.

This not only results in high 3D image quality, it also means that 2D characters can be displayed with perfect legibility without the need for any sort of 2D/3D conversion-structure. That is, left and right pixels can simply be made to display the same content, in which case a full, perfectly proportioned character will be perceived. Further, horizontal (i.e., left-right) pixel shifting can be conducted in order to make 2D characters appear at varying depths in the overall image. With this design, then, both 3D and 2D images can be displayed simultaneously in the same picture with no need for 2D/3D mode-conversion, and the display structure itself is both thin and uncomplicated.

2.2 RGB Stripe Arrangement

An important factor in the success of this design is the color arrangement in the color filter. In a conventional LCD, the filter has a vertical RGB stripe pattern, and the RGB dots in pixels are arranged horizontally. In order to apply such a design to our LCD, we would have to make the horizontal pitch of each dot one sixth of the vertical pitch, which would result in an undesirable imbalance in dot density. That is why we have chosen to use a horizontal RGB stripe pattern (see Fig. 2). Since the horizontal pitch of a dot is 3/2 of the vertical pitch, the resulting dot density is much better balanced, and this better balance also makes it easier to improve resolution.



(a) Horizontal (b) Vertical

Figure 3. Color Arrangement Used for Calculations

In order to confirm the superiority of a horizontal RGB stripe pattern, we calculated the relationship between aperture ratio and resolution for both horizontal and vertical patterns. Figure 3 shows the pixel arrangements for these patterns. For each, we used a black matrix grid whose width was fixed at 6um. The pitch of individual right-eye/left-eye pixel sets, each consisting of 6 RGB dots, was varied from 254um (100ppi) to 64um (400ppi). As may be seen in Figure 4, which shows the results of our calculations, a horizontal RGB stripe pattern offers higher resolution for all aperture ratios.

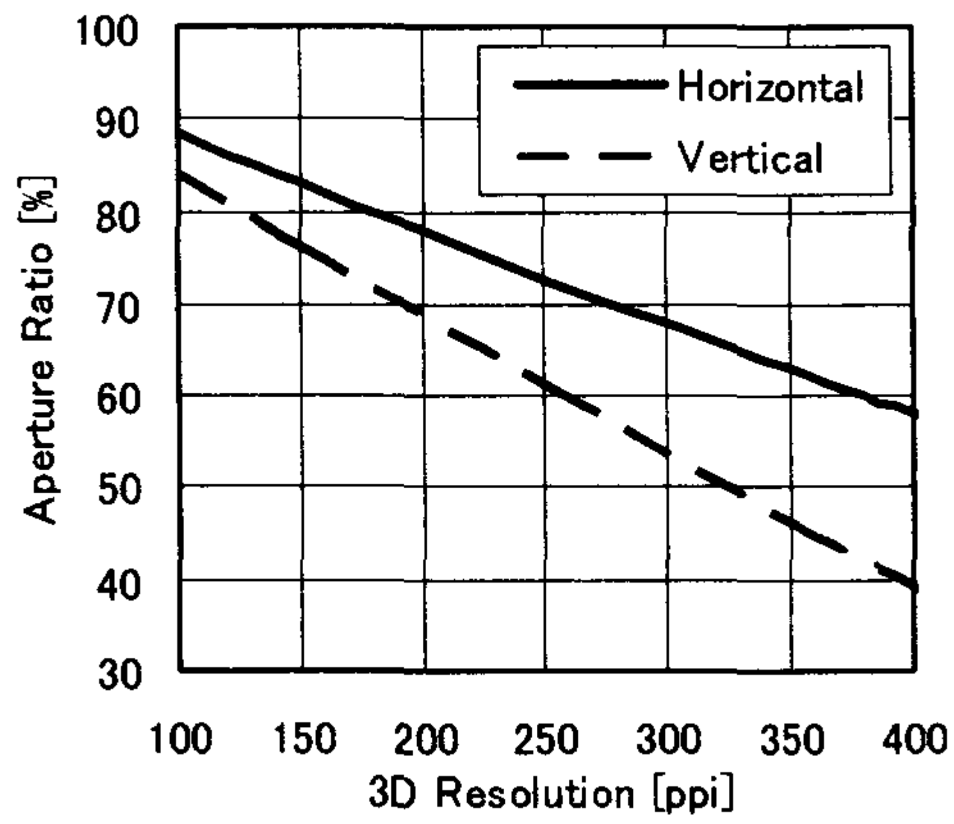


Figure 4. Aperture Ratio vs. Resolution for Two RGB Stripe Pattern Directions

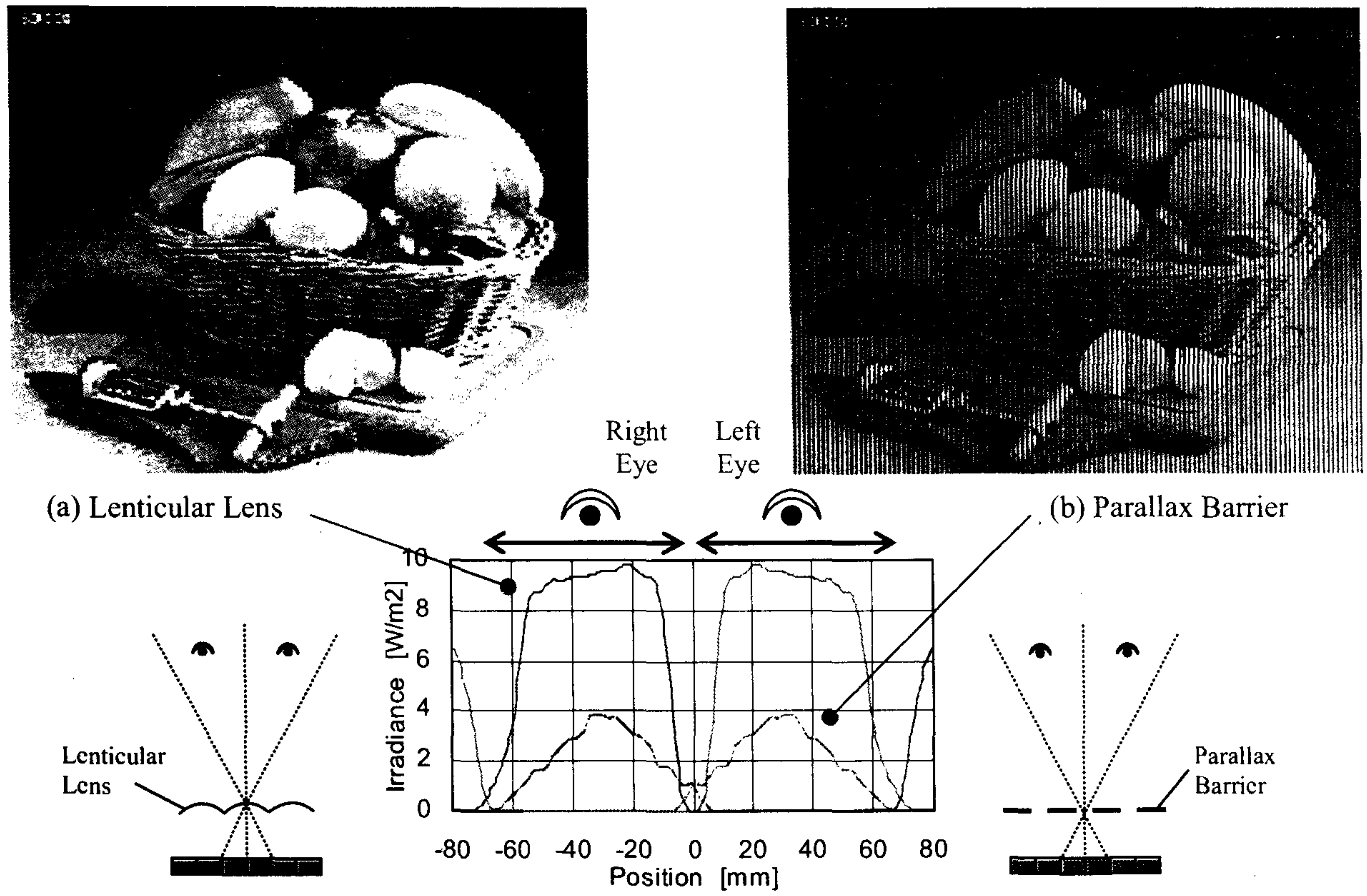


Figure 5. Irradiance vs. Horizontal Eye-Position

3. Optical Element

In selecting the optical element needed for our LCD, we chose to use a lenticular lens rather than a parallax barrier. We did this in order to avoid the loss of display brightness that results from the use of a parallax barrier, which hides left-eye pixels from the right eye and vice versa. Another reason for not choosing to use a parallax barrier is that, although such barriers are easily producible with photo lithography, they result in an undesirable "pinstripe" look.

A lenticular lens, by way of contrast, refracts the light of pixels in such a way that right and left images are separated into different spaces. There is no loss of brightness and no pinstripe effect. In order to confirm the superiority of the lenticular lens approach for our design, we used a ray tracing method to simulate, for each of the approaches, the dependence of irradiance levels on horizontal eye-position (see Fig. 5). As may be seen in sample images (also illustrated in Fig. 5), which are based on the simulations, the lenticular-lens-based 3D display is brighter than that with a parallax barrier. Furthermore, since there is no loss of brightness also in a reflective mode, the lenticular-lens-based 3D display is suitable for reflective-type and transflective-type LCDs that employ ambient light. This is important for mobile use.

4. Display Specifications and Images

Table 1 shows the LCD specifications. As is usual with LCDs, three dots (R, G, B) form each individual pixel. Each single dot is a rectangle 54um wide and 36um long (i.e., each pixel is a rectangle 54um wide and 108um long). Horizontal and vertical resolutions are, respectively, 470ppi and 235ppi. As viewed in 3D display form with a lenticular lens, these resolutions are equal, 235ppi each. We used p-Si TFTs to form a data driver and a gate driver, which were then integrated on a glass substrate. Total thickness of the 3D display, including the lenticular lens and polarizers, is only 2.0mm.

Figure 6 shows photos of sample images for the 2D/3D display. The upper image is a photograph of a full screen, and the lower image is an enlarged photo of a portion displaying small characters. Stereo pair images are separately viewed by the left and right eyes and are effectively perceived as a 3D image of high quality. 2D characters are perceived accurately and can be made to appear at different depths. Although the smallest character is only of 8 point size, its legibility is high, as may be inferred from the photo of the image shown in the figure.

5. Conclusion

We have developed a high-resolution 2D/3D autostereoscopic display in the form of a 470 x 235ppi poly-Si TFT LCD with a novel pixel arrangement called HDDP. 3D image quality is especially high in a lenticular-lens-equipped 3D mode because both horizontal resolution and vertical resolution are high, and because these resolutions are equal. 3D and 2D images can be displayed simultaneously in the same picture. In addition, 3D images can be displayed anywhere and 2D characters can be made to appear at different depths with perfect legibility. No switching of 2D/3D modes is necessary, and a thin and uncomplicated structure makes the design especially suitable for mobile terminals.

6. Acknowledgements

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7. References

[1] G.J. Woodgate et. al., "High Efficiency Reconfigurable 2D/3D Autostereoscopic Display," SID03 Digest (2003).

[2] http://www.nttdocomo.com/presscenter/pressreleases/press/file/200304081329210039 8.pdf

[3] http://www.casio.co.jp/release/2003/fs_3d.html

Table 1. LCD Specifications

Display Size	2.5 inch diagonal
Display Area	34.56mm(H) x 51.84mm(V)
Dot Number	320 x 2(RL) x 480 x 3(RGB)
Dot Pitch	54um(H) x 36um(V)
Pixel Number	640 x 480 : VGA
Pixel Pitch	54um(H) x 108um(V)
Pixel Density	470ppi(H) x 235ppi(V)
Color Arrangement	Horizontal RGB Stripe Pattern
Panel Thickness	2.0mm (including lenticular lens and polarizers)

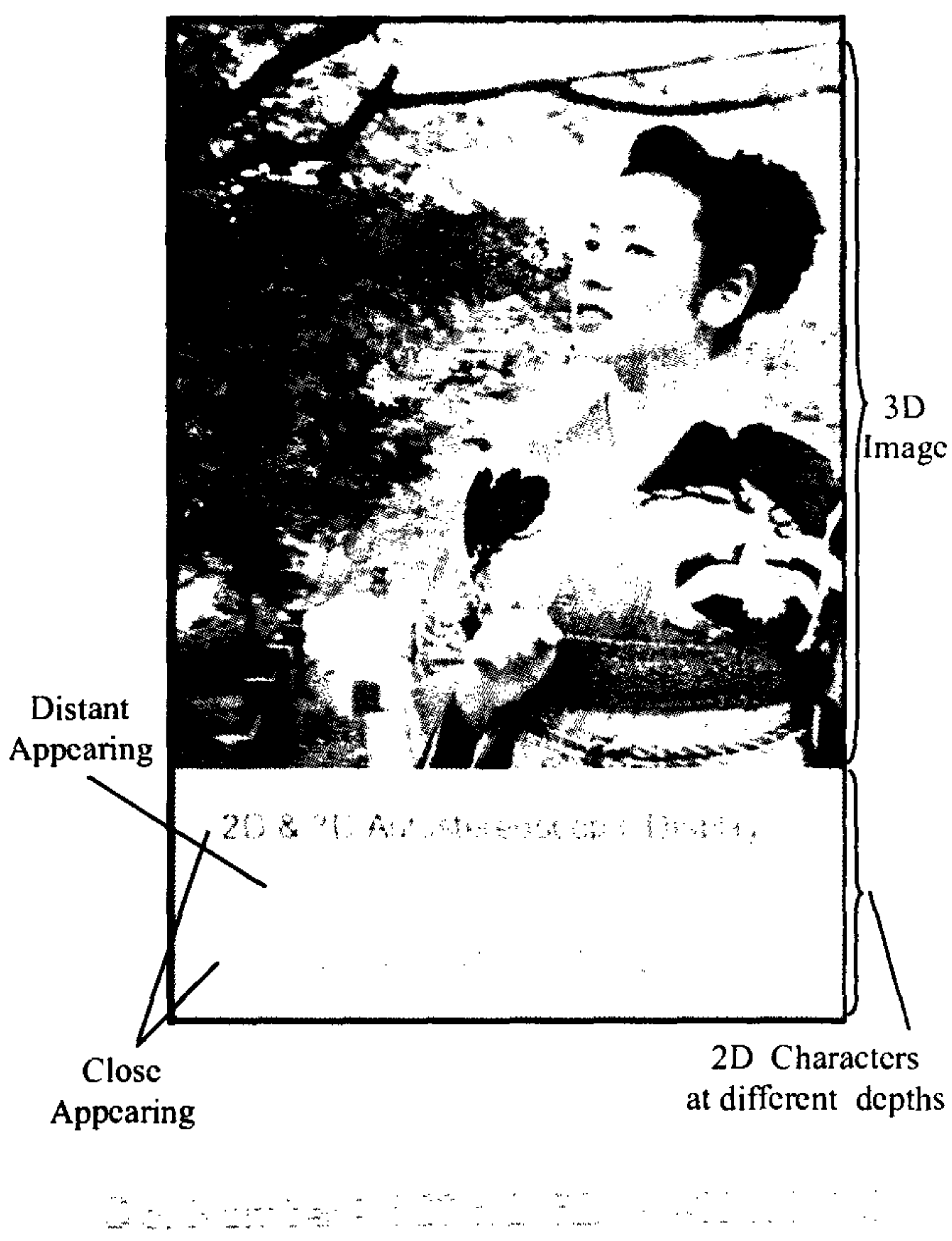

Figure 6. Photos of Sample Images