INVITED PAPER *Special Section on Electronic Displays*

Development of Electronic Tile for Decorating Walls and 3D Surfaces

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SUMMARY We have proposed and developed e-Tile for wall decoration and ornaments for interior/exterior. A prototype of 2 m × 2 m large energy-saving reflective panel was realized by arraying 400 e-Tiles on a flat plane. Prototypes of cubic displays were also realized by constructing e-Tiles to cubic shape. Artistic display effects and 3D impression could be found in these cubic prototypes. We hope e-Tile is a promising solution to extend the application field of e-Paper to decorative use including architectural applications.
key words: *e-Paper, electrophoretic, reflective, wall, 3D*

1. Introduction

A lot of studies have been continued using various displaying principles for development of the electronic paper [1]–[18]. Application field of Electronic Paper is now expected to expand from document displays [19]–[21] to wall decoration and ornaments for interior/exterior. We have been proposing and developing e-Tile (Electronic Tile) for this kind of extended applications [22], [23].

Figure 1 shows mapping of applications for reflective displays including e-Paper. Promising new market is expected for reflective displays especially in "large" and "public" region on this map. Because, reflective displays have advantages of energy saving and visibility under sunlight [24]–[26]. We also hope not too vivid expressions by reflective displays are ideal for keeping cityscape favorable.

In this paper, we focused on the advantage of the prototypes of e-Tile, especially in terms of energy conservation.

2. Concept of e-Tile

Figure 2 shows concept of reflective e-Tile and Fig. 3 shows its prototype. Simple display units of e-Tile, which typically consists of 100 pixels in a 100 mm × 100 mm square board, enable easy construction of large wall display [27]–[30]. Any size of large display area can be realized simply by arraying the necessary number of e-Tiles.

Manuscript received March 8, 2022.
Manuscript revised June 5, 2022.
Manuscript publicized September 30, 2022.
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DOI: 10.1587/transele.2022DII0002

3. Prototyping of e-Tile

3.1 Basic Units

We have built a practical prototype of e-Tile using electrophoretic display method. Figure 3 shows a 10 cm square e-Tile in which 100 units of 1 cm pixels are arranged. Ta-

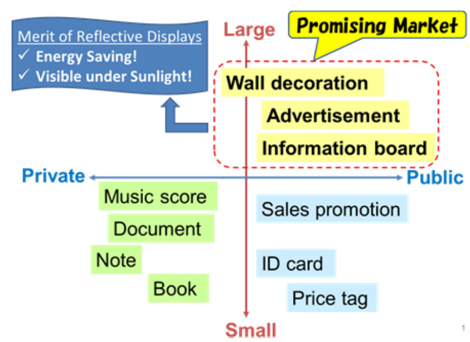


Fig. 1 Applications of reflective displays including e-Paper.

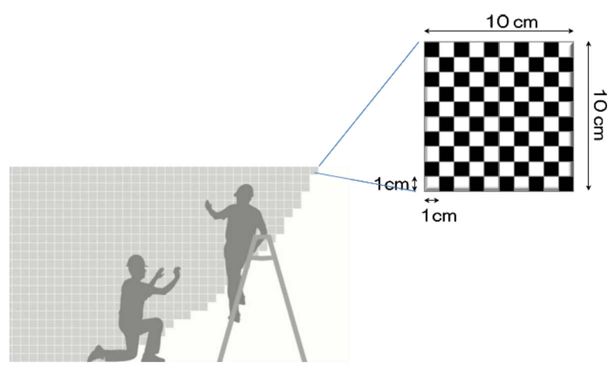
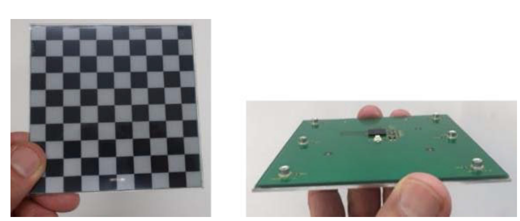


Fig. 2 Concept of e-Tile.



(a) Display side (b) Back side

Fig. 3 Prototype of e-Tile.

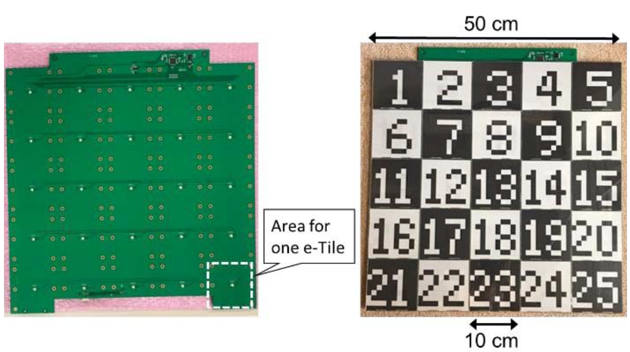
ble 1 shows the specifications of the prototype e-Tile. The tile weight is only 42 g and the thickness is 5.5 mm. Tile surface is covered with acrylic resin to ensure mechanical surface strength and moisture resistance. Each pixel on the tile is directly connected to a driver circuit on the tile and is individually driven.

In this practical prototyping, we prepared a base panel (50 cm square: Fig. 4) for mounting 25 tiles. It is assumed that a factory will ship base panels with 25 tiles already mounted on it. The practicality is assured by the simple installation method of mounting this 50 cm square base panel on the wall at the site. Table 1 shows the main specifications of the prototypes of e-Tile and base panel.

Figure 5 shows typical examples of displayed image of 1 m square using e-Tiles. Figure 6 shows a prototype display system construction using e-Tile for 1 m^2 display area. A square area of 1 m × 1 m (100 × 100 = 10,000 pixels) is covered by using four base panels and one control unit.

Table 1 Specification of prototype e-Tile.

Item		Specs
Display method		Electrophoretic display
Dimensions		100 mm x 100 mm x 2 mm (42 g)
Pixel size		10 mm x 10 mm
Number of pixels		100 pixels / tile
Reflectance		36.6% (white), 3.5% (black) for D65
Contrast ratio		10.5 (white / black)
Image expression		Binary black and white
Driving method		Segmented driving
Base panel	size	500 mm x 500 mm (900 g)
	capacity	25 tiles



(a)Without e-Tiles (b) Mounted with 25 piece of e-Tiles

Fig. 4 Base panel for arraying 25 e-Tiles.

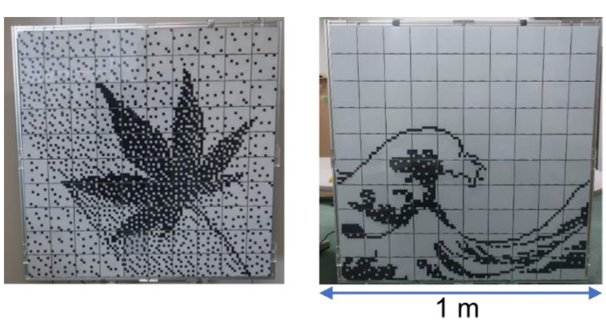


Fig. 5 Prototype of 1 m square panel [constructed with 100 e-Tiles].

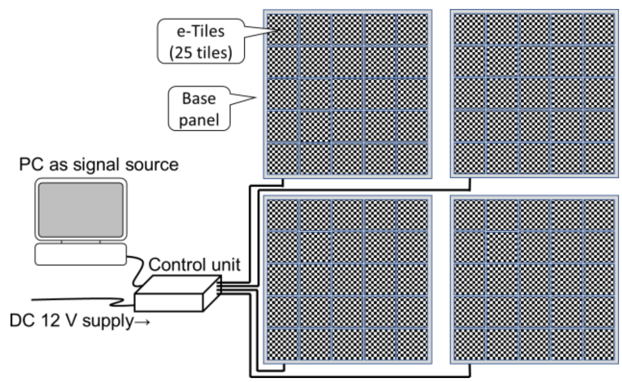


Fig. 6 Basic construction of the prototype display system using e-Tile.

3.2 Large Panel for Wall Decoration

A prototype of large panel model for wall decoration was realized by arraying e-Tile on a flat plane. Figure 7 shows a prototype of 2 m × 2 m square panel (4 m^2) constructed with 400 piece of e-Tiles. Table 2 shows specifications of the 2 m × 2 m square panel. Figure 8 shows a scene of demon-

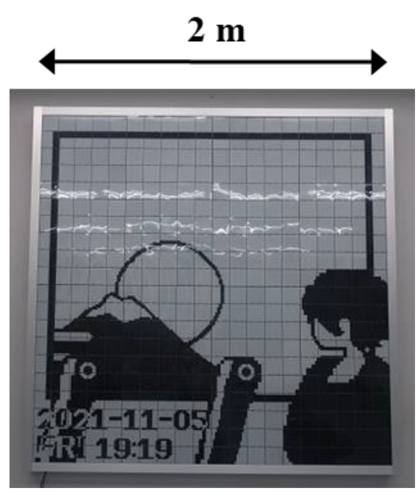


Fig. 7 Prototype of 2 m × 2 m square panel formed with 400 e-Tiles.

Table 2 Specification of a large display panel constructed with array of e-Tiles.

Item	Spec
Panel Size	2 m × 2 m
Number of tiles	400 tiles
Number of pixels	40,000 pixels
Power consumption	4.4 watt
Electricity cost (24 hours/day operation)	9 \$/year (1,000 ¥/year)

Fig. 8 Demonstration experiment of e-Tiles at a bus waiting room in a university.

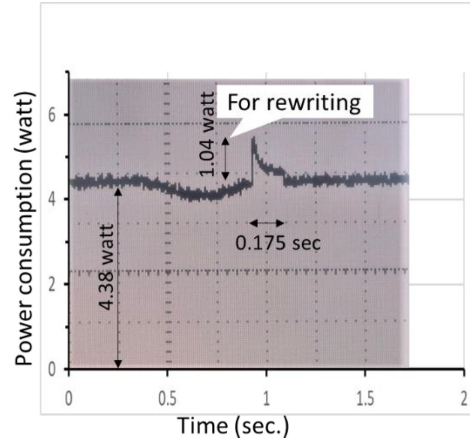
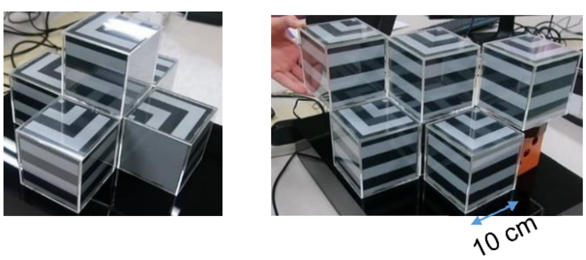


Fig. 11 Power consumption indicated by a driving wave form for 4 m^2 display area using e-Tile.

(a) Floating black cube (b)Floating trigonal pyramid

Fig. 9 30 cm cubic display formed with 25 e-Tiles.



(a) Masonry blocks (b) Bumpy wall

Fig. 10 10 cm cubic displays formed with 5 e-Tiles for each cube.

stration experiment of e-Tile at a bus waiting room in a university. Variations of the wall design were enjoyably appreciated by students.

3.3 Cubic Displays

Prototypes of cubic displays were also realized by constructing e-Tiles to cubic shape. Figure 9 shows a prototype of 30 cm cubic display constructed with 25 piece of e-Tile. Figure 10 shows prototypes of 10 cm cubic displays constructed with 5 piece of e-Tiles for each cube. Artistic display effects and 3D impression could be found in these prototypes.

4. Measurement of Power Consumption

Figure 11 shows a measured waveform of power consumption by e-Tiles when the entire area of the 2 m × 2 m square display region (4 m^2) was refreshed between all black and all white. The measured value includes power consumptions of 4 control units (see Fig. 6) for operating totally 400 e-Tiles on the16 base panels. The triangular wave part with a time width of 0.175 sec and a wave height of 1.04 watt is serving for rewriting, and the residual flat wave part of 4.38 watt is the standby power of circuits of the 4 control units ready for driving e-Tiles. The average power consumption including this standby power is calculated as 4.40 watt (when rewriting every second), which is, in fact, almost the same as the standby power.

In the case, for example, when rewriting once a minute, the average power consumption is 0.7 watt if assuming that all-OFF is performed except for totally 10 seconds before and after the rewriting operation. In the same way, if rewriting is performed once every 10 minutes (all-OFF except for totally 10 seconds before and after rewriting), the average power consumption is calculated to be 0.07 watt.

Figure 12 shows the relationship between the rewriting cycle and the power consumption when the all-OFF state is inserted between the rewriting sequences of 10 second. This kind of power saving operation is enabled by the non-volatile displaying characteristics of the electrophoretic display method. This way of operation can minimize power consumption of e-Tile display system. Rather long rewriting interval of 10 minutes or more is reasonable enough when assuming practical applications such as variable wallpaper.

Table 3 shows comparison of power consumption of e-Tile and other major display methods fit for digital signage. This table also shows calculated results of CO_2 emission. LED displays and liquid crystal displays, which constantly need power even for only keeping images, are shown to consume over 500 watt of electricity for operating 1 m^2 display

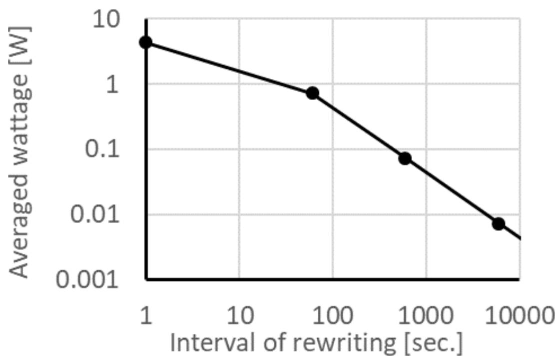


Fig. 12 Averaged wattage of 4 m^2 display area using e-Tile when all-OFF state is inserted between rewriting timing longer than 60 sec.

Table 3 Power consumption and CO_2 emission per 1 m^2 display area.

	Wattage	Annual power consumption*1	Annual Expense*2		CO_2 Emission*3
	W/m^2	kWh/m^2	¥/year	$/year	kg/year
e-Tile*4	1.1	10	250	2.3	5
LCD*5	500	4,400	110,000	1,000	2,200
LED*6	600	5,300	140,000	1,200	2,600

*1. Supposed operation: 24 hours×365 days
*2. Supposing 26 Yen/kWh (110 Yen/dollar)
*3. Supposing 0.5 kg/kWh
*4. When not introducing the all-OFF state.
*5. Calculated from a typical LCD: SONY GXD-L52H1 [52 inch, 380 W]
*6. Calculated from a typical LED: NEC LED-SD100AB [96 cm Square, 540 W]

area. It is remarkable that the power consumption of e-Tiles is calculated to be around 1/500 even when not introducing all-OFF state between rewriting sequence.

The energy saving ability of e-Tile is remarkable, and its CO_2 emission is naturally extremely low. This power saving characteristics of e-Tile also suggest the ability of continuing to present evacuation information by using solar cells or small batteries even in the event of a power outage by disasters.

5. Conclusions

1) Prototype of 2 m × 2 m square panel formed with 400 e-Tiles were demonstrated.
2) Remarkably low power consumption of e-Tile was measured on the 2 m × 2 m square panel.
3) Prototypes of 30 cm and 10 cm cubic displays were demonstrated as an expanding application of e-Tile.

Our results suggest that e-Tile can be expected to have unique position, in large panel applications, as a power saving and modest expression reflective medium different from the emissive displays such as LED and LCD. We hope e-Tile is a promising solution to extend the application field of e-Paper to decorative use including architectural applications.

Acknowledgments

The authors would like to express their special thanks to the Electronic Paper Consortium of JBMIA (Japan Business Machine and Information System Industries Association) and its members especially Hirohito Shibata, Keisuke Hashimoto, Ryosuke Kuwada, Satoshi Nebashi, Tatsumi Takahashi, Yasuhiro Kinoshita, Yasuji Fukase, Yasushi Kaneko for their earnest assistance in developing the concept and design of e-Tile. The authors would also like to express their special thanks to Shigeru Miyahata, Tomo Kishigami, Ichiro Koshito, Ryuji Komeda, of the Minister of Economy, Trade and Industry for their support and encouragement. The authors also thank to the diligent students Ryota Nojima, Yusuke Sekiguchi, Yu Lirong, and Si Cheng for their contribution to the contents design for the e-Tile.

References

[1] M. Omodani, "What is electronic paper? The expectations," SID 2004 Digest, pp.128–131,2004.
[2] M. Omodani, "Expecting readability," Information Display, vol.12, no.4, pp.28–31, 2004.
[3] I. Ota, U.S. Patent, No.3668106.
[4] I. Ota, "History of electrophoretic displays and proposal of a novel cell structure for lateral particle movement display devices," Proc. IDW 2009, EP 1-1, 2009.
[5] R. White, "An electrophoretic bar graph display," Proc. SID, vol.22, pp.173–180, 1981.
[6] M. Saito, T. Mori, R. Ishikawa, and T. Tamura, "An electrical twisting ball display," SID 82 Digest, pp.96–97, 1982.
[7] S. Shiwa and Y. Hoshino, "Electrophoretic display method using ionographic technology," SID 88 Digest, pp.61–62, 1988.
[8] B. Comiskey, J.D. Albert, and J. Jacobson, "Electrophoretic ink: A printable display material," SID 97 Digest, pp.75–76, 1997.
[9] E. Nakamura, H. Kawai, N. Kanae, and H. Yamamoto, "Development of electrophoretic display using microcapsulated suspension," SID 98 Digest, pp.1014–1017, 1998.
[10] N.K. Sheridon, E.A. Richley, J.C. Mikkelsen, D. Tsuda, J.M. Crowley, K.A. Oraha, M.E. Howard, M.A. Rodkin, R. Swidler, and R. Sprague, "The Gyricon rotating ball display" Journal of the SID, vol.7, no.2, pp.141–144, 1999.
[11] K. Shinozaki, "Electrodeposition device for paper-like displays," SID 02 Digest, pp.39–41, 2002.
[12] R.A. Hayes and B.J. Feenstra, "Video-speed electronic paper based on electrowetting," Nature, vol.425, pp.383–385, 2003.
[13] R.A. Hayes, B.J. Feenstra, I.G.J. Camps, L.M. Hage, T. Roques-Carmes, L.J.M. Schlangen, A.R. Franklin, and A.F. Valdes, "A high brightness colour 160 PPI reflective display technology based on electrowetting," SID 04 Digest, pp.1412–1415, 2004.
[14] T. Yashiro, "Flexible electrochromic display," IDW '13, pp.1300–1303, 2013.
[15] H. Akita, Y. Awatsu, and Y. Takizawa, "Development of twisting balls for e-paper by a microchannel device," IDW '14, pp.1188–1191, 2014.
[16] B. Gally, A. Lewis, K. Aflatooni, W. Cummings, S. Ganti, M. Todorovich, and R. van Lier, "A 5.7" color Mirasol® XGA display for high performance applications," SID '11 Digest, pp.36–39, 2011.
[17] T. Kinjo, N. Saito, and M. Omodani, "Vivid image projection system using e-paper active screen," Journal of the SID, vol.20, no.10, pp.559–565, 2012.
[18] K. Hashimoto, "Optimum approach for product development which is using electrophoretic paper-like display system," Proc. IDW '13,

pp.1322–1323, 2013.

[19] K. Fujisaki and M. Omodani, “Evaluations of efficiency and comfort in paper and electronic mediums in handwriting tasks,” Journal of the Imaging Society of Japan, vol.60, no.3, pp.232–236, 2021.

[20] S. Inoue and M. Omodani, “Analysis of fatigue difference between paper and displays—Measurements of near point distance,” Journal of Imaging Science and Technology, vol.56, no.6, pp.60504-1–60504-6, 2012.

[21] H. Shibata, Y. Fukase, K. Hashimoto, Y. Kinoshita, H. Kobayashi, S. Nebashi, M. Omodani, and T. Takahashi, “A proposal of future electronic paper in the office—Electronic paper as a special-purpose device cooperating with other devices—,” ITE Trans. Media Technology and Applications, vol.4, no.4, pp.308–315, 2016.

[22] M. Omodani, S. Ishi, and Y. Adachi, “Concept of e-tile and its prototyping,” SID 2018 Digest, pp.1601–1603, 2018.

[23] M. Omodani, Y. Adachi, and H. Shibata, “Prototyping of e-tile,” Proc. IDW ’18, pp.1248–1251, 2018.

[24] D.J. Oostra, “Reflective electro-wetting displays for out of home display applications” Proc. IDW ’19, pp.1400–1403, 2019.

[25] M.D. McCreary and J. Xi, “Improving patient experience with electrophoretic display technology,” Proc. IDW ’20, pp.747–750, 2020.

[26] A. Henzen, “Reflective displays and green technology,” Proc. IDW ’21, pp.750–752, 2021.

[27] M. Omodani, T. Masuyama, and H. Shibata, “Prototyping of practical e-tile and estimation of its image impression from distant observers,” SID 2020 Digest, pp.726–729, 2020.

[28] T. Masuyama and M. Omodani, “Prototyping of practical e-tile and evaluations of joint gap area effect,” Proc IDW ’20, pp.757–760, 2020.

[29] M. Omodani and H. Yaguchi, “Concept of e-tile for wall decorations and its prototyping,” Proc. ICFPE 2021, 2Rm104-08-01, 2021.

[30] M. Omodani, R. Nojima, Y. Sekiguchi, and H. Yaguchi, “Electronic tile for decorating walls and 3D surfaces,” Proc. IDW ’21, pp.744–745, 2021.

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