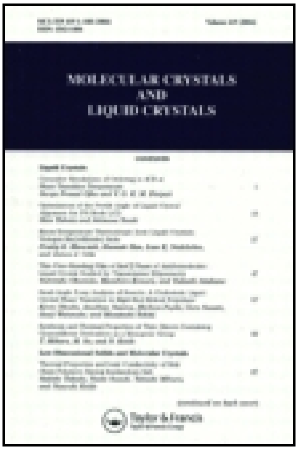
MOLECULAR CRYSTALS AND LIQUID CRYSTALS

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 10 Nov 2009

To cite this article: Seung-Min Ryu, Dong-Yol Yang, Je-Yong So, Lee-Soon Park & Tae-Hoon Kim (2009): Fabrication of Step-Formed PDP Barrier Ribs with High Aspect Ratio by X-Ray Lithography, Molecular Crystals and Liquid Crystals, 514:1, 209/[539]-218/[548]

To link to this article: http://dx.doi.org/10.1080/15421400903240829

Mol. Cryst. Liq. Cryst., Vol. 514, pp. 209/[539]–218/[548], 2009

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400903240829

Fabrication of Step-Formed PDP Barrier Ribs with High Aspect Ratio by X-Ray Lithography

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X-ray lithography has been used widely for the fabrication of nano/micro structures. This process was applied to the fabrication of barrier ribs with a high aspect ratio for plasma display panel (PDP). The design of X-ray mask and X-ray exposure process were optimized to fabricate highly precise barrier rib pattern for PDP.

Keywords: barrier rib; plasma display panel; photosensitive paste; X-ray lithography

INTRODUCTION

Plasma display panels (PDPs) are thin, light, digitally driven displays, and offer a wide viewing angle with short response time due to their inherently excellent characteristics as emissive displays. However, in order to increase the efficiency of PDP the discharge space and area of phosphor layer need to be improved. This can be accomplished by adopting a closed-cell type structure of barrier ribs in PDP panel. In addition, the width of the barrier ribs should be reduced in order to

This research was supported by the Advanced Display Manufacturing Research Center (ADMRC), Regional Innovation Center Program of the Ministry of Knowledge Economy, Republic of Korea. And the research at PLS has been supported by the Ministry of Science and Technology, Korea.
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increase the discharge space and opening ratio of the cells on the PDP panel with the same number of pixels [1].

Closed-type PDP cells have been employed in the industry to solve the problems related to low discharge efficiency and cross-talk among proximate cells in stripe-type PDP cells [2–3]. New designs involving closed-type discharge cells such as SDR (Segmented electrode in Delta color arrayed Rectangular sub pixel) [4] and HEXA (High-Efficiency Hexagonal Array structure) [5] have been introduced to increase the coating area of phosphor layer. Semi-closed type discharge cells such as waffle-type barrier ribs [6] and step-formed box barrier ribs [7] were also reported to increase the discharge space and to reduce the time required to evacuate gases in the PDP panel fabrication. Therefore, it is important to manufacture semi-closed cells with ultra-thin barrier ribs for the realization of high definition (HD) PDP and easy exhaustion of gases. The barrier ribs with top width of less than 30 μm at a pitch of 150 μm are required for a 42 inch high definition PDP with an 80% opening ratio of cells.

Several processes have been developed to fabricate barrier ribs of PDP including screen printing [8], sandblasting [9], etching [10–11], molding [12], and lithographic processes by UV [13] and X-ray [14]. In particular, patterning of barrier ribs by X-ray lithography offers special advantage for the fabrication of step-formed barrier ribs with narrow top width less than 30 μm. In this work materials and process for the X-ray lithographic method of patterning barrier ribs have been studied in comparison with the UV photolithographic method.

EXPERIMENTAL

Materials and Process for Patterning PDP Barrier Ribs

A photosensitive barrier rib paste was made by dispersing barrier rib powder containing glass frit and aluminum oxide into a photosensitive organic vehicle composed of binder polymer, UV functional monomers, oligomer, photoinitiator, and solvent. Additives used in the organic vehicle include UV absorbent, polymerization inhibitor, surfactant, and dispersant. Dispersion of barrier rib powder in a organic vehicle was conducted by a ceramic three-roll mill (Exakt 50, Germany). The powder used in the paste has an approximate composition of PbO 60.0 wt%, SiO_2 10.7 wt%, Al_2O_3 29.0 wt%, and trace (0.3 wt%) amounts of ZrO_2. A mixed photoinitiator (Irgacure 379, 907) was obtained from Ciba Specialty Chemicals and was used as received. The viscosity of the barrier rib paste was measured with a Brookfield viscometer and was adjusted to a range of 3,000~5,000 cPs by adding

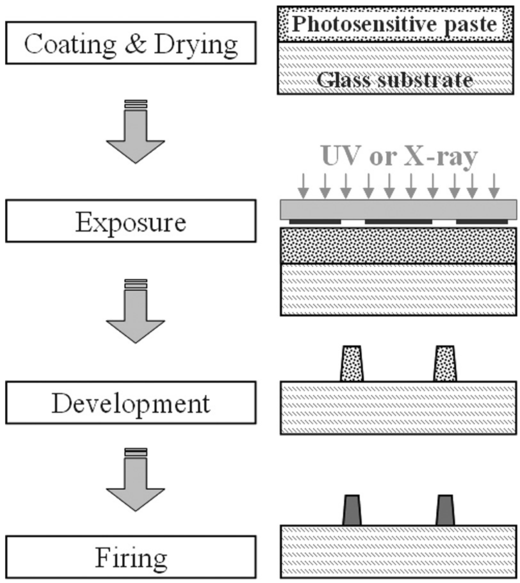


FIGURE 1 Patterning of PDP barrier ribs by lithographic method with UV light or X-ray source.

butylcarbitol (BC) solvent. The thickness of the dried photosensitive layer on the glass substrate was varied in a range of 30∼200 μm. After X-ray or UV light exposure, the photosensitive layer on the glass substrate was developed with 0.5 wt% of sodium carbonate aqueous solution. The whole process of patterning PDP barrier ribs by lithographic method using X-ray or UV light source is shown in Figure 1.

Mask Design for Step-Formed Barrier Ribs

The design of UV photomask for fabrication of step-formed barrier rib is shown in Figure 2(a) and 2(b). The first UV photomask (type A) used in the exposure of the first photosensitive barrier rib layer on the glass substrate had a rectangular pattern with a horizontal white open pattern width of 40 μm (W_h) and a vertical white pattern width of 120 μm (W_v) at a horizontal pitch of 450 μm (P_h) and a vertical pitch of 1,030 μm (P_v), respectively. The second UV photomask (type B) had a stripe pattern with a white pattern width of 40 μm (W_v) at a horizontal pitch of 450 μm (P_v). Specific parameters of the UV photomask are given in Table 1.

The X-ray mask was fabricated by combination of photolithographic and electroplating processes. As shown in the Figure 2, the first X-ray

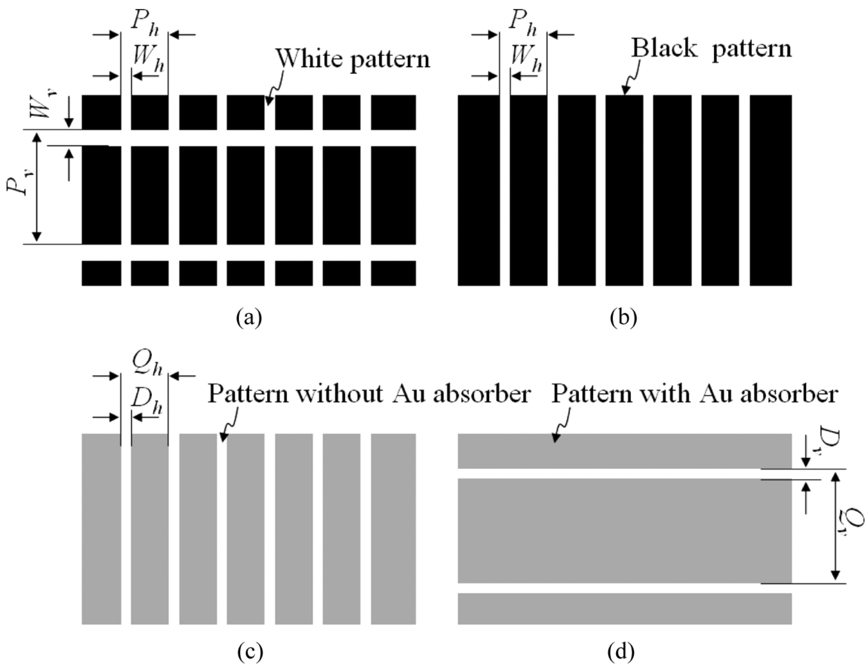


FIGURE 2 Mask design for fabrication of step-formed barrier ribs; (a) the first UV photomask (type A), (b) the second UV photomask (type B), (c) the first X-ray mask (type C), and (d) the second X-ray mask (type D).

mask (type C) had an open Au width of 25 μm (D_h) at a pitch of Q_h and the second X-ray mask (type D) also had open Au width (D_v) of 25 μm at a pitch of Q_v. In X-ray mask, thin X-ray absorber layer (Au) is not sufficient enough to cut the X-ray. Therefore, the optimal X-ray exposure was determined by varying the X-ray dose with a 30 μm Au absorber layer [14]. The SEM images of the Au X-ray masks are shown in Figure 3. Specific parameters of the X-ray mask used in the X-ray lithography are given in Table 2.

TABLE 1 Specific Parameters of the UV Photomask Shown in the Figure 1

Photomask (type A)	P_v (pitch of white pattern, μm)	450
	P_h (pitch of white pattern, μm)	1030
	W_h (width of horizontal white pattern, μm)	40
	W_v (width of vertical white pattern, μm)	120
Photomask (type B)	P_v (pitch of white pattern, μm)	450
	W_v (width of vertical white pattern, μm)	40

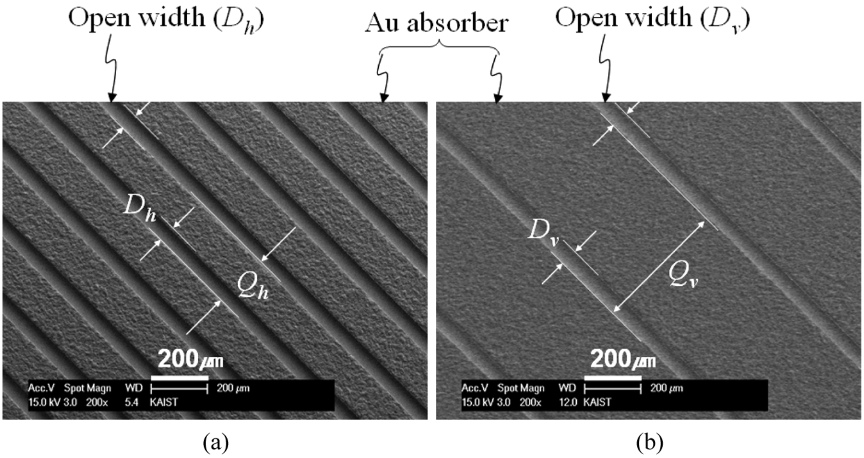


FIGURE 3 SEM images of Au X-ray mask on the Si wafer substrate; (a) the first X-ray mask (type C) and (b) the second X-ray mask (type D).

X-Ray Exposure System

The dried photosensitive paste (i.e., layer) on the glass substrate was exposed to X-rays ($\lambda = 0.1 \sim 10\,\text{nm}$) through the X-ray mask after alignment of the X-ray mask and barrier rib coated substrate. X-ray irradiation was carried out with an energy of 2.5 GeV at a beam current range of 110∼190 mA using the X-ray Nano-Micro Machining beam line (9C1)) at the Pohang Accelerator Laboratory (PAL). The X-ray dose was calculated by using the specific parameters at the X-ray Nano-Micro Machining beam line (9C1) given in Table 3.

TABLE 2 Specific Parameters of the X-Ray Mask used in X-Ray Lithography

X-ray mask (type C)	Q_h (pitch of Au, μm)	150
	D_h (width of pattern w/oAu, μm)	25
	Height of Au (μm)	30
	Seed layer (nm)	Cr (10)/Au (30)
	Membrane (μm)	Si (500)
X-ray mask (type D)	Q_v (pitch of Au, μm)	490
	D_v (width of Au, μm)	25
	Height of Au (μm)	30
	Seed layer (nm)	Cr (10)/Au (30)
	Membrane (μm)	Si (500)

TABLE 3 Specific Parameters used in X-Ray Exposure at the X-Ray Nano-Micro Machining Beam Line

Acceleration voltage (GeV)	2.5
Bending magnet (T)	1.323
Beryllium window (μm)	508
Helium chamber (mm)	400
Polyimide (μm)	30
Distance to source (m)	15
Mask substrate (μm)	500 (Si)
Seed layer (μm)	Cr (0.1)/Au (0.3)
Au Absorber (μm)	30
Beam current (mA)	180
Scanning speed (mm/sec)	30

Results and Discussion

UV Photolithographic Patterning of PDP Barrier Ribs

The process of UV photolithography to fabricate step-formed barrier ribs is shown in Figure 4. First, photosensitive barrier rib paste was coated with a thickness of h_0 onto the glass. The paste was dried for 10 min at 110°C using an IR oven to remove solvent. After aligning the first photomask (type A) with the glass substrate, UV light was irradiated through the photomask. Additional photosensitive paste was then coated with a thickness of Δh followed by drying for 10 min at 110°C using the IR oven. After aligning the second photomask (type B) with the glass substrate, UV light was irradiated through the mask. The exposed barrier rib panel was developed with a 0.5 wt% sodium carbonate aqueous solution at a spray pressure about $2\,kg/cm^2$.

Step-formed barrier ribs obtained by UV photolithography are shown in Figure 5. It was noted that a doubly UV exposed barrier rib area ($1030 \times 40\,\mu m^2$) with 40 μm open width in the UV photomask was increased to more than 60 μm in width as shown in Figure 5(c). This enlarged width of the rib was caused by the scattering of UV light in the dried barrier rib layer due to the different reflective index values of the inorganic barrier rib powder and organic vehicle part. The enlarged ribs would decrease the plasma discharge space in the PDP cells leading to lowering of efficiency.

Barrier Ribs Patterned by X-Ray Lithography

As a preliminary experiment of X-ray lithography, stripe-type barrier ribs with 200 μm uniform height were fabricated using the first (type C) and the second (type D) X-ray masks, respectively. In this

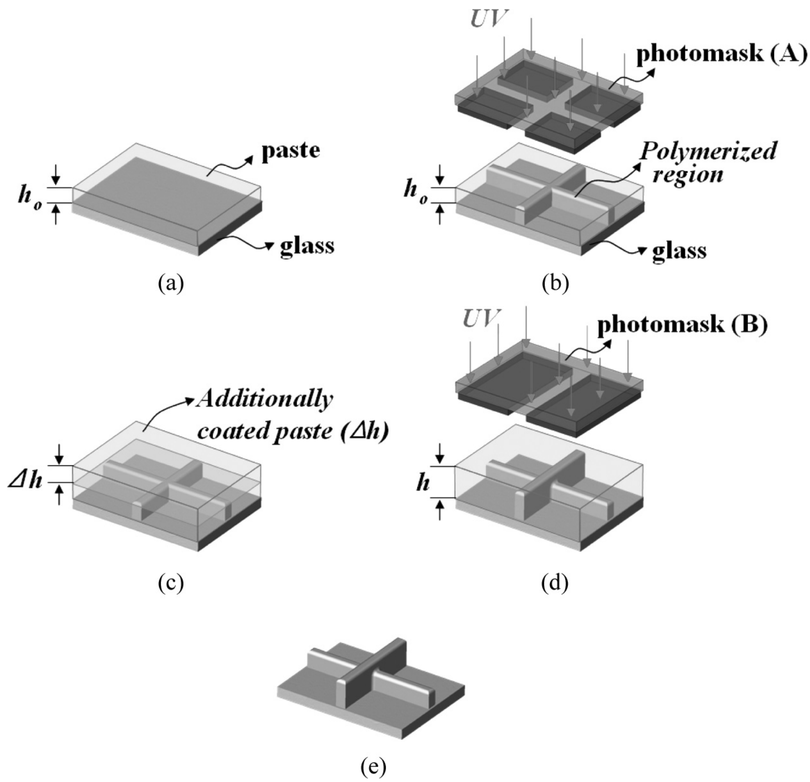


FIGURE 4 Photolithography process used to fabricate step-formed barrier ribs: (a) coating and drying photosensitive paste; (b) photomask (type A) alignment and first UV exposure; (c) additional coating of the photosensitive paste; (d) photomask (type B) alignment and second UV exposure; and (e) development of barrier ribs.

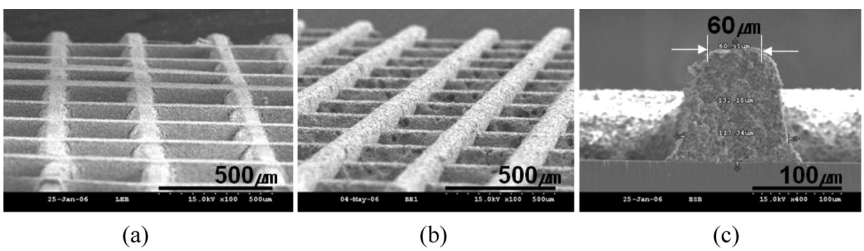
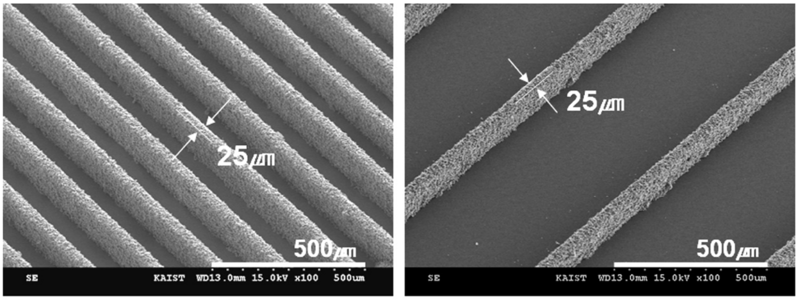
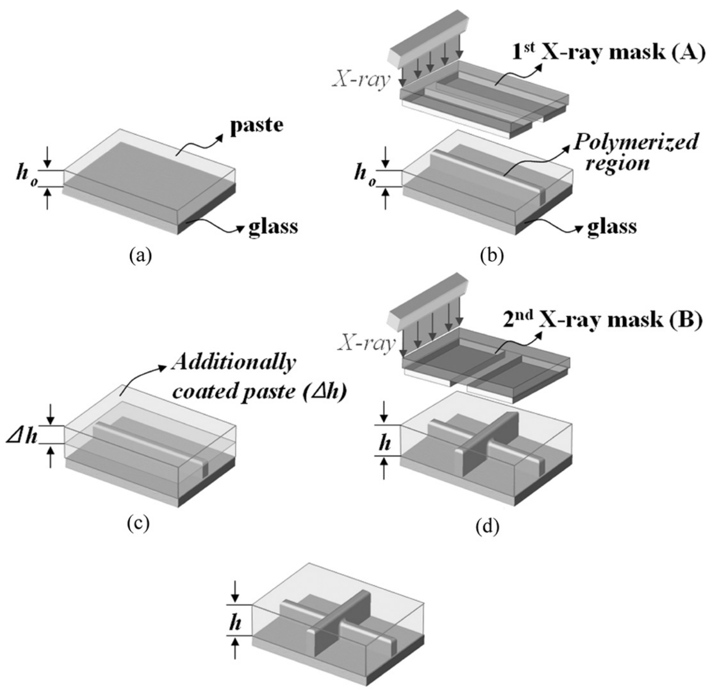


FIGURE 5 Step-formed barrier ribs by photolithography: (a) first layer barrier ribs; (b) step-formed barrier ribs; and (c) cross-section of step-formed barrier ribs.



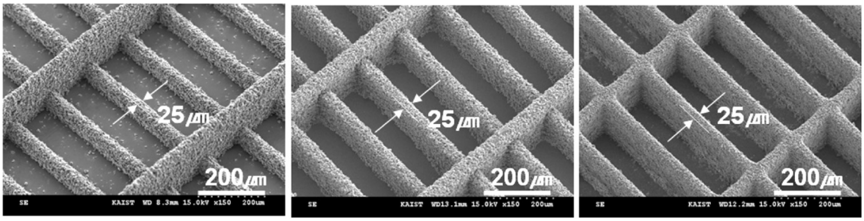
(a) (b)

FIGURE 6 Barrier ribs with a height of 200 μm fabricated by: (a) the first X-ray mask (type C) and (b) the second X-ray mask (type D).



(a) (b) (c) (d) (e)

FIGURE 7 X-ray lithography used to fabricate step-formed barrier ribs: (a) coating and drying photosensitive paste; (b) X-ray mask (type C) alignment and first X-ray exposure; (c) additional coating of the photosensitive paste; (d) X-ray mask (type D) alignment and second X-ray exposure; and (e) development of barrier ribs.



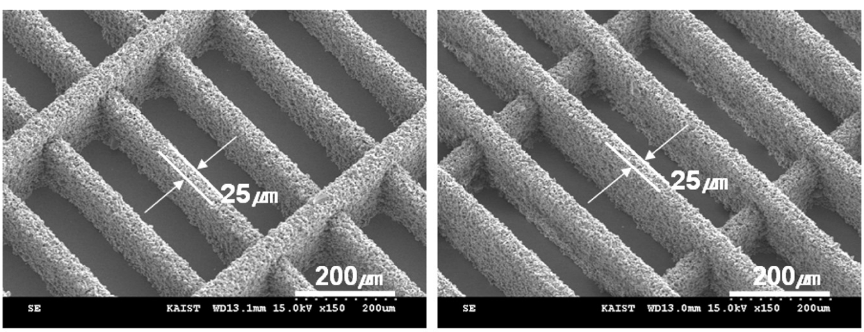
(a) (b) (c)

FIGURE 8 Step-formed barrier ribs with and total height (h) of 200 μm and aspect ratio of 8 various slit heights: (a) $h_0 = 50\,\mu m$, $\Delta h = 150\,\mu m$; (b) $h_0 = 150\,\mu m$, $\Delta h = 50\,\mu m$; and (c) $h_0 = 200\,\mu m$, $\Delta h = 0\,\mu m$.

experiment, no scattering phenomenon was observed between the inorganic barrier rib and the organic vehicle materials in contrast to the UV photolithography, thus allowing fabrication of thin PDP cells with high aspect ratio as shown in Figure 6.

The X-ray lithography process to make step-formed barrier ribs with different heights is illustrated in Figure 7. First, a photosensitive barrier rib paste was coated and dried with a thickness of h_0 onto the glass substrate. After aligning the first X-ray mask (type C) with the glass substrate, the first exposure of X-ray was conducted. After additional coating and drying of the photosensitive paste, X-ray was irradiated through the second X-ray mask (type D), followed by the development process.

Since the discharge space and exhaust characteristics of PDP panel could be dependent on the initial coating height (h_0) and additional



(a) (b)

FIGURE 9 Different types of step-formed barrier ribs with 50 μm slit height: (a) the X-ray mask (C) used prior to the X-ray mask (type D); and (b) the X-ray mask (type D) used prior to the X-ray mask (type C).

coating height (Δh) [7], step-formed barrier ribs with slit heights (Δh) of 0, 50, and 100 μm were fabricated using X-ray masks (types C and D), as shown in Figure 8. It was also demonstrated that PDP cells with different geometry could be obtained by changing the order of application of the X-ray masks as shown in Figure 9 while maintaining the silt height (Δh) of 50 μm.

The enlargement of the barrier rib width in the doubly exposed area ($25 \times 25\,\mu m^2$) was minimal in the X-ray lithography so that barrier ribs with high aspect ratio and large discharge space could be obtained.

CONCLUSIONS

In this study step-formed barrier ribs of PDP with a high aspect ratio were successfully fabricated by X-ray lithography using two different X-ray masks. In contrast to the UV Photolithography, the enlargement of barrier ribs on the doubly exposed area was not observed so that step-formed barrier ribs with upper width of 25 μm and aspect ratio of 8 could be obtained by using X-ray lithography.

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