High-performance Barrier Rib Formation Processes for High-efficiency PDPs

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Abstract

We reported two new techniques of barrier rib formation that are applicable to a variety of structures for high-efficiency PDPs suitable for mass-production [1]. *These two methods are mold replication and direct glass sculpting. Especial progress has since been made in improving these methods to be more suitable for high-efficiency PDPs with the DelTA cell structure.*

This paper reports photolithographic fabrication methods for the masters used in mold replication. The masters for more complex barrier rib forms are easier to make with these methods. The paper also reports a process that combines the direct glass sculpting method with an ink-jet printing method of electrode formation.

1. Introduction

High-efficiency PDPs with closed cells, such as those with the Deep-waffle [2] or DelTA [3-5] structure, have recently been demonstrated. According to one report [6], perfectly closed cell structures that have a symmetric geometry—such structures include honeycomb cells, waffle cells, and box cells—have a good geometry because the structures are not distorted by the firing process. In contrast, open cell structures, which consist of stripe barrier ribs or meander barrier ribs, have advantages in phosphor formation and exhaust processing. This is because adjacent cells are connected spatially.

We have improved barrier rib formation methods to enable reliable and steady production of the DelTA cell structure. The DelTA cell structure consists of meander barrier ribs, which can utilize more of the advantages of both the closed cell structures and open cell structures. A PDP with this structure is highly efficient, is suitable for dispense methods of phosphor formation, and has good exhaust conductance.

2. Results and Discussion

Working to improve barrier rib formation methods, we made progress in two new methods, mold replication and direct glass sculpting, which are especially suitable for meander barrier ribs in our DelTA cell structure.

2.1 Mold replication

Mold replication is a transfer technique that can form the barrier ribs and dielectric layer at the same time on the rear substrate having the address electrodes. This method can be divided into two processes, a mold formation process and a mold replication process. A conceptual diagram of the method is shown in Fig. 1. In the mold formation process, molds are reproduced from the one master with a shape similar to the barrier ribs. In the mold replication process, each mold is coated with the barrier rib material and dielectric layer material, which we called the adhesive paste. After the barrier ribs and dielectric layer dry and harden, they are transferred to the substrate, followed by adhesion to the substrate.

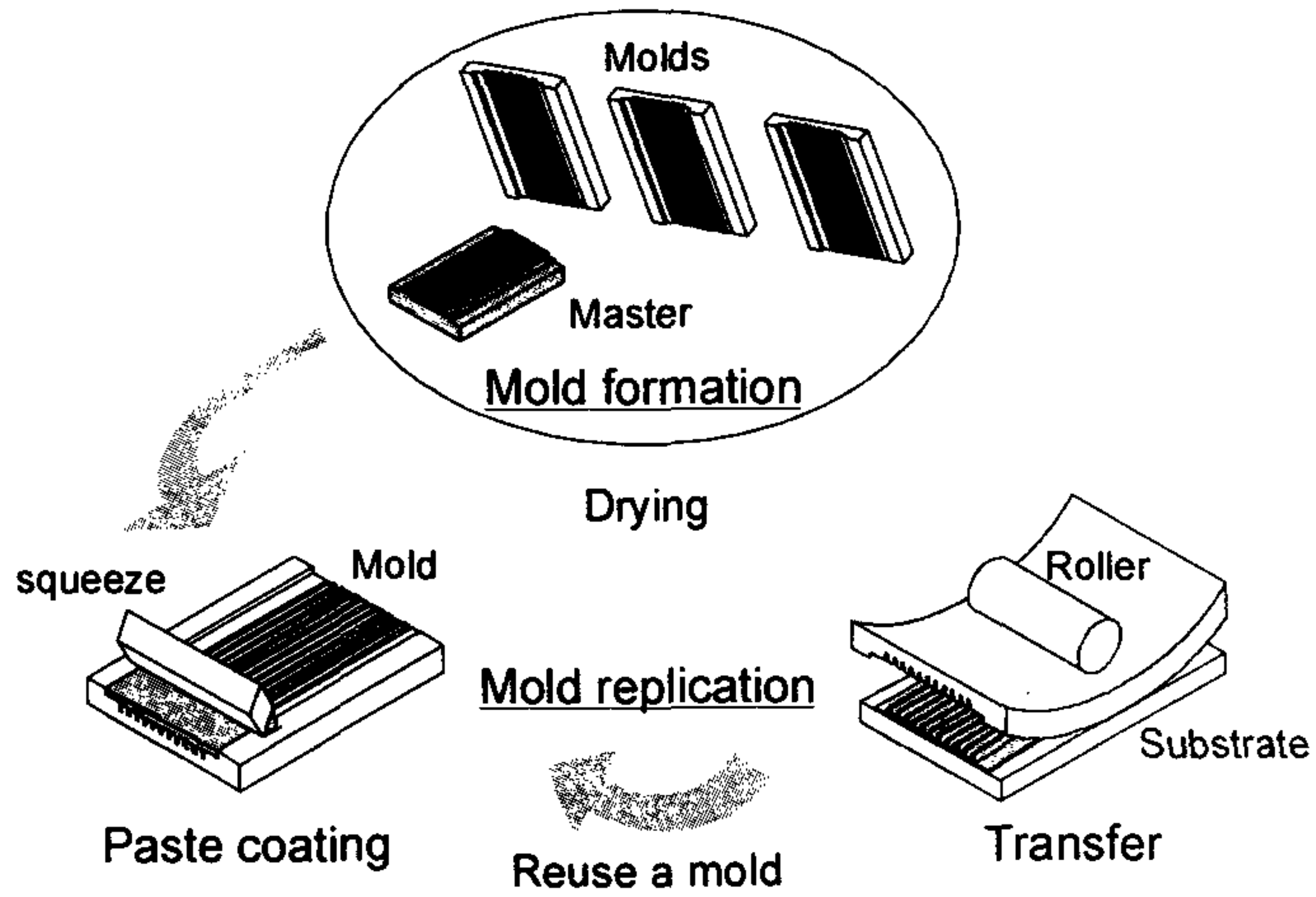

Figure 1. Mold replication method.

Since the barrier ribs and the insulating layer are formed simultaneously, the printing and firing of the insulating layer in conventional methods are eliminated, which reduces the required number of furnaces and amount of printing equipment. We used this method to make a silicone rubber mold, which was chosen because it can be recycled. To test the durability of the mold, we ran over 100 test prints and verified that the mold was not damaged and that the accuracy of reproducibility was good. With use of silicone rubber molds and for the reasons mentioned above, this method has material costs and investment costs that are about half those of conventional techniques, according to our estimates.

Using a high-precision master and this method, we can fabricate barrier ribs in a variety of patterns; where the top has excellent flatness and the side walls slope steeply (see Fig. 2).

An important consideration in this method is how a master is created. As the master, a metallic master shaped by machine grinding or plating is available; but it is easier to use a photolithographic fabrication method. It has the advantages of low costs, a short production time, and a capability to easily form a variety of cell structures, such as meander barrier ribs (Fig. 3). Furthermore, it can be used to fabricate multi-height meander barrier ribs (Fig. 4), which include short ribs separating cells so that more of the advantages of the open cell structures and closed cell structures can be provided.

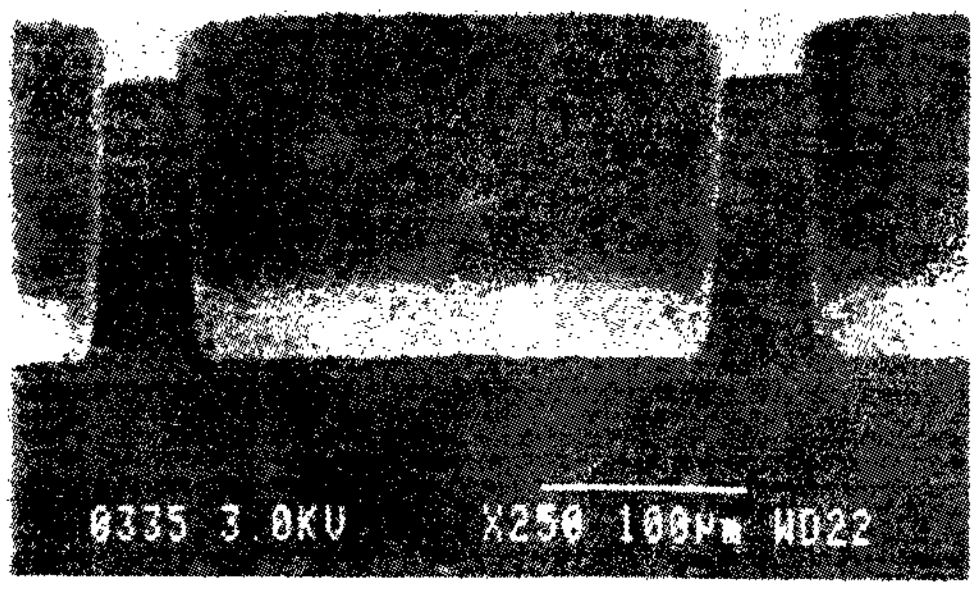

Figure 2. Box cell structure formed by mold replication.

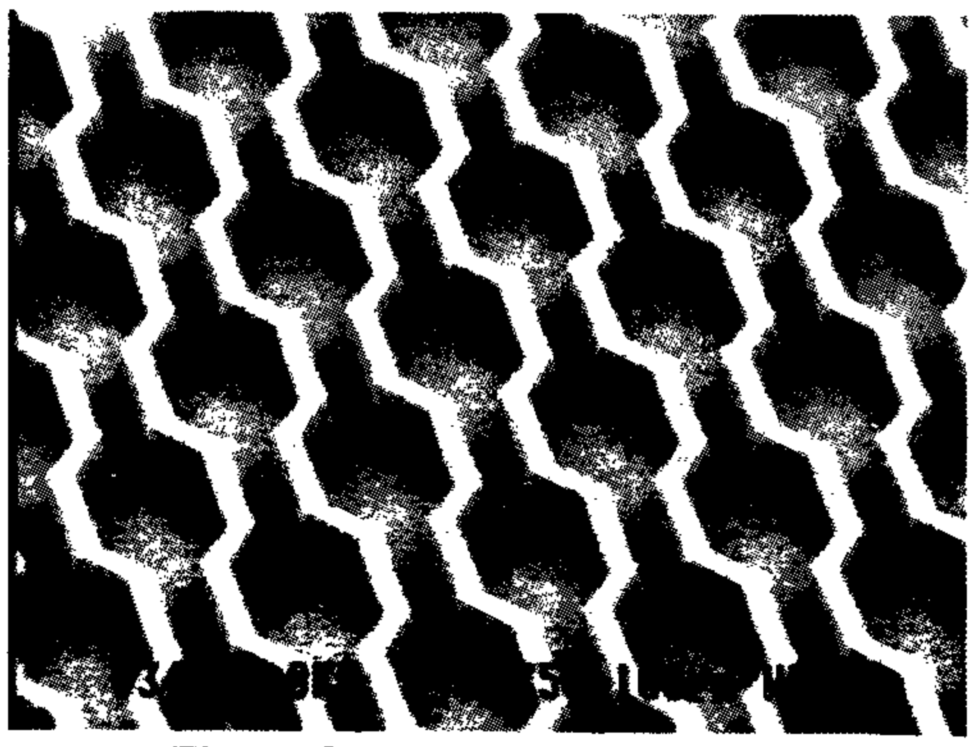

Figure 3. Meander barrier ribs formed by mold replication.

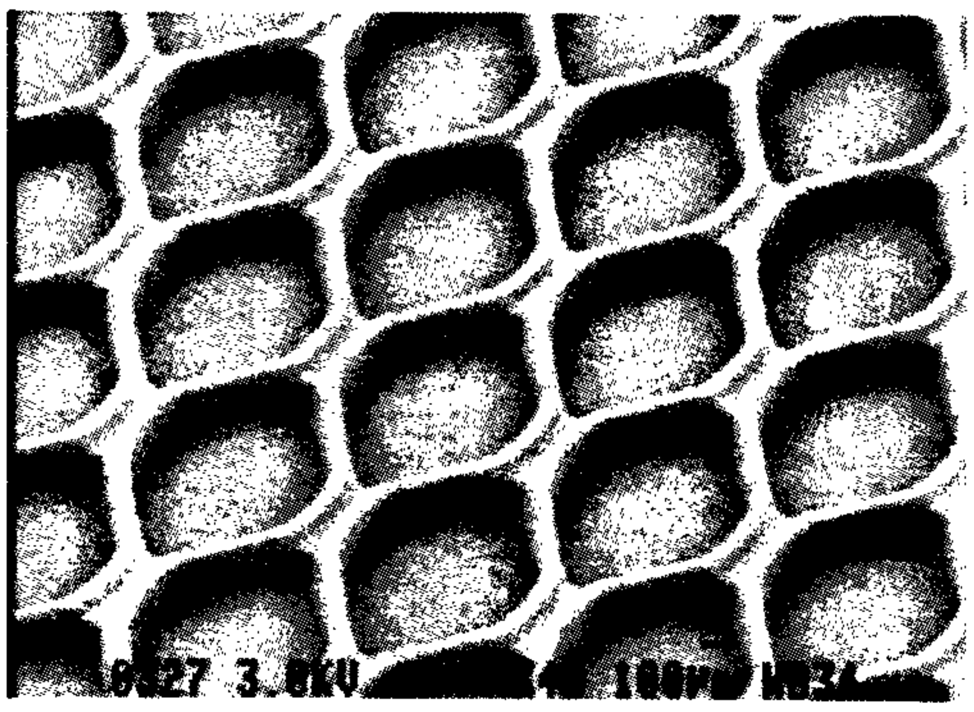

Figure 4. Multi-height meander barrier ribs formed by mold replication.

These multi-height meander barrier ribs are hard to be distorted by the firing process because its short-rib part prevents distortion. In addition, because adjacent cells in this structure are not divided by a horizontal barrier rib, the barrier ribs do not act as obstacles in cases involving dispense methods of phosphor formation, and they have good exhaust conductance.

Photolithographic fabrication method for the master

Procedure with back-side exposure

In a photolithographic fabrication method for the master, we used a procedure with back-side exposure because it results in stronger adhesion to the substrate of a photosensitive material and in side wall angles that are more suitable for mold removal. Our process for this technique consists of the following steps, as shown in Fig. 5:

(1) The desired mask pattern is formed on a glass substrate using a metal material.
(2) Dry film resist (DRF) is laminated on the glass substrate until the desired thickness is obtained.
(3) Exposure from the rear of the substrate is done until a pattern image is exposed.
(4) The substrate is developed until the master is completed.
(5) A mold is produced from this master.

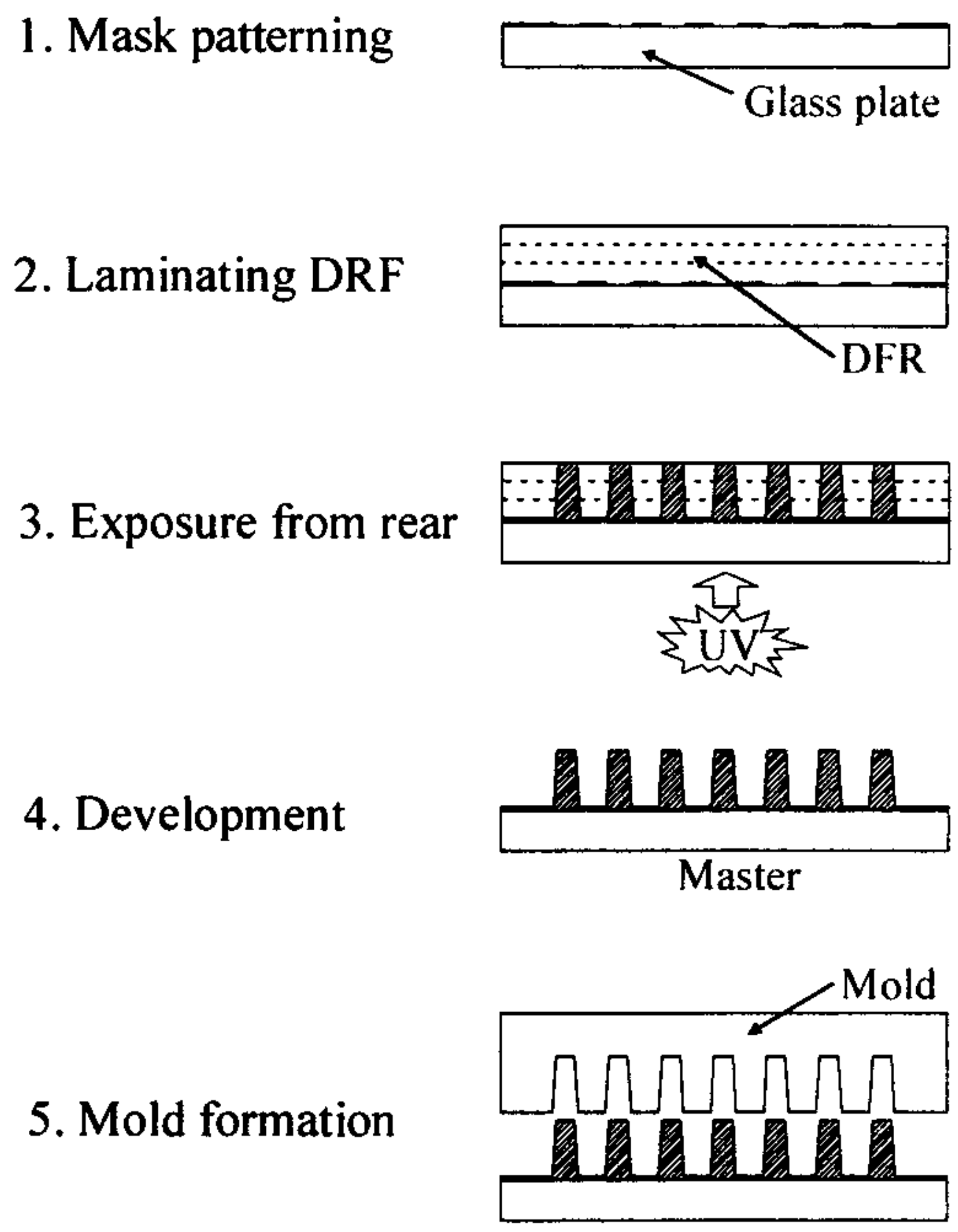

Figure 5. Process flow, with back-side exposure, of a photolithographic fabrication method for the master

Using this method with back-side exposure, we can make the master whose rib form is tapered automatically from bottom to top because of the attenuation effect of light (see Fig. 2).

Multi-stage exposure method

The master for multi-height meander barrier ribs can be formed using a multi-stage exposure method. In this method, the steps of photosensitive material lamination and exposure are repeated several times, and everything is developed at one time in the last step. Our process for this technique consists of the following steps, as shown in Fig. 6:

(1) The desired mask pattern is formed on a glass substrate using a metal material.

(2) DRF is laminated on the glass substrate until the thickness required to make short ribs is obtained.
(3) Exposure through a photomask from the front is done until a short-rib pattern image is exposed.
(4) After new DRF is laminated on the surface, exposure from the rear of the substrate is done until a tall-rib pattern image is exposed.
(5) The substrate is developed until the master is completed.

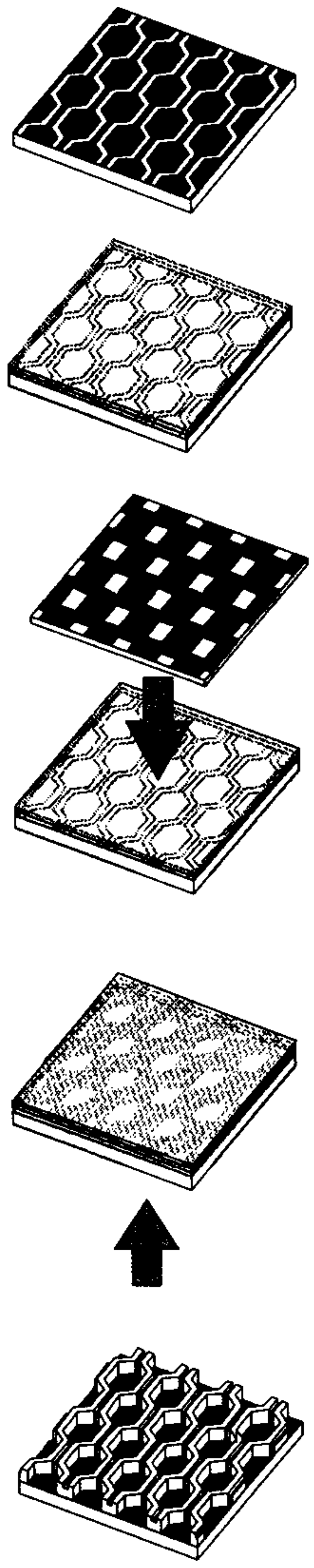

Figure 6. Process flow with of multi-stage exposure, of a photolithographic fabrication method for the master

As explained above, our process uses two kinds of exposure. However, in situations where back-side exposure is difficult to accomplish, a similar master can be produced even if exposure of the short-rib part from the front and lamination of a new DFR is followed by exposure of the tall-rib part from the front. For the exposure through a photomask from the front in such cases, irradiating parallel light obliquely across the substrate gives the master an acceptable side wall angle, one which is more suitable for mold removal (see Figs. 7 and 8)

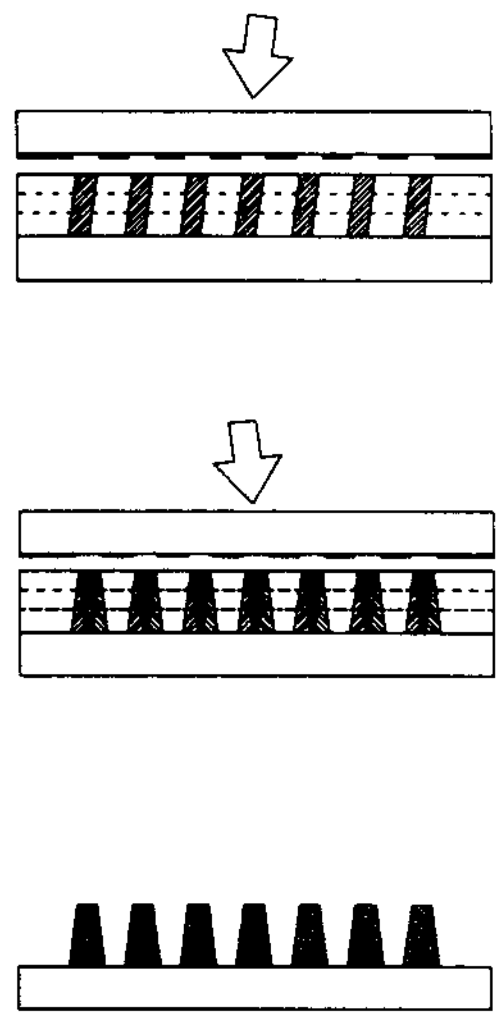

Figure 7. Process flow, with oblique exposure, of a photolithographic method for the master

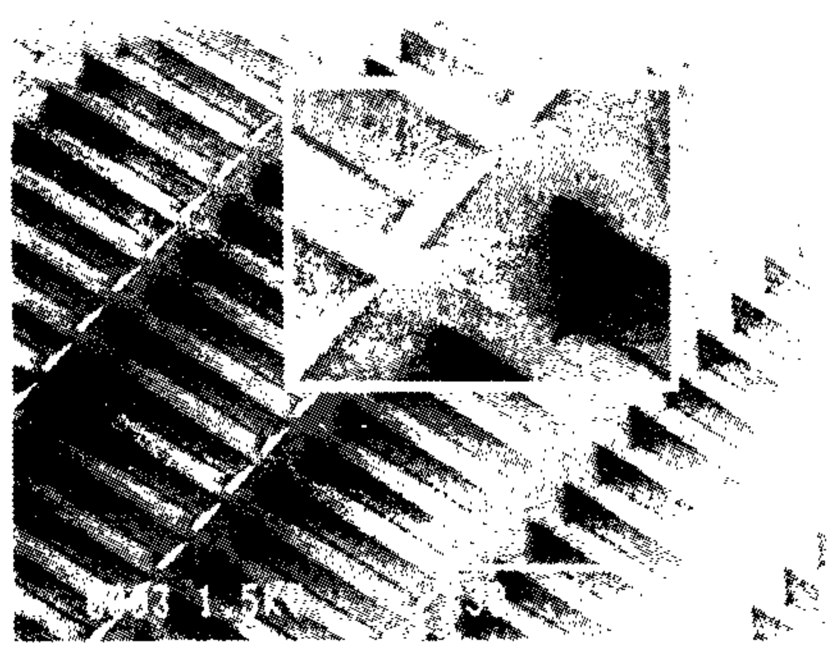

Figure 8. Master with a box cell structure, produced in a procedure with oblique exposure

We fabricated prototype panels with stripe barrier ribs and compared their performance with that of panels with ribs formed conventionally by sandblasting. Figure 9 is a photograph of a test panel fabricated with our mold replication method. Its performance was confirmed to be equivalent to that of panels with ribs formed by sandblasting. With an eye toward mass production, we are pushing toward development of a process for producing larger panels.

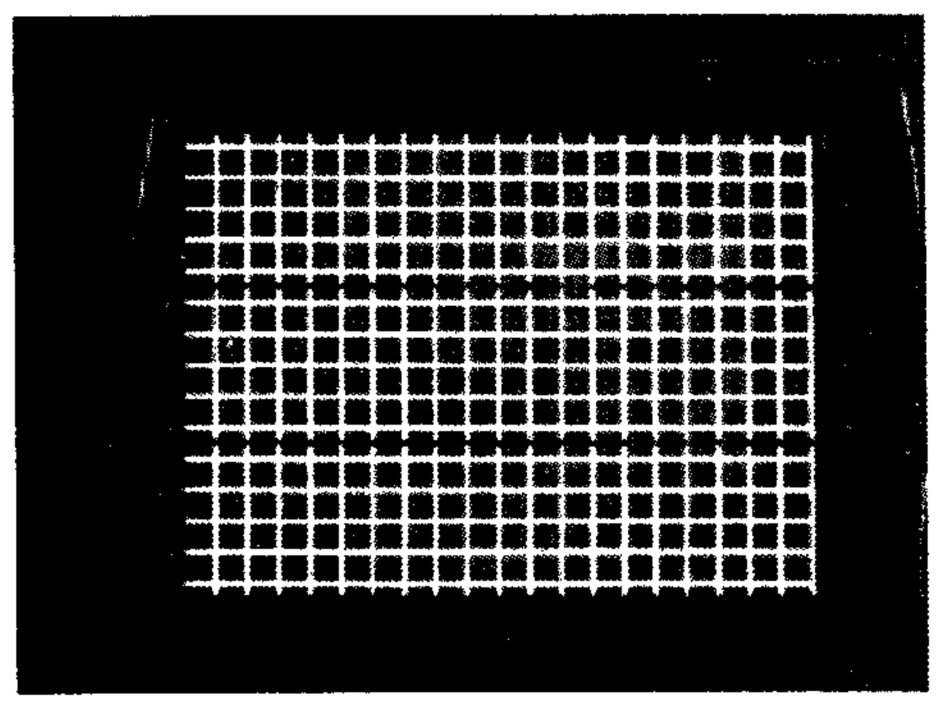

Figure 9. Photograph of a test panel fabricated using our mold replication method

2.2 Direct glass sculpting

In direct glass sculpting, barrier ribs are formed by sculpting the glass substrate directly, using a sandblasting machine. Then, the address electrodes are formed. Since the barrier ribs are made with the glass substrate, the material costs and fixed costs including operating costs and investment costs are dramatically lower. This process is more suitable for meander barrier ribs and larger panels because there is no firing in the barrier rib formation process and because it is hard to shrink the barrier ribs during firing in dielectric layer formation. Furthermore, this method is ideal for the open cell structures such as stripe barrier ribs and the DelTA cell structure, which consists of meander barrier ribs, since it is used to form barrier ribs before address electrodes.

The uniformity of the barrier rib height (depth) is excellent. A height of 165±5 μm was measured, indicating that the height can be controlled to within 5 μm. Although the average surface roughness was ±1 μm, no address electrode broke. This degree of roughness thus does not contribute to electrode breakage.

Our process for this technique consists of the following steps, as shown in Fig. 10:

(1) DRF is laminated on a glass substrate, and a pattern is applied by exposure.
(2) The glass substrate is engraved by sandblasting.
(3) A metal film is deposited by sputtering after removal of the DRF.

Note: This step is not required when an ink-jet printing method of electrode formation is used.

(4) The pattern of the address electrode is applied by photolithography or ink-jet printing.
(5) The substrate is coated with an insulating layer, and this is followed by drying and firing.

Note: This step may not be required.

Although address electrodes can be formed using photolithographic methods (see Fig. 11), we tried in this work to combine this direct glass sculpting method with the ink-jet method of electrode formation [7].

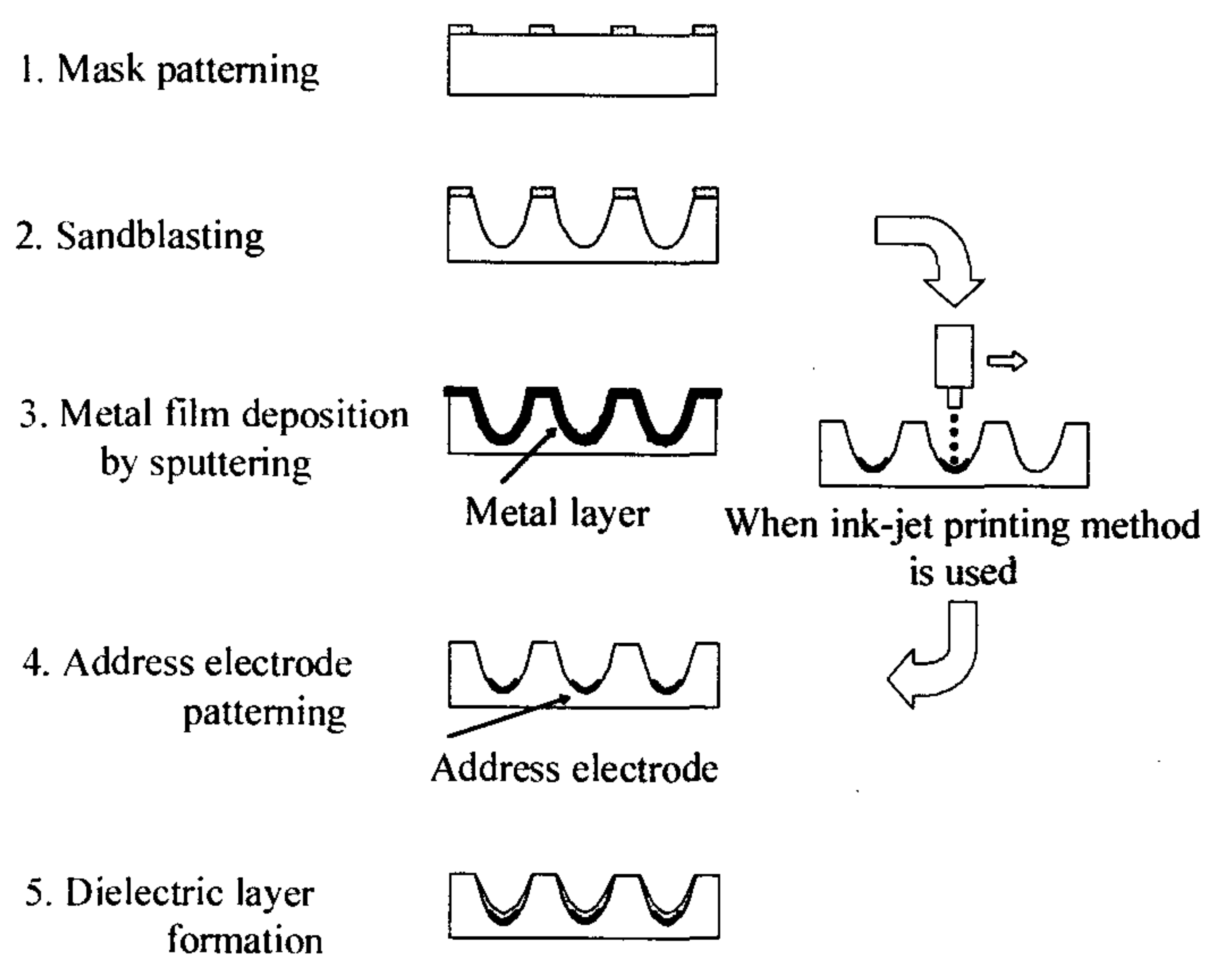

Figure 10. Process flow of our glass sculpting method

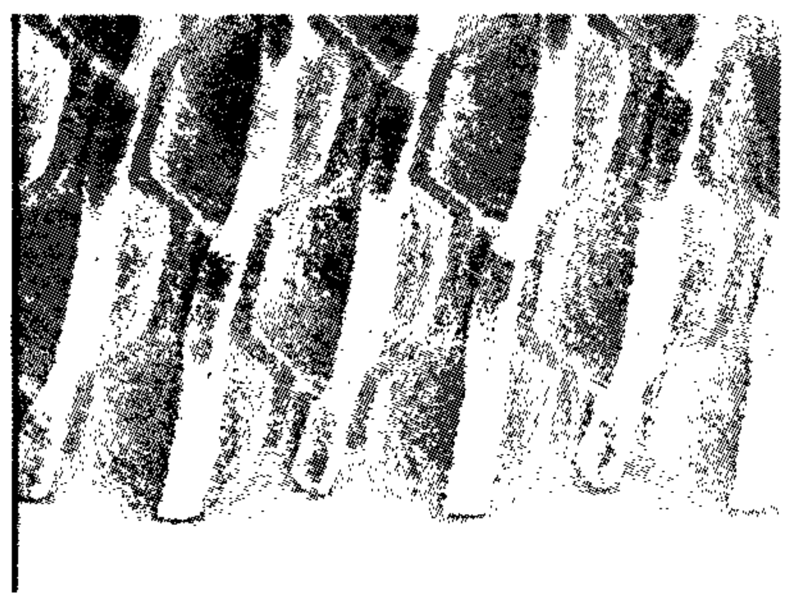

Figure 11. Glass-sculpted meander barrier ribs with electrodes formed using photolithography.

Electrode formation using ink-jet printing

After the formation of barrier ribs, the address electrodes are formed directly using ink-jet printing. The electrodes made with an ink-jet printing process are cured at 300°C for 30 minutes in a furnace. Since this method does not use the metal film deposition process, photolithography process, and etching process, investment costs are sharply reduced.

Shown in Fig. 12, the electrodes made with ink-jet printing are equivalent to those formed using photolithographic methods.

Figure 12. Glass-sculpted meander barrier ribs with electrodes formed using ink-jet printing.

The bottom of the barrier ribs is curved, raising concern that the volume of the discharge cell could be smaller than that of a cell fabricated using conventional techniques. We were able to resolve this issue by forming phosphor and dielectric layers that followed the curve (see Fig. 13).

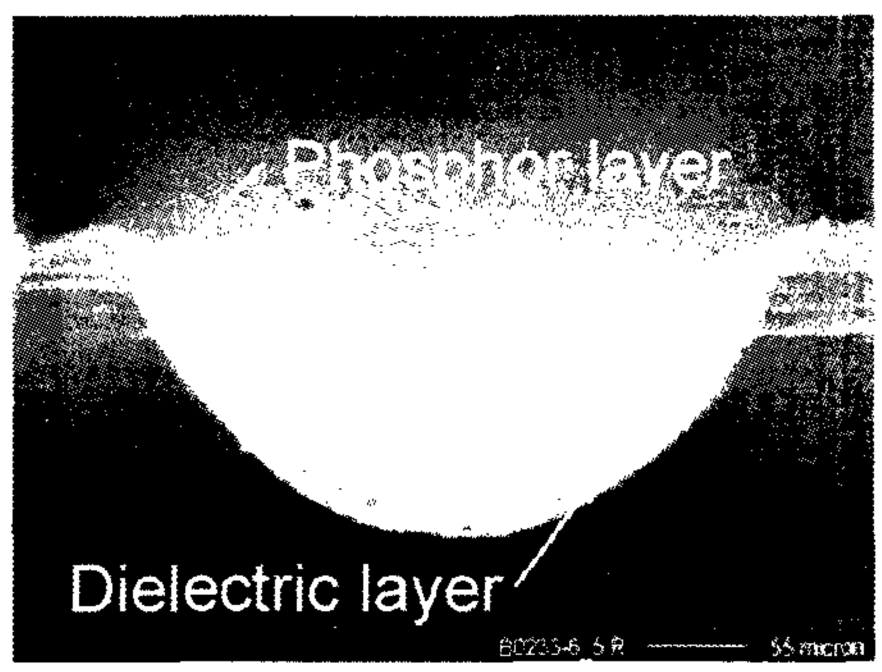

Figure 13. Cross-section of a cell after dielectric layer and phosphor formation.

We fabricated test panels that have the DelTA cell structure and a pixel pitch of 1020 μm. By designing narrow channels between the barrier ribs and using sandblasting, we were able to allocate areas for the address electrodes and improve evacuation. The depth of the narrower channels was controlled to within 40 μm of that of the deepest part of the cells. The address electrodes of these panels were fabricated using photolithographic methods. The performance of the panels with ribs formed using our direct glass sculpting method was compared with that of panels with ribs formed using conventional techniques. Figure 14 is a photograph of one of the test panels. The performance of these panels is excellent and equivalent to that of the conventional panels.

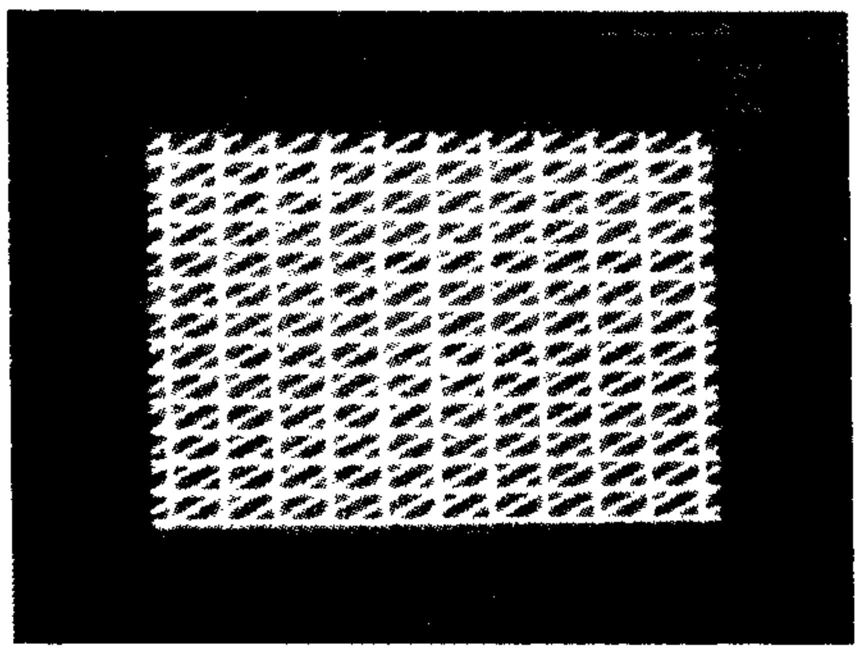

Figure 14. Photograph of a test panel fabricated with our direct glass sculpting method.

3. Conclusion

The DelTA cell structure, which consists of meander barrier ribs, provides the advantages of both the closed cell structures and open cell structures. We have further developed two methods of forming the barrier ribs in the DelTA cell structure.

A PDP with this structure is highly efficient, is suitable for dispense methods of phosphor formation, and has good exhaust conductance. Our mold replication and direct glass sculpting method of barrier rib formation technologies simplify the total PDP production process. High-performance manufacturing technologies for PDPs are achieved with these techniques.

6. Acknowledgements

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7. References

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