FPD 用高精度フォトマスクブランクスの開発

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Nikon’s High-definition Photomask Blanks for Flat Panel Displays

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フォトマスクブランクスは，微細な配線パターン等を転写するために，パターン形成用の遮光膜・位相シフト膜を石英ガラス製のフォトマスク基板の上に成膜した製品である．フォトマスクブランクスを用いてパターンを転写したガラスプレートは，フラットパネルディスプレイ（FPD）として TV やスマートフォンに使用されている．

FPD の大型化に伴い，FPD を露光するためのフォトマスクブランクスも大型化しており，最も大型の G10世代では 2 m 四方近くある．大型のフォトマスクブランクスにおいては，平面度の面内均一性，遮光膜・位相シフト膜の光学特性面内均一性という要素が大きな課題となる．なぜならば，フォトマスク基板のサイズが大きいので，均一に表面を研磨する技術，スパッタリング法によりパターン形成用膜を広範囲にわたり均一に成膜する技術，広いエリアを精度よく測定する技術が確立し難いためである．同時に，基板平面度の面内均一性・膜の面内均一性はパターンの転写精度に大きな影響を及ぼすため，FPD 露光装置側からの要求が厳しいためでもある．

ニコン製 FPD 用高精度フォトマスクブランクスは，非常に高い基板平面度，膜の光学特性面内均一性を有し，次世代の高精細ディスプレイの製造に不可欠な製品である．また，その測定値は，高い測定精度を誇るニコン製の測定装置により保証されている．

Photomask blanks consist of a photomask substrate and a binary film or a phase shift film on the surface to transfer the circuit pattern. High-volume panels with transferred circuit pattern are embedded into flat panel displays (FPDs).

The demand for larger-sized displays has been increasing, and, accordingly larger panels are required. Currently the largest photomask substrate size is approximately 2 m × 2 m (G10 Mask). Uniformities of flatness and optical characteristics are significant issues in realizing larger-sized photomask as attaining these uniformities over large areas is highly challenging. However, these uniformities require pattern-transfer accuracy; therefore, the demand for high-definition photomask blanks must be satisfied.

Nikon’s high-definition photomask blanks exhibit high precision over G10 photomask area, such as the higher flatness uniformity, optical characteristics uniformity resulting from Nikon’s high precision polishing, film deposition and measurement technologies.

In this report, we introduce these excellent properties of these photomask blanks for application in advances FPD Panels.

Key words　FPD フォトマスクブランクス，フォトリソグラフィー，平面度測定，重ね合わせ精度，位相シフト膜
FPD photomask blanks, photolithography, flatness measurement, overlay, phase shift mask

1 Introduction

Liquid crystal and organic EL displays present images by controlling the emission color and brightness of each pixel. Although a thin-film transistor circuit is formed on the display to control the light emission, in FPD lithography, the pattern of this circuit is transferred from the original plate using light (Fig. 1). By repeating the transfer from original plates having different wiring patterns, a circuit having a three-dimensional wiring pattern can be eventually transferred. Displays are mass-produced by performing this transfer process on a large number of panels. The quartz glass, which forms the original plate, is called the photomask substrate, whereas the film (light-shielding / phase-shift) formed on its surface, and used for pattern formation that becomes the original plate, is called a photomask blank.

The size of the display is increasing year by year, while the size of the photomask original plate is also increasing correspondingly. The largest photomask, called the Generation 10.5 photomask (hereinafter called the G10 mask blank, and the one without a film formed on the surface is called the G10 substrate), has a size of approximately 2 m × 2 m.

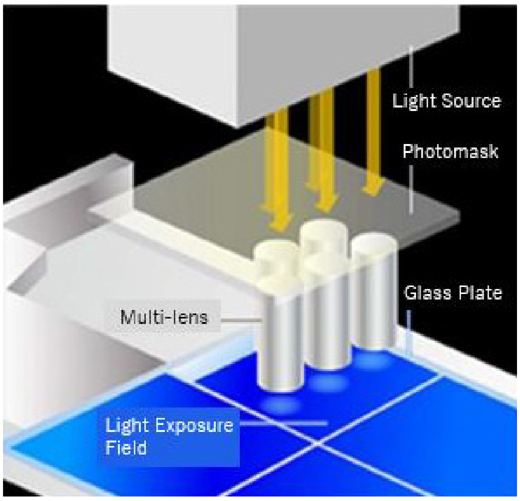


Fig. 1 State of light exposure in an FPD exposure device[1].

When forming a film for pattern formation on a G10 substrate, the film forming area is also close to 2 m × 2 m, making it an extremely large photomask blank. In this paper, we introduce photomask substrates with high flatness to improve the pattern transfer performance.

Moreover, there are variations in the film of the circuit pattern forming layer; it can be a light-shielding mask (binary film), whose purpose is to transfer the pattern by blocking the light exposure, or a phase-shift film, whose purpose is to make the light exposure semi-transparent and invert the phase to improve the contrast of the transferred pattern (Fig. 2). In this paper, we introduce the phase-shift film required for the mass production of high-definition displays.

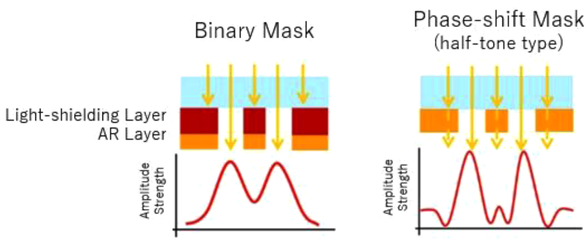


Fig. 2 Film structure of the pattern forming film.

2 Characteristics required for the FPD photomask blanks

The performance of the photomask blanks greatly influences the pattern transfer characteristics. For example, when setting a photomask on an FPD exposure device, deflection occurs, which must be corrected. However, because this correction is based on the premise that the photomask substrate is a perfect flat surface, if the flatness of the photomask substrate is insufficient, the correction deviates greatly. Further, if the in-plane uniformity optical property of the light-shielding film and phase-shift mask used in pattern formation is low, it will lead to dimensional deviation of the circuit when the pattern is transferred to the glass plate. Therefore, photomask blanks are required to have the aforementioned high in-plane uniformity, that is, they must have a high precision.

However, as mentioned earlier, because photomask blanks for FPDs have become comparatively large in the recent years, it is difficult to meet the aforementioned requirement. Therefore, it is necessary to have a polishing technology that can increase the flatness of a quartz glass surface with a maximum size of around 2 m × 2 m, a film-forming technology that can improve the in-plane uniformity optical property of light-shielding films, and phase-shift masks of size approximately 2 m × 2 m, as well as a measurement technology that can measure these physical property values repeatedly over a wide area with high accuracy.

3 Characteristics of the High-precision Photomask Blanks used in Nikon FPD

Nikon FPD photomask substrates have high in-plane flatness uniformity. In addition, the in-plane uniformity optical property of the photomask blank, on which the light-shielding film and phase-shift mask are formed, is high, even in maximum-sized G10 mask blanks. Hence, it is an important product in the manufacture of next-generation high-definition displays.

• **In-plane flatness uniformity**

The in-plane flatness of the G10 substrate is shown in Fig. 3. For all of the front, back and plate thickness variations (total thickness variation, TTV), an in-plane flatness uniformity of 3 μm or less has been achieved. Further, it can be seen that the flatness is extremely high compared to the normal specifications of 20 μm for the front and back surfaces, and 30 μm for the plate thickness. We have commercialized this photomask substrate with the specification called Super Flat Mask (SFM)-SS. Other standards are also available, which are shown in Table 1.

In order to obtain such high flatness even with G10 substrates, a polishing technology that can control the flatness of any part of the substrate is required, and Nikon has been refining its polishing technology by accumulating know-hows over the years.

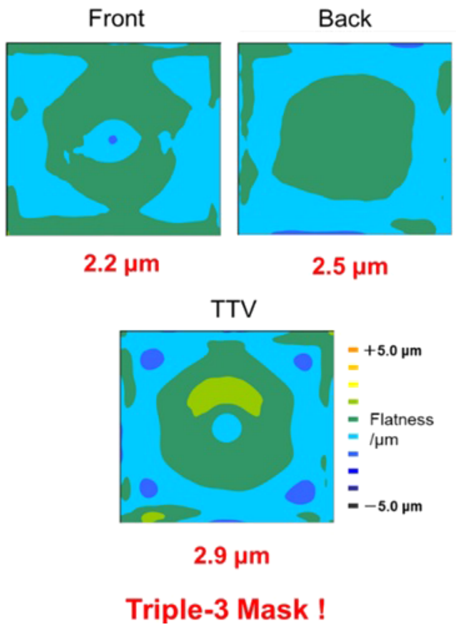


Fig. 3　In-plane flatness of G10 substrate.

Table 1　Flatness specifications of photomask substrates

Subjects	SFM-SS	SFM-S	SFM	Normal
Flatness of front surface	≦ 3 μm	≦ 5 μm	≦ 7 μm	≦ 20 μm
Flatness of back surface	≦ 3 μm	≦ 5 μm	≦ 10 μm	≦ 20 μm
TTV (Total Thickness Variation)	≦ 3 μm	≦ 5 μm	≦ 10 μm	≦ 30 μm

• Photomask substrate flatness and overlay accuracy

With the cooperation of a display manufacturer, we evaluated the flatness effect of the photomask substrate on the pattern overlay accuracy (overlay), during the low-temperature poly silicon (LTPS) TFT manufacturing process.

The schematic diagram of the evaluation procedure is given in Fig. 4. The photomask substrate, glass plate, and light exposure, are of the sixth generation. Considering the error influence, three glass plates were prepared. We compared the overlay accuracy among 14 patterns that are required to have high accuracy (between A-B, between B-C, and between B-D of the figure). The size of the photomask substrates used for comparison was 800 × 920 mm; the flatness levels were of two types, normal specification and SFM-S; the overlay accuracy was normal specification × normal specification; and the two sets, SFM-S × SFM-S, were used. The overlay accuracy was measured for 168 points (= 14 points * 3 rows * 4 scans) per glass plate, and a total of 504 points for 3 glass plates, while the variation 3 σ was obtained.

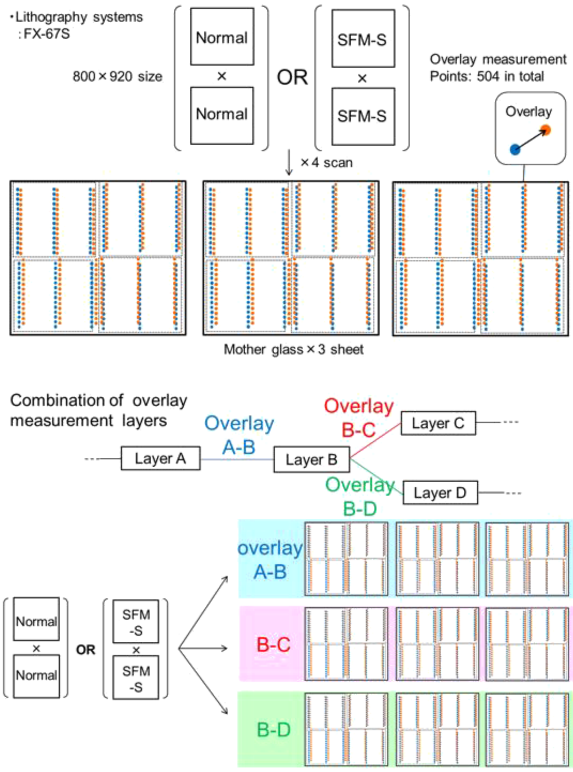


Fig. 4　Procedure for checking overlay accuracy based on the flatness of the photomask substrate.

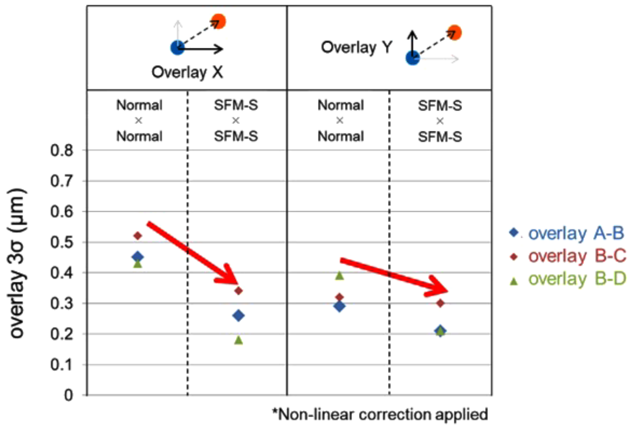


Fig. 5　Results of the overlay accuracy verification experiment.

From the results, it can be observed that the overlay accuracy improved when using SFM-S, compared to the photomask substrate with normal specifications (Fig. 5). In other words, using a photomask substrate with high flatness is suitable for the production of high-definition displays.

4 Measurement technology to support high-precision blanks

Even if a photomask substrate with high flatness is manufactured, its flatness cannot be guaranteed unless measured accurately. Further, even if a photomask blank with high in-plane uniformity optical property is manufactured, if the optical properties cannot be measured accurately, the in-plane uniformity will be worse than it actually is due to the variations of the measuring equipment.

Thus, high-precision measurement technology is indispensable for the production of high-precision photomask blanks. In this paper, we introduce the Nikon flatness measuring instrument ALGS (Analyzer for Large size Glass Surface). With ALGS, the flatness can be accurately measured at multiple points even on a G10 substrate, while the in-plane flatness uniformity can be precisely adjusted.

• Photomask substrate flatness measuring instrument ALGS

The Nikon flatness measuring instrument ALGS is a device that can measure the flatness of the photomask substrate with high accuracy. Sizes up to G10 substrate can be mounted.

The high accuracy is due to the adoption of a highly rigid frame that suppresses the deformation and vibration of the entire device, and a substrate holding system that suppresses the distortion of the substrate that occurs when the measuring instrument is set in.

Moreover, since it is a device manufactured in-house, detailed analysis of the flatness measurement results is carried out, and the device is being remodeled to expand and improve its precision year by year.

ALGS also verifies the deviation accuracy by performing periodic measurements while changing the substrate posture, whose results are demonstrated in Fig. 6.

From Fig. 6, it can be seen that the measurement deviation is suppressed to 0.4 μm, which is sufficiently accurate to guarantee the measurement value of SFM-SS. Thus, the quality of the Nikon photomask blanks is assured by high measurement technology.

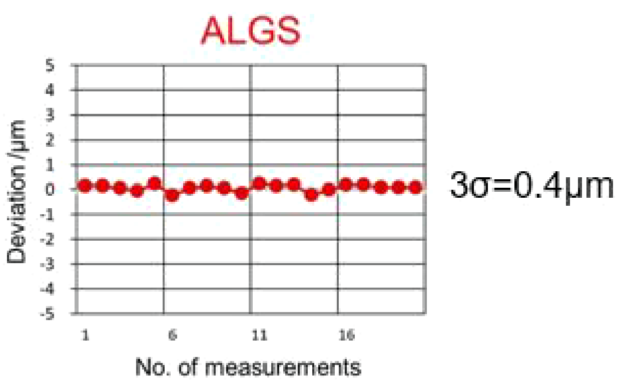


Fig. 6 Repeated flatness measurement reproducibility of ALGS.

• In-plane uniformity optical property

In a light-shielding or a phase-shift film formed on a photomask substrate, low uniformity optical property leads to deterioration of the imaging characteristics. Hence, it is required that the light-shielding film has high reflectance, whereas the phase-shift film has high transmittance and in-plane uniformity of the film. In this paper, we focus on the phase-shift film.

The in-plane uniformities of the transmittance and phase shifting angle of the G10 Cr phase-shift mask blank are given in Fig. 7. The general specifications of high-definition phase shift mask blanks are a transmittance in-plane uniformity of 0.7%, and a phase shifting angle in-plane uniformity of 10° . From the figure, it can be deduced that the specifications for high-definition masks have been achieved, regardless of whether it is a G10 mask blank or not.

Such high in-plane uniformity optical property is obtained by feedback control based on the local changes in the film-forming conditions. This is Nikon's unique method that improves the in-plane uniformity by measuring the in-plane uniformity of the immediately preceding batch and automatically adjusting the film-forming conditions at the locations where deviation from the target value is large.

• Cross-sectional shape of the phase-shift film

The phase-shift film requires not only the in-plane uniformity optical property, but also a nearly vertical cross-sectional shape after pattern formation. If the cross-sectional shape is inclined, the amount of phase shifting angle in the inclined portion greatly deviates from 180°, which leads to the reduction of contrast improvement effect, as the amplitude cancellation of the exposed light at the edge of the pattern is weakened.

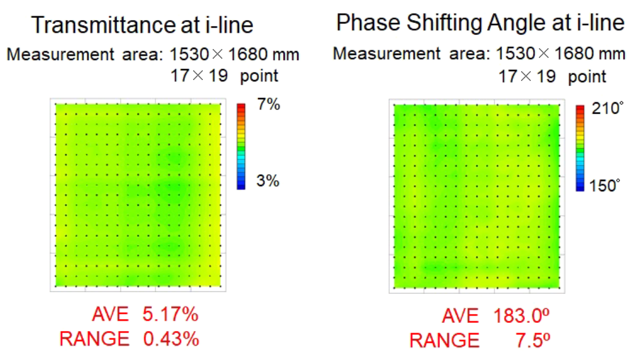
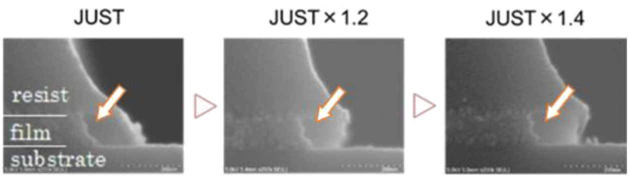


Fig. 7 In-plane uniformities of the transmittance and phase shifting angle in G10 Cr phase-shift mask blanks.

The cross-sectional shape of the Cr phase-shift mask after pattern formation is shown in Fig. 8. It can be seen that as the time of immersion of the Cr film in the etching solution increases, the cross-sectional angle of the film becomes almost vertical. Hence, even in terms of cross-sectional shape, Nikon's phase-shift mask is suitable for the mass production of high-definition displays.



* JUST: Time taken for the film to be dissolved completely, as seen visually

Fig. 8 Cross-sectional SEM image of the Cr phase-shift film after pattern formation.

5 Summary

Nikon photomask blanks have high in-plane uniformities of the substrate flatness, with optical properties guaranteed by high measurement technology, which are preserved even in the G10 mask blanks. These are the high-precision photomask blanks suitable for mass production of next-generation high-definition displays.

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