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Simulation on Optical Performance of Wire Grid Polarizers Considering Process Uniformity

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ABSTRACT: Wire grid polarizers (WGPs) have potential to replace absorptive polarizing films because of the possibility to enhance the optical performance in liquid crystal display (LCD). Typical WGPs consist of metallic wires, which have high aspect ratio and narrow pitch sizes. Although there have been many fabrication approaches, they have been considered as a difficult process to obtain relevant uniformity in a large area for commercial uses. In this work, we study the effects of the process non-uniformity to optical performance in LCDs. When we assume the uniformity of metal film thicknesses and widths of the line patterns as 10%, the uniformity of transmittance is less than 5%. However, the extinction ratio, which is the ratio of white and black states, has a 30% of uniformity. In addition, we discuss the effect of the alignment distortion between two polarizers to the display performance.

KEYWORDS: wire grid polarizers, liquid crystal display, uniformity, simulation, metal wire

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I. INTRODUCTION

Liquid crystal displays (LCD) have been commercially available in smartphones, TVs, etc. In principle, LCDs need two polarizers and we can modulate the transmittance by controlling the orientation of liquid crystal. Currently, display companies use absorptive polarizing in the panels. Recently, wire grid polarizers (WGPs) have received attention because the reflective polarizer can improve the LCD brightness by recycling the polarized light.[1-10] A lot of company expect that WGPs have potentials to replace conventional polymeric polarizer films and be applied to beam splitter for projection display devices. In addition, the fabrication of WPGs on LCD panel (In cell polarizer) has gained much interest due to the development of quantum dot light emitting diodes (QLEDs). WGPs are arrays of thin metallic line patterns standing on a transparent substrate. [1-3] Typically, aluminium lines with nanometre scale widths and spaces are placed on a glass substrate. Also, the line patterns have high aspect ratio (the ratio of height versus width). Through a WGP, transverse magnetic (TM) light, which is in perpendicular direction of metallic lines, can transmit. On the other hand, transverse electric (TE) light is reflected on WGPs. The TM and TE light can be determined by the orientation of the other WGP. Although WGPs are highlighted due to possible applications, the difficulty of the fabrication is the bottleneck to be commercialized. To fabricate WGPs, there have been a lot of attempts including nanoimprint lithography followed by metal dry etching,[1, 3] oblique metal deposition onto polymeric nanolines to realize thin metallic wires with high aspect ratio [8-10] and chemical mechanical polishing (CMP) after metal deposition on a transparent nanopatterns. [6] In the typical semiconductor process such as metal deposition and metal dry etching, we have to consider the process uniformity especially in large area fabrication. The variation of metal film thickness and width of metallic lines can be a source of a variation of optical properties such as luminance through WGPs. Although there were several reports on the simulation of WGPs by adjusting the design parameters, there were few works on the simulation for the estimation on the uniformity of brightness originated by process non-uniformity. In this work, we perform an optical simulation by rigorous coupled wave analysis (RCWA) to estimate the performance uniformity such as transmittance and extinction ratio. For the process aspect, we fixed the uniformity of thickness and width of metal lines as 10 %. In addition, we calculate the uniformity of optical performances when we consider the rotational uniformity due to the alignment distortion of two polarizers.

II. RESULTS & DISCUSSION

Figure 1(a) shows the schematic illustration of WGPs. On a glass substrate, metallic nanowires are placed in a regular way. The geometric parameters of the metal lines are widths (w), spaces (s) and heights (h). The definition of aspect ratio (AR) is the ratio of a height and a width (AR = h/w). Figure 1(b) is the schematic to explain the polarization in WGPs. The TE light is reflected because of joule heating and TM light is transmitted through WGPs. Figures 1(c-d) show an example showing the polarization with commercial WGPs.

When the orientation of the polarizer is perpendicular to the metal lines, the polarizer is transparent (Figure 1(c)). On the other hand, the polarizer is in parallel orientation with the other polarizer, the transmission becomes almost zero (Figure 1(d)).

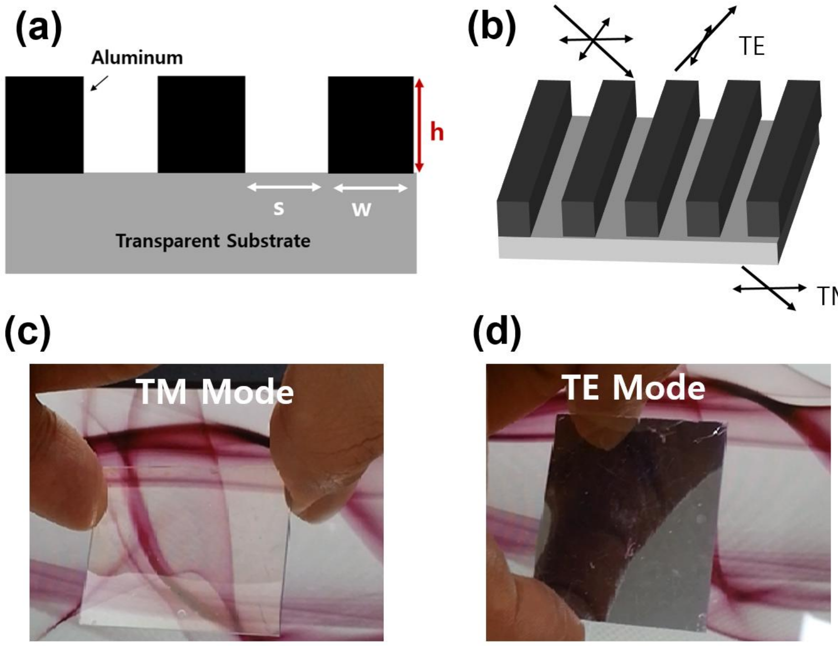

Figure 1. (a) A schematic of metal lines of a WGP. (b) An illustration showing the reflected and transmitted lights through a WGP. Pictures showing (c) transmitted light through a WGP (TM mode), (d) reflected rays on a WGP (TE mode).

To estimate the optical properties of WGPs, we used a commercial package for the optical simulation with RCWA methods (G-Solver). We investigate the variations of transmittance as well as extinction ratio (ER), which is the ratio of the transmittance of TM and TE modes (ER = TM/TE). We fixed the process variation as 10%. For example, when we set the metal film thickness as 100 nm, the minimum and maximum thicknesses are 90 nm and 110 nm. The uniformity is defined as below.

Thickness uniformity (%) = (maximum thickness – average thickness)/ average thickness (1)

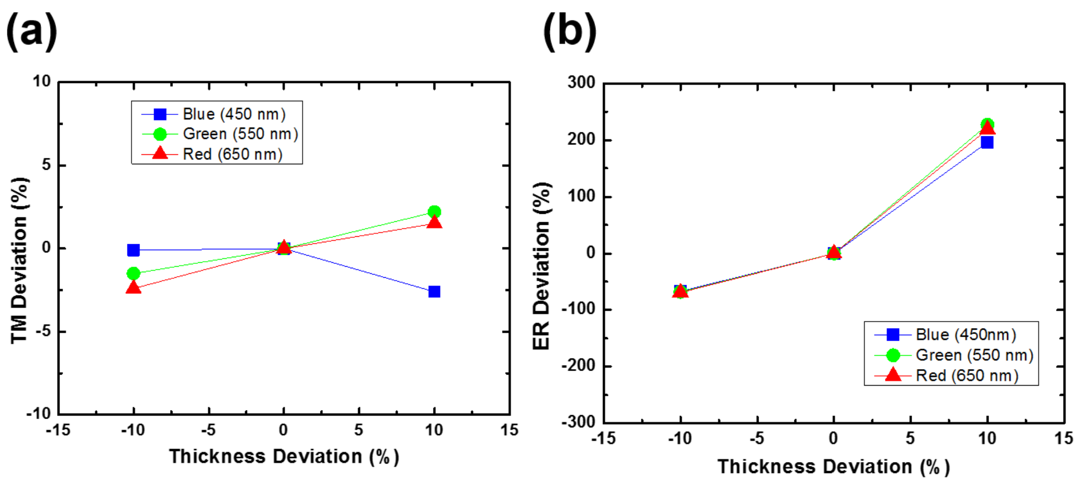

Figure 2. Graphs of (a) TM deviation and (b) ER deviation from the average when the thickness deviation is 10 %.

Figure 2(a) shows a graph showing the transmittance (TM) deviation versus the width deviation. We obtained the deviations with wavelengths of 450 nm for blue colour, 550 nm for green colour, 650 nm for red colour. We set a standard the geometrical parameters for a WGP as 50 nm of width, 50 nm of space and 150 nm of height. The transmittance is within 10% of range of uniformity and less than 5% in every wavelength. On the other hand, the extinction ratios (ERs), which are related to contrast ratios (CRs) in display panels show 30% to

230 % of deviation from the average value because the transmittance in TE mode has high deviation. It means the black level can be different in a large area. In the semiconductor processing, typically, aluminium films are deposited by the sputtering process. When we consider a large area fabrication, the uniformity of metal film thickness is dependent of the sputtering environments, such as power, pressure, etc. Because we can assume that the process window is within 10%, the simulation results can be a guidance of the control of black mode in the device.

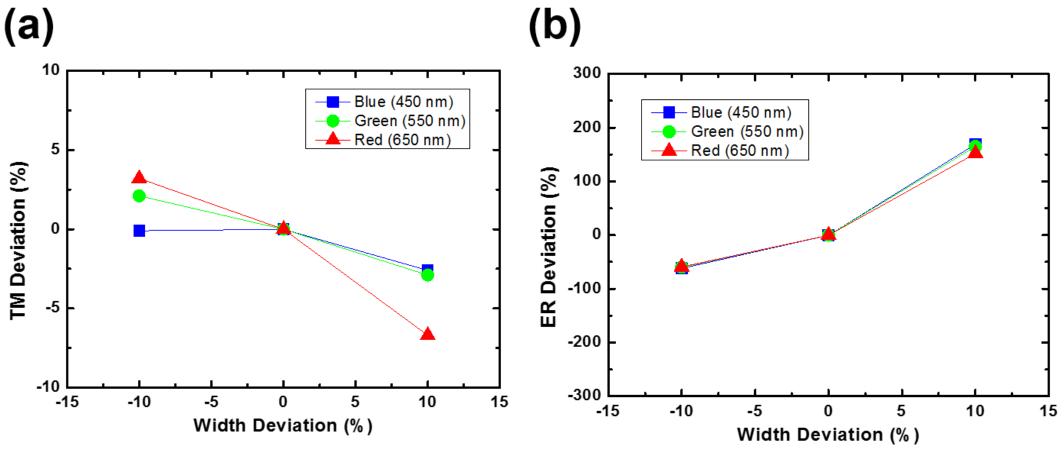

Figure 3. Graphs of (a) TM deviation and (b) ER deviation from the average when the width deviation is 10 %.

Figure 3(a) shows a graph of transmittance when the deviation in the line width is 10% with different wavelengths (450, 550 and 650 nm). The transmittance deviation is within the range of 10% and the range is less than 5% in case wavelengths are 450 and 550 nm. As shown in Figure 3(b), however, the deviation of ER is in the range of 33% to 200% because there are significant differences in black mode. The width deviation depends on the photolithography as well as dry etching process. Especially, the variation of photoresist (PR) thickness during the photolithography can be one of the reasons of non-uniformity. Skewness during dry etching process can be a source of the process deviation. Because non-uniformity is inevitable, black level control should be controlled in the device panel.

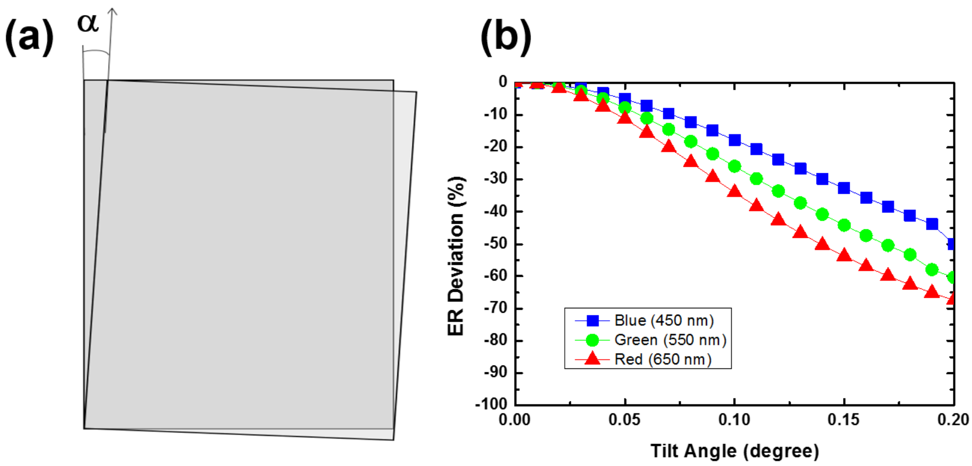

Figure 4. (a) A schematic illustration on the definition of tilting angle between two polarizers. (b) A graph showing ER deviation depending on tilting angles.

When we attach the polarizing film on the substrate of display panel, there could be a distortion during the lamination. Because there are two polarizers, the orientation of polarizing films could be important when we consider the optical performance. Figure 4(a) shows the definition of tilting angle between two polarizers. The deviation of transmittance when we varied the tilting angle from 0 degree to 1 degree, there was no change in transmittance. As shown in Figure 4(b), there are decreases in ER if there is the distortion of the polarizing orientations.

III. CONCLUSION

In conclusion, we conduct an optical simulation by RCWA to calculate the performance uniformity such as transmittance in TM mode and extinction ratio (ER). When we assume that the process uniformity (sputtering or photolithography) is 10%, there are few effects on the transmittance uniformity. However, ERs show significant changes, for example, 3 times of the average value. The simulation results can be the guidance of black level control in display devices. Also, we consider the tilting angle during the lamination and ER can be decreased when there is a distortion of orientation.

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