Development of Siloxane-based UV Curable Resins for 100 nm Pitch Wire Grid Polarizer

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Wire Grid Polarizer

The light in nature is electromagnetic waves (EW) which travels with the wave oscillations perpendicular to the direction of propagation. A polarizer or polarizing film is a component used to pass only a specific polarization direction of EW. Polarizers are essential parts of modern display devices such as TFT LCD and AMOLED. The current display industries use polarizing films made by polyvinyl alcohol first being adsorbed with iodine, then stretching and orientating it. This process induces the film polarization characteristics that only light with a certain oscillation direction can pass through. These polarizing films are easy to be manufactured in large sizes and relatively low cost. However, since they used organic dyes to realize the polarizing characteristics, stability at high temperature and life time are always issues.

A regularly spaced metal line on the substrate such as Si wafer, quartz glass or transparent substrates can function as a wire grid polarizers (WGPs). When an incident unpolarized EW meets WGP, the electromagnetic field oscillating parallel to the wires will be reflected in the same manner as a thin metal

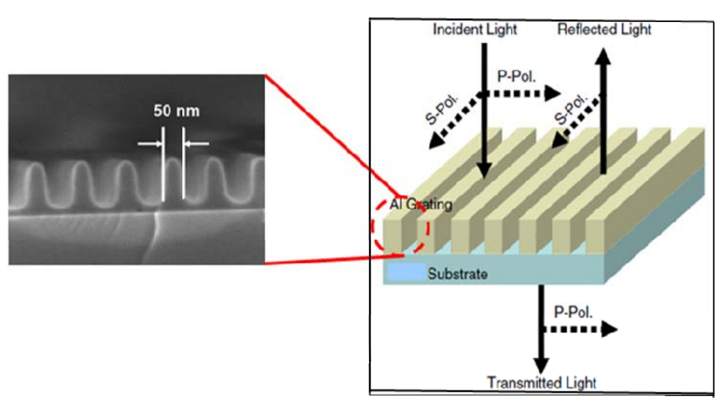

Figure 1. Principles of wire grid polarizer.

sheet with some energy loss due to the Joule heating. On the other hand, the component of EW perpendicularly oscillating to the wires will not induce electron movement in the metal along the polarization because electron movement is hindered by the non-metallic spacing between the wires. Therefore, the perpendicular oscillating component of the EW will pass through the grid as schematically depicted in Figure 1. This principle indicates that the metal width and non-metallic spacing (pitch) and nature of metal are important factors for WGP and the pitch should be less than 150 nm to be effectively used in visible spectrum.

Since WGP is a reflective polarizer, it is possible that the brightness of LCD can be enhanced by replacing the bottom polarizer with the WGP. The usual bottom polarizer absorbs the parallel oscillating EW (P1) and transmits the perpendicular oscillating EW (P2) thus the light intensity becomes half of the original after pass through the bottom polarizer. But WGP reflects most of the P1 back to the backlight where it is converted into P2 (polarization recycling), thus increasing brightness is achieved.[1]

There are varieties of methods available for the fabrication of WGPs which involve the combination of the following process, metal deposition, nanoimprinting, and reactive ion etching. A general process is shown in Figure 2.[2] First, aluminum is deposited on glass substrate and UV or thermal resin is coated on top of Al. Nanopattern is transferred by pressing the mold into the resin with heating (thermal resin) or UV irradiation (UV resin). The residual resin at the bottom of the pattern is removed by oxygen plasma to expose the Al surface. Aluminum is then etched by reactive ion etching (RIE) and finally, resin is removed by stripping to produce WGP.

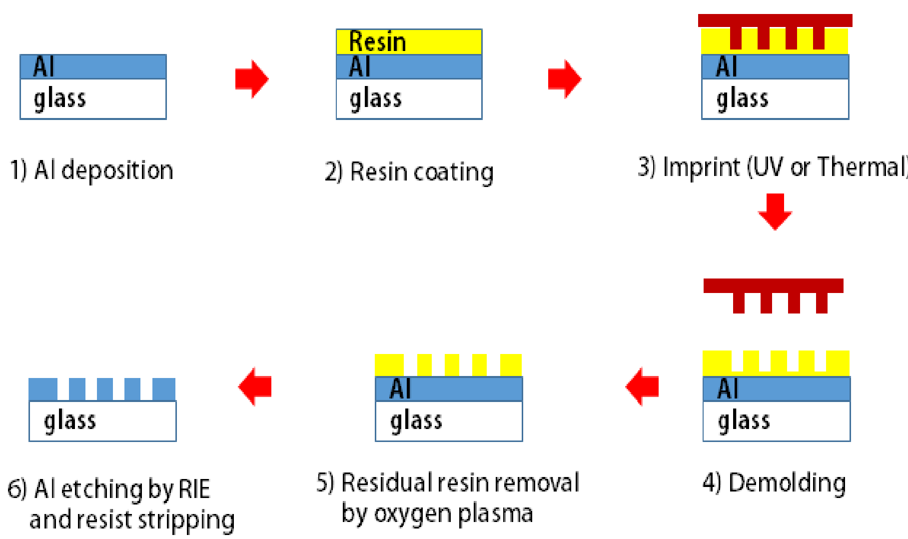

Figure 2. General fabrication process of WGP preparation.

Literature survey showed that many variations in process and structures are possible to prepare nano WGPs. Ultrahigh contrast and transmittance was obtained by SiO_2 coating on top of Al as the etch stop layer and by the 146 nm pitch mold using immersion interference lithography.[2] Park et al reported a simple way to produce nano metal line on top of substrate by transferring the solidified Ag nanoparticles using liquid bridge.[4] Angled deposition of Al at the both side of nanopatterned resist produced the AL encapsulated patterns and RIE to remove the top coated Al provided the double side Al coated nano WGP which showed high contrast and good trasmittance.[5]

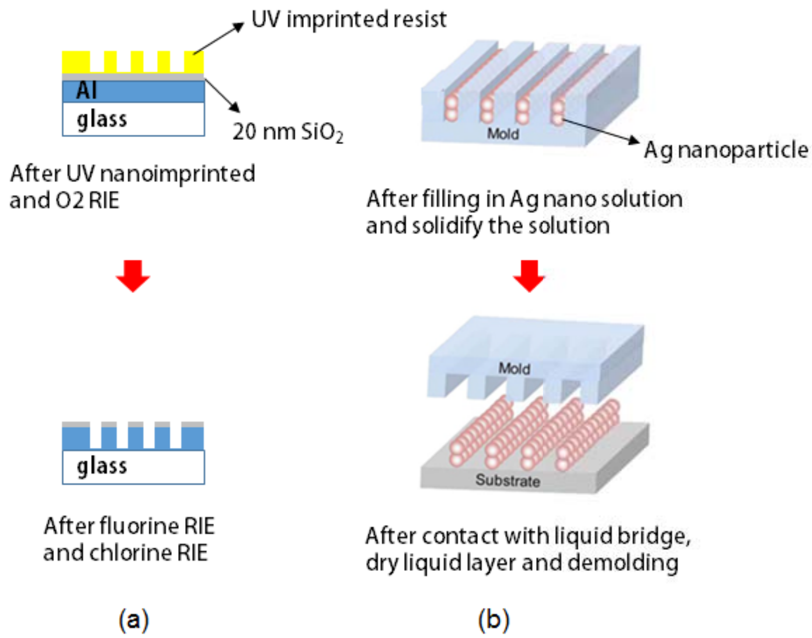

Figure 3. Various methods for the fabricating nano WGP: (a) using SiO_2 as etch stop, (b) direct transferring Ag nanoparticles with liquid bridge, and (c) etching top Al layer after double shadow deposition.

Formulation of UV Resins and Fabrication of WGPs

UV nanoimprint lithography (UV-NIL) and Roll-to-Roll UV nanoimprint lithography (R2R-NIL) are one of the promising techniques due to its low cost, simple process, and great precision for various electronic applications.[6] For the realization of 100 nm pitch R2R-NIL, UV curable resins were formulated by using siloxane-based acrylates or fluorinated siloxane-based acrylates to precisely control the patternability, resin viscosity, and R2R-NIL processability (Figure 4).

Our first formulation for 100 nm pitch nanoimprinting process was controlled to provide the viscosity of under 10 cPs. This formulation was successfully applied for UV-NIL with flat mold, while

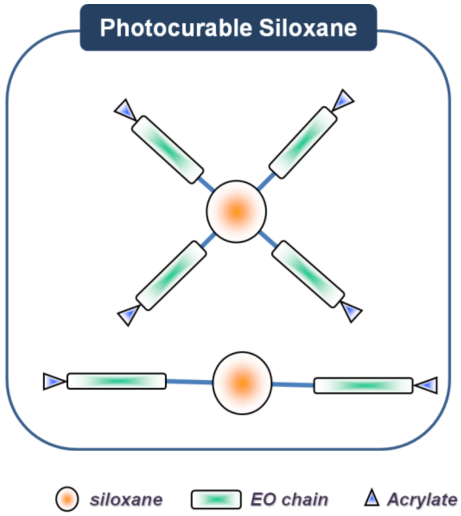

Figure 4. Schematic structures of siloxane based UV resins.

pattern transfer was impossible with R2R-NIL due to the low viscosity. Such low viscosity of the UV resins caused the improper deposition on the substrate because of excessive flowing property. To solve such problems, urethane acrylate oligomers with high viscosity was introduced to provide proper viscosity and high curing density for the R2R-NIL process. The obtained UV curing resins (KUV-10) possess proper viscosity for R2R process, low shrinkage during polymerization and high transparency to UV light (Table 1). The curing time of the resins was measured by photo DSC and shrinkage during curing process and etching resistance of the polymers were investigated depending on the ratio of siloxane-based acrylates. As shown in Figure 5, 100 nm pitch pattern was precisely formed with constant residual layer with KUV-10 by R2R-NIL process. Roll-to-Roll process was performed with the web rate of 6 mm/s and the pressure of 12 kg/cm^2 under the UV irradiation of 1.5 kW. The resultant pattern fabricated by KUV-10 exhibited a high resolution of 100 nm pitch, as well as the high durability and excellent releasing properties.

The 70 nm thickness of Al layer was deposited on 100 nm pitch KUV-10 pattern to produce flexible WGP on a poly(ethylene terephthalate) film by using a R2R-NIL. Al was deposited by vibration

Table 1. Characteristics of the optimized UV-NIL resin (KUV-10)

formulation	viscosity (cps)	refractive index	surface energy	adhesion	shrinkage (%)
KUV 10	106	1.4965	51.50	5B	8.23

deposition method to avoid Al deposition on the bottom part of the pattern, which can cause the decrease in the transmittance of the film. The optical performance of the polarizer was confirmed by transmittance for both transverse magnetic (TM) and transverse electric (TE) modes (Figure 6).

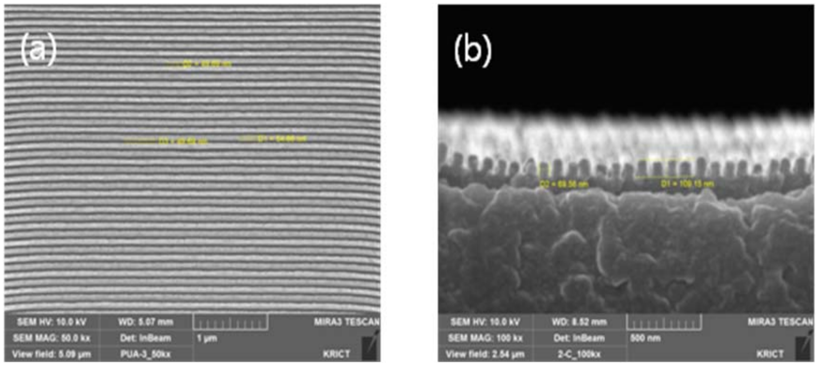

Figure 5. SEM images of (a) R2R nanoimprinted 100 nm pitch pattern and (b) cross section of the pattern from KUV-10.

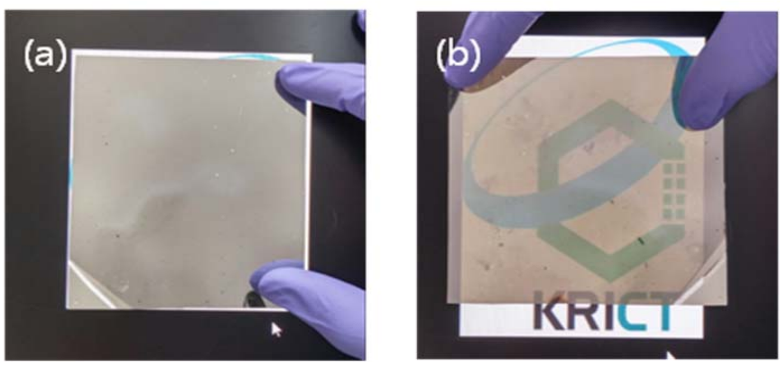

Figure 6. Images of 100 nm pitch polarizer film fabricated by R2R-NIL: (a) TM and (b) TE mode, respectively.

Flexible Replica Mold for 100 nm Pitch NIL

To fabricate the flexible replica mold with UV resins, precise patternability and good demolding property with the master mold are essential characteristics for the UV resins. In addition, pattern on the replica mold should be easily transferred to the UV nanoimprinting resin and demolded from the UV resin. Generally, thermally curable polydimethylsiloxanes (PDMSs) are used for materials for the flexible replica mold, however, it is quite difficult to form the pattern pitch under 200 nm.

In this study, fluorinated siloxane based resins were designed and synthesized for UV resins for the replica mold. Based on this resin, various fluorinated additives were formulated to realize good demolding property and patternability to satisfy the requirements for the replica mold. Especially, by adding urethane acrylate based on siloxane moieties, the pattern transferring property can be further enhanced. Pattern with 100 nm pitch was properly transferred to the optimized replica UV resin (KRUV-2) by the master mold and then with this replica mold pattern was consecutively transferred to KUV-10, as shown in Figure 7.

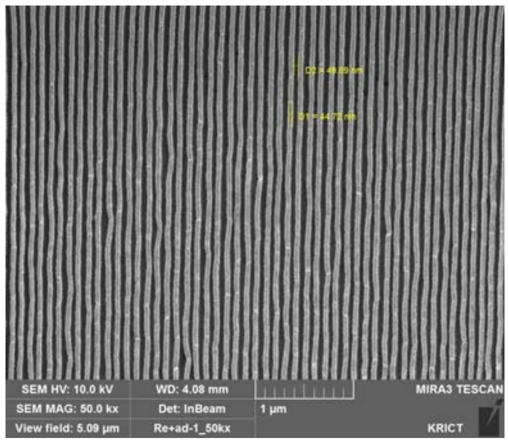

Figure 7. SEM image nanoimprinted KUV-10 from KRUV-2 replica UV resin.

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