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Imprinted Moth-Eye Antireflection Patterns on Glass Substrate

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Sub-micron sized, conical shaped moth-eye structure was transferred to thermoplastic polymer film, such as polyvinyl chloride (PVC) using hot embossing process. Since master template was made of polycarbonate, embossing temperature and pressure were carefully maintained to 100°C and 10 atm. Conical shaped moth-eye pattern was reversed to tapered hole pattern on PVC film. Hot embossed PVC film was then used as transparent template for subsequent UV nanoimprint process, in order to form the conical shaped sub-micron moth-eye structure on glass substrate. After thin layer of Si oxide and monolayer of self-assembled, silane based molecules was coated on hot embossed PVC film. UV nanoimprint process was done on the glass substrate using hot embossed PVC film. As a result, the transmittance of glass substrate was increased from 91 to 94% for single side patterned and 96% for both side patterned glass substrate for the spectral range of 350 to 800 nm.

Keywords: moth-eye structure, anti-reflection nano-pattern, nano imprint, hot embossing, polymer template, reflectance, polyvinyl chloride (PVC)

1. INTRODUCTION

The antireflection property is very important in various kinds of industrial applications including flat panel displays such as LCD (liquid crystal display) and PDP (plasma display panel), solar cell module, lenses, and optical films.[1-4] Although multi-layered optical film has been used for anti-reflection functionality, the overall production process is quite complicated and the anti-reflection property has been found to be limited to a specific spectral region. Many different kinds of anti-reflection characteristics have been found in nature, and they commonly consist of several hundred nanometer sized features. Unlike the multi-layered anti-reflection surface, these anti-reflection surfaces can maintain the anti-reflection property for a wide spectral range. This is the so-called 'moth-eye' structure, named after the anti-reflection nature of nocturnal insects, such as moths. A moth's compound eye is covered with 2~400 nm sized features and thus shows near zero reflectance characteristics.[5,6] Due to the 2~400 nm sized features, which are smaller than the wavelength of visible light, the effective refractive index on the patterned surface varied gradually and, thus, the reflection of light on the patterned surface is drastically suppressed. A FDTD (finite difference time domain) simulation was done for a glass substrate covered with conical shaped features. A commercially available fullwave simulator was used to simulate the reflectance of glass substrate with nano-patterns. The refractive index of glass was given at 1.5. A reflectance value for 632 nm wavelength light on the glass surface was simulated by varying the height and the diameter of the cones. The result of the simulation is shown in Fig. 1. The diameter of the cone was changed from 100 to 1000 nm and the height of the cone was also varied from 100 to 500 nm. According to the simulation results, un-patterned glass substrate has an approximately 4% of reflectance value for 632 nm wavelength light. The surface with cone patterns, smaller than 500 nm, has a much lower value of reflectance. However, the reflectance value increases with the diameter of the cones. The reflectance for 632 nm wavelength light also decreases with an increase in the height of the cones.

Since such a near zero reflectance characteristic is very useful for many industrial applications and can be simply be realized by forming sub-micron sized features on substrates, various patterning techniques, including hot embossing[7] and nano-imprint lithography,[8] anodizing,[9] nano-sphere lithography,[10] and laser holographic lithography[11] have been tried and continuously developed to form nano-sized features and transfer them onto large area substrates. In this paper, the moth patterns of polycarbonate film were reversely transferred to the PVC film by hot embossing. The surface of hot embossed PVC film was then treated for anti-stiction and used as the transparent template for the UV nanoimprint. Finally, on the glass substrate, moth eye nano-

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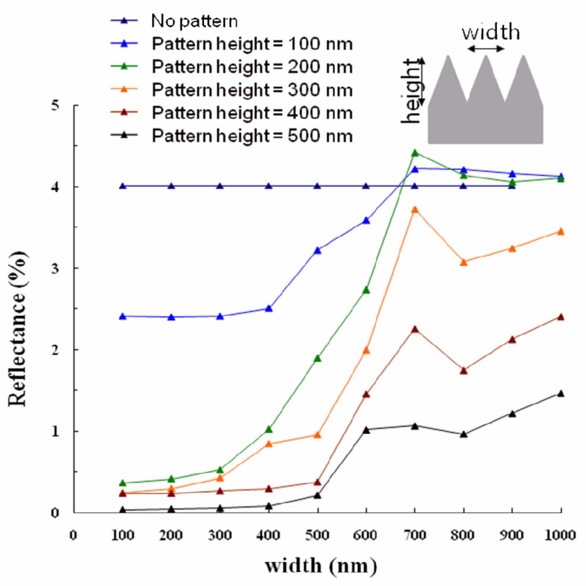

Fig. 1. A FDTD (finite difference time domain) simulation of glass substrate, covered with sub-micron sized conical shaped patterns. A reflectance value for 632 nm wavelength light at the glass surface was simulated with varying the height and diameter of cones. According to the simulation, reflectance value for 632 nm wavelength light reduced as the diameter of cones decreased and the height of cones increased.

patterns were formed using UV nanoimprint lithography.

2. EXPERIMENTAL PROCEDURE

In order to transfer the nano-patterns of polycarbonate plate to PVC films without degradation, a hot embossing process was done at relatively low temperature (100°C) and low pressure (10 atm). PVC was chosen due to its low glass transition temperature and excellent formability.[12] Furthermore, PVC has high transparency in UV and low surface energy, which can prevent stiction during the imprint process. Thus, hot embossed PVC films can be used as transparent templates for UV nanoimprint. A 10 nm thin layer of SiO_2 layer was then deposited on the PVC film by RF sputtering. A trichloro-silane based SAM (self-assembled monolayer) layer was coated to prevent stiction of the imprint resin during the UV nanoimprint process.[13] Due to the nano-patterns and the SAM anti-stiction layer on the PVC film, the contact angle of DI water on the PVC film was as high as 140° and this means the surface was very hydrophobic.

Using the hot embossed PVC film as a template, the UV nanoimprint process was proceeded to form the moth-eye nano-patterns on the glass substrate. UV curable, methacrylate based monomer resin with a refractive index of 1.47 was used. The UV curable resin was solvent free and is commercially available from the Chemoptics Company in Daejeon, Korea.

Both the hot embossing and the UV nanoimprint process

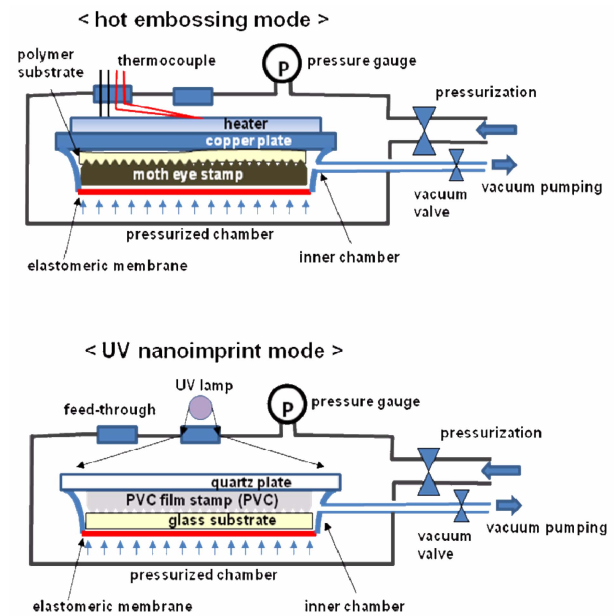

Fig. 2. The schematic of imprint system for hot embossing and UV imprint process. The actual pressing is done by pressurization of outer chamber for uniform pressing over large area substrate.

were done by the same imprint system, made by NND in Seoul, Korea. For uniform pressing over a large area substrate and effective contact and delivery of pressing force between the template and the substrate, a dual chamber imprinting system was used. The schematic of the imprint system is shown in Fig. 2. The imprint system consists of an outer chamber for pressurization; a stack of template and substrate was placed within the inner chamber. Vacuum is applied to the inner chamber to fix the stack of template and substrate and actual pressing is done by pressurization of outer chamber. Both the hot embossing and the UV imprint can be done in the same system. An electrical heater and copper plate is inserted for hot embossing and they are switched to transparent quartz plate and UV lamp for UV nanoimprint process.

3. RESULTS AND DISCUSSION

SEM micrograph and AFM measurement result of the hot embossed PVC film are shown in Figs. 3(a) and (b), respectively. A 150 nm narrow pit pattern with 300 nm in pitch was formed on the surface of the PVC film and the depth of the pit pattern was about 120 nm. Both SEM micrograph and AFM measurement results revealed that the hot embossing process was successfully done on the PVC film; however, many defects were incorporated since the hot embossing process was done at low temperature and pressure. Figure 3(c) shows the reflectance value of the un-patterned PVC film and hot embossed PVC film. Regardless of the high concentration of defects on the hot embossed PVC film, as low as 1% of reflectance value was obtained in spectral range from 300 to 900 nm, while un-patterned PVC film showed 2.5~3.0% of reflectance value. This result implies that reflectance can be decreased by forming the nano-sized patterns on the surface and this effect is very tolerant to the defects.

Nano-sized pattern of hot embossed PVC films were successfully transferred to glass substrate by UV nanoimprint lithography. A mixture of methacrylate monomers with UV initiator, whose refractive index was about 1.47, was used as the UV imprint resin. The UV imprint was proceeded in the same system, used for hot embossing, after replacing electrical heater and copper plate with a transparent quartz plate. UV imprinting was done at room temperature and 5 atm of pressure was applied to transfer the patterns. Top view and oblique view SEM micrographs of glass plate with UV imprinted resist pattern are shown in Figs. 4(a) and (b),

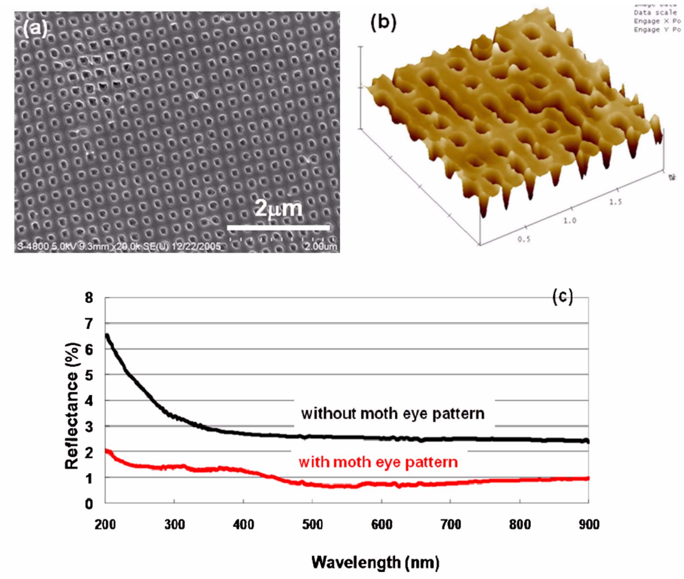

Fig. 3. (a) SEM micrograph of hot embossed PVC film, (b) AFM measurement result of hot embossed PVC film, (c) reflectance measurement of un-patterned and hot embossed PVC films. Regardless of the high concentration of defects on hot embossed PVC film, as low as 1% of reflectance value was obtained in spectral range from 300 to 900 nm, while un-patterned PVC film showed 2.5-3.0% of reflectance value.

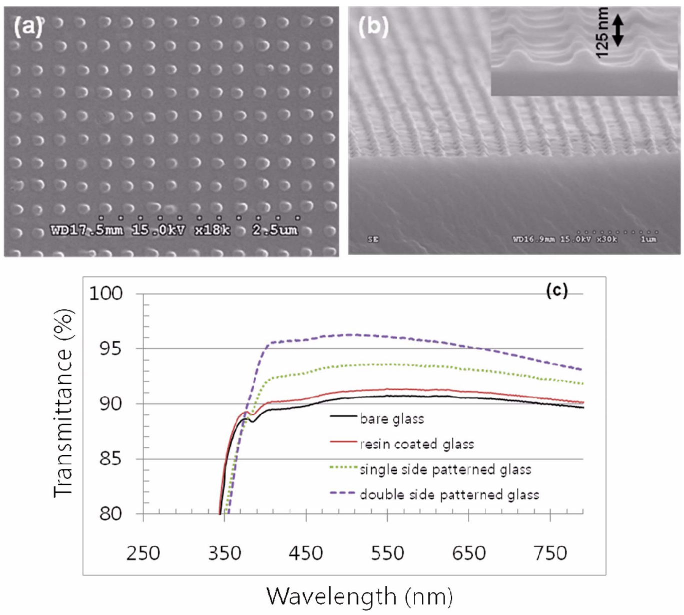

Fig. 4. (a) Top view SEM micrographs of glass plate with UV imprinted resist pattern, (b) Oblique view SEM micrographs of glass plate with UV imprinted resist pattern, (c) Transmittance values of the bare glass plate, the glass plate coated with UV imprint resin, the single side patterned glass plate with moth-eye structure and the both side patterned glass plate with moth-eye structure with respect to the wavelength from 350 to 800 nm.

respectively. Figures 4(a) and (b) showed that a conical shaped resist pattern of 100 nm in diameter and 300 nm in pitch was formed on the surface of glass plate and the height of the cone pattern was less than 70 nm. Transmittance values of the bare glass plate, the glass plate coated with UV imprint resin, the single side patterned glass plate with moth-eye structure, and, the both sides of the patterned glass plate with moth-eye structure were shown in Fig. 4(c). For the spectral range of 350 to 800 nm, the transmittance value of bare glass substrate and glass substrate coated with UV imprint resin was about 90%; however, the transmittance value for the single side patterned glass plate increased to 94% and that for both side patterned glass plate increased to 96%. Regardless of the low aspect ratio conical patterns on glass substrate, the transmittance value increased up to 6%. Further increase of transmittance value can be achieved by forming the high aspect ratio patterns on the glass plate.

4. SUMMARY

Moth-eye structure patterns were formed on a glass substrate using UV nanoimprint lithography. Due to the moth-eye nano-structures on the glass substrate, which were made of UV imprint resin, the transmittance value of the glass plate was increased from 90 to 96% for the wavelength from 350 to 800 nm.

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