Journal of Materials Processing Technology 238 (2016) 1–6

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Fabrication of metallic nanomesh structures using phase shift lithography and its application to touch screen panels

Sung-il Chung[a,*], Pan Kyeom Kim[a], Young-woo Kwon[a], Tae-gyu Ha[a], Ji-won Hur[b], Kyu-man Lee[b,c]

[a] Miryang Nano Center, Korea Electrotechnology Research Institute, Nano Science and Technology Building, Pusan National University Miryang Campus, 1268-50, Samnangjin-ro, Samnangjin-eup, Miryang-si, Gyeongsangnam-do, 50463, Republic of Korea
[b] PE-Task Team, Wooree Newoptics, 314 Nam-myeon, Hyuam-ro 392beon-gil Yangju-si Gyeonggi-do, 11407, Republic of Korea
[c] Department of Conversing Technology, Hoseo Graduate School of Venture, Nambusunhwan-ro 2497, Gwanak-gu, Seoul, 06724, Republic of Korea

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form 16 June 2016
Accepted 2 August 2016
Available online 3 August 2016

Keywords:
Transparent conducting electrodes
Phase shift lithography
Touch screen panel
Metal mesh
Ag paste
Nanomesh-shaped nickel mold

ABSTRACT

This study reports on the fabrication process of a nanomesh-shaped nickel mold by using phase shift lithography. We also present its application to a transparent electrode film for a touch screen panel. A suitable gap between the checkerboard- shaped patterns on a photomask was chosen to obtain the nickel mold with a mesh-shaped pattern connected to each other. A nanomesh-type trench pattern was transferred from the nickel mold onto a polyethylene terephthalate film through the imprinting lithography process with ultraviolet light. The nanomesh- embedded electrode pattern was fabricated by filling the nanotrench with Ag paste. The light transmittance and sheet and line resistance of the nanomesh-type transparent conducting electrode film were evaluated. The TCE film was then applied to a 7 in. touch sensor module.

1. Introduction

Transparent conducting electrodes (TCE) are a key component in many optoelectronic devices, including photovoltaics (Granqvist, 2007), organic light-emitting diode (OLED) (Gu et al., 1996), and touch screen panels (TSP) (Bae et al., 2010). Currently, indium tin oxide (ITO) is widely used as an electrode material because of its high optoelectronic performance. However, the brittleness of ITO (Chen et al., 2001) increases the need for substitutional materials, such as carbon nanotube, graphene, metal mesh, and random networks of metallic nanowires (Gaynor et al., 2011). The capacitive-type TSP of a large-area particularly requires a transparent electrode with a much lower sheet resistance, without decreasing the transmittance to achieve multi-tasking and multi-touch function with high quality. Thus, bodies of researches on the metal-mesh-based TCE film have been actively performed in the field of touch panel industry.

The two types of metal-mesh-based TCE film are the protruded and embedded patterns. On the one hand, the protruded pattern is made on the polymer substrate through the printing (Choi et al., 2015a, 2015b), lift-off (Kim et al., 2015), and etching processes (Hautcoeur et al., 2011), among others. On the other hand, the embedded pattern can be fabricated by filling the trench structures on the flexible substrate with electrode material (Chen et al., 2012). The embedded mesh pattern on the flexible substrate (e.g., polyethylene terephthalate (PET) film) may generally cause a better adhesion than the protruded mesh pattern because the metallic pattern deposited on the polymer substrate is likely attacked by humid air, which is passed through the polymer substrate (Choi et al., 2015a,b). In addition, the embedded pattern, which successfully filled the trenches with a high aspect ratio, may be formed thicker than the protruding pattern. Consequently, the TCE film with an electrode embedded in the trench pattern with a high aspect ratio has a lower sheet resistance at a given light transmittance (van de Wiel et al., 2013).

(Yu et al., 2013) fabricated the embedded micromesh-type TCE film with superior transparency and sheet resistance compared to the conventional ITO films. However, appearance problems, such as the moiré phenomena and the pattern visibility issue, must be solved so that the micromesh-shaped transparent electrodes can be applied to the TSP (Shin and Park, 2015). One of the best methods to solve these TSP problems is the use of nanomesh for the TCE film.

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[*] Corresponding author.
E-mail address: sichung@keri.re.kr (S.-i. Chung).

http://dx.doi.org/10.1016/j.jmatprotec.2016.08.002
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We report herein on the fabrication process of metallic nanomesh structures by using phase shift lithography. We then present its application to a transparent electrode film for a touch screen panel. The nickel mold was prepared through the phase shift lithography (Rogers et al., 1997) and electroforming processes (Kim and Mentone, 2006). A nanomesh-type trench pattern was transferred from the nickel mold onto a PET film through the imprinting lithography process with ultraviolet (UV) light. The nanomesh-embedded electrode pattern was then fabricated by filling the nanotrench with Ag paste. The TCE film, on which the Ag paste-based nanomesh pattern was embedded, was then finally applied to the 7 in. TSP module.

2. Experimental details

2.1. Nickel mold preparation

We fabricated the nickel mold to form a nanotrench pattern on the PET film through the phase shift lithography process. The process has the advantage of quickly and economically fabricating a nanopattern on a large area using a phase mask with UV light. Kwak et al. (2012) stated that the nanomesh pattern can be fabricated through the phase shift lithography with a specially designed elastomeric phase mask.

Fig. 1 shows a schematic illustration of the fabrication process of the nickel mold that formed a nanotrench pattern. First, a photomask (Cr mask) with a checkerboard-shaped pattern was placed on a substrate to prepare the master pattern for the phase mask. A positive tone photoresist (AZ GXR 601, AZ Electronic Materials) was coated in 2 μm thickness on the substrate, and baked at 110 °C for 1 min (Fig. 1(a)). A UV exposure with an intensity of 30 mJ/cm^2 was then performed. Subsequently, the photoresist was developed for 90 s in a 300MIF developer (AZ Electronic Materials). Fig. 1(b) shows that the checkerboard-shaped pattern can be fabricated on the glass substrate.

An elastomeric phase mask was then fabricated from the master pattern. For the phase shift lithography process, the air gap between the phase mask and the photoresist provided a significant effect on the pattern line width because the light intensity difference at the interface between the wall and the air region on

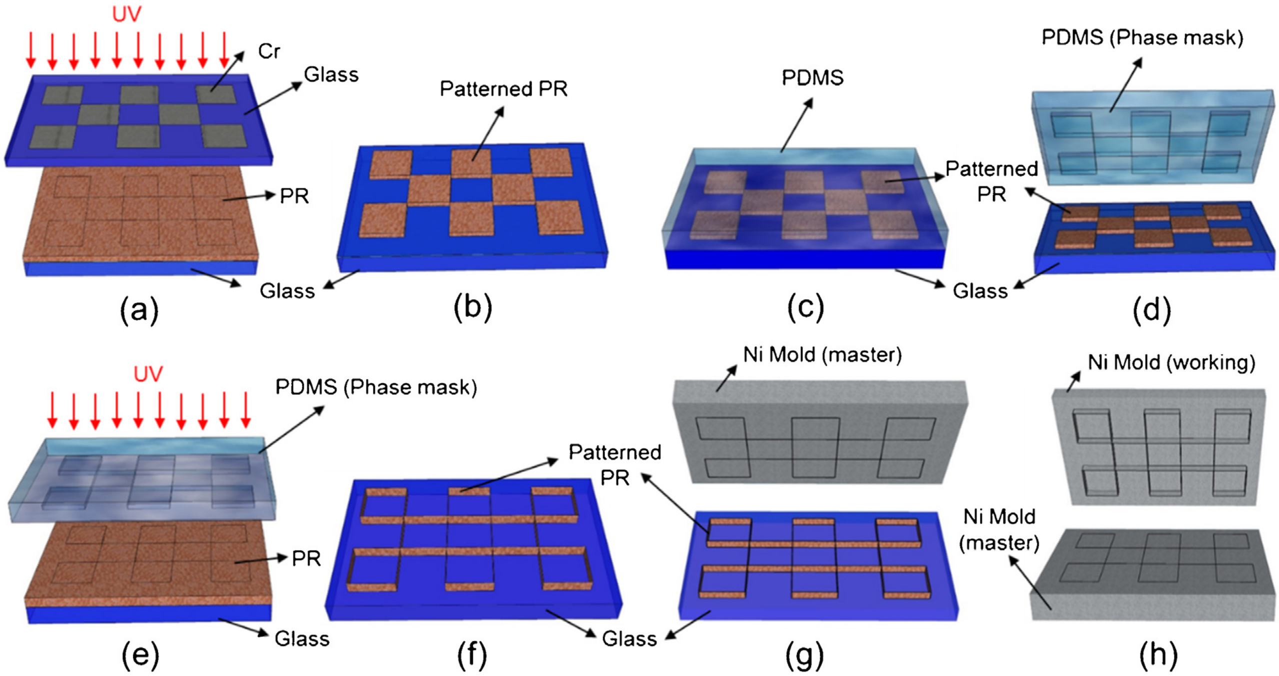

Fig. 1. Schematic illustration of the nickel mold fabrication process through phase shift lithography process: (a) photo lithography process with a conventional photomask (Cr mask), (b) master pattern for a phase mask, (c) PDMS pouring and curing process, (d) phase mask, (e) phase shift lithography process with a phase mask, (f) master pattern for a nickel mold, (g) master mold (mesh-shaped trench structure), and (h) working mold (mesh-shaped protruded structure).

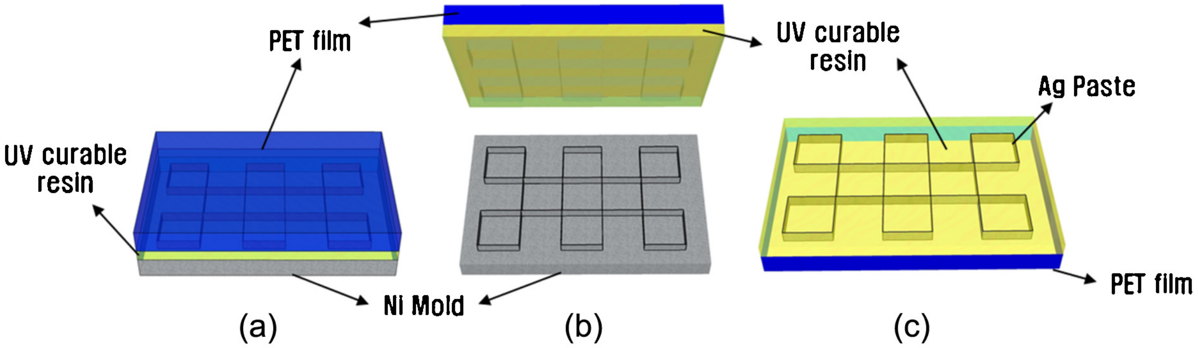

Fig. 2. Schematic illustration of the fabrication process of the Ag paste-based nanomesh electrode: (a) Pouring process of UV curable resin over a working mold, (b) Peeling off the nanotrench-patterned film and (c) the Ag paste filled TCE film.