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Screen-offset printing for fine conductive patterns

Ken-ichi Nomura [a,*], Hirobumi Ushijima [a], Ryosuke Mitsui [b], Seiya Takahashi [c], Shin-ichiro Nakajima [b]

[a] Flexible Electronics Research Center, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan
[b] Product Development Center, Japan Aviation Electronics Industry, Limited, 3-1-1 Musashino, Akishima, Tokyo 196-8555, Japan
[c] Production Engineering Department, Connector Division, Japan Aviation Electronics Industry, Limited, 3-1-1 Musashino, Akishima, Tokyo 196-8555, Japan

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ABSTRACT

Screen printing is a useful method for fabricating electrodes or signal wires of electronic devices. However, finer patterns, e.g., 50-μm-wide, are difficult to form. Herein, we introduce a newly developed printing technique called "screen-offset printing," as a candidate method for solving this problem. In this process, first, ink patterns are screen-printed on a silicone-resin blanket; they are then transferred from the blanket to an object. In the present study, we analyze the features of screen-offset printing by observing printed conductive patterns, and elucidate the impact of this method by comparing the experimental results of screen-offset printing and conventional screen printing. In addition, we demonstrate the fabrication of fine patterns with a line and space (*L*/*S*) of 50/50 and 30/30 μm.

1. Introduction

Printing technology has attracted much attention because of its potential to create a new paradigm in electronics fabrication [1–3]. Compared with the conventional subtractive process based on a photolithographic technique, printing allows additive-type patterning, which reduces both environmental load and fabrication cost. Among various printing methods, screen printing is widely used owing to its high machine reliability, low cost of screen mask, and simple fabrication process. For instance, electrodes or signal wires of devices such as solar cells [4–8], multilayer ceramic capacitors [9–13], and touch screen panels [14] are fabricated either partly or completely using screen printing. As a matter of course, the size of screen-printed patterns has decreased owing to technological advancement, and this has led to higher-performance electronic devices. At present, the minimum width of mass-produced screen-printed conductive patterns is approximately 70 μm. However, patterns of considerably lower widths are very difficult to form. There may be many causes underlying such difficulty, but the major one seems to be the bleeding of the ink printed on a substrate [15]. Bleeding can possibly be prevented using high-viscosity ink. However, high-viscosity ink often results in faint prints because the ink barely passes through the screen mesh. Therefore, this problem could be solved by improving the printing process rather than the ink itself.

To address this issue, we have newly developed "screen-offset printing," which is a combination of (i) screen printing onto a silicone-resin blanket and (ii) ink transfer from the blanket. The present paper introduces the procedure of this new printing method. Furthermore, we detail its features by comparing conductive patterns formed by screen-offset printing and conventional screen printing and demonstrate the fabrication of 50- and 30-μm-wide patterns.

2. Experimental section

Fig. 1 shows a schematic image that explains the screen-offset-printing process. An ink is directly printed onto an objective in conventional screen printing. However, in screen-offset printing, the ink is first screen-printed on a silicone-resin blanket with a flat surface and then transferred to an objective. In the present experiment, we used a hand-powered screen-printing machine (Tokyo Process Service ZT320-T3) for screen printing and a rubber hand roller for ink transfer. Ag ink (Namics HIMEC Type ×7109), containing diethylene glycol monobutyl ether as the main solvent, was employed as the conductive ink, and polydimethylsiloxane (PDMS, Shin-Etsu Chemical) was used as the blanket material. The Ag ink pattern was formed on a ceramic green sheet, which has a ceramic dielectric layer on a polyethylene terephthalate film. Two screen masks were employed: screen Mask A (Tokyo Process Service) with a 300-μm-wide straight-line pattern and screen Mask B (Murakami) having 10 straight lines with a line and space (*L*/*S*) of 50/50 μm. In addition, Mask B has another 10 straight lines

* Corresponding author. Tel.: +81 29 861 2995; fax: +81 29 861 6821.
E-mail address: k-nomura@aist.go.jp (K.-i. Nomura).

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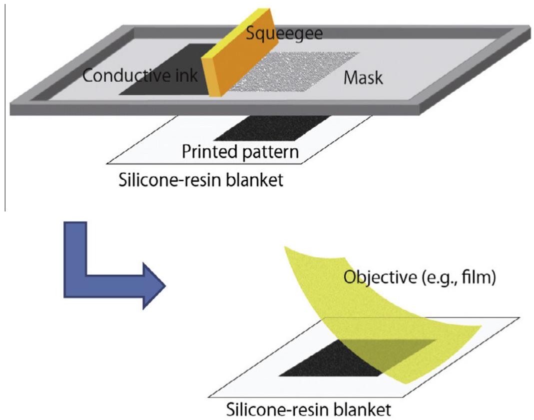

Fig. 1. Schematic image of screen-offset printing.

Table 1
Specifications of screen masks used in this study.

Screen mask	Mesh count (inch^{-1})	Wire diameter (μm)	Mesh thickness (μm)	Emulsion thickness (μm)
A	325	28	48	14
B	500	16	20	10

with an L/S of 30/30 μm. The mesh count, wire diameter, mesh thickness, and emulsion thickness of each screen mask are summarized in Table 1. The fabricated patterns were observed using confocal laser scanning microscopy (CLSM, Olympus and Shimadzu LEXT OLS3500/SFT-3500) and optical microscopy (Keyence VW-9000 with a lens kit VH-Z100R).

3. Results and discussion

First, a 300-μm-wide straight-line Ag pattern was printed using Mask A. Fig. 2(a) shows a three-dimensional CLSM image of the pattern formed by the conventional screen-printing method. The pattern has a round cross section because of ink bleeding. Furthermore, its sidewall is significantly winded. The maximum width is approximately 330 μm, but the designed width is 300 μm. Fig. 2(b) shows the CLSM image of the pattern formed by screen-offset printing. The pattern has a rectangular cross section, sidewall winding is decreased significantly, and the pattern retains its ~300-μm width. Fig. 2(c) and (d) show microscopic images corresponding to Fig. 2(a) and (b), respectively. From these figures, it is also found that ink bleeding occurs in the case of screen printing, whereas screen-offset printing can prevent ink bleeding. It has been reported that PDMS absorbs the various organic solvents in ink [16], thus resulting in the ink printed on the PDMS blanket having a very high viscosity; such ink is also called “dry ink” [17]. Therefore, the ink does not bleed on the blanket, as clearly indicated by the transferred pattern shown in Fig. 2(d) and its retained rectangular shape shown in Fig. 2(b). This implies that for screen-offset printing, it is important to choose an ink such that PDMS can absorb associated solvents.

In some cases, the winding of a conductive pattern, as shown in Fig. 2(a), may be fatal for electronic devices, especially high-frequency devices such as radio frequency identification (RFID) tags, which operate at ultra-high frequencies (UHF). This is because winding results in high electrical resistance since current flows along the surface of the conductive pattern owing to the skin effect [18,19]. For example, the skin depth of Ag is around 1.5 μm at 2.45 GHz [19]. From this viewpoint, it is preferable to form patterns with straightened sidewalls, and the fact that screen-offset printing can realize this is important.

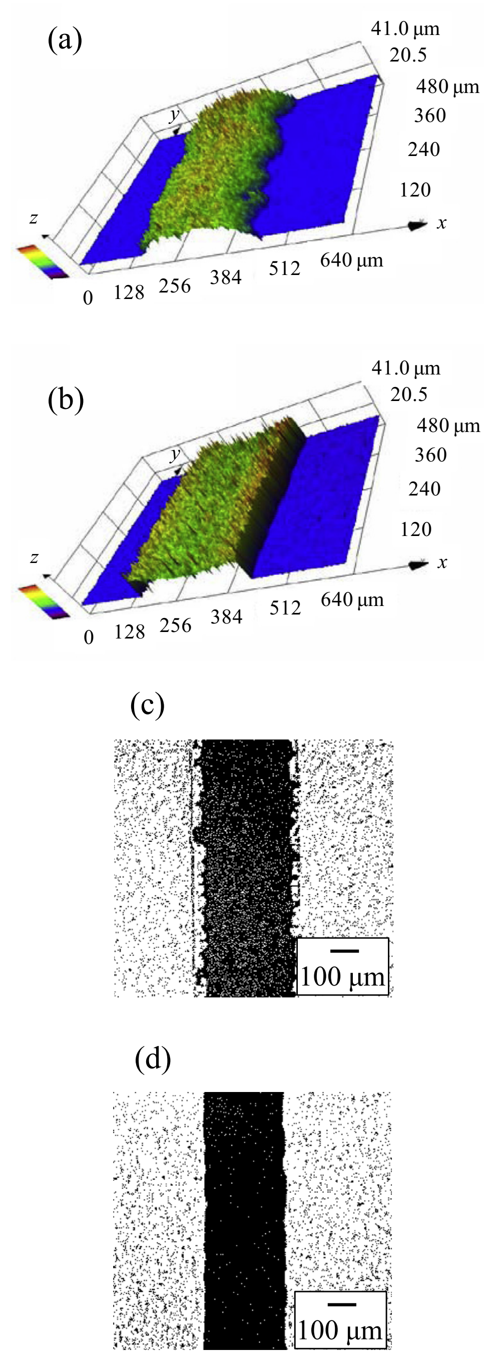

Fig. 2. Three-dimensional CLSM images of Ag patterns fabricated using (a) conventional screen printing and (b) screen-offset printing. (c) and (d) show microscopic images corresponding to (a) and (b), respectively.

In addition, recent electronic devices fabricated using screen printing, especially touch screen panels and solar cells, warrant finer conductive patterns for achieving improved functionalities and properties. To this end, a fine Ag pattern was printed using Mask B. Fig. 3(a) and (b) show the 50/50-μm patterns fabricated using conventional screen printing and screen-offset printing, respectively. The pattern widths increase in the case of screen printing owing to ink bleeding (Fig. 3(a)), whereas the patterns maintain their original widths in the case of screen-offset printing (Fig. 3(b)). Fig. 4 shows the 30/30-μm patterns formed using (a) screen printing and (b) screen-offset printing. Ten discrete straight