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Printing Technology for Stress-Free Human Monitoring Devices

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Abstract

Human monitoring has attracted considerable attention for various reasons, including its potential in the extension of healthy life expectancy. The key to successful human monitoring is the elimination of stress-inducing factors. Thus, sensors should be positioned such that users do not feel discomfort during monitoring. Printing technology that uses a soft silicone blanket can fabricate fine conductive sensor patterns on various substrates (e.g., film, textiles, and adhesives) and complex shapes. Consequently, sensor structures can be fabricated on any everyday object in such a way that the sensors are unnoticeable. This study presents newly developed printing techniques and their application in devices designed for stress-free use, e.g., a proximity sensor and a textile-based sensor.

1. Introduction

Across the globe, the average life expectancy has been increasing continuously, which may be attributed to advancements in various technologies, especially medical technologies. However, the declining birth rate and the growing aging population have created a major challenge in the form of a dwindling working population, which is especially severe in Japan [1]. Thus, the burning issue is the extension of *healthy life expectancy* through daily health management.

For successful independent daily monitoring of healthcare metrics by individual, the most crucial factor is that sensors should be arranged such that users do not feel discomfort. The ultimate solution is non-contact and invisible sensors. Another solution is to fabricate sensors onto everyday objects such as clothes, furniture, and stationery to ensure that these devices are unnoticeable. However, these everyday objects rarely have extensive flat surfaces because they have complex shapes, and it is difficult to fabricate conductive sensor patterns onto such surfaces.

To address this challenge, printing techniques that use a silicone blanket have been developed, with conformal printing being the most promising. These printing techniques can fabricate patterns onto complex surfaces, including spherical surfaces and textiles with bumpy surfaces and voids. This study examines the newly developed printing techniques and their application in devices designed for stress-free use.

2. Transfer printing using a silicone blanket

Figure 1 presents a schematic illustrating screen-offset (SOS) printing using a silicone blanket: ink is first screen-printed onto the blanket, and then the ink patterns on the blanket are transcriptionally fabricated on the final substrate [2]. There are two critical characteristics of the blanket that facilitate successful pattern formation. One is that silicone absorbs organic solvents in ink [3]. Thus, the ink patterns become a solid-like phase on the blanket, and smudging does not occur even if the substrates are highly permeable materials such as paper and textiles. The second is that silicone is soft. Thus, silicone deforms along with the complex surfaces while transferring the ink pattern. There are other transfer printing techniques, such as gravure-offset [4] and reverse-offset printing [5], which are suitable for fabricating fine patterns, whereas SOS printing excels at forming thicker patterns. This should be considered when selecting what technique to apply.

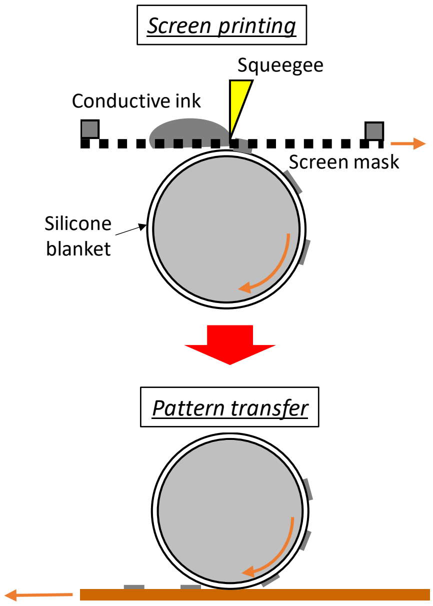

Fig. 1 Schematic illustrating screen-offset printing.

3. Stress-free applications and related technologies fabricated using SOS printing

In conformal printing, the ink patterns stretch slightly during printing. Thus, thick patterns are preferable for preventing open circuits. In this respect, SOS printing is the most suitable among other printing techniques. This section explores some applications in stress-free devices and relevant fabrication technologies that use SOS printing.

Film-Type Proximity Sensor Fabricated Using Duplex Printing

SOS printing can achieve duplex printing via a combination of screen printing [6]. Using this technique, a mutual capacitance type film-type proximity sensor can easily be fabricated (Fig. 2(a)). AC voltage is applied to the top electrodes while the bottom electrode is connected to GND. The lines of electric force leak spatially due to the difference in electrode size. If a human body enters this leak space, the capacitance of the sensor decreases, indicating that a human is in the vicinity of the sensor. If we place the sensor on the backside of a bed, the breathing of the individual on the bed can be monitored (Fig. 2(b)) without the users noticing the sensor.

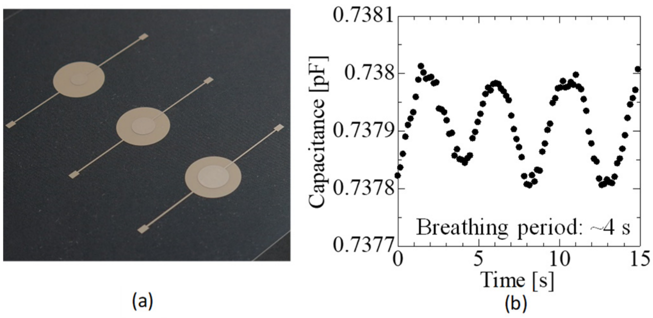

Fig. 2 (a) Film-type proximity sensor fabricated using duplex printing. (b) Breathing detection using the film-type proximity sensor positioned on the backside of a bed.

Textile-Based Sensor

Textiles are extensively utilized in the medical, fashion, and furniture industries. Figure 3(a) presents images of a cotton textile fabric on which Ag ink has been fabricated. Although ink generally bleeds in textiles because of its fluidity, this 500-µm-wide ink pattern bridges over the voids of the textile without smudging. Furthermore, the ink does not permeate the bottom surface. With this technique, we successfully fabricated a blood leakage sensor for hemodialysis that distinguishes blood from other liquids from electrical impedance spectra [7]. Figure 3(b) presents another application: a shade lamp, with a logo fabricated onto textile using Ag ink. The logo blends into its environment as a design artifice, but it is also an electrode of a self-capacitance type proximity sensor, functioning as a non-contact-type switch of the lamp.

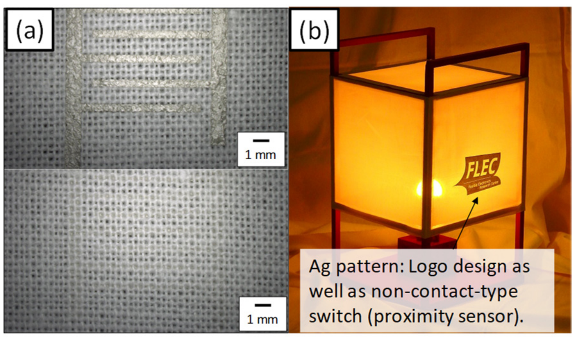

Fig. 3 (a) Textile-based sensor for blood leakage detection with SOS-printed electrodes. (b) Shade lamp with SOS-printed proximity sensor electrode functioning as a light switch.

Printed Wire Bonding

To drive fabricated devices, interconnection between the printed patterns and electrodes of the electronic chips or components is indispensable. Thus, we introduced two SOS printing-based room temperature interconnection techniques that address the challenges of flexible interconnection using adhesives [8] and printed wire bonding. Figure 4(a) presents an example of an adhesive-type flexible interconnection. Thin Si chips with face-up and face-down pads are interconnected via an adhesive force. SOS printing easily forms patterns on adhesives, which is challenging with other printing methods. Figure 4(b) presents the printed wire bonding technique achieved using SOS printing. The printed wires run on a 200-µm-thick ASIC chip with face-up pads. SOS printing can be used extensively for fabricating various devices and interconnections.

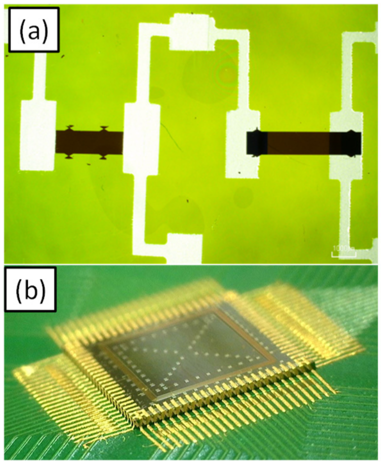

Fig. 4 (a) Adhesive-type interconnection. The wires were fabricated using SOS printing. (b) Printed wire bonding for interconnection of Si chips.

4. Conclusions

SOS printing using a soft silicone blanket can be applied to various substrates, including textiles, adhesives, and complex-shaped objects on which it is challenging to fabricate patterns using conventional methods. This conformal fabrication technique is expedient for creating stress-free sensors such as invisible non-contact type sensors and those that blend with the environment.

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