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Repairing of Pattern Defects on OTFT by Fountain Pen Nano-Lithography

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The patterning by Fountain-pen nano-lithography (FPN) with silver nanoparticles ink was reported. The FPN, a kind of pen-type nano-lithography technique, enables on-demand patterning of micro-meter size at wide area. At first, preparation of silver nanoparticles ink and patterning condition by FPN with the ink were investigated. Then the printed wires with disconnection of OTFT were repaired by FPN with the ink. The repaired lines showed electrical conductivity. These results suggest the possibility that the FPN technique is able to become powerful tool for repairing of device patterning.

Keywords Nano eNabler; pen-type lithography; silver nanoparticles ink

Introduction

Recently, the electronics device fabrication by printing has been studied extensively [1–5]. The printing technique with stamps is suitable for quantity production using stamps repetitively. However not all of printed pattern are completed finish. Some patterns have defects and/or disconnections. In many case, existing only one defective, printed pattern is not worked at all. If inferior products are repaired in each case, it is expected improving yield. Therefore research and development of the repairing technique for printed pattern is also important subject.

Since arbitrary patterning is required in the case of the pattern repair, direct patterning methods is effective more than using stamp or mask print methods. The typical direct printing technique is ink-jet printing. Recently, device fabrication by ink-jet printing is extensively studied [1–3]. However, minimum printable line width by conventional ink-jet system is 10 μm. On the other hand, patterning width for OTFT fabrication by microcontact printing using silicone rubber stamp has achieved sub-micrometers [5]. In that surroundings, it is also required to develop the methods for pattern repair and fabrication by others direct patterning methods.

The pen-type nano-lithography, using SPM probe or cantilever as a pen point, enables direct patterning of micro/nano-meter size [6–13]. Fountain-pen

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nano-lithography is one of the pen-type lithography techniques. The technique uses the modified AFM cantilever with an ink reservoir and a microchannel as a pen point [9–13]. The liquid-ink is filled in the reservoir on the pen point, and then flow onto the surface when in contact. The technique is able to draw micrometer-size dots and lines on large area, since the reservoir keeps enough amount of the ink. In previously, we reported the patterning of silane coupling molecules at wide area using the FPN [11].

The FPN patterning mainly has done for biomaterials and bio-related materials [10,12]. There are very rare cases of patterning for the electronics devices [13]. It is expected that FPN become powerful tool for repairing and fabrication of organic devices, if the technique is able to pattern of metallic, conductive and/or semiconductor materials.

In this work, we demonstrate the patterning of silver nanoparticles ink by FPN. Silver nanoparticles ink is often used to fabricate electrodes and wire lines on OTFT. At first, we describe ink preparation, and demonstrate patterning of dot array and line and space. Then we tried pattern repair for disconnection on printed wire patterns of OTFT by the FPN. The repaired wire showed ohmic resistance. It suggests that the technique has a potential to become repair tool for electric device patterning.

Experimental

The substrates used for patterning were a glass and a polycarbonate film with printed wiring. Used silver nanoparticles ink was purchased from NIPPONPAINT Co., Ltd. Patterning was carried out by Nano eNabler^{TM} system with surface patterning tool (SPT) (BioForce Nanoscience Inc., USA.) [9,10]. The Nano eNabler is equipped with a high-resolution XYZ motion control platform and surface contact force detection system. The SPT corresponds to the fountain-pen part with a microchannel and an ink reservoir in the system. The microchannel width of used SPTs was 10 μm. Also the SPTs were treated by VUV lamp (eximer lamp with $\lambda = 172$ nm) before loading the ink. FPN patterning was confirmed by the optical microscope, VH X 1000 system (KEYENCE Co. Japan). Pattern thickness was measured by microfigure measuring instrument, Surfcorder ET4000 (Kosaka Laboratory Ltd. Japan).

Results and Discussion

The FPN patterning by using only the original silver nanoparticles ink was not successful. The ink was dried and did not through the microchannel on the SPT. To resolve the problems, the ink required some additives, which was for preventing drying and to passing through the microchannel on the SPT. Ethanol is the main dispersant of the silver nanoparticles ink. The ink also includes some surfactants and more. The additive is required properties which is not only increasing of vapor pressure and adjusting the viscosity but also having affinity for these materials and keeping dispersibility of the silver nanoparticles. Some additive, as glycerin and 2,4-dimethyl-1,5-pentanediol etc., were nonqualified. We found that diethylene glycol (DEG) was one of suitable additive materials for the silver nanoparticles ink.

Figure 1 shows optical microscopy images of NeN patterning results using the silver nanoparticles ink with DEG 25%. Figure 1(a) is 5×5 dot array. These dots diameter was from 16.2 μm to 24.2 μm. The average of them was 21.5 μm. And Figure 1(b) and (c) shows whole image and closeup image of the line and space

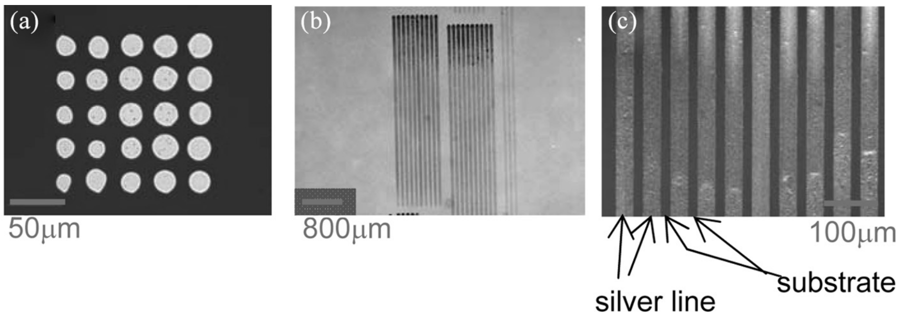

Figure 1. Optical microscopy images of NeN patterning on the glass with the silver nanoparticles ink (a) was 5×5 dot array pattern; (b) was line and space pattern; and (c) is close up image of Figure 1(b).

pattern, respectively. Theses lines length and width were more than 2 mm and around 36 μm, respectively. The NeN set-up was able to draw multiple lines longer than 5 mm (not shown). These dots diameter and lines width were reasonable, since the width of the microchannel and the pen-tip was 10 μm and 30 μm, respectively.

In the case of dot array pattern (Fig. 1(a)), dots size had varied. One of the reasons is difference of local surface wettability on the patterning field. In the array pattern, the NeN patterning direction was from low to upside, and from left to right. Thus left lower dot was starting point, and top right dot was finish point. In major trend of the dot diameter on the array pattern, left lower dot was small. Dots become larger with progression of patterning, and dots at the right area were approximately same diameter. It is suggested that the ink supply from the tip-point to the surface at the initial period is indefinite, and it become constant supply with patterning. It is considered that the factors determining the ink supply amount, for example viscosity, surface tension, and vapor pressure of the ink, are also the reasons for patterning size decision.

Then we tried to repair of printed wire pattern with disconnection on an OTFT by using the NeN with the silver nanoparticles ink. Figure 2(a) shows optical microscopy image of printed wire pattern with disconnection on a polycarbonate film. The lengths of the wires between electrodes were about 2.8 mm and 3.3 mm. All printed lines had wire disconnections around center. Figure 2(b) and (c) shows repaired the pattern defects by NeN with the silver nanoparticles ink. The defect parts on these lines were buried by the ink.

The silver nanoparticles ink shows conductivity after annealing. The specimen film was annealed at 450 K 30 minutes after patterning. Then, to confirm conductivity of these lines, we measured electric resistance of these repaired lines against 1.0 V between the electrodes. As a result, some lines showed ohmic resistance. Table 1 shows the thickness and electric resistance of the repaired parts and non-broken wire patterns. The resistance of repaired parts was relatively large comparing with originals. The thickness of the repaired parts was thinner than originals. It means that cross section is smaller than originals one. This is one reason of high resistance of repaired parts. The resistance and thickness of the original patterns showed similar resistance and similar thickness. In contrast, the resistance of the repaired parts showed around 150 Ω, although the thickness has variability. This suggests that other factors also contribute the resistance increasing. One factor

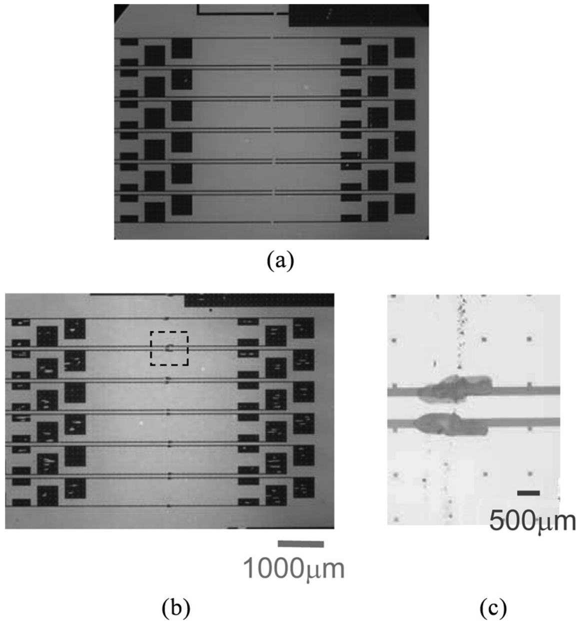

Figure 2. Optical images of pattern repairing by NeN. These wire patterns were printed on the polycarbonate film. These lines had electrodes on both sides (a) was of before repairing image. All lines had disconnections around wire center; (b) was of after repairing image; and (c) was close up image of repaired parts. The close up part is of square area in Figure 2(b).

would be nonuniform thickness of the repair parts. Additionally, the contact between repaired parts and remaining parts would not be smooth. For example, drying the ink on the repair part, the repair parts would have cracks, air bubbles, precipitations of surfactants from the ink, and/or contaminations. The silver nanoparticles would aggregate inhomogeneously. These factors would become a barrier for the contact. These matters would depend on drying process of the ink, ink property, surface conditions and the environment at patterning and drying

As previous mentioned, surface property and ink property such as viscosity, surface tension and vapor pressure, and environment factors at drawing and drying are contribute patterning size as well as expression of the function. We conclude that

Table 1. Electric resistance and pattern thickness of wire-patterns. Electric resistance was measured between the electrodes. The measurement was done for each three wire patterns of repaired part and non-broken (original one)

	Electric resistance [Ω]	Thickness [nm]
Original wire pattern (1)	105.6	246
Original wire pattern (2)	99.1	238
Original wire pattern (3)	101.3	244
Repaired part (1)	135.1	95
Repaired part (2)	147.7	134
Repaired part (3)	143.4	65

these factors are influenced to other factors, which is related in the ink, pen-tip, substrate and the environment. To control the figure and the function by the NeN patterning, more consideration of the relation between these factors is required.

Summary

We demonstrate the patterning by the FPN using the silver nanoparticles ink. At first, dot array pattern and line and space pattern were demonstrated. And then we tried pattern repair for disconnection on printed wire patterns of the OTFT by the FPN. The repaired wires showed ohmic resistance.

These results suggest that the technique has a potential to become repair tool for electric device patterning. However, to control patterning size and to get the function of the patterned ink, it is necessary further study not only ink and surface properties and environment at drawing and drying process but also the relations between above factors.

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