Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp439-440

Direct Formation of Metal Patterns for Flexible Electronic Devices

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Abstract

In this work, the selective electroless plating method is used to direct fabricate high-resolution and highly conductive metal patterns on flexible substrates for applications in large-scale flexible integrated circuits and devices. The surface of the substrate was first modified and patterned by UV irradiation assisted with the photomask. After that, the selective electroless plating is studied. The surface states of substrates before and after UV-ozone treatment were analyzed for understanding the selective electroless plating process. The plating parameters including temperature, stirring rate, and time were investigated to achieve high-resolution and highly conductive metal patterns. The achieved metal patterns were evaluated in terms of conductivity, adhesion test, and flexibility. Finally, multi-layer metal patterns and possible applications are demonstrated.

1. Introduction

In recent years, flexible electronic devices have attract-ed increasing attention because they are bendable and even foldable. Some possible applications have been developed, such as folding displays, wearable solar cells, and wearable biomedical sensors, which will be widely used in next-generation smart electronic devices and medical equipment. Flexible circuits are one of the most crucial parts of flexible electronic devices, which need to be highly conductive, flexible and high-resolution.

Many microfabrication methods, such as photolithography, electron beam lithography, ink printing, screen printing, vacuum evaporation, and magnetron sputtering, have been developed to fabricate metal patterns on the surfaces of various substrates. Over the past decades, the photolithography technique has been a dominant method for metal patterning. However, this method as one subtractive manufacturing process is time-consuming, material-wasting, and requires expensive equipment and harsh manufacture condition. In contrast, printing methods as additive manufacturing process are simple and efficient. In addition, printing method enables electronic circuits and devices to be highly compatible with various plastic substrate materials rather than conventional hard silicon wafers or printed circuit boards, which is giving rise to new flexible electronic devices. Nevertheless, the printing methods also have some issues, such as the need for appropriate conductive inks, high sintering temperatures, low conductivity, poor adhesion between printed patterns and substrates, and relatively low resolution.

Selective electroless plating, benefiting from an auto-catalytic redox reaction to deposit a thin-layer metal on a catalyst-preloaded substrate, is one of the promising methods for fabrication of metal patterns on various plastic substrates [1]. It belongs to the additive manufacturing process with high utilization efficiency of materials and is able to fabricate highly conductive metal patterns. However, to realize the high-resolution metal patterns by electroless plating is still challenging. Cai et al. reported on a new patterned electroless metallization process in which catalytic nanoparticles was accurately adsorbed on substrates masked by a high-resolution lithographically patterned sacrificial resist layer [2]. A high resolution of 500 nm pitch was successfully demonstrated. Zhang et al. reported on another strategy for selective electroless plating of high-resolution patterns through the laser direct structuring technology [3]. However, these assisted electroless plating methods are complicated and not suitable for large-scale flexible integrated circuits and devices. Direct formation of metal patterns on flexible substrates is much more promising [4]. Through the selective surface modification processes, such as UV-ozone treatment and oxygen plasma treatment, potential surface patterns (i.e. different surface states) on the substrates are realized and subsequently induce the direct formation of metal patterns by electroless plating. However, the formation of metal patterns highly relies on the substrate and surface modification processes, which is rarely discussed and reported.

In this work, high-resolution metal patterns are directly formed on the flexible substrates without the help of lithographically patterned sacrificial resist layer and laser direct structuring technology. The surface states of substrates before and after UV-ozone treatment were analyzed for understanding the selective electroless plating process. The achieved metal patterns were evaluated in terms of conductivity, adhesion test, and flexibility. Finally, possible applications are demonstrated.

2. Experimental section

Selective surface modification of flexible substrates was performed by UV irradiation assisted with a photomask. The irradiation time was ranged from 200 s to 600 s. After that, the UV-modified substrates were electroless plated with copper (Cu). A commercially available Cu plating bath was used. The achieved Cu patterns were observed by optical microscope and field-emission scanning electron microscopy. In addition, the resistance and flexibility of achieved Cu patterns were evaluated by multimeter and bending machine.

3. Results and discussion

Fig.1 shows the process of direct formation of metal patterns on flexible substrates. With the help of the photomask, UV light can modify the surface of substrates selectively, resulting in homogeneously wetting domain arrays on the polymer surface. The UV treated substrates is oxidized and generate polar groups such as carboxylic acid (COOH-) or other peroxide functional groups that tend to absorb catalyst strongly [5]. After that, the electroless plating of Cu is conducted to form Cu patterns. It is found that the higher temperature of the Cu plating bath induces the faster formation of Cu patterns. However, if the temperature is too high, the Cu will form in the areas without UV treatment. Therefore, in the current work, the temperature is set at 40 °C. The stirring rate affects the formation of Cu patterns heavily. It found that when the stirring rate decrease to 0, the formation of Cu patterns is efficient and clear.

Fig. 2 shows the optical microscope image of achieved Cu patterns. As seen, the Cu patterns keep well-defined shapes, sharp edges, and a smooth surface even though their width is as fine as 5 µm. The resistance of plated Cu patterns was evaluated. When the length and width of Cu patterns are 20 mm and 3 mm, respectively, the resistance is about 0.8 Ω. In addition, the plated Cu patterns have high flexibility and their resistance is kept stable after 1000 bending cycles.

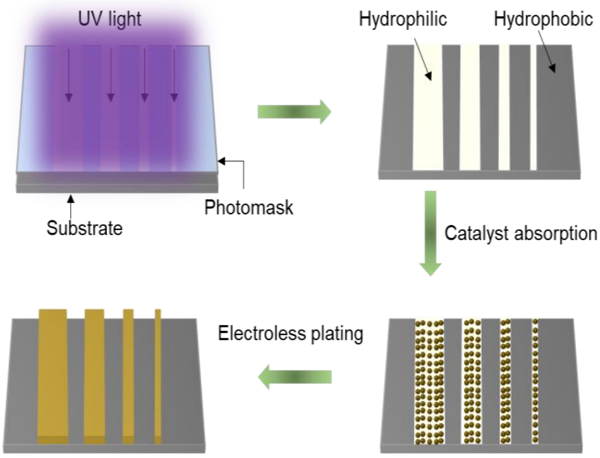

Fig. 1 Schematic illustration of direct formation of metal patterns using the selective surface modification and electroless plating.

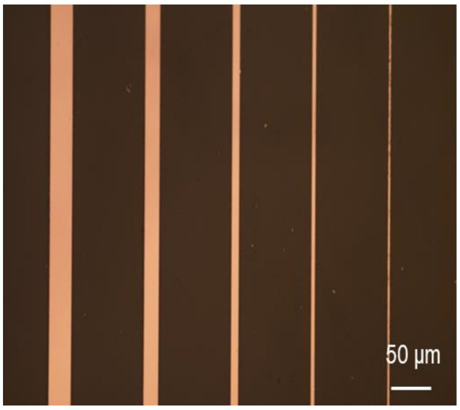

Fig. 2 Optical microscope image of achieved Cu patterns.

4. Conclusions

Direct formation of highly conductive and high-resolution Cu patterns on flexible substrates was successfully realized by selective surface modification and electroless plating.

Acknowledgements

This work was financially supported by a Grant-In-Aid for Scientific Research (No. 26286040 and 17H02769) from the Ministry of Education, Culture, Sport, Science, and Technology of Japan and the New Energy and Industrial Technology Development Organization (NEDO), Japan.

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