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Fabrication of Large-area Nano Metal Meshes by Strip-off Method

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Abstract

A novel method is verified by combining interference lithography, atomic layer deposition, nanoimprint, and the strip-off method to fabricate nano metal meshes for organic electronic device applications.

1. Introduction

The long channel length of traditional horizontal-channel organic thin film transistors may cause high operational voltage and low output current. The solution-processed space-charge-limited transistor (SCLT) can easily control the length of its vertical channel by adjusting organic layer thickness. Metal mesh base-electrodes shown in Fig. 1 controls ON/OFF state of the channel as switches. However, the leakage current is the main factor that limits the switching performance of SCLT devices [1], [2]. In this work we introduce a novel method which combines interference lithography (IL) and low-temperature atomic layer deposition (ALD) to fabricate an Al_2O_3-covered rods-array photoresist pattern imprint mold. The 100 nm diameter metal meshes as the base-electrodes for the SCLT devices could be fabricated by nanoimprint lithography (NIL) and the strip-off method.

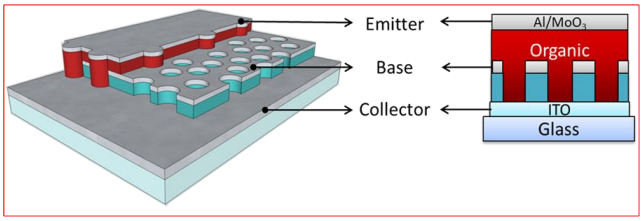

Fig. 1 The Schematic diagram of an SCLT.

2. Experimental Results

Fabrication process

First, the photoresist rods-array pattern was fabricated by applying double-exposure IL as schematically shown in Fig. 2(a). The aluminum oxide thin film coated on the pattern was made by low-temperature ALD process as shown in Fig. 2(b) to ensure the pattern was durable enough to behave as an almost-permanent mold. Then h-PDMS was spun over the mold to duplicate the pattern as depicted in Fig. 2(c) which served as a stamp. The pattern of imprint resist shown in Fig. 2(e) was fabricated by NIL using the stamp as shown in Fig. 2(d). After the resist residue was removed by O_2 plasma, aluminum layer was deposited on the pattern surface. Then a conventional tape was used to strip off the metal layer on top of the pattern as shown in Fig. 2(g). After removal of the residual resist with acetone, the Al hole-array pattern could be obtained as depicted in Fig. 2(h).

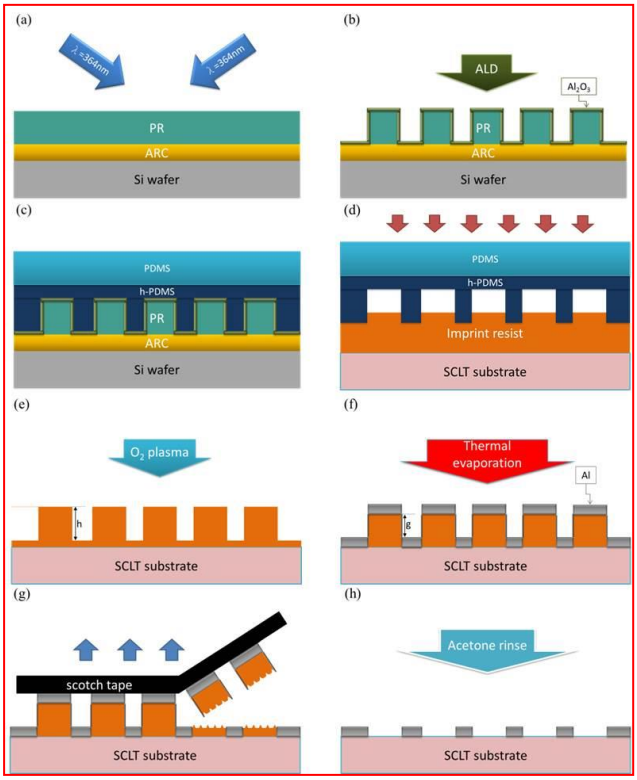

Fig. 2 Fabrication process of nano metal meshes on a SCLT substrate.

Results and discussion

NIL is useful at patterning on organic substrates, but it requires original pattern mold to be imprinted. The imprint molds are generally made from Si, SiO_2, or other rigid ma-

terials. IL is capable of fabricating large-area nano patterns in a fast and cheap way [3]. A PR layer is usually used as a sacrificial etch mask and then completely removed after the pattern is transferred from the PR layer to the rigid substrate by using etching method. However, it is known that fine-tuning the profile of etched pattern is hard during mold fabrication, especially for the high aspect ratio pattern. In contrast, fine-tuning the profile of PR pattern is much easier. The Al_2O_3 thin film on the PR surface is strong enough to protect the inner polymer structure [4]. Since oxygen, moisture and other components in the air are isolated from the inner PR structure, the lifetime of pattern would be prolonged. The ALD-assisted Al_2O_3-covered PR pattern could therefore be directly used as an imprint mold with good profile collimation as shown in Fig. 3.

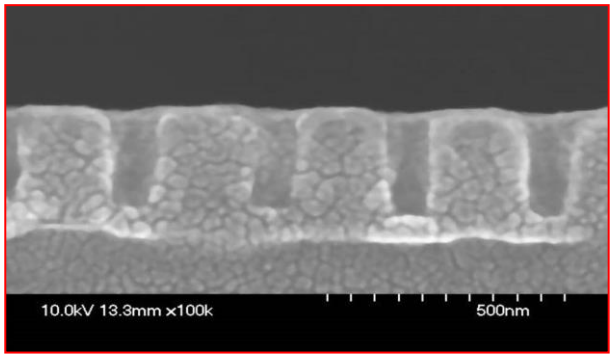

Fig. 3 Cross-section SEM photo of the Al_2O_3-covered PR mold.

In imprinted SCLTs fabrication process reported previously [1], the imprint resist pattern was used as an etch mask for aluminum wet-etching. However, the products and residues produced in the Al wet-etching process often remained on the surface of vertical channel of SCLT, causing large leakage current. In this work, the non-etching lift-off process is introduced to avoid such a drawback. The imprint resist pattern now becomes a sacrificial layer after metal evaporation process.

There are several factors which determine the yield of lift-off process: metal thickness, sidewall inclination of patterned structure and collimation of evaporating metal particles. There must be enough gap (g) between the metal layers as shown in Fig. 2(f) for solvent to get in; the metal layer thickness should be well controlled. Due to the mismatch between the sidewall inclination and the metal particle's collimation, some metal thin film may be deposited on the surface of patterned structure's sidewall as shown in Fig. 2(f). The thicker the metal layer was deposited, the thicker the metal film on sidewall would be, which blocked solvent to dissolve the sacrificial layer. In this work, the metal thickness was limited to be no more than 20 nm when achieving high yield. Note that the thickness of metal layer for the electrode of SCLT should be around 40 nm [1]. The supersonic vibration could help remove the metal attached to the sacrificial layer, but damage to the desired metal pattern on the substrate might also incur. A simple strip-off method was introduced to fabricate the thicker large-area metal nano pattern with high yield.

A conventional tape (Scotch®, 3M) was used here to help the removal of the undesired metal layer. The tape was attached on the top of patterned area on SCLT and then peeled off from it. The metal stuck to the tape was removed without damaging the metal pattern on the substrate. Metal thin film on sidewall was also stripped at the same time. With help of strip-off process, the large-area nano metal meshes thick enough to be the electrodes of SCLT could be obtained as shown in Fig. 4.

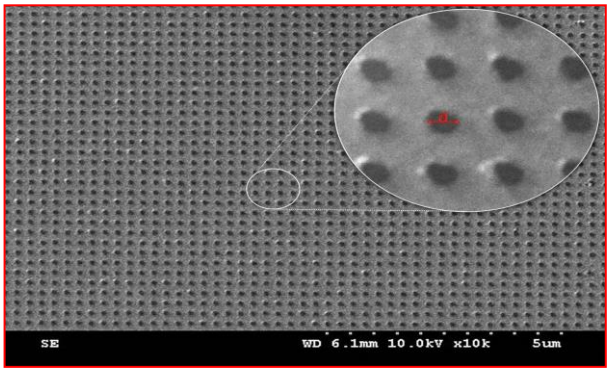

Fig. 4 Large-area Al nano meshes (d=100 nm) fabricated with help of strip-off method.

3. Conclusions

A process which combines IL, ALD, NIL, and strip-off methods to generate 100 nm diameter metal meshes over a large area with high yield has been demonstrated. The metal-etch-free method is mostly attributed to the physical strip-off process using a conventional scotch tape. With the same sacrificial layer thickness, the metal meshes were twice thicker than the one fabricated by the traditional lift-off method. Since no metal-etch process was involved, the leakage current of SCLT could be significantly reduced.

Acknowledgements

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