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Impedance matching of organic semiconductor devices using nanostructured interface

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Abstract

Nanostructures are known to have an effective structure that can increase the energy transfer between different media as the impedance at the interface is gradually changed. We improved the charge transfer from the electrode to organic semiconductor layer of organic device by using the nanopattern effect by impedance matching. Periodic gold nanostructured electrodes were fabricated by a nanoimprint lithography technique. The charge transfer between organic film and nanostructured electrode can be enhanced. In nanostructured organic device with a 200 nm space, electric current was improved by 40 times compared to that without patterns. The mechanism of enhanced current was understood with help of numerical simulation. We believe that these findings will suggest a new strategy of interfacial design for lowering the contact resistance between organic semiconductor and the electrode.

1. Introduction

The field of organic electronic devices is promising in various applications such as organic light-emitting diode, organic photovoltaic, and organic field effect transistor due to its flexibility, low cost, solution-based processing, easy organic synthesis, light weight, and low temperature process, compared with Si-based devices [1-2]. Basically, the characteristics of the organic device strongly depend on the interaction and structure at the interface of devices. Therefore, it is important to tailor the structure and interface of the device for the performance of the organic device. In particular, the manipulation of the interface between the metal and the organic semiconductor is a key factor to control the electronics [3].

To date, various strategies have been developed for the interface design of organic devices between metal and organic semiconductor. For instance, the modification of the interface includes SAM (self-assembled monolayer) processing, the insertion of thin films such as metal oxides, graphene oxide, or the mixing of nanomaterials such as doped carbon nanomaterials with organic semiconductors [3]. However, the complexity in the interface arising from defects related to the chemical interactions has not been understood fully.

In this study, we applied periodic nanopatterned electrode to organic devices using nanoimprint lithography. Nanopattern is an effective structure to increases charge transfer due to gradual change in impedance at the interface between discrete media [4]. Therefore, we aimed to add an impedance matching layer at the interface between the two media physically, and this strategy was also proposed to improve charge injection from the electrode by using impedance matching of nano effects.

2. Results and Discussion

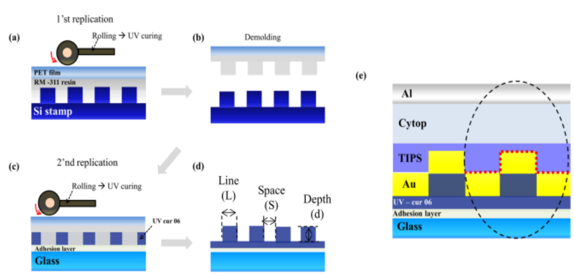

Figure 1. Fabrication step of an organic device with periodic nanostructure.

Figure 1 shows the fabrication step of an organic device with a periodic nanostructure. In order to perform nanopatterning of the electrode, the pattern was transferred to the polymer on a glass using a nanoimprint technique (Fig. 1a-d). Gold (Au) of the bottom electrode was deposited using an E-beam evaporator (Fig. 1e). As mentioned above, the pattern is a line, and its specifications are line (L)/space (S) 200-nm/200-nm, L/S 200-nm/400-nm, and L/S 200-nm/800-nm. The depth (d) is equal to 200-nm (Fig. 1c). In order to improve the adhesion between Au and 6,13-Bis(triisopropylsilylethynyl)pentacene (TIPS), a self-assembled monolayer (SAM) was treated on the bottom electrode, and the organic layer spin coating was conducted. A Cytop film was used as a dielectric layer, and was spin-coated on the TIPS. The upper electrode was deposited using aluminum (Al) as a thermal evaporator.

Figure 2 shows current-voltage (I-V) characteristics for Au/TIPS/Cyotp/Al devices for different nanospaces. The spaces are 200-nm, 400-nm, and 800-nm. As the space of the pattern changed, the current values of device were changed. The current value in the space of the 200-nm electrode was about 70μA.

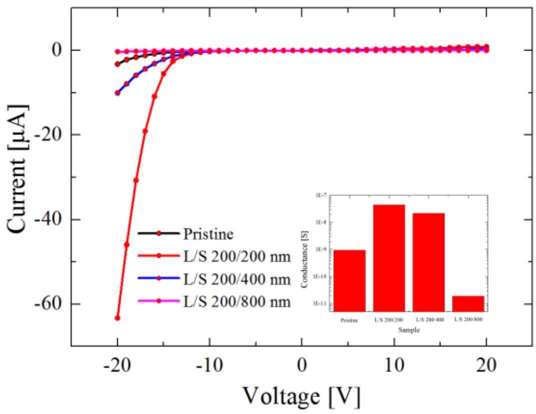

Figure 2. I-V characteristics of nanopatterned organic device. The inset shows the comparison of electrical conductivities

Obviously, the current change of the organic device is considered and affects the contact resistance. We tried to calculate the change of G_1 (TIPS layer's conductivity) induced by nanopattern effect. G_1 is calculated by a steady state current using G_2. The carrier injection from Au electrode to TIPS was improved by L/S 200/200 nm pattern.

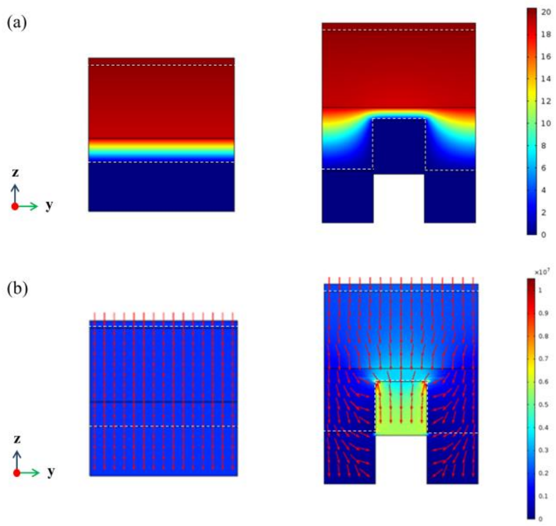

Figure 3. Numerical results of the nanopatterned organic devices for electron injection: (a) electric potential and (b) current density

The numerical simulations are performed using an AC/DC module of COMSOL Multiphysics in steady state. The electrical conductivities of each material, σ_{TIPS} and σ_{cytop}, were calculated by using I-V curve. Assuming static currents and fields, the electric field E must satisfy the following equation:

$$\nabla \cdot J = 0$$
$$J = \sigma E$$
$$E = -\nabla V$$

where J is the electrical current, σ is the electrical conductivity E is the electric field, and V is the applied electrical potential. The nanosize effects caused the potential difference, and current in the TIPS/nanopatterned interface, which could explain the enhancement of charge injection (Fig. 3).

3. Conclusions

In the current study, we fabricated the periodically nanostructured organic semiconductor device using nanoimprint technology. The electrode was used to improve the organic device characteristics. We analyzed the cross section image of the nanopatterned organic device to look into pattern formation, and then analyzed the charge behavior induced by the presence of nanopattern. The size of nanopattern was controlled in the region from 100 to 200 nm. We optimized the pattern using a focused ion beam. To evaluate the presence and the size of patterns on the organic device performance, we measured the electric characteristics of devices by analyzing carrier injection and transport. By adjusting the patterning size to control the contact of metal and an organic semiconductor, we controlled the charge injection and transport of devices. Our nanopatterned organic device showed a low contact resistance. We, therefore, anticipate that our idea of using nanopattern will lead to a new way to control a transport at the interface in engineering applications.

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