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Compression of Organic Thin-films by Cold Isostatic Pressing for Enhanced Device Properties

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Abstract

There are many spatial gaps in organic films, which impede carrier injection and transport. In this study, cold isostatic pressing (CIP) was applied to organic films in order to compress those gaps. Our results showed that tiny microscopic gaps in amorphous films are difficult to be compressed; conversely, large macroscopic gaps in polycrystalline films can be compressed. The gap compression led to an enhancement of the electrical properties of organic films. Moreover, CIP markedly improved the performances of organic light-emitting diodes, field-effect transistors, and solar cells containing polycrystalline layers. These findings are important for a better understanding of detailed carrier injection and transport mechanisms of organic devices and would lead to improved performance of future organic devices.

1. Introduction

It is expected that charge-carrier injection and transport characteristics of organic films are affected by spatial gaps present in them [1]. Amorphous films are often used in organic light-emitting diodes (OLEDs), and have tiny microscopic gaps formed by inefficient molecular packing. On the other hand, polycrystalline films are mainly used in organic field-effect transistors (OFETs) and organic solar cells (OSCs), and have large macroscopic gaps between grains and the other grains, substrates, or electrodes. If gaps can be compressed, electrical properties of organic films may be enhanced.

Cold isostatic pressing (CIP) has been widely used to compress and mold metal, ceramic, plastic and composite powders into certain forms. Previously, Kanari et al. reported that this CIP treatment compresses gaps in a vacuum-deposited metal-free phthalocyanine (H_2PC) film and improve its mechanical properties [2]. However, there is no report on effect of CIP on electrical properties of organic devices. In this study, we performed CIP treatment, where high pressure is applied to organic films through a water medium, on several kinds of organic films and organic devices, and evaluated their film and device properties.

2. Results and discussion

Sample fabrication and measurements

Organic films or hole-only devices (glass/ITO/organic layer/Al) were prepared by vacuum-deposition or spin-coating (Fig. 1). The sample was put between PTFE sheets and vacuum-sealed in a polymer bag. The polymer bag was soaked into water in a metal container and then applied 200 MPa for 60min. The sample was taken out of the bag. Thicknesses of the as-fabricated and CIP-treated organic films were measured with a surface profilometer (DektakXT, Bruker). To prevent scratching the CuPC, pentacene, and H_2PC surfaces with the cantilever of the profilometer, the entire surfaces of substrates with these films were coated with

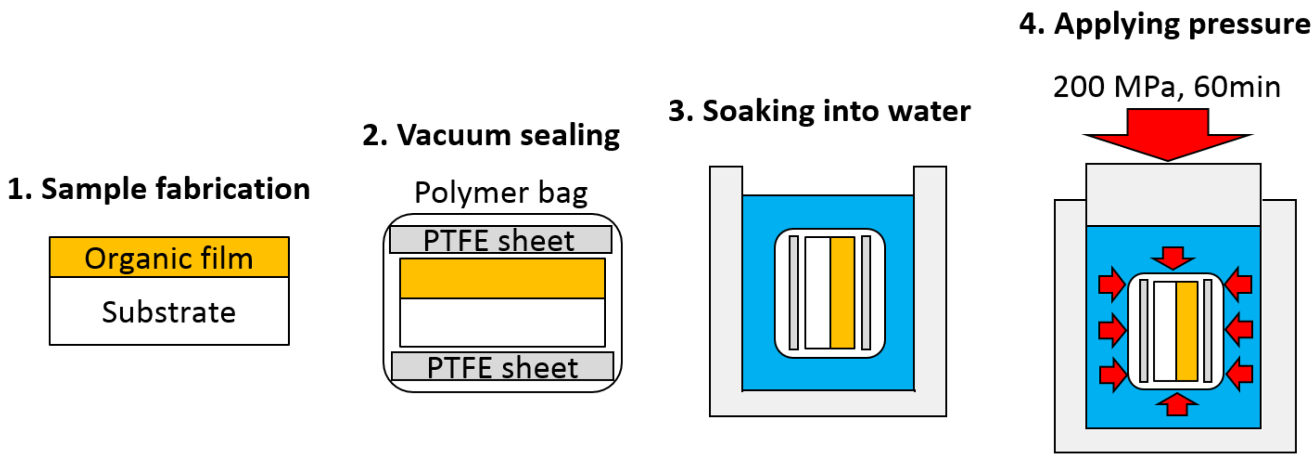

Figure 1. Schematics of cold isostatic pressing (CIP)

a 20-nm Al protection film by vacuum deposition just before the thickness measurement. Current density-voltage (*J-V*) characteristics were measured with a semiconductor parameter analyzer.

CIP treatment on vacuum-deposited H_2PC films

CIP treatment induced a 2000-times increase in a hole mobility of a vacuum-deposited H_2PC film as shown in a red square symbol of Fig. 2 [3,4]. We compared the film thicknesses, surface morphologies, structural properties, and hole traps of as-deposited and CIP treated H_2PC films to determine the reason for the observed mobility increase. As a result, we attributed the mobility increase to the gap crush, rearrangement of crystal axis, disappearance of deep hole traps, and decrease in hole-trap density.

Investigation of CIP effect on various organic films

Relationship between current enhancement and gap compression is shown in Fig. 2 [4]. In this figure, J_0 and J are the current densities of the as-fabricated and CIP-treated hole-only devices with amorphous and polycrystalline organic films, respectively; d_0 and d are the thicknesses of the as-fabricated and CIP-treated amorphous and polycrystalline organic films used for the hole-only devices, respectively. Both J/J_0 and d/d_0 were almost unity for the devices with vacuum-deposited amorphous films of α-NPD and tris-PCz. For a F8BT film fabricated by spin-coating, J/J_0 was around five while d/d_0 was almost unity. Meanwhile, J/J_0 greatly increased as d/d_0 decreased for the devices containing polycrystalline films of CuPC, pentacene, and H_2PC, indicating that the thickness decrease (gap compression) is strongly correlated with the current enhancement. From these results, we concluded that our CIP method is useful for gap compression and current enhancement, especially for polycrystalline films.

CIP treatment on organic devices containing H_2PC layers

CIP treatment was performed on OLEDs, OSCs, and OFETs containing H_2PC layers [4]. For OLEDs, where H_2PC was used as a hole injection layer, drive voltages at 100 mA/cm^2 decreased by 2 V and external quantum efficiencies increased 1.5 times. For OSCs with H_2PC as a p-type layer, conversion efficiencies increased about 1.5 times. For OFETs with H_2PC as a semiconductor layer, hole mobilities increased 16 times. These improvements result from enhanced carrier injection and transport by CIP treatment and indicate that CIP treatment is effective to enhance the performance of organic devices with polycrystalline layers and various device structures.

3. Conclusions

By utilizing CIP treatment, macroscopic gaps in polycrystalline films were compressed, but microscopic gaps in amorphous films were not be compressed. The gap compression by CIP leads to the enhanced performance of organic devices as well as electrical properties of a wide variety of polycrystalline films.

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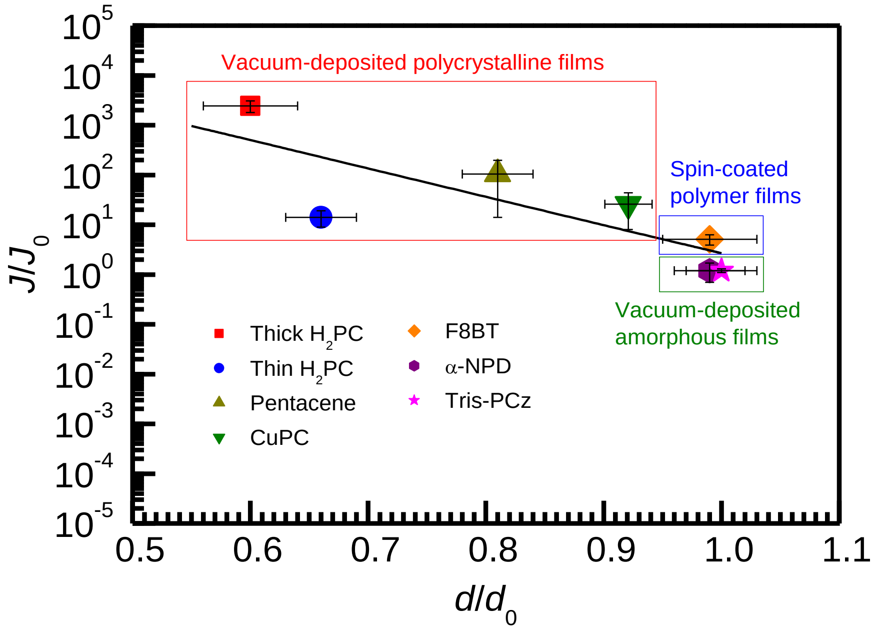

Figure 2. Relationship between current enhancement and gap compression for several organic films