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Very facile fabrication of aligned organic nanowires based high-performance top-gate transistors on flexible, transparent substrate

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ABSTRACT

Aligned single-crystalline organic nanowires (NWs) show promising applications in flexible and stretchable electronics, while the use of pre-existing aligned techniques and well-developed photolithography techniques are impeded by the large incompatibility with organic materials and flexible substrates. In this work, aligned copper phthalocyanine (CuPc) organic NWs were grown on flexible and transparent poly(dimethylsiloxane) (PDMS) substrate *via* a grating-assisted growth approach. Furthermore, a simple yet efficient etching-assisted transfer printing (ETP) method was used to achieve CuPc NW array-based flexible top-gate organic field-effect transistors (OFETs) with a high mobility up to 2.0 $cm^2 V^{-1} s^{-1}$, a small operating voltage within ±10 V, a high on/off ratio >10^4, and excellent bend stability with bending radius down to 3 mm. It is expected that the high-performance organic NW array-based top-gate OFETs with exceeding bend stability will have important applications in future flexible electronics.

1. Introduction

Single-crystalline organic nanowires (NWs) based organic field-effect transistors (OFETs) continue to be of great interest because of remarkable improvements on the device performance in recent years [1–4]. The unique one-dimensional (1D) geometry and single-crystal quality of the organic NWs offer the possibility to construct OFETs with unprecedented performance [5–7]. They have emerged as important components for future integrated, flexible, and transparent organic electronics [8–10]. Nevertheless, the large incompatibility of organic materials with traditional microfabrication techniques, such as photolithography, metallization, and lift-off, seriously impedes their applications in integrated devices. As an alternative, some more simple and direct methods, e.g., shadow mask and inkjet print were often utilized to fabricate the organic NW based OFETs, but the poor precision and limitation in minimum feature size remain issues for these techniques [11–16]. For the sake of simplifying the processing technique, most of the organic NWs based OFETs in current reports possess a bottom-gate architecture [15,16]. However, the high operation voltage and difficulty for device integration make the bottom-gate OFETs not suitable for practical applications. By contrast, the top-gate architecture, along with the use of high-*k* dielectric, can endow the OFETs with much more superiorities in terms of low operating voltage, large on/off ratio, and high integration level [17–20]. Therefore, it is much

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desirable to develop a feasible method for large-scale integration of organic NWs based OFETs with more sophisticated architecture.

Generally, the choice of device substrates is restricted by the processing temperature, compatibility with chemicals, and handling requirements. So, most of the organic devices are fabricated on rigid, flat, and smooth substrates like SiO_2/Si and glass [11–16]. However, to meet the expanded requirements on flexible and transparent electronics, electronic skin, and biosensing, there has been a growing interest to construct the organic devices on non-conventional substrates such as poly(dimethylsiloxane) (PDMS), polyethylene terephthalate (PET) and paper [11,21]. It is expected that the use of non-conventional substrates can grant the organic devices with more desirable properties, such as flexibility, stretchability, transparency, and biocompatibility, and thereby impact a range of important applications [22,23]. In spite of the large progress of organic NW devices, flexible OFETs based on the organic NWs are rarely studied because of the huge challenge in device construction and organic NW alignment.

Herein, aligned single-crystalline copper phthalocyanine (CuPc) organic NWs were directly grown on PDMS substrate through a facile grating-assisted growth approach, lessening the requirements for accurately positioning and arranging the organic nanostructures on substrates. Furthermore, a simple yet efficient etching-assisted transfer printing (ETP) method was used to achieve the large-scale transfer of the pre-fabricated high-dielectric-constant (high-*k*) top-gate electrodes onto the CuPc NWs, forming the NW array based OFETs. Thanks to the high crystal quality of the CuPc NWs, the devices possessed an optimum mobility of about 2.0 $cm^2\,V^{-1}\,s^{-1}$. Moreover, owing to the use of high-*k* dielectric and thin PDMS substrate, the flexible devices exhibited superior performance in terms of small operating voltage, high on/off ratio, and excellent bend stability. It is expected that the high-performance, flexible top-gate OFETs will have important applications in future low-cost and high-integration organic electronics.

2. Experimental section

2.1. Aligned CuPc NW growth

For the physical vapor deposition (PVD) growth of the aligned CuPc NW arrays, 10 mg CuPc powder (J&K, >90%) was used as the source material and placed at the high-temperature zone (400 °C), while the PDMS grating substrate was placed at the low-temperature zone (150 °C) of a quartz tube furnace. The CuPc powder was purified by sublimation before evaporation. The period of the grating structure is 800 line and the depth of the grating trenches is 400 nm. The reaction chamber was flushed and filled with 70 sccm Ar carrier gas after it was evacuated to a base pressure of 10 Pa. The pressure in the tube was 300 Pa during the growth. A layer of wathet blue product could be observed on

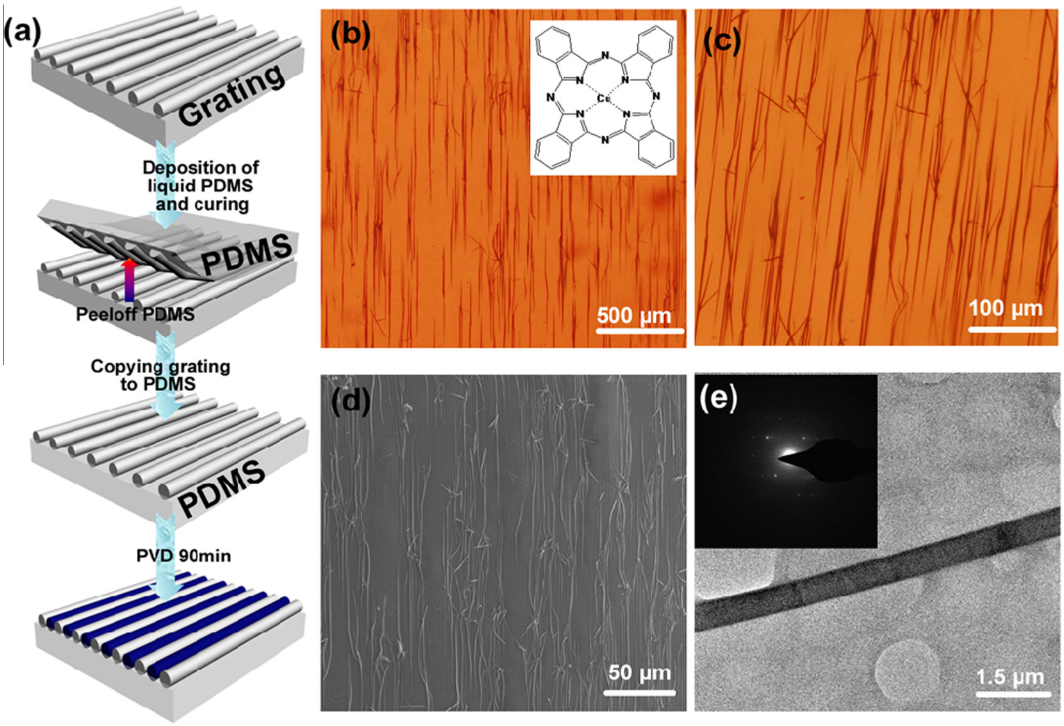

Fig. 1. (a) Flow chart shows the grating-assisted method for CuPc NW array growth. Representative (b and c) optical microscope and (d) SEM images of the CuPc NWs grown on grating substrates. Inset in (b) shows the molecular structure of CuPc. (e) TEM image of a CuPc NW. Inset shows the corresponding SAED pattern.