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Surface-Mounted MOF Templated Fabrication of Homochiral Polymer Thin Film for Enantioselective Adsorption of Drug

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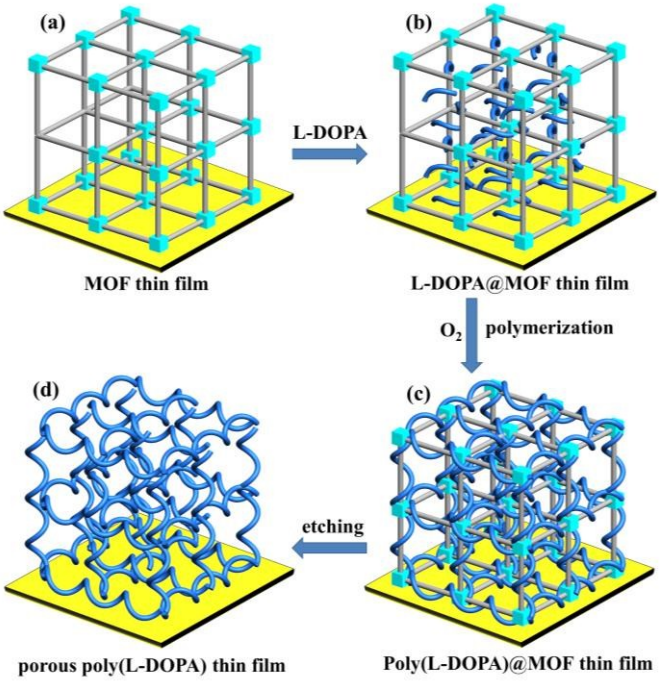
A self-polymerized chiral monomer 3,4-dihydroxy-L-phenylalanine (L-DOPA) has been introduced into pores of achiral surface-mounted metal organic framework (SURMOF), and then the homochiral poly(L-DOPA) thin film has been successfully formed after UV light irradiation and etching SURMOF. Remarkably, suh poly(L-DOPA) thin film exhibited enantioselective adsorption of naproxen. This work opened a SURMOF-templated approach for preparing porous polymer thin film.

Due to chirality, the living organisms can display biological responses to different enantiomers in drugs, pesticides or waste compounds.[1-3] Thus, recognition and separation of enantiomers are important for application in the modern pharmaceutical industry. [4-6] Homochiral porous polymers combining "chirality" and "porosity" are good candidates for this aim.[7-10] Basically, the most effective application of such homochiral polymers is to form thin film with uniform morphology. However, it is still a big challenge to prepare homochiral polymer thin films for enantioselective adsorption. [11-13]

In this work, we use surface-mounted metal organic framework (SURMOF) as template to synthesize homogeneous polymer thin film for enantioselectivity due to they have some advantages as reported in the literatures[14-17]. In addition, marine organisms such as barnacles and mussels carrying catechol groups have been prepared to investigate their adhesives nature for specialty applications, which can self-polymerize on a wide range of inorganic and organic solid surfaces, such as metals, polymers, ceramics and semiconductors. [18, 19] As an economic chiral marine organism precursor, 3,4-dihydroxy-L-phenylalanine (L-DOPA) [21, 22] can self-polymerize to chiral poly(L-DOPA) even under ambient conditions. In order to fabricate poly(L-DOPA) thin film, the crystalline metal organic framework (MOF)[20-22] may provide a good template. The basic idea is shown in Scheme 1. The L-DOPA monomers are loaded into the pores of a SURMOF by using immersion method (Scheme 1a-b). Then this L-DOPA loaded SURMOF is treated with UV irradiation under air and the Poly(L-DOPA) will be formed in the pores (Scheme 1c). After etching the SURMOF, the chiral Poly(L-DOPA) thin film with porous structure can be obtained successfully (Scheme 1d). Remarkably, such poly(L-DOPA) thin film exhibits enantioselective adsorption of R-/S-naproxen.



Scheme 1. The growth process from MOF thin film, L-DOPA loaded MOF thin film to chiral poly(L-DOPA) thin film.

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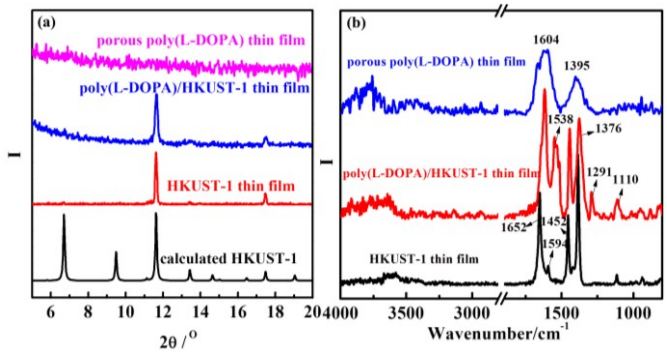

Figure 1. The characterization of the growth process from MOF thin film, L-DOPA loaded MOF thin film to chiral poly(L-DOPA) thin film: (a) XRD and (b) IRRAS.

MOF HKUST-1 was chosen in this work, since it has 3-D framework with large porosity and it can easily form thin film by using liquid-phase epitaxial method.[12] The XRD data showed that HKUST-1 thin film grown on a OH-functionalized Au substrate (QCM substrate) revealed peaks at 11.7° and 17.6°, identified as the (222) and (333) peaks of simulated HKUST-1 (Figure 1), demonstrating the presence of a well-defined, preferential growth orientation of HKUST-1 thin film (along [111] orientation). The SEM image in Figure 2a showed a crystalline HKUST-1 and homogenous surface. This pristine HKUST-1 thin film was used to load L-DOPA by immersing the sample into L-DOPA solution (ethanol/H_2O 9:1), and the resulting sample was illuminated with UV irradiation under air atmosphere for 30 min. The intense XRD peaks revealed the framework can keep the crystallinity (Figure 2b). The new IR absorbance bands at 1538 and 1291 cm^{-1} showed the L-DOPA was loaded into HKUST-1 and polymerized to acid amides. After UV light irradiation for 30 mins, the sample was put into water for etching the HKUST-1 support, because HKUST-1 is not stable in water. Thus, the porous poly(L-DOPA) thin film was formed on substrate after water treatment for 12 h (Figure 1a), and the HKUST-1 thin film was destroyed.

The absorbance bands (1604 and 1395 cm^{-1}) in the IR spectrum indicate that the poly(L-DOPA) polymers are still attached on the substrate. The solid state ^{13}C NMR spectrum (Figure S1) showed that there were resonance at 176 ppm (carboxylate groups), 142 ppm (phenol carbons), 120 ppm (pyrrolic carbons) and 115 37 and 57 ppm (side chain carbons) in the structure (inserted image in Figure S1) of poly(L-DOPA). The SEM images also show the homogeneous polymer surface (Figure 2c). Compare to the XPS data of HKUST-1 thin film, the XPS spectrum of poly(L-DOPA)@HKUST-1 thin film revealed a strong N peak at 400 eV (Figure 2d-e). After etching the MOF, the disappeared peak at 934.7 eV demonstrated the MOF was removed after water treatment (Figure 2f), which also can be demonstrated by ICP data with a ~0.05 % Cu atom percentage in the material. These characterizations demonstrated that HKUST-1 was completely destroyed and poly(L-DOPA) remained on the substrate. Furthermore, the patterned sample SURMOF HKUST-1 was prepared by micro contact printing (μCp)[23-25] approach (Figure S2). Then the patterned poly(L-DOPA)@HKUST-1 was also obtained by self-polymerized L-DOPA in the HKUST-1 framework. After water treatment, the AFM images of patterned poly(L-DOPA)@HKUST-1 and pristine HKUST-1 samples before and after water treatment were studied in Figure S3. The AFM result showed that the unchanged height profiles (Figure S4) demonstrated the poly(L-DOPA) thin film was formed on the substrate. In contrast, the pattern of pristine SURMOF HKUST-1 was missing after the same water treatment.

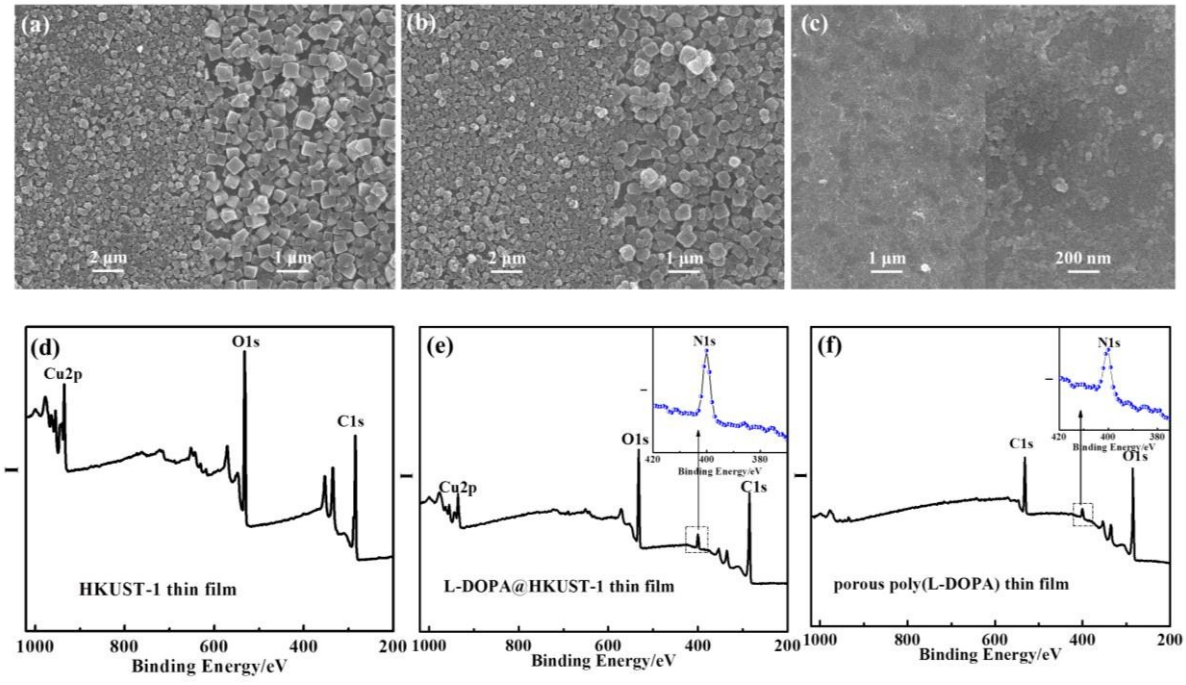

Figure 2. SEM images of HKUST-1 thin film (a), poly(L-DOPA)@HKUST-1 thin film (b) and porous poly(L-DOPA) thin film (c); and their XPS data: (d) HKUST-1 thin film, (e) poly(L-DOPA)@HKUST-1 thin film and (f) porous poly(L-DOPA) thin film.

In order to study the chirality of obtained poly(L-DOPA) thin film, the quartz glass with –OH functional group was chosen as the growth substrate.[26] The XRD data and photo images showed that

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similar procedure was used to prepare poly(L-DOPA) thin film on glass (Figure S5 and S6). Both of L-DOPA and poly(L-DOPA) have positive CD signal (Figure 3) demonstrating the chiral L-DOPA and poly(L-DOPA). However, the CD peak of poly(L-DOPA) thin film is at 360 nm, which is different from that of L-DOPA (294 nm). This may be due to the chromophore groups around the chiral centre was changed when there is a self-polymerization process from L-DOPA molecules to poly(L-DOPA).

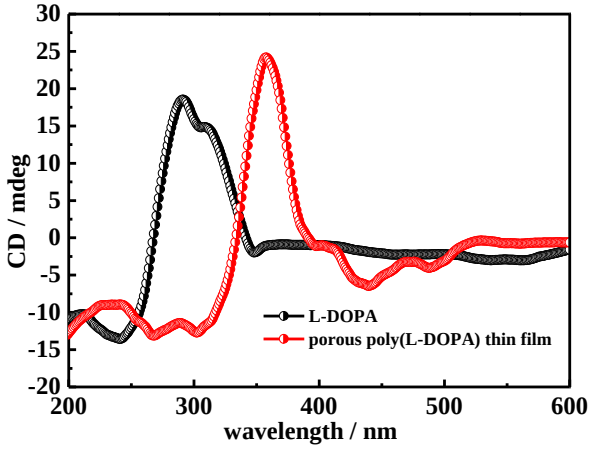

Figure 3. CD of powder L-DOPA and resulted porous poly(L-DOPA) thin film.

As a chiral and water stable porous polymer, porous poly(L-DOPA) thin film provides a good candidate for the drug recognition and separation. In order to investigate of the enatioselective adsorption of porous poly(L-DOPA) thin film, a pair of drug molecule R-/S-naproxen was chosen and the enantiomers was demonstrated by CD signal in Figure S7.[13] The pharmacological activity resides in S-naproxen, while R-naproxen can cause some undesired side effects. Therefore, it is beneficial to distinguish and separate R-/S-naproxen in the modern pharmaceutical industry.

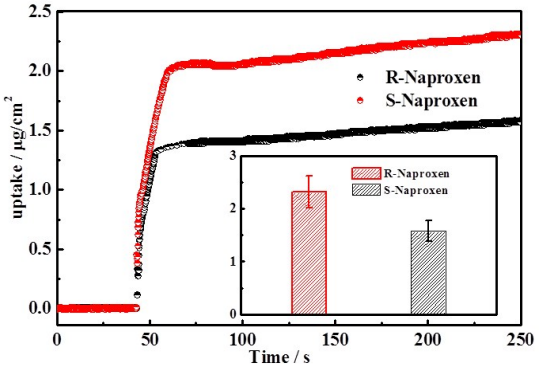

Figure 4. The uptake of R-naproxen and S-naproxen adsorption in chiral poly(L-DOPA) thin film.

In order to demonstrate the porosity of obtained thin film, the ethanol adsorptions of pristine HKUST-1, poly(L-DOPA)@HKUST-1 and poly(L-DOPA) thin film were carried out by QCM (Figure S8). The decreased uptake (from 5.6 μgcm^{-2} to 0.6 μgcm^{-2}) demonstrated that the L-DOPA was loaded in the pores. After removing the MOF framework, the uptake increased to 3.7 μgcm^{-2}, which showed there was a porous poly(L-DOPA) thin film.

A quartz crystal microbalance (QCM) is applied for investigating the enantioselective adsorption in homochiral thin films.[27, 28] Here both R- and S-naproxen was diluted into ethanol for preparing the same concentration of 0.5 mM, and the pure ethanol was used for the baseline. Under the same measurement condition, the mass uptakes of poly(L-DOPA) thin film were ~2.32 $\mu g/cm^2$ for S-naproxen and ~1.57 $\mu g/cm^2$ for R-naproxen, respectively (Figure 4). The CD spectra (Figure S8) for pol(L-DOPA) thin film after loading R-naproxen and S-naproxen also showed pol(L-DOPA) can adsorption the drug molecules. The enantioslective adsorption ability can be calculated by the equation of $e = (m_S\text{-}m_R)/m_S \times 100\%$, where e denotes the enantioselectivity, m_S and m_R is the uptake of S-naproxen and R-naproxen enantiomers, respectively. Thus, the eantioselectivity of naproxen in this poly(L-DOPA) thin film was calculated to be ~32%. In contract, the substrate and L-DOPA loaded HKUST-1 with tiny porosity (Figure S9) could not provide the space for adsorption of naproxen. In addition, the subequal uptake of R-/S-naproxen in the pristine HKUST-1 thin film (Figure S10) showed there was scarcely enantioselectivity.

In summary, we have successfully developed a new method toward the synthesis of homochiral polymer thin film by using SURMOF template. The resulting homochiral poly(L-DOPA) thin film can effectively separate R-/S-naproxen with enantioselecitivity of 32%. This work leads a SURMOF-templated approach for preparing porous homochiral polymer thin film.

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