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Fabrication of CdS thin films assisted by Langmuir deposition, self-assembly, and dip-pen nanolithography

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Abstract−Thin CdS films were fabricated by Langmuir deposition, self-assembly, and dip-pen nanolithography methods. Firstly, LB films of saturated arachidic acid and LS films of unsaturated 10,12-pentacosadiynoic acid were reacted with cadmium ions and exposed to H_2S gas. Formation of CdS crystal was observed with Fourier transform infrared (FTIR) spectra and atomic force microscope (AFM). Secondly, mercaptohexadecanoic acid was self-assembled on Au substrate and was reacted with CdS colloidal particles. At pH=9.1, the density of CdS colloids immobilized on Au substrate was very high compared to one at pH=5.0. Finally, thin films of CdS were also prepared on silicon and Au substrates by cadmium chloride-coated AFM tip and successive exposure of H_2S gas. Localized formation of CdS crystal was suggested with AFM and depth-profiling Auger electron microscopy (AES).

Key words: CdS, Langmuir-Blodgett Film, Langmuir-Schafer Film, Self-assembled Monolayers, Dip-pen Nanolithography

INTRODUCTION

Renewable energy generated from natural resources such as sunlight, wind, tides, geothermal heat, etc. has been much investigated for it can reserve Earth from global warming by reducing environmental pollutants. Especially, solar cells have attracted a great deal of interest in both academic researches and industrial needs. Many materials including silicon, II-IV semiconductor compounds, carbon nanotube, graphene, etc. have been used to make heterojunction-based solar cells. Among these materials, cadmium sulfide (CdS) is a representative due to its wideband gap of 2.42 eV at room temperature, good photoconduction, high electron affinity, and inexpensive preparation [1-4]. Methods for generating CdS include chemical vapor deposition, laser deposition, electrochemical deposition, and precipitation [5-7].

For the past decades, many organic materials have been reported to be coated on substrates with nanometer-scale by Langmuir-Blodgett (LB) [8,9], Langmuir-Schafer (LS) [10,11], and self-assembled monolayers (SAMs) [12,13]. Such organic templates prepared by these methods can offer better control of the molecular density of surface functional on which CdS nanoparticles are deposited and have an advantage of lower preparation costs due to their mild process conditions at normal temperature and pressure.

On the other hand, direct coating methods such as microcontact printing (μCP) [14,15], nanoimprinting [16,17], scanning probe lithography (SPL) [18,19] e-beam lithography [20] have been investigated to accurately deposit organic materials in nanometer-scales for applications to nanometer-scale molecular electronics and devices possessing advanced functions. In addition to the miniaturization, the fabrication of nanometer-scale domain on a target position over surfaces is beginning to play an important role in related fields. Recently, dip-pen nanolithography (DPN) [21-24] technique invented by Mirkin et al. has been widely used in various fields due to its ability to deposit accurate nano-pattern of both organic and inorganic materials.

In this work, we report a variety of routes to simple deposition of CdS thin films by Langmuir deposition, self-assembly, and DPN methods at room temperature. Firstly, LB films of saturated arachidic acid and LS films of unsaturated 10,12-pentacosadiynoic acid were reacted with cadmium ions and exposed to H_2S gas for 1 h. Formation of CdS thin films was confirmed with FTIR spectra and AFM. Secondly, mercaptohexadecanoic acid was self-assembled on Au substrate and was reacted with CdS colloidal particles. At pH=9.1, the density of immobilized CdS colloids was very much higher than one at pH=5.0. Finally, thin nanometer-scale CdS crystals with predetermined pattern at target local positions were prepared on silicon and Au substrates using dip-coated AFM tips. Localized formation of CdS crystal lines with width less than 50 nm was confirmed with AFM and AES after exposure of H_2S gas for 1 h. These methods to form thin CdS films could be potentially applicable to increase photo-responsive electronic devices.

EXPERIMENTAL SECTION

1. Materials

Arachidic acid (eicosanoic acid; 99%) and 10,12-pentacosadiynoic acid (PCDA; 99%) were purchased from Aldrich and Farchan Laboratory, respectively. Chloroform (99.8%), ethanol (99.8%), and 16-mercaptohexadecanoic acid (MHA; 90%) were purchased from Fluka. Cadmium chloride ($CdCl_2$; 99.9%) and sodium mercaptoacetate (99%) were obtained from Aldrich and Sigma, respectively. All surfactants and solvents were used without further purification.

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