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Room temperature deposition of high figure of merit p-type transparent conducting Cu–Zn–S thin films and their application in organic solar cells as an efficient hole transport layer

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High figure-of-merit p-type transparent conducting Cu–Zn–S thin films with Zn doped CuS structure were successfully deposited by Successive Ionic Layer Adsorption and Reaction (SILAR) method at room temperature. Films were deposited with an optimal Cu:Zn:S ratio of 75:25:50 in the precursor solution. The thickness of the films was controlled by varying the number of deposition cycles. The composition, structure, morphology, electrical, electronic and optical properties of the as deposited films were studied in detail. All the films exhibited relatively high conductivity and transparency resulting in high figure-of-merit values. Overall, the hole concentration and conductivity are in the range of degenerately doped semiconductors. The Cu–Zn–S film deposited with 40 nm thickness has an electrical conductivity of more than 1000 S/cm and average optical transparency greater than 81% in the visible region. These values are higher than most of the other reported p-type transparent conducting materials, especially for room temperature deposition. Conventional bulk heterojunction organic solar cells were fabricated with structure ITO/Cu–Zn–S/P3HT:$PC_{71}BM$/ZnO/Al, where Cu–Zn–S is the hole transport layer. The best configuration resulted in an efficiency of 1.87% suggests the suitability of Cu–Zn–S thin films as a hole transport layer in organic solar cells.

1. Introduction

Transparent conducting materials (TCMs) are those materials that possess both high optical transparency and high electrical conductivity. These materials are an important component in a number of electronic devices including flat-panel displays, touchscreens, light emitting diodes (LEDs), solar cells and many other optoelectronic devices [1–3]. In LEDs and solar cells, they are typically used as low resistance electrical contacts transparent to light. The most widely used and studied TCMs are n-type semiconductors. For example, Sn-doped In_2O_3 (ITO), F-doped SnO_2 (FTO), Al-doped ZnO (AZO) are all n-type and are being used commercially in optoelectronic devices as transparent conductors [2,4]. ITO is the most extensively used TCM with optical transparency above 90% and electrical conductivity ~10^4 S/cm [3,5,6]. However, p-type semiconducting materials with comparable transparency and conductivity are not so well developed [1,4,7]. Since a p–n junction is the key building block of most semiconductor devices, p-type TCMs of similar quality could open up new design spaces for optoelectronic devices and transparent electronics [7,8].

The most reported p-type TCMs till now are Cu-based semiconducting transparent oxides. $CuAlO_2$, successfully deposited by Kawazoe et al., in 1997, having a room temperature conductivity of up to 1 S/cm, is regarded as the first reported p-type Transparent Conductive Oxide (TCO) [9]. A series of p-type Cu(I) based delafossites, with structure $CuMO_2$ (M = Ga, In, Y, Sc, Cr) were reported subsequently as optically transparent oxides initiating extensive attention to these type of materials [10–15]. However, the deposition of most of these TCO films is realized through physical deposition methods such as pulsed laser deposition (PLD), sputtering and evaporation techniques [9–15]. These methods involve a high vacuum environment, sophisticated equipment and either a

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