Printed p-type CuI TFTs

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Abstract

Printing technique offers several advantages in manufacturing electronics such as a direct writing of materials, reduction of chemical waste, and reproducibility with high-resolution scale, which are not affordable from other solution-based approaches. Especially for the TFTs fabrication, printing can significantly simplify manufacturing processes by directly defining the channel area, the gate, and the source and drain contacts, allowing for much low costs and high throughput manufacture of TFTs. Most of the printed TFTs have been mainly associated with p-type organic semiconductors and n-type metal oxide semiconductors. In this paper, printed p-type CuI semiconductors are demonstrated for the application of TFTs.

1. Printed CuI TFTs

γ -CuI semiconductor exhibits p-type characteristics among α, β, γ three different crystalline phases of CuI. (1) The CuI film has several advantages as an active channel layer for p-type TFTs such as high transparency in the visible wavelengths (Eg = 3.1 eV) and simple film preparation method. γ-CuI powder was dissolved in acetonitrile solvent. The resulting precursor solution served as CuI ink without the aid of any additives. Piezoelectric printing (Dimatix DMP-2831, Fujifilm) was applied to manufacture the printed CuI film. Stable CuI ink droplets were ejected through nozzles mounted on a printer cartridge by setting 11.5 µs and 24 V pulse at a frequency of 20 kHz. The dimension of the printed film was readily controlled by drawing software installed in the printer. The film was printed on a substrate at room temperature. As-printed film was immediately placed on a hot plate set to 120 ºC for 30 min. The as-printed film can be simply converted into dense and uniform CuI film after its drying at 120 ºC. The resulting CuI film was characterized with band gap, XRD, and AFM analysis (Figure 1). The electrical properties of the film were also studied by using Hall effect measurement. The film was printed on soda lime glass substrates for analysing band gap, XRD, and electrical properties, while SiO_2/Si substrate was used for AFM analysis. The printed CuI film showed average roughness of 7.2 nm and band gap was measured to be around 3 eV, indicating the transparency in the visible wavelengths. It was found that the film forms preferably with (111) crystal plane. Electrical property results demonstrate that the printed CuI film possesses the p-type nature with average Hall coefficient of 1.22 (Table 1). These results clearly indicate that the continuous and dense CuI film was successfully grown on the substrates via inkjet printing technique.

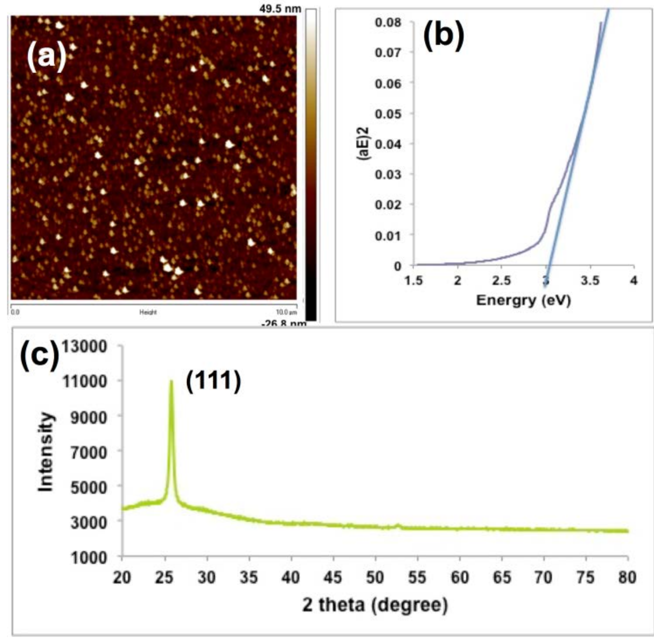

Figure 1. Characterization of printed CuI films: (a) AFM image, (b) band gap analysis, and (c) XRD pattern.

Table 1. Electrical properties of printed CuI film

Electrical properties	Resistivity [Ω cm]	Conductivity [Ω cm]$^{-1}$	Avg. Hall Coeff.	Hall mobility [cm^2/Vs]
Results	0.12	8.99	1.22 (p-type)	11.2

The printed CuI film was used for TFTs application. For the device fabrication, test keys on display glass having a substrate structure of SiO_2/Mo/Glass were used. After O_2 plasma treatment of the substrate for cleaning and improved hydrophilicity, the CuI ink was directly printed onto the substrate at room temperature, followed by drying at 120 ºC for 30 min. on a hot plate. A gold source and drain electrodes were deposited on the printed film using thermal evaporation method. Device performances were evaluated right after the electrode deposition at room temperature. The device is highly conductive exhibiting the linear increment of the drain current as a function drain voltage as shown in Figure 2a. The device is also barely modulated by the gate voltage due to the high conductivity of the film. The CuI is known as moisture sensitive material and it is expected that moisture adsorption of the film causes the film to be highly conductive, rendering unsuitable for the TFTs. One of the approaches to prevent the moisture adsorption is to utilize a passivation layer on top of the CuI film. SU-8 has been applied as a passivation layer for n-type metal oxide TFTs, and therefore it could be a potential passivation layer for the CuI film.(2) For the passivation process, the SU-8 material was dispersed onto the CuI TFT that is placed on a hot plate set to 150 ºC. The scheme of the encapsulated CuI TFTs with SU-8 is shown in Figure 2b. Device performances of the encapsulated TFTs changed dramatically, showing an excellent gate modulation and saturated drain current at high drain voltage (Figure 2c). A transfer curve of the encapsulated TFTs, obtained at Vd= -40V, exhibits turn-on voltage of around 14 V and on-off ratio of 10. The field-effect mobility was calculated to be 0.12 cm^2/Vs. The encapsulated CuI TFTs operated consistently over time and repeatedly yield similar device characteristics, indicating successful encapsulation of the CuI TFTs using dispersed SU-8. The overall device performances are comparable to reported vacuum-processed p-type TFTs.(3) However, there is still room to improve the device performances by optimizing process parameters, controlling moisture and interfaces.

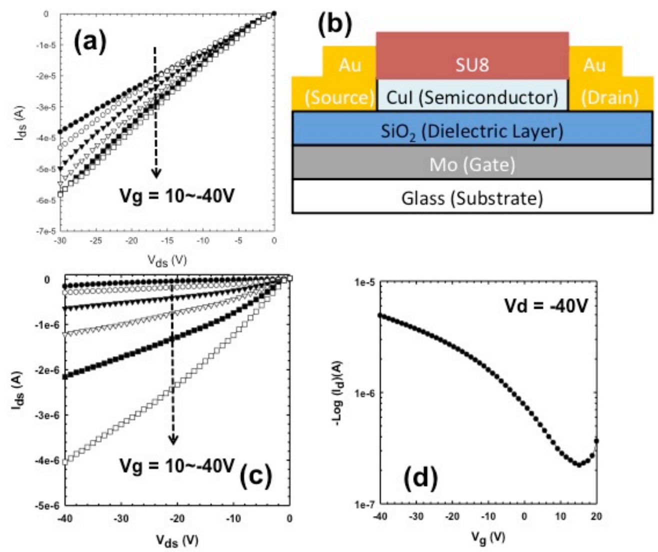

Figure 2. *(a) Output characteristics of CuI TFTs, (b) Scheme of encapsulated CuI TFTs, (c) Output characteristics and (d) Transfer curve of encapsulated CuI TFTs.*

References

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