Electronic Supplementary Material (ESI) for RSC Advances.


# Supporting Information (SI)

## Phase transformations of novel $Cu_xS$ nanostructures as highly efficient counter electrodes for stable and reproducible quantum dot-sensitized solar cells

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**Table S1.** Atomic ratios of copper sulfides determined by SEM-EDX quantitative analysis

| Thin films | Cu (at%) | S (at%) | Ratio (Cu/S) | Average Ratio |
|---|---|---|---|---|
| **$Cu_2S$ (Thin film1)** | 66.05 | 33.5 | 1.98 | |
| **$Cu_2S$ (Thin film2)** | 67.1 | 32.9 | 2.03 | 2.01±0.02 |
| **$Cu_2S$ (Thin film3)** | 66.9 | 33.1 | 2.02 | |
| **$Cu_{1.75}S$ (Thin film1)** | 64.2 | 35.8 | 1.79 | |
| **$Cu_{1.75}S$ (Thin film2)** | 63.8 | 36.2 | 1.76 | 1.76±0.03 |
| **$Cu_{1.75}S$ (Thin film3)** | 63.4 | 36.6 | 1.73 | |
| **$Cu_{1.12}S$ (Thin film1)** | 53.6 | 46.4 | 1.15 | |
| **$Cu_{1.12}S$ (Thin film2)** | 53.2 | 46.8 | 1.13 | 1.13±0.02 |
| **$Cu_{1.12}S$ (Thin film3)** | 52.9 | 47.1 | 1.12 | |
| **CuS (Thin film1)** | 51.9 | 49.1 | 1.07 | |
| **CuS (Thin film2)** | 51.4 | 48.6 | 1.05 | 1.03±0.04 |
| **CuS (Thin film3)** | 49.3 | 50.7 | 0.97 | |

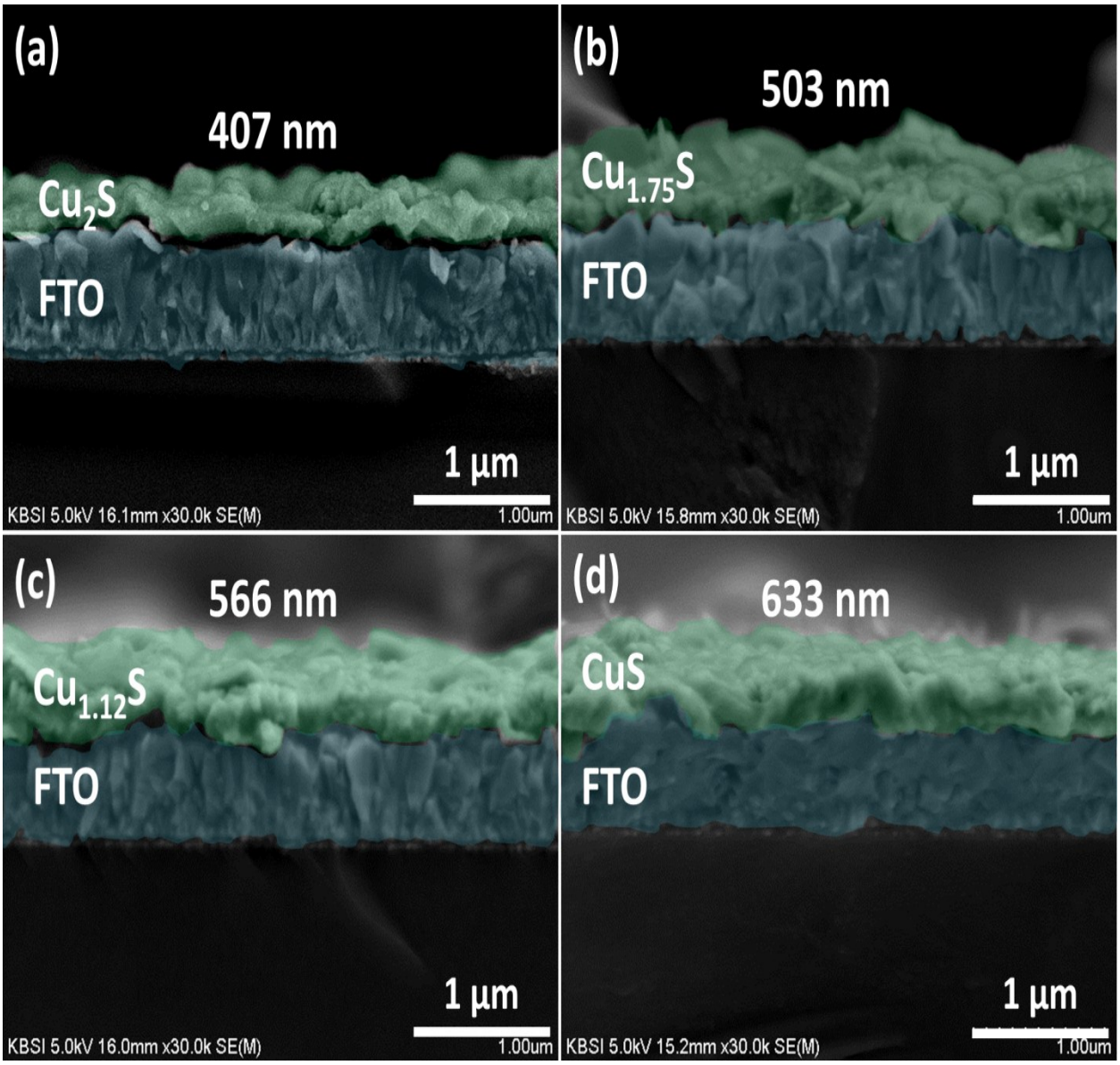


**Fig. S1** Cross-sectional SEM images of (a) $Cu_2S$, (b) $Cu_{1.75}S$, (c) $Cu_{1.12}S$, and (d) CuS thin film on the surface of FTO.

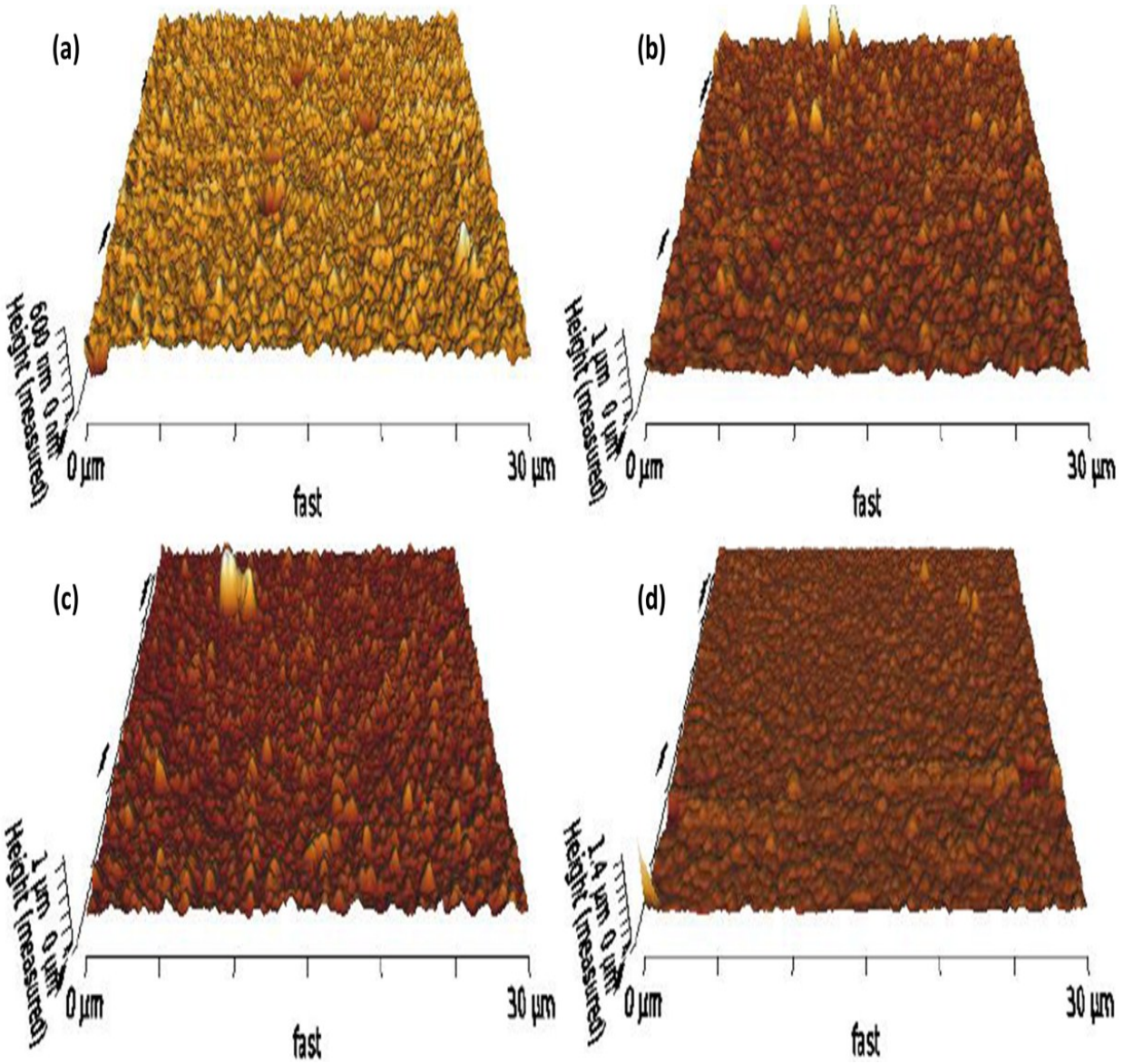


**Fig. S2** 3-Dimensional (3D) AFM images of (a) 0.005 mM, (b) 0.01 mM, (c) 0.02 mM, and (d) 0.03 mM L-cysteine based $Cu_xS$ thin films on FTO substrate ($Cu_2S$, $Cu_{1.75}S$, $Cu_{1.12}S$, and CuS).

**Table S2.** Solar cell parameters of QDSSC (multiple cells) with various $Cu_xS$ and Pt CEs

| Counter Electrode | $V_{OC}$ (V) | $J_{SC}$ (mA $cm^{-2}$) | FF | η (%) |
|---|---|---|---|---|
| **$Cu_2S$ (Cell1)** | 0.642 | 17.31 | 0.528 | 5.88 |
| **$Cu_2S$ (Cell 2)** | 0.645 | 17.32 | 0.527 | 5.89 |
| **$Cu_2S$ (Cell 3)** | 0.640 | 17.33 | 0.531 | 5.90 |
| **$Cu_{1.75}S$ (Cell 1)** | 0.640 | 15.86 | 0.523 | 5.32 |
| **$Cu_{1.75}S$ (Cell 2)** | 0.642 | 15.85 | 0.522 | 5.33 |
| **$Cu_{1.75}S$ (Cell 3)** | 0.644 | 15.84 | 0.521 | 5.32 |
| **$Cu_{1.12}S$ (Cell 1)** | 0.640 | 15.29 | 0.521 | 5.10 |
| **$Cu_{1.12}S$ (Cell 2)** | 0.646 | 15.26 | 0.518 | 5.11 |
| **$Cu_{1.12}S$ (Cell 3)** | 0.637 | 15.23 | 0.524 | 5.09 |
| **CuS (Cell 1)** | 0.643 | 14.46 | 0.525 | 4.89 |
| **CuS (Cell 2)** | 0.642 | 14.44 | 0.527 | 4.90 |
| **CuS (Cell 3)** | **0.642** | 14.45 | 0.527 | 4.90 |
| **Pt (Cell 1)** | 0.514 | 9.71 | 0.265 | 1.32 |
| **Pt (Cell 2)** | 0.517 | 9.98 | 0.263 | 1.36 |
| **Pt (Cell 3)** | 0.511 | 10.03 | 0.264 | 1.35 |

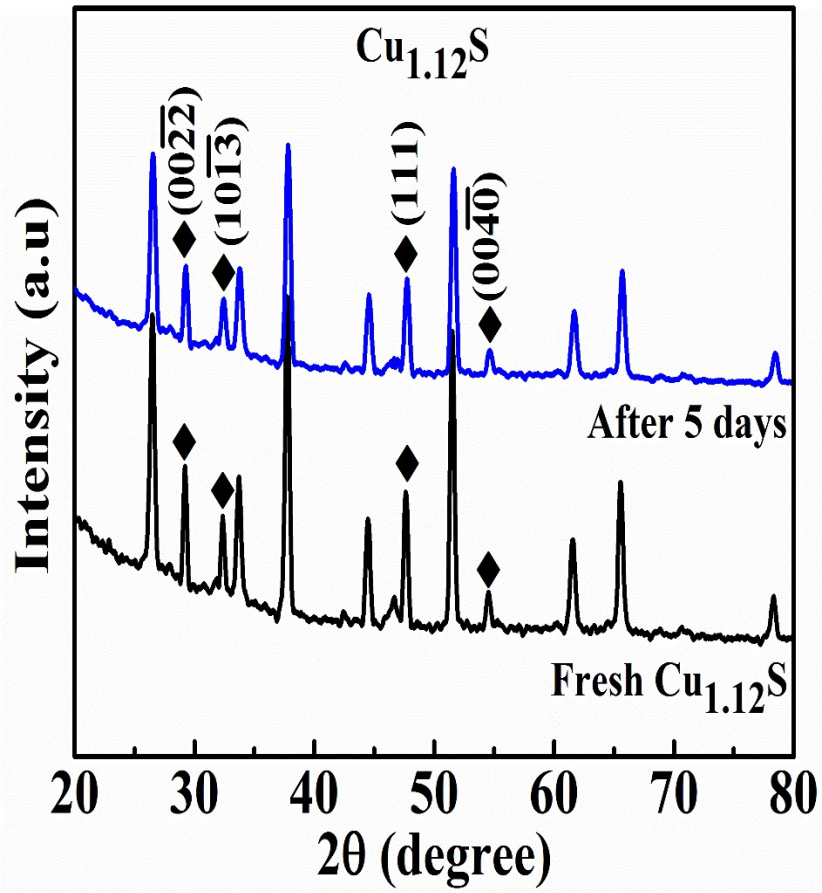


**Fig. S3** XRD spectra of the as-prepared $Cu_{1.12}S$ CE, the $Cu_{1.12}S$ CE after 5 days of immersion in the polysulfide electrolyte.