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Supplementary Information

Solution-Based Ag-Doped ZnSe Thin Films with Tunable Electrical and Optical Properties

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AFM Imaging of the deposited films

The morphology of the Ag-doped ZnSe thin films was characterized by atomic force microscope (AFM), Figure S1. For films doped with $AgNO_3$ concentration in the order of 10^{-1} M to 10^{-3} M, some precipitates are clearly observed on the surface of the ZnSe films, as shown in Figure S1 (A)-(C). For reduced $AgNO_3$ concentration, the precipitates are not as clearly observed, as shown in Figure (D)-(F).

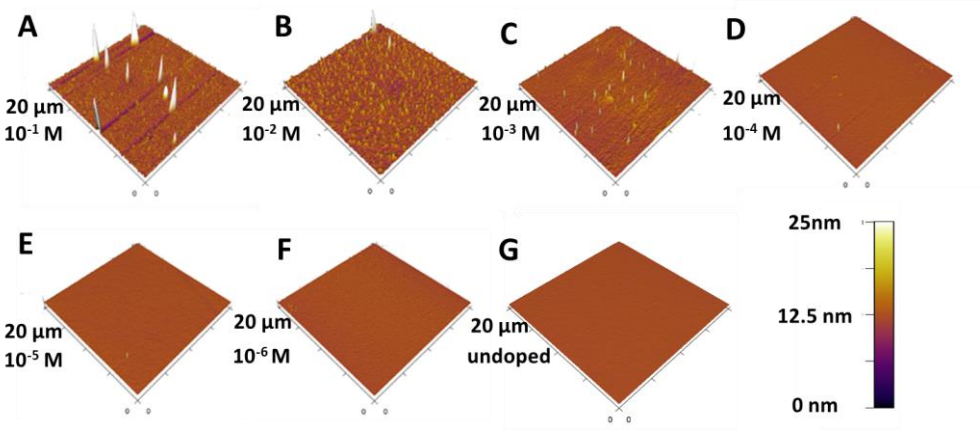

Figure S1 AFM images of ZnSe thin films with doping concentration in the range of 10^{-1} M to 10^{-6} M.

SEM (scanning electron microcopy) imaging of the deposited film

The morphology and thickness of the undoped and Ag-doped films were characterized using SEM (scanning electron microcopy). Figure S2 A and C show the cross-section view and top-view of non-doped (intrinsic) ZnSe films, respectively. Figure B and D show cross-section view and top-view of 10^{-4} M $AgNO_3$ doped ZnSe films, respectively. The doping has no significant effect on the ZnSe thickness, as shown in Figures S2 A and B. The minor difference in thickness (~1.5 nm), may be due to local variations during the SEM image analysis. The top-view images shown in Figures S2 C and D indicate that surfaces of the undoped ZnSe and 10^{-4} M $AgNO_3$ doped ZnSe remain uniform.

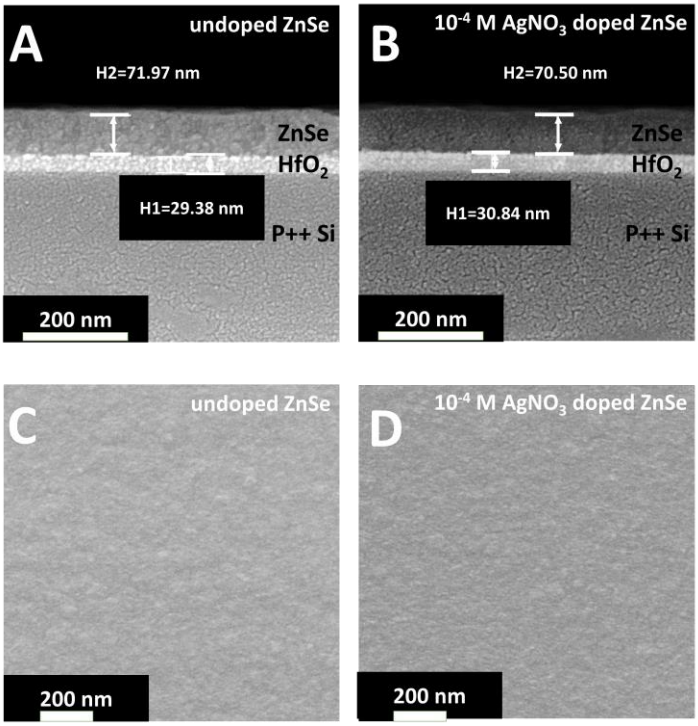

Figure S2 Cross-section view and top-view of undoped ZnSe film (images A and C), and 10^{-4} M $AgNO_3$ doped ZnSe film (images B and D).

XRD results for doped ZnSe thin films

XRD patterns of doped ZnSe also demonstrate the formation of Ag_2Se, as shown in Figure S3. The diffraction peaks observed for 10^{-1} M and 10^{-2} M $AgNO_3$ doped samples

correspond to orthorhombic phase Ag_2Se (JCPDS No. 24-1041), consistent with the Raman results. The broad peaks for lower concentrations indicate that the un-doped and lightly doped ZnSe films are likely amorphous.

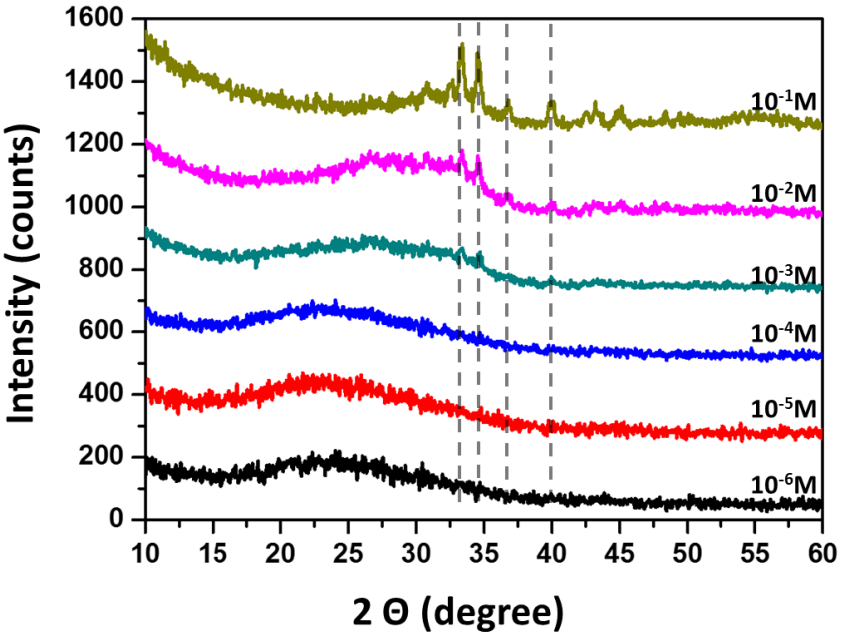

Figure S3 XRD spectrums of doped ZnSe films with different doping solution concentrations. Dash lines are diffraction peaks of orthorhombic phase Ag_2Se from JCPDS Card with reference number 24-1041. These four diffraction peaks correspond to 33.497° (112), 34.728° (121), 36.977° (013) and 39.966° (031).

Preparations of Hall samples

For Hall effect measurements two methods of sample fabrication were used: for high resistivity films photolithography and for low resistivity samples shadow mask. Specifically, samples doped with 10^{-1} M, 10^{-2} M and 10^{-3} M $AgNO_3$ were prepared using shadow mask (pink region in Figure 6) and the remaining samples were prepared using the photolithography method described above (purple region in Figure 6). Figure S4 shows the structures used for Hall Eeffect measurements.

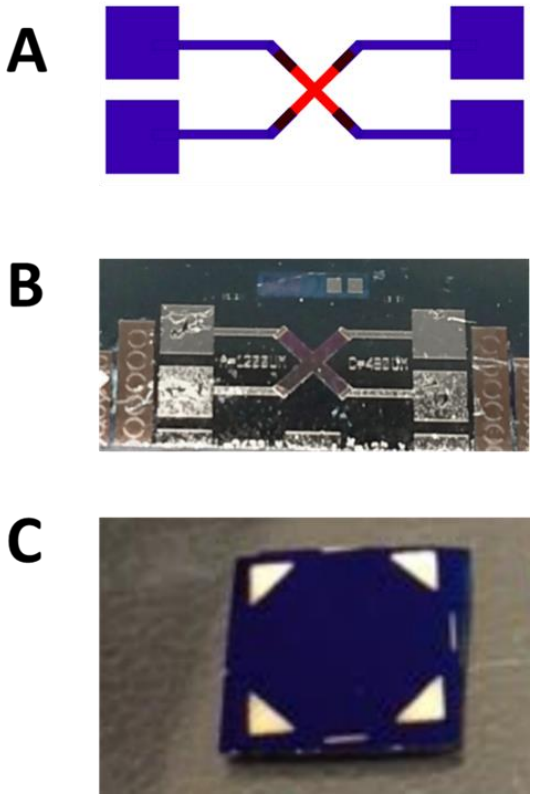

Figure S4 A) Hall electrodes pattern in blue and ZnSe thin film area in red for the photolithography design. Figure B shows an optical image for the 10^{-4} M $AgNO_3$ doped ZnSe sample fabricated via photolithography. Image C is an optical image of 10^{-1} M $AgNO_3$ doped ZnSe Hall sample fabricated via shadow mask method.

Calculating the Atomic Ratio

The intensity (I) of a photoelectron peak from a homogeneous solid in a simplified form is given by [1-2]:

$$I = JC\sigma\xi T\lambda$$

$$C = I/J\sigma\xi T\lambda = I/JF$$

where J is the photon flux, C is the concentration of the element/ion of-interest in the solid, σ is the ionization cross-section, ξ is the spectrometer angular acceptance, T is the spectrometer transmission function, and λ is the IMFP (inelastic mean free path). The term F is called the atomic sensitivity factor, which

incorporates all the terms associated with the spectrometer and the specimen.

The atomic fraction of one element (*A*) in a 2-component system (*A*-*B*) can be determined using the following expression,

$$Atomic\ \%\ A = (I_A/F_A) / [(I_A/F_A) + (I_B/F_B)]$$

In this paper, this is a 3-component system: Ag doped as Ag_2Se, Ag doped as ZnSe-Ag and Zn. We calculated atomic ratio using the following expression

$$Atomic\ \%\ A = (I_A/F_A) / [(I_A/F_A) + (I_B/F_B) + (I_C/F_C)]$$

References

[1] J. M. Walls, Methods of Surface Analysis: Techniques and Applications. Cambridge University Press 1989.

[2] F. P. J. M. Kerkhof , J. A. Moulijn, Quantitative analysis of XPS intensities for supported catalysts, *J. Phys. Chem.*, **1979**, *83* (12), pp 1612–1619