

Supplementary Information

Atomic layer deposition of germanium – doped zinc oxide films with tuneable ultraviolet emission

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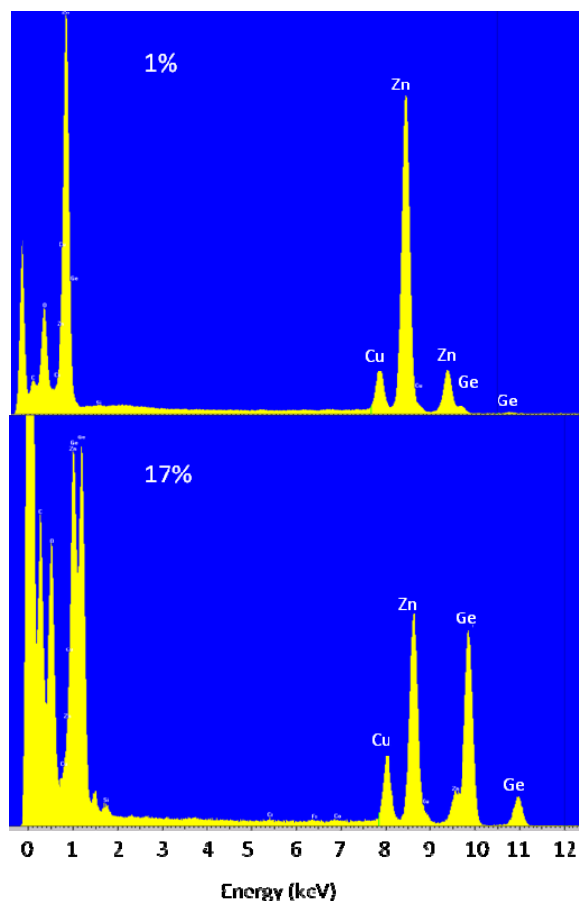


Figure S1. Energy dispersive X-ray spectra recorded at 300KV in the TEM of 1% Ge-doped ZnO and 17% Ge-doped ZnO films grown as-grown at 250°C.

The error in measuring the Ge:Zn ratio is less than 5%. The estimation of the relative Ge incorporation is of the same order of magnitude.

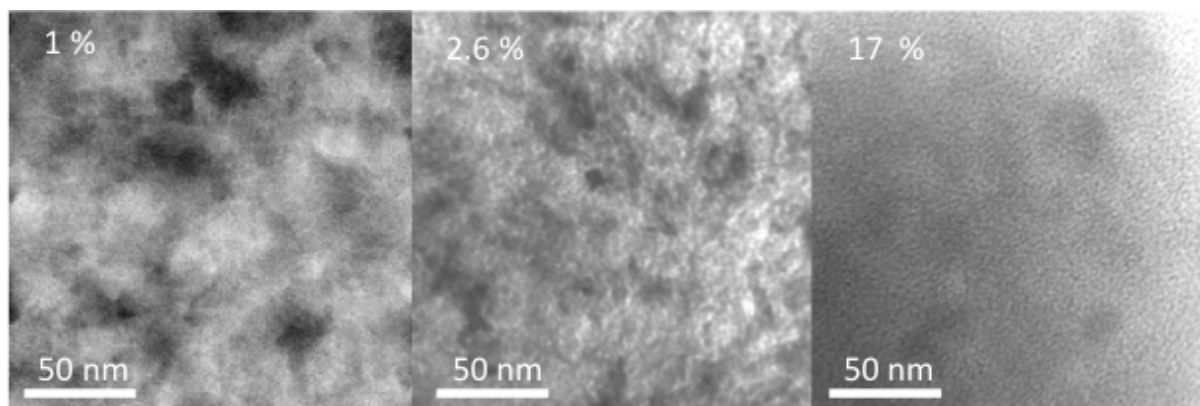


Figure S2. Bright field TEM images of 1%, 2.6% and 17% Ge-doped ZnO films

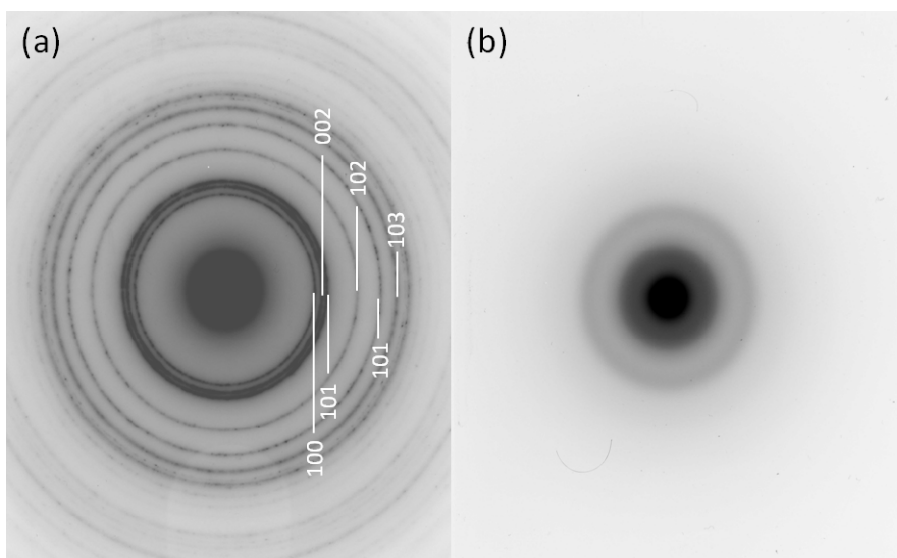


Figure S3. Selected area X-ray diffraction pattern recorded at 300KV in the TEM of: (a) 1% Ge-doped ZnO; (b) of the 17% Ge-doped ZnO film grown as-grown at 250°C

Figure S3 shows selected area X-ray diffraction patterns from (a) 1% Ge-doped ZnO; (b) of the 17% Ge-doped ZnO film grown as-grown at 250°C. The pattern indexing of (a) is consistent with hexagonal ZnO. Figure (b) shows that the 17% Ge-doped ZnO film is effectively amorphous. No germanium oxide diffraction features are evident in either of the 1% or 17% Ge-doped films.

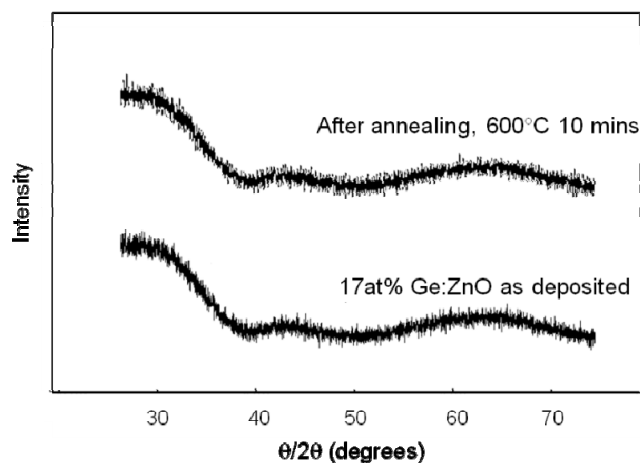


Figure S4. X-ray diffraction pattern of the 17% Ge-doped ZnO film grown as-grown at 250°C and after annealing.

Figure S4 indicates the continuing amorphous character of the 17% Ge-doped ZnO film after annealing at 600°C in air for 10 minutes. The as-deposited film pattern is effectively amorphous and devoid of diffraction features and is unchanged by annealing.

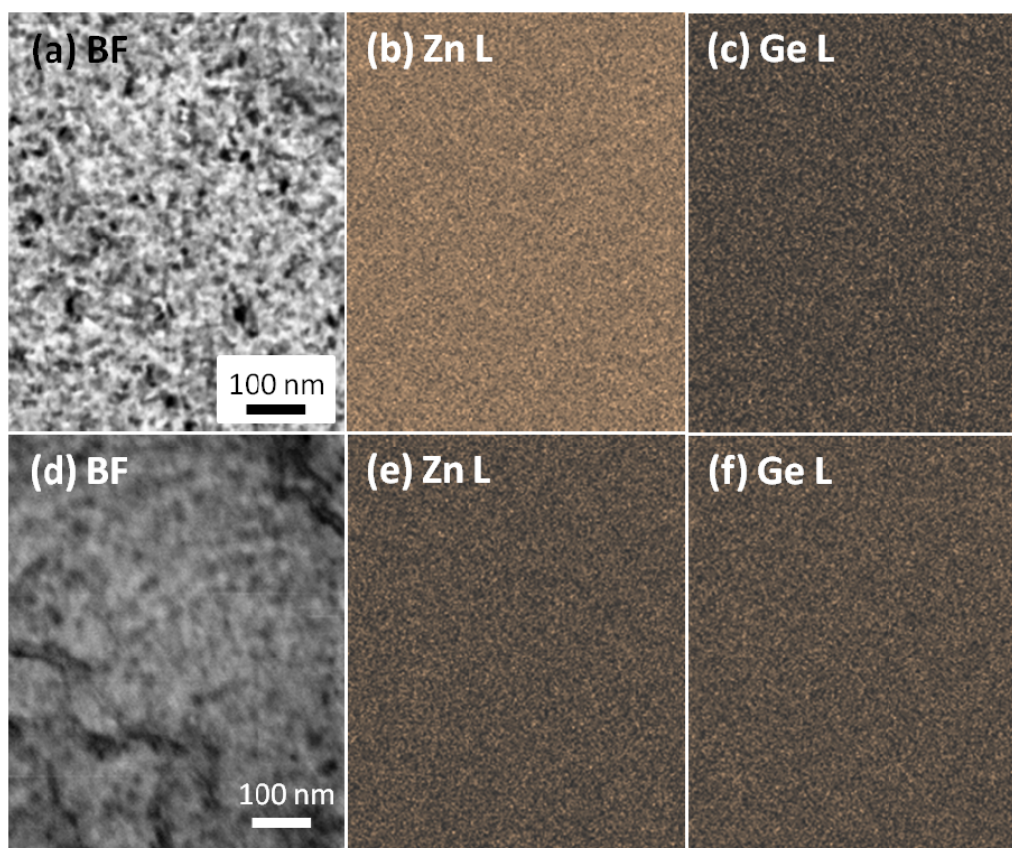


Figure S5. Bright field image and Energy dispersive X-ray maps recorded at 300KV in the TEM of: (a-c) 1% Ge-doped ZnO; (d-f) of the 17% Ge-doped ZnO films grown as-grown at 250°C. Magnification x 100,000 times.

The distributions of Zn and Ge are compared in Figure S4. The energy dispersive X-ray maps illustrate the uniform distributions of the elements and the absence of any segregation.

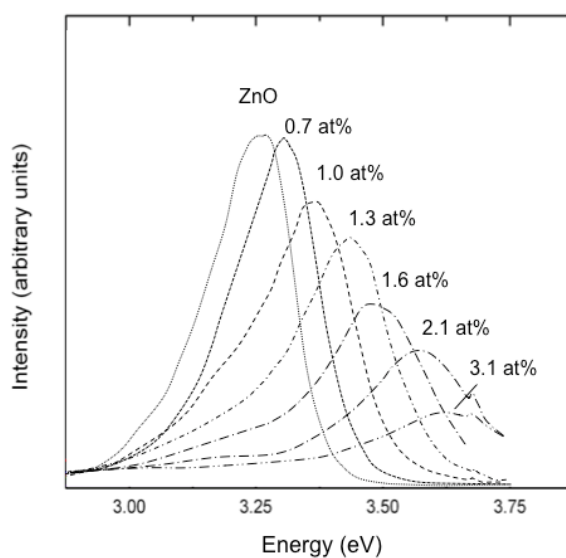


Figure S6. Absolute PL spectra of ZnO:Ge films with varying Ge doping levels deposited at 250°C.