The Short Period $\{CdO/ZnO\}_m$ SLs Grown on *m*-Al_2O_3 by MBE

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Introduction

A set of 3 $\{CdO/ZnO\}_m$ superlattices (SLs) were grown by plasma assisted MBE (PA-MBE) on *m*-plane sapphire substrates (Al_2O_3) and differ from each other:

- the first epitaxial layer (Table 1)
- the thickness of the CdO and ZnO layers (Table 1).

The growth parameters were constant (oxygen flow and radio frequency (RF) power, Zn and Cd flows):

- growth temperature: 360 °C;
- growth rate: ~ 1.5 nm/nm.

After growth, rapid thermal processing (RTP) were carried out under conditions of 900°C in oxygen (O_2) for 5 minutes.

Sample	Growth time (min) {CdO/ZnO}	Thickness of {CdO/ZnO} layers, nm	Number of layer pairs	{CdO/ZnO} SLs Period (nm) XRD	{CdO/ZnO} SLs Period (nm) TEM	Energy gap (eV)
A	6/1	8/1	25	11±2	10	2.97
B	3/3	5/5	25	12±5	9	3.04
C	6/1	12/1.5	25	10±3	13,5	2.67

Results: XRD data of $\{CdO/ZnO\}_m$ SLs

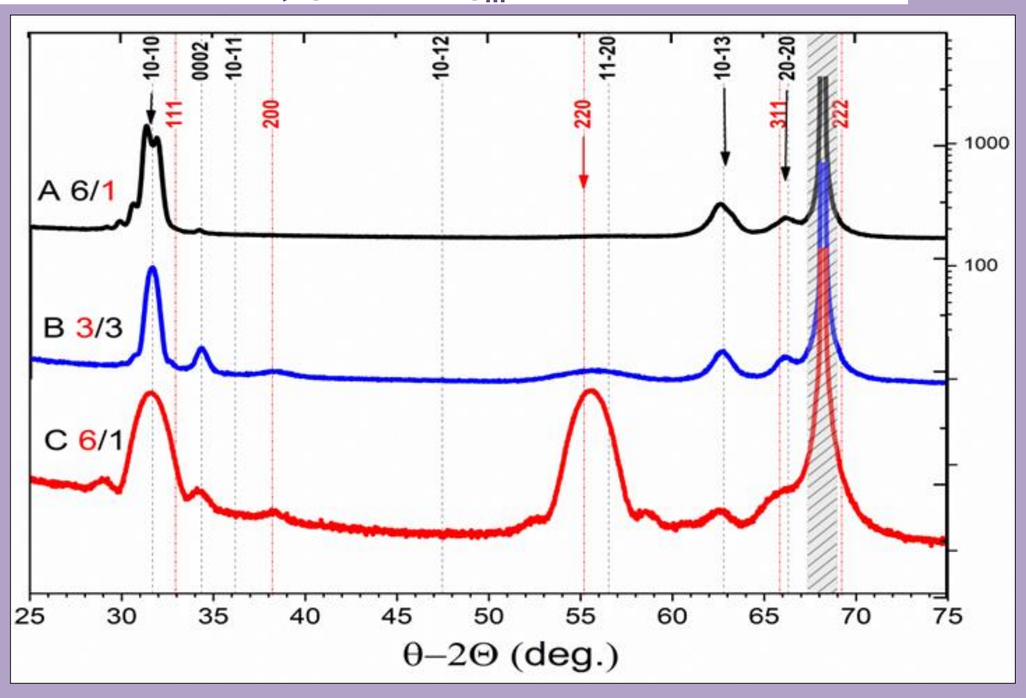

Fig. 1. Low angle resolution θ/2θ XRD patterns of the *as grown* $\{CdO/ZnO\}_m$ SLs. Red dotted lines represents XRD peaks position of cubic phases of pure CdO and grey dotted lines position of the wurtzite ZnO pure phases[1].

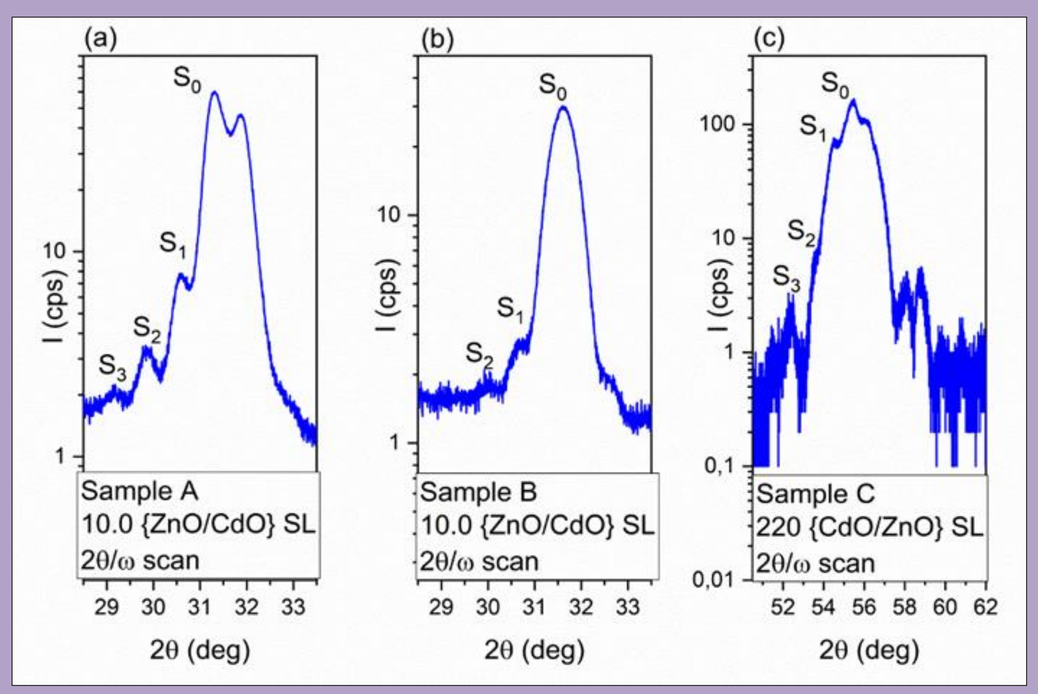

Fig. 2. HR-XRD 2θ/ϖ patterns of the *as grown* $\{CdO/ZnO\}_m$ SLs (a) $\{ZnO_{8nm}/CdO_{1nm}\}_{25}$; (b) $\{CdO_{5nm}/ZnO_{5nm}\}_{25}$; (c) $\{CdO_{12nm}/ZnO_{1.5nm}\}_{25}$[1].

- HR-XRD measurements reveal SL-like behavior of patterns with central peaks located at about 31.5 º and 55.4º corresponds to hexagonal and cubic structures, respectively.
- Zero ordered peaks (S_0) and higher orders of superlattice-related satellite peaks (S_1, S_2, S_3) are observed for all *as grown* SLs.
- Based on the distance from HR-XRD patterns (**Fig. 2**) the SL period (Λ) were determined (Table 1) by

$$\frac{2\sin\theta_n - 2\sin\theta_{SL}}{\lambda} = \pm\frac{n}{\Lambda}$$

θ_n is the n-th order peak in diffracted curve, θ_{SL} is the zero-peak order.

Results: morphology of as grown SLs

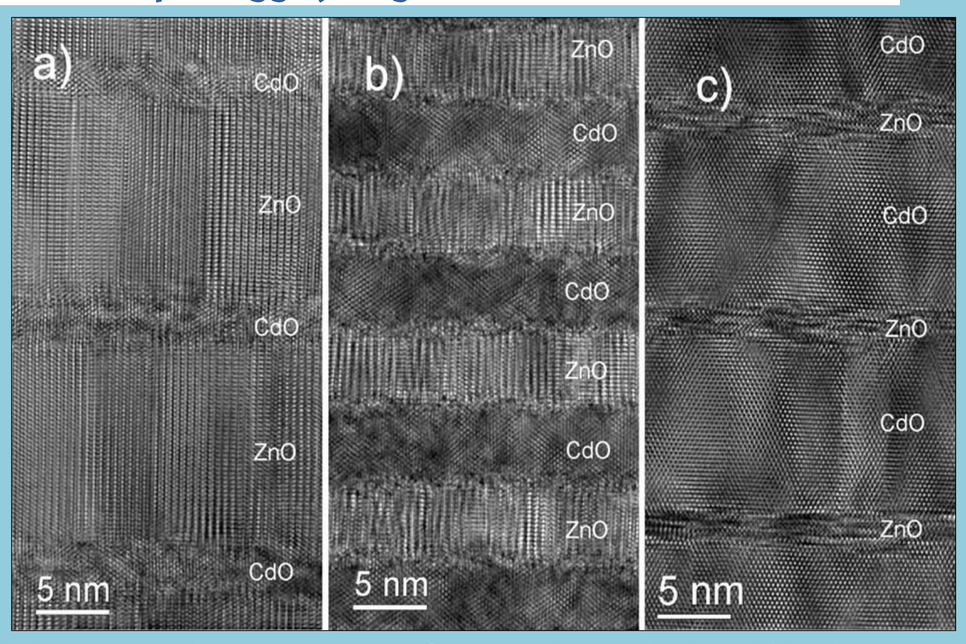

Fig. 3. Cross-sectional HR-TEM images of *as grown* SLs (a) $\{ZnO_{8nm}/CdO_{1nm}\}_{25}$; (b) $\{CdO_{5nm}/ZnO_{5nm}\}_{25}$; (c) $\{CdO_{12nm}/ZnO_{1.5nm}\}_{25}$[1].

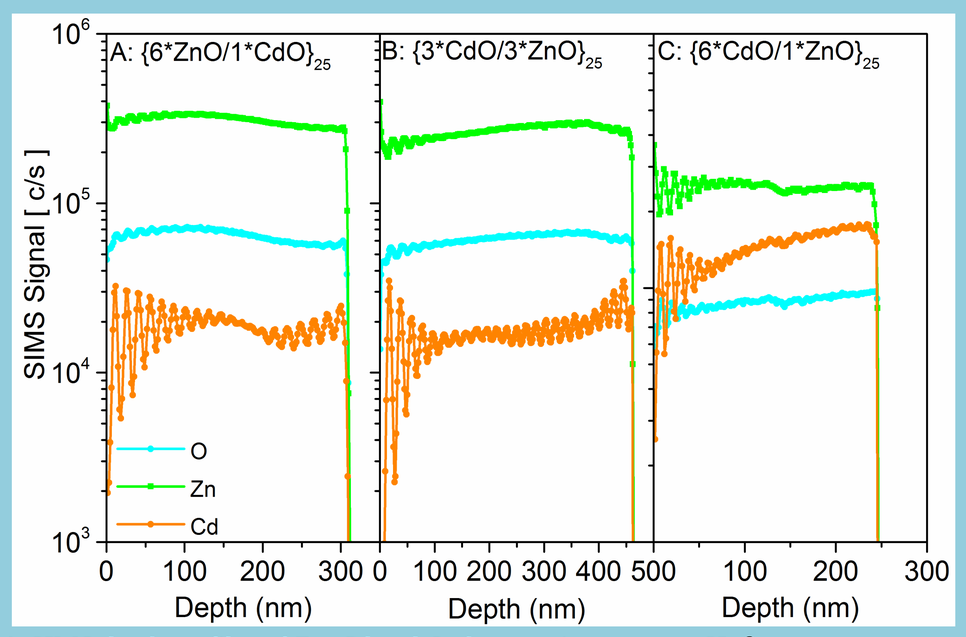

Fig. 4. SIMS depth profiles of Zn, Cd and O elements in *as-grown* SLs[2].

- HR-TEM images proved the wurtzite structure of ZnO layers and the rocksalt structure of CdO layers (**Fig. 3**).
- The SIMS data show the individual CdO and ZnO layers are clearly traceable and their order reflects the planned structures (**Fig. 4**).

Results: annealed SLs (RTP at 900ºC in O_2 for 5 min)

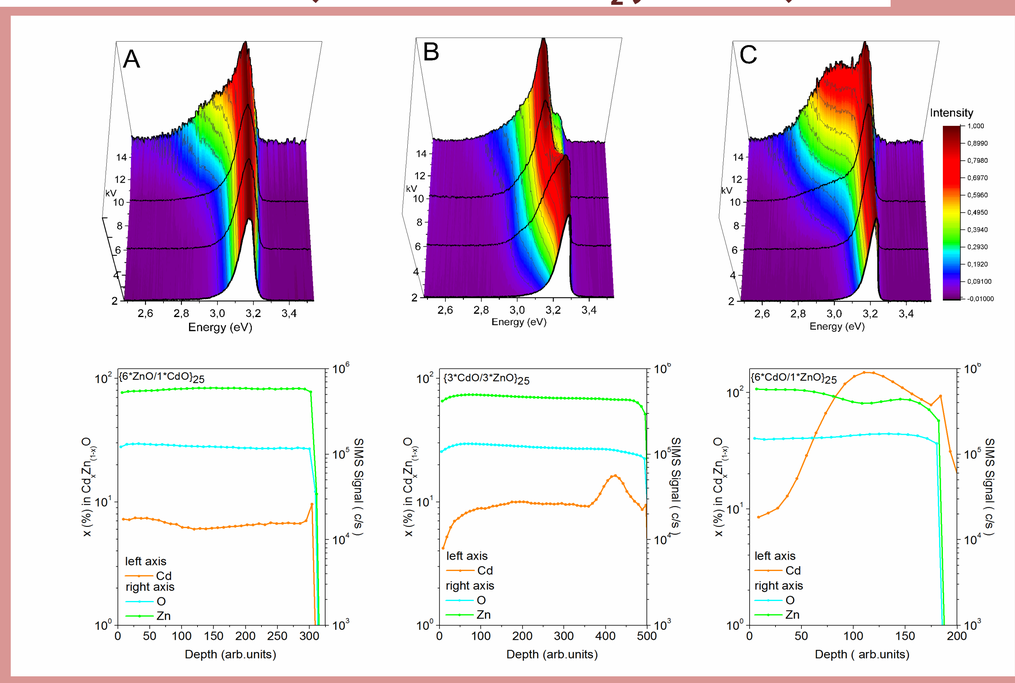

Fig. 5. The SIMS depth profiles of Cd, Zn and O elements in annealed $\{CdO/ZnO\}_m$ SLs compared to 3D CL spectra of $\{CdO/ZnO\}_m$ SLs at different electron beam kinetic energies (2, 6, 10 and 15 kV)[2].

- The thickness of the individual CdO and ZnO layers affects the final homogeneity of the Cd distribution in the annealed structures.
- Depth profiling using SIMS and depth-dependent CL confirmed the presence of Cd- or Zn-rich regions in depth in some of the annealed samples.

Conclusion

- The $\{CdO/ZnO\}_m$ SLs were grown by PA-MBE on *m*-Al_2O_3 substrates.
- The ZnO sublayer structure retains the wurtzite crystallographic structure regardless of the thickness of the ZnO layers, when, as CdO sublayers, they crystallize mainly in the cubic rocksalt structure (**Fig. 1** and **Fig. 3**).
- Satellite peaks are observed in all samples (**Fig. 2**).
- The SL period calculated using XRD is in good agreement with the period calculated from TEM data (Table 1).
- As a result of RTP, the well-defined initial crystal structure of the SLs is degraded.
- An inhomogeneous distribution of Cd is often observed in the annealed structures.
- The SIMS depth profiles revealed Cd segregation, which is reflected in the CL spectra taken from different depths of the layer (**Fig. 5**).

References

[1] E. Przeździecka, et al., Crystal Growth & Design. 22, 2, 1110–1115 (2021)
[2] A. Lysak, et al., Materials Science in Semiconductor Processing. 142, 106493 (2022).

Acknowledgements

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