Influence of As doping on the properties of MBE grown nonpolar ZnO thin films

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Introduction

In the last years, a great interest toward development of applications based on doped ZnO films is observed. Most of the growth experiments on ZnO were conducted using C- or A-plane sapphire substrates. There is considerable interest to grow high-quality ZnO based films in nonpolar directions to avoid polarization effects[1]. It is also extremely important to understand defects occurring in nonpolar ZnO layers because the presence of defects affects optical properties of grown samples.

Samples

- Epitaxial ZnO layers doped with As were grown on *r*-Al_2O_3 substrates by plasma assisted MBE using. The As Knudsen cell temperature was varying between 190-220°C.

Results

All as-grown samples showed n-type conductivity, but we found that the concentration of As atoms (measured by SIMS) increased much faster with the increase of the As effusion cell temperature than the concentration of electrons. Such behavior may suggest an amphoteric nature of the As-dopant and presence of n-type As-related defects instead of the expected p-type ones.

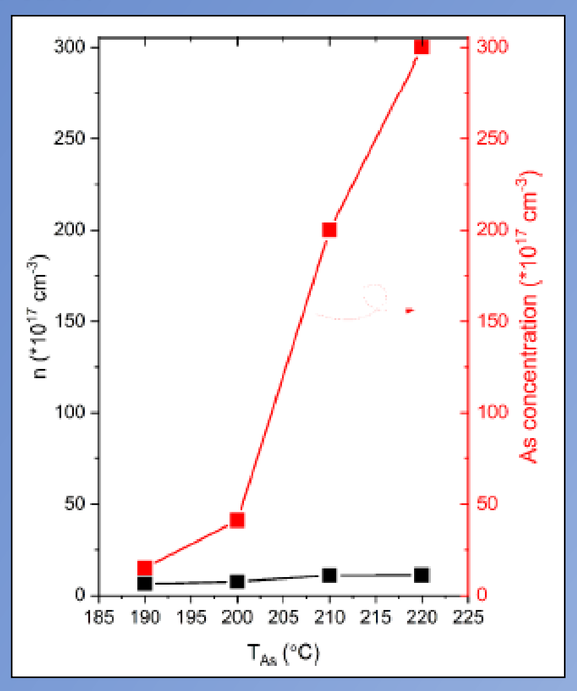

Fig. 1. Concentration of electrons and As atoms vs temperature of the As cell. Points are experimental data, lines - guides to the eyes.

Table 1. The results of the Hall effect measurements at RT, where *n* is the carrier concentration and μ_n mobility.

As, *T* °C	*d*, µm	*ρ*, Ohm*cm	μ_n, $cm^2/V*s$	*n*, 10^{17} cm^{-3}	n_{As}, 10^{17} cm^{-3}	E_g, eV	E_u, meV
0	0.6	1.78	8	7.24	7.5	3.321	37.81
190	0.43	1.59	6.18	6.35	15	3.336	35.03
200	0.52	1.43	6.37	7.52	41	3.325	39,95
210	0.5	2.29	5.63	10.97	200	3.313	46.6
220	0.46	1.27	5.85	11.09	300	3.318	4.98

Results: Optical transmittance spectra

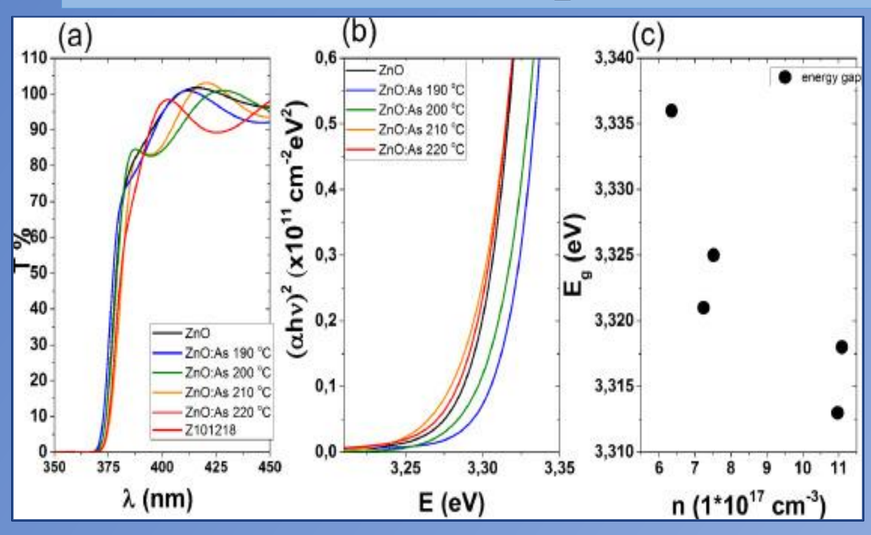

Fig. 2. (a) Experimental transmission spectra of As-doped ZnO films, (b) Tauc plot dependence on As-effusion cell temperature, (c) energy gap as a function of carrier concentration.

The optical band gap of thin ZnO films doped with As varies from 3.313 to 3.336 eV depending on the As-effusion cell temperature.

An increase in the concentration of charge carriers in ZnO films does not lead to a shift in the fundamental absorption edge to the high-energy region of the spectrum.

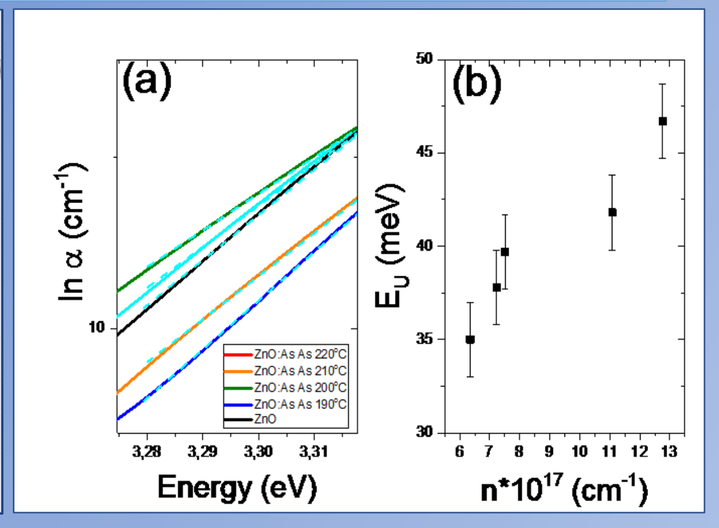

Fig. 3. (a) Ln of the absorption coefficient as a function of photon energy (b) Urbach tails as a function of RT carrier concentration.

An increase in ZnO film As-doping does not result in band gap widening (ΔE_{BM}), so the B-M effect is not observed. We observe the band gap narrowing effect, whose origin is described by various interactions involving carriers and ionized impurities[3,4].

The calculated values of Urbach energy being in the interval 35 – 47 meV.

Results: Photoluminescence properties

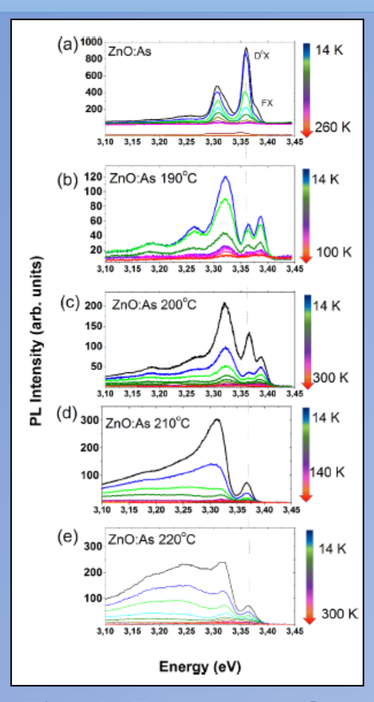

Fig. 4. Temperature dependent PL for ZnO samples with different concentration of As.

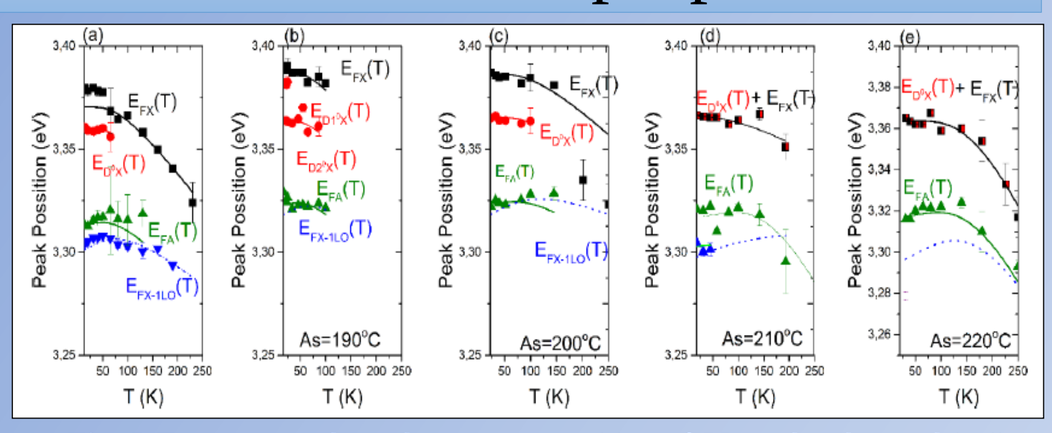

Fig. 5 Temperature dependent energy position of PL peaks observed in "as grown" ZnO:As nonpolar samples, where E_{D^0X} is the energy of excitons bound to neutral donors, E_{FX} is the free exciton transition energy, E_{FA} is the energy of free electrons to neutral acceptors and E_{FX-LO} is the energy of first phonon replica of free exciton.

Localization energy of the observed donors are: about 11 meV in ZnO, ~6 meV and ~23 meV in ZnO:As (As 190) and ~21 at ZnO:As (As 200).

Conclusion

Not all As atoms are electrically active in ZnO samples numbers of no active atoms most probably increase when we increase the number of all As atoms in ZnO nonpolar layers.

The Urbach energy increase with concentration of electrons, what can suggest that disorder in samples increase with electron concentration.

Relatively intensity of the visible peaks drastically changes with As doping.

References

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