Research of electrical, optical and structural characteristics of Ga-doped ZnO coatings received by magnetron sputtering on a polymeric substrate

Matiss Mishels-Piesins, Edmund Machevsky, Imants Ashmanis, Viktor Kozlov
Sidrabe Inc., 17 Krustpils Street, Riga, LV-1073 Latvia
e-mail: matiss@sidrabe.eu

Introduction

Abstract

- Gallium-doped ZnO (GZO) thin films were deposited by magnetron sputtering on PET and glass substrates in a roll-to-roll coater
- Dependence of material characteristics upon its deposition conditions and substrate pre-treatment were studied
- The films show a typical ZnO wurtzite structure and c-axis orientation
- Electrical resistivity is strongly increased directly above erosion zones while optical transparency is not influenced

Motivation

While Al-doped ZnO films on glass have been recently brought into production as a low-cost TCO for silicon solar cells, they are not applicable to plastic substrates due to elevated deposition temperatures.

The most promising low-cost TCO for flexible substrates and a wide range of applications is ZnO doped with Gallium.

The electrical properties of this material are highly dependent on the process parameters, therefore it needs thorough investigation and optimization of the deposition technology.

Object of interest

- Gaining understanding of GZO deposition process in general
- Discovery and elimination of problematic aspects in industrial-scale process
- Development of commercially viable technology process equipment

Experimental

Setup

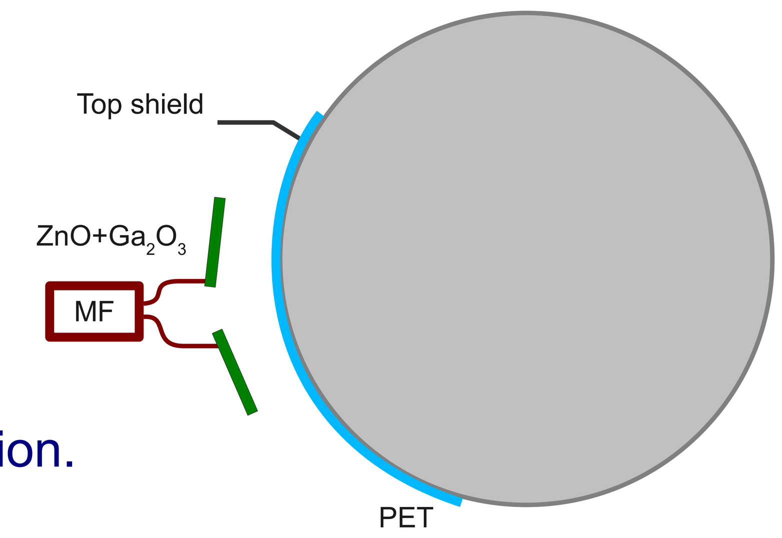
- Coater: 600 mm roll width
- Base pressure: $< 1 \cdot 10^{-5}$ Torr ($< 1.3 \cdot 10^{-3}$ Pa)
- Target-substrate distance: 100 mm
- Magnetrons: Dual, planar, 800x120 mm
- Target: Ceramic, conducting
- Dopant: ≈ 2.5 % Ga_2O_3
- Substrate: DuPoint Melinex ST504 175 µm
- Pretreatment: Glow discharge (Ar + O_2)

Varied process parameters

- Pressure: 0.8 to $4 \cdot 10^{-3}$ Torr (0.1 to 0.5 Pa)
- Gases: 200 to 300 sccm Ar; 0 to 10 sccm O_2 or H_2O or H_2
- Power: 0.5 to 2.5 W/cm²
- Substrate T°: Room Temperature to 90°C
- Operation: Single magnetron DC or dual magnetron MF
- Magnets: Standard balanced, unbalanced, 2 types with stronger center

Layout for static deposition

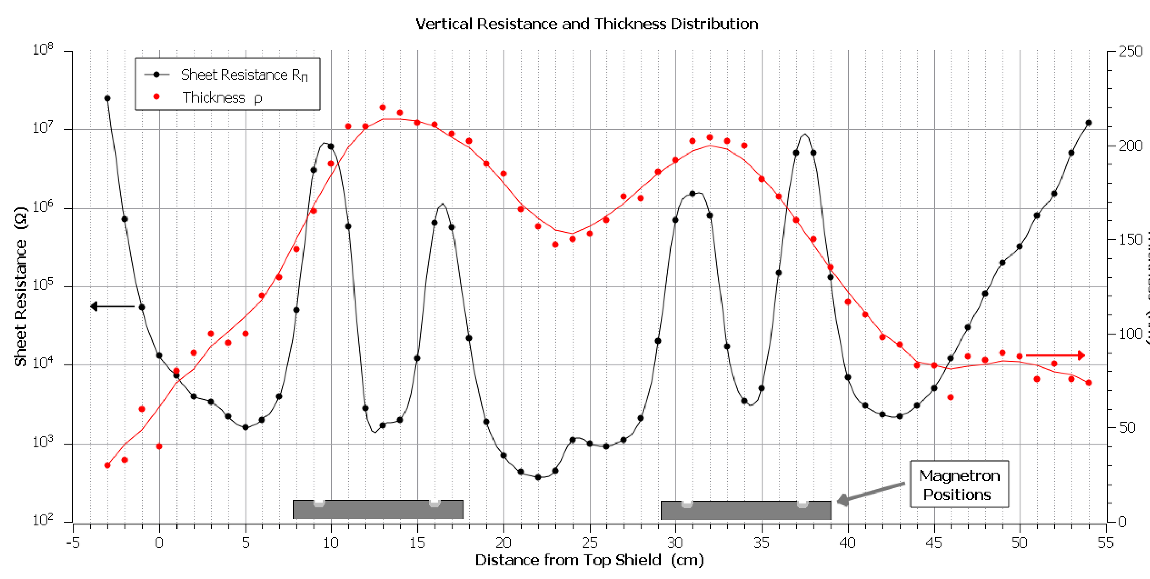
Static PET samples were prepared on a continous foil, quickly winding into and out of the needed position.



Glass samples were prepared similarly, limited to two samples per run.

Results & Discussion

Peaks in resistivity and erosion zones

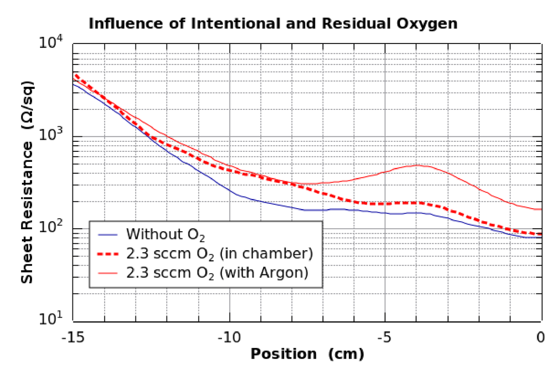


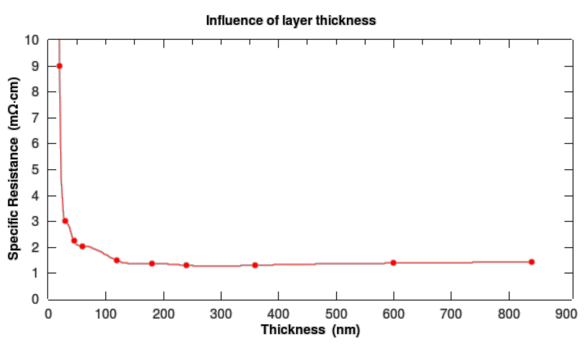
Sharp peaks appear directly above erosion zones. Their minimal height is 3·Rmin. Height mostly depends on process pressure.

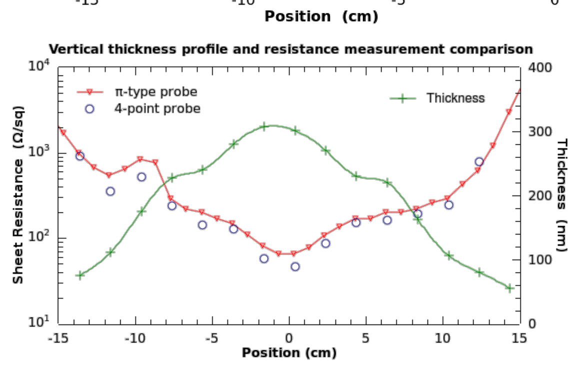
Effects of pressure, O_2 and thickness

$p_W \approx 1.4 \cdot 10^{-3}$ Torr (0.2 Pa)

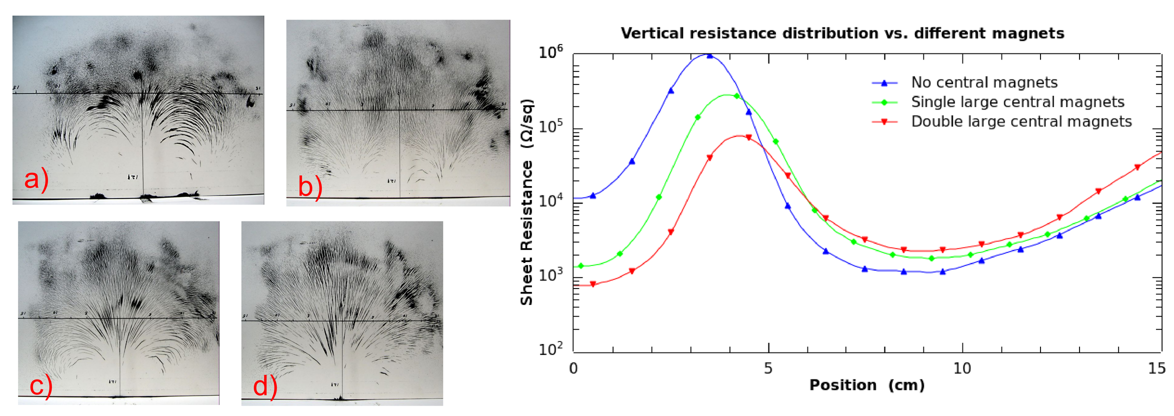
Deviations from optimal p_W lead to increased resistance and higher peaks.







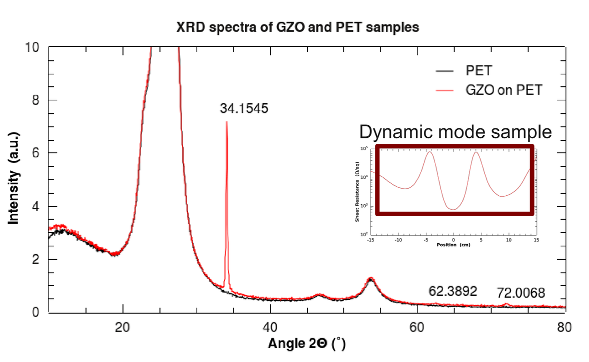
Influence of magnetic field

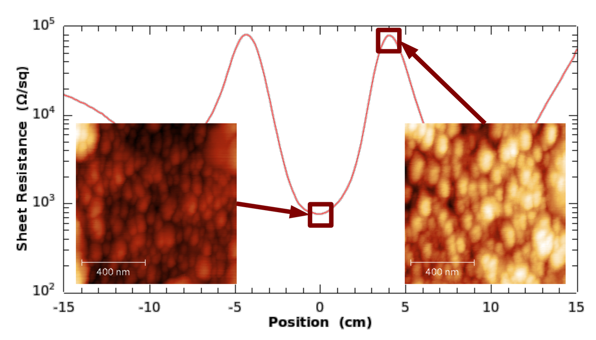


A considerable change in magnetic field from balanced (a) to unbalanced (b) or to a very strong central field (c, d) resulted only in a subtle shift of peaks. Unbalanced system produced higher resistance at the center of magnetron, most probably due to intensive ionised particle flux.

Results & Discussion

Structural properties



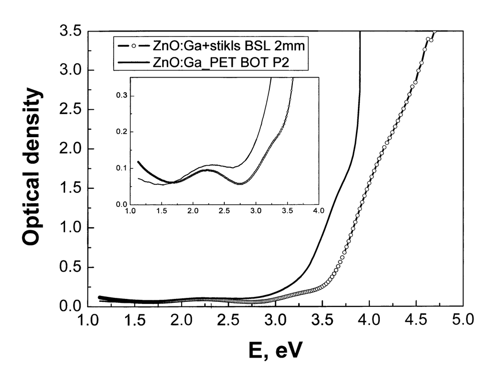


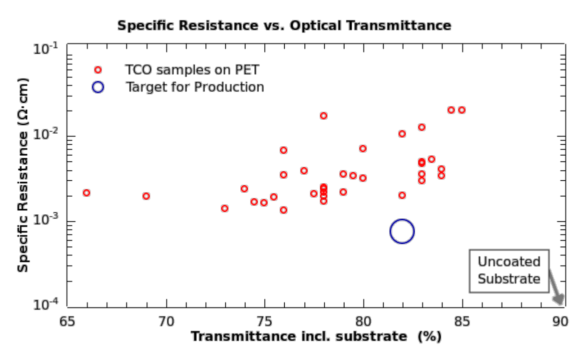
Structure is typical for a sputtered ZnO, with strongly preferred c-axis orientation and smooth surface ($R_a \approx 10$ nm).

AFM images did not reveal any significant differences between film surface in low and high resistance regions.

Raising substrate temperature to 90°C prior to deposition reduced outgassing from PET and slightly lowered dynamic mode film resistance.

Electrical and optical properties





Introduction of a SiO_2 barrier layer yielded a reduction in specific resistance ~1.6 times. Using glass substrates allowed for ~2 times lower resistance.

Inserting a bias grid just before the substrate indicated a -20 V self-bias potential, but applying an external bias didn't produce any substantial difference in specific resistance.

Scattered transmittance values originate from uneven system warm-up time before growth.

Conclusions

- GZO thin films were prepared by magnetron sputtering, achieving specific resistance of $1.5 \cdot 10^{-3}$ Ω·cm and transmittance of > 83%
- Best results were obtained without additional oxygen and with a SiO_2 barrier layer
- Addition of ≈ 1% H_2 provided a slight reduction of peaks and resistance with no SiO_2 barrier layer
- Carrier density for thick samples is $\approx 3 \cdot 10^{20}$ cm^{-3}, hall mobility ≈ 11 cm²/(V·s)
- Origin of high resistance peaks in static samples is unclear, not influenced by magnetic system, DC or MF mode, not revealed by AFM images
- Dynamically deposited samples have higher specific resistance due to those peaks