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

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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

<table>
<thead>
<tr>
<th>Coater</th>
<th>600 mm roll width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base pressure</td>
<td>&lt; 1·10⁻⁸ Torr (&lt; 1.3·10⁻⁸ Pa)</td>
</tr>
<tr>
<td>Target-substrate distance</td>
<td>100 mm</td>
</tr>
<tr>
<td>Magnetrons</td>
<td>Dual, planar, 800x120 mm</td>
</tr>
<tr>
<td>Target</td>
<td>Ceramic, conducting</td>
</tr>
<tr>
<td>Dopant</td>
<td>≈ 2.5 % Ga₂O₃</td>
</tr>
<tr>
<td>Substrate</td>
<td>DuPont Melinex ST504 175 µm</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>Glow discharge (Ar + O₂)</td>
</tr>
</tbody>
</table>

Varied process parameters

| Pressure      | 0.8 to 4·10⁻¹¹ Torr (0.1 to 0.5 Pa) |
| Gases         | 200 to 300 sccm Ar, 0 to 10 sccm O₂, or H₂ |
| 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 |

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, O₂ and thickness

pₚ = 1.4·10⁻¹¹ Torr (0.2 Pa)

Deviations from optimal pₚ 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 in 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 (R₄ = 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 SiO₂ 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 1.5·10⁻⁸ Ohm cm and transmittance of > 83%
• Best results were obtained without additional oxygen and with a SiO₂ barrier layer
• Addition of ~ 1% H₂ provided a slight reduction of peaks and resistance with no SiO₂ barrier layer
• Carrier density for thick samples is ~ 3·10¹⁹ 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

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