Fabrication of transparent ITO/Ga-doped ZnO coating as a front panel electrode toward efficient thin film solar cells

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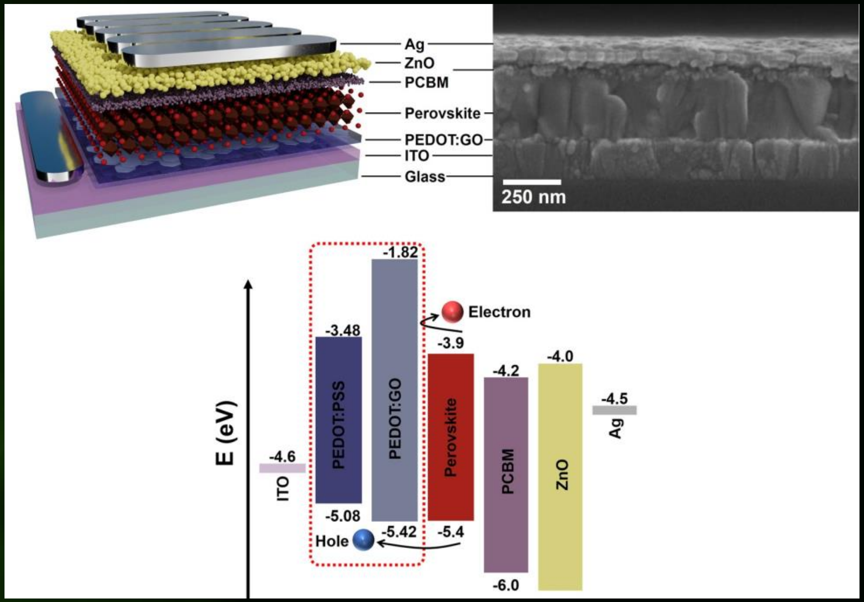
Aim/Novelty

- **Aim:** To prepare electrode for solar cell that is highly conductive, highly transparent for the visible light, highly reflective for the infrared range and smooth. This is a precondition for reduced optical and electrical losses in the solar cells, resulting in an efficiency increase.

- **Novelty:** According to the literature, the effect of the oxygen partial pressure during sputtering on the ZnO doped by Ga (GZO) film's morphology and the optical properties has not been yet investigated. In this work we tried to fill this gap by preparing GZO/ITO system by RF sputtering of GZO films at different oxygen pressures for application in CdS/ZnS core-shell quantum dots/perovskite low-cost solar cell.

State-of-the-art



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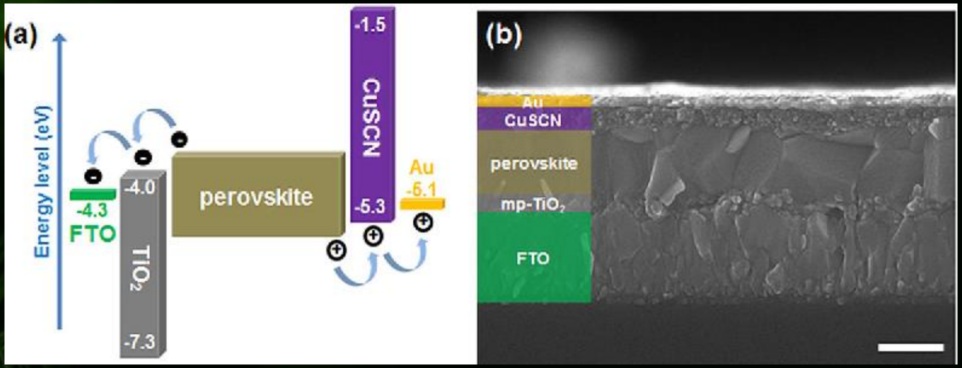
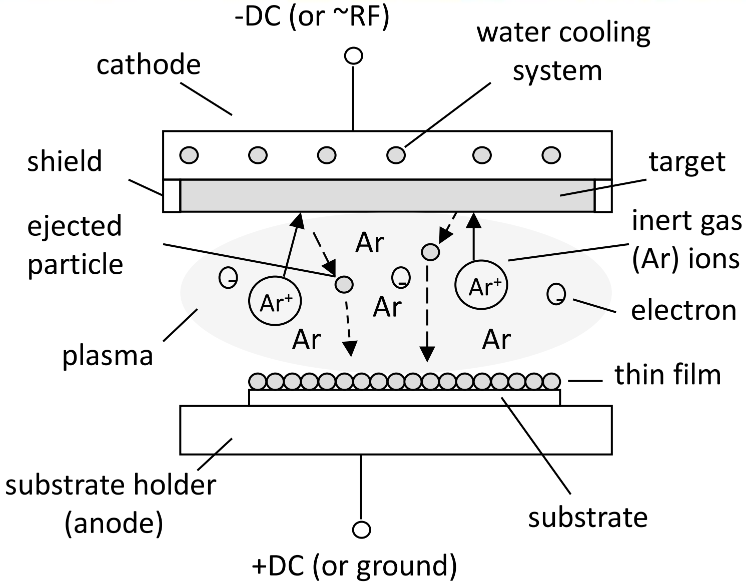
Currently, the most widely spread transparent conductive electrode (TCE) is made of indium tin oxide (ITO) or fluorine tin oxide (FTO). For energy level alignment with the perovskite photoconductors are used conductive polymers (PEDOT:PSS), or titanium dioxide (TiO_2). However, they are not effective optical filters and cannot reject neither infrared, nor ultraviolet component of the sun spectrum



Chem. Sus. Chem. **918** 2592 (2016)

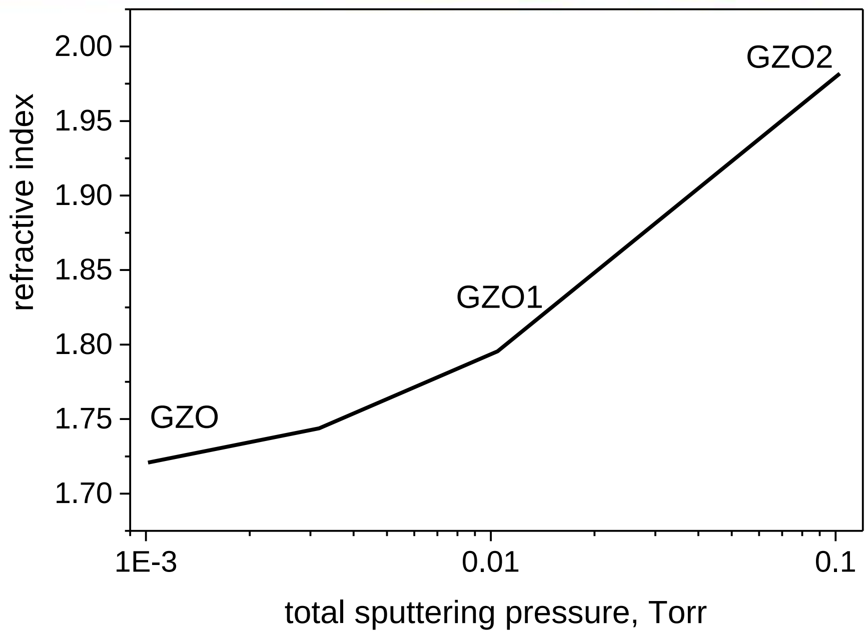
Experiment



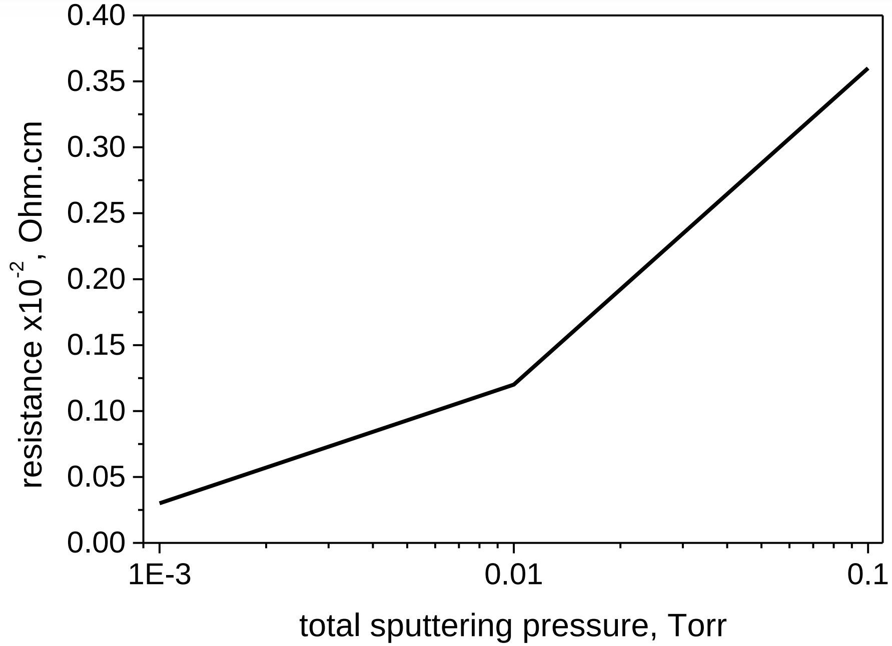
RF and DC sputtering of ITO/GZO and Al electrodes, respectively

Thin films of ZnO doped by Ga (GZO), and ITO/GZO were prepared by RF sputtering of 3 inches-diameter targets positioned 12 cm above glass substrates. The sputtering voltage was kept constant for all sputtered combinations and it was 0.85 kV for the ITO films and 0.7 kV for the GZO films. The total sputtering pressure in the chamber (argon) was 1.10^{-3} Torr for the sample of single layer GZO and bi-layer ITO/GZO without additional oxidation. For the ITO/GZO1 the total sputtering pressure (argon + oxygen) was 1.10^{-2} Torr due to introduction of oxygen, which corresponds to 10% oxidation. For ITO/GZO2 the total sputtering pressure (argon + oxygen) was 1.10^{-1} Torr due to introduction of more oxygen, which corresponds to 20% oxidation. Simple solar cell was produced by spin coating of the functional layers.

Results



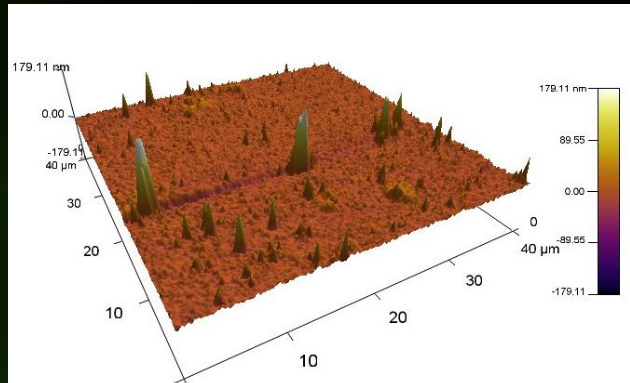
Refractive index of GZO in the IR region, sputtered at different total sputtering pressures due to additional target oxidation.



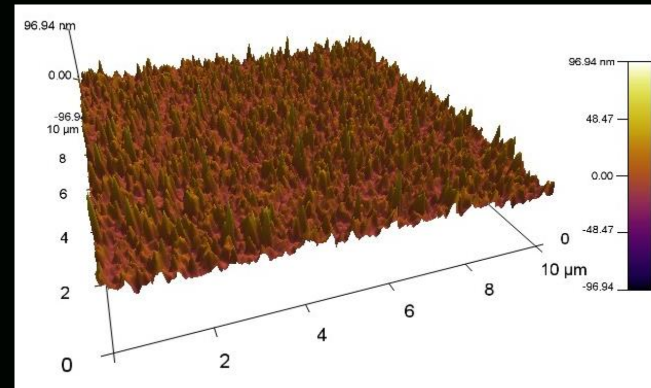
Electrical resistance of ITO/GZO at different total sputtering pressures due to additional target oxidation.

It can be noted an increase of the refractive index of GZO from 1.72 without additional oxidation of the target, to 1.98 after 10^{-1} Torr introduction of oxygen. The GZO single layer showed a resistivity of 1.67×10^{-2} Ω.cm. Insertion of ITO resulted in a resistance decrease to 0.03×10^{-2} Ω.cm.

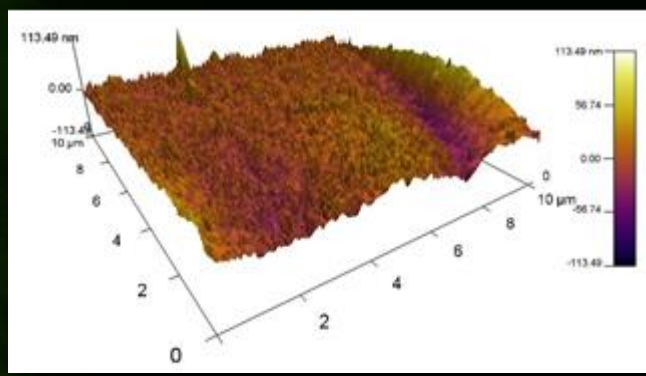
Results



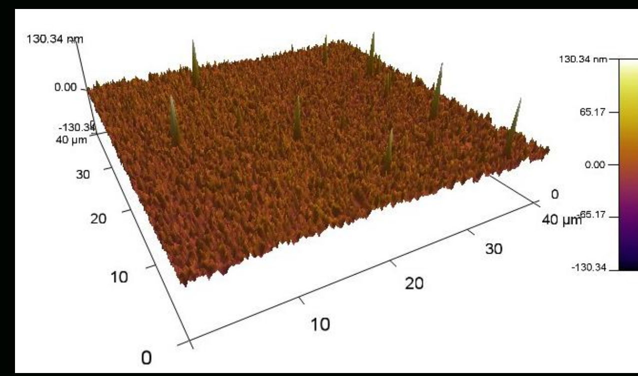
GZO: Ra = 13 nm



ITO/GZO: Ra = 16 nm



ITO/GZO1: Ra = 9.5 nm



ITO/GZO2: Ra = 7.1nm

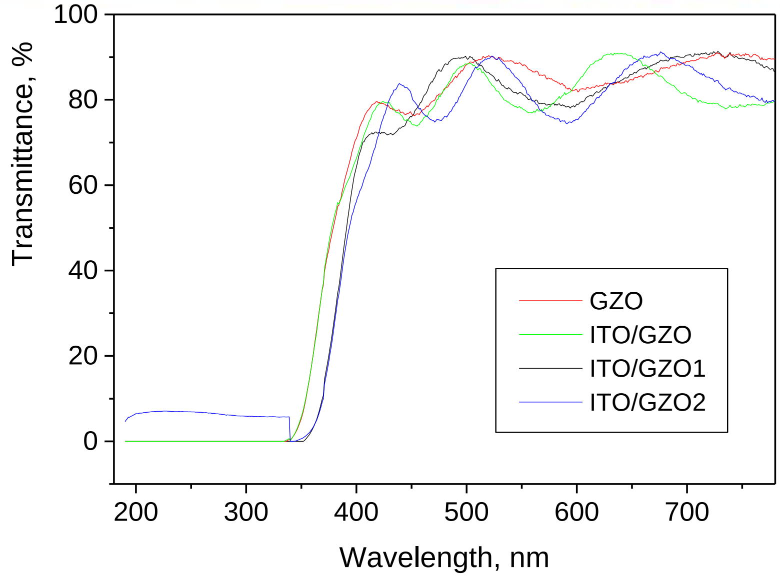
AFM images of GZO film; bi-layer ITO/GZO without additional oxidation; ITO/GZO1 with 10 % and ITO/GZO2 with 20% of oxidation. Ra is average roughness.

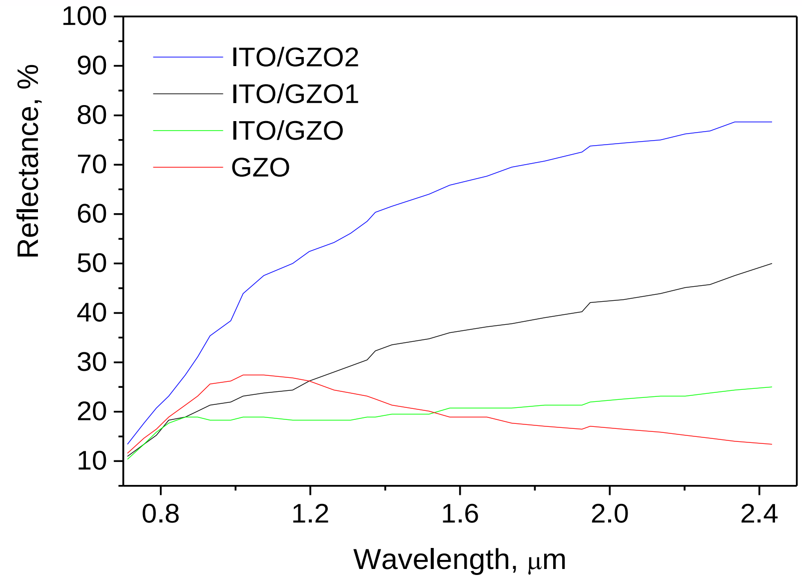
Results

Although great number of hills existed in ITO/GZO films as compared to single GZO they were more uniformly distributed and less sharp due to the ITO insertion. Further, the number and height of the sharp peaks decreased with the oxygen content increase during sputtering.

The smoother films are expected to result in the decrease of the optical losses during transmittance of the visible light. To investigate this relation, the transmission spectra in broad wavelength region between 190 nm and 800 nm were measured as a function of the oxygen content.

Results



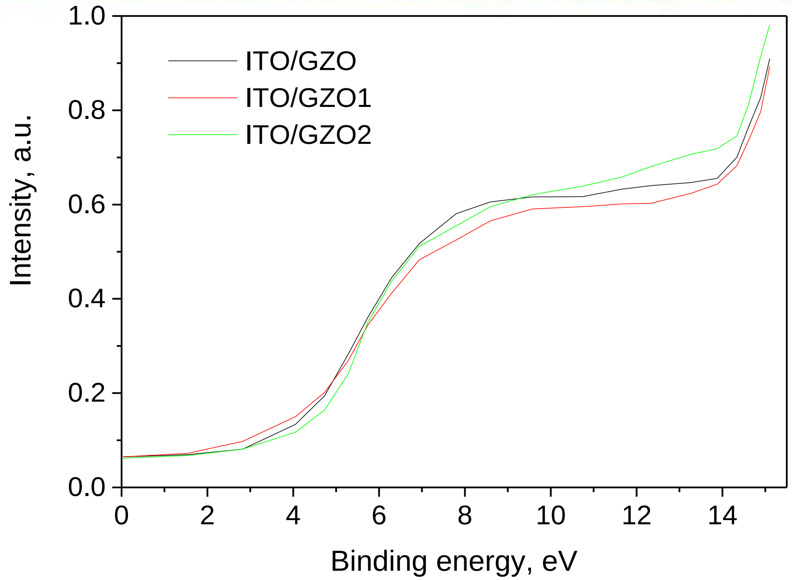


Optical transmittance in the UV-VIS range of single GZO layer and bi-layer coatings ITO/GZO without and with additional oxidation during sputtering.

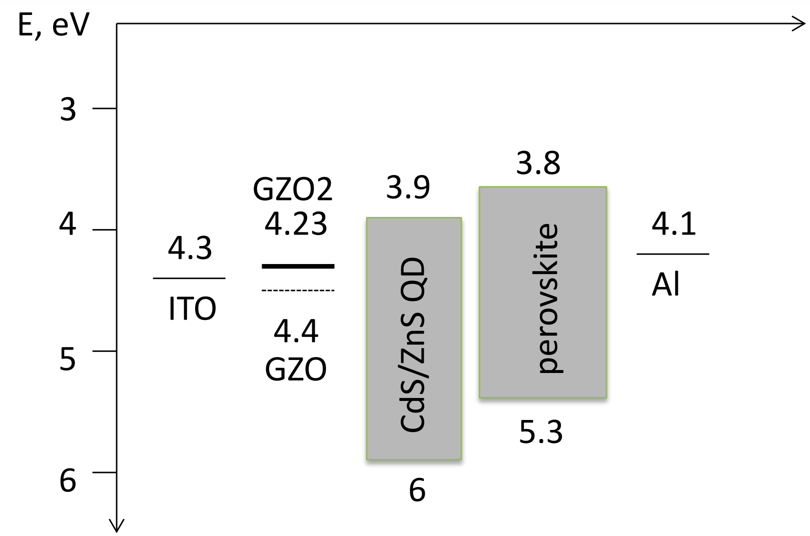
Optical reflection in the NIR range of single layer of GZO and bi-layer coatings ITO/GZO without and with additional oxidation during sputtering.

The mean optical transmittance of the ITO/GZO2 film in the visible region was 91.3% and the transparency for the UV component was 6%. IR wavelengths reflection and respectively heat rejection was greater than 65 % for ITO/GZO2.

Results



UPS spectra for determination of the work function of ITO/GZO at different oxidation degree.



Energy band diagram of CdS/ZnS core-shell quantum dots/perovskite solar cell with optimal ITO/GZO2 film as TCE.

With an increase of the oxidation degree, the work function of GZO2 decreased to 4.23, thus forming breakdown of the interface barrier height from 0.4 eV into two partitions – 0.33 eV and 0.07 eV. Therefore, the solar cells will have enhanced electrons extraction at the interface and increased performance is expected.

Conclusions

- ITO/GZO by-layered coatings were deposited on glass substrates by RF sputtering at various oxygen contents. The electrical and optical properties of the bi-layer system were strongly affected by the oxidation degree and the surface roughness of the GZO layer.
- The optical data showed that the additionally oxidized GZO films with ITO underlayer exhibited slightly differed mean visible transmittance over 90%, but the difference of the reflection spectra in the IR range is more significant – the films IR rejection ability differs with almost 40 %.

- GZO2 is characterized with a lower work function than GZO and intermediate work function between the CdS/ZnS core-shell quantum dots used in solar cells and the ITO film. This suggests facilitation of the electron extraction from the absorber to the cathode.

- In summary, ITO/GZO2 could serve as a transparent conductive electrode and sunshade coating. Additionally, UV filtration is achieved, which is expected to slow down the aging processes in the cells.

- The future work will be related to impedance spectroscopic study for detailed estimation of the contact properties of solar cells implementing ITO/GZO as a front filtering electrode and determination of the electrical losses at the bi-layer coating's interface.

THANK YOU FOR YOUR ATTENTION!

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