ZnO based transparent electrodes deposited by Spatial Atomic Layer Deposition (SALD)

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Objectives

- Towards Indium-free transparent conductive materials (TCMs) [1]

ZnO based TCMs

- Aluminum doped Zinc Oxide (AZO): Low-cost, high transparency (~90%), potential to reach resistivity as low as 10^{-4} Ω.cm
- ZnO coated silver nanowire (AgNW) networks: flexible, high transparency & conductivity and improved thermal-electrical stability [2]

- Advanced thin film fabrication method: fast, low temperature, vacuum-free, easy to scale up

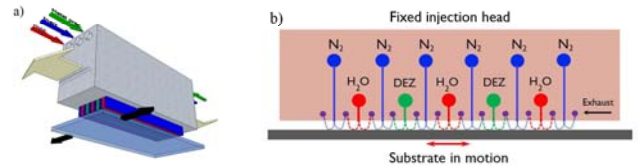
Spatial Atomic Layer Deposition (SALD)

Conclusions

- High transparency, uniformity and conformity of both AZO films and ZnO coated AgNW networks have been obtained by SALD.
- UV assisted annealing in vacuum enhances significantly AZO film conductivity by reducing trap density in grain boundaries.
- Coating AgNW networks with thin layer of ZnO shows a significant improvement of thermal-electrical stability

Perspectives: Post-treatment to improve AZO film conductivity; integration of optimized film to silicon heterojunction solar cells

Spatial Atomic Layer Deposition



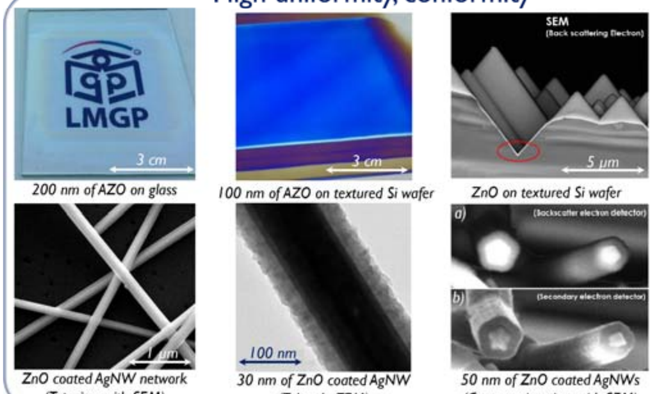
- Precursors are constantly injected in different locations, as shown in a) [3],[4]
- Substrate moves through different gas flows, as shown in b).
- Small gap (50µm – 200µm) between injector and substrate, as well as the inert gas channels, prevent different precursors from mixing.

Substrate will be exposed sequentially to oxidant, inert gas, metal precursor, then inert gas again and so on. The self-terminating adsorption process allows depositing one monolayer of desired material per cycle.

Advantages: low T (≤ 200 °C), high uniformity, conformality
AND fast, easy and cheap to scale up thanks to atmospheric processing

Results

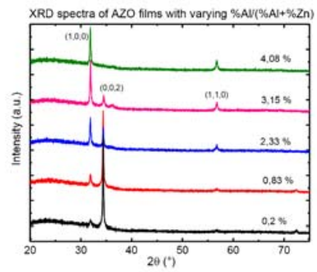
High uniformity, conformality



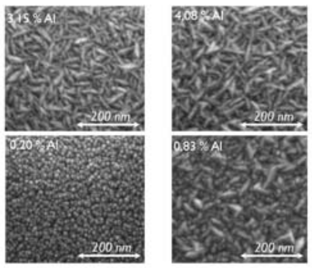
200 nm of AZO on glass — *100 nm of AZO on textured Si wafer* — *ZnO on textured Si wafer*
ZnO coated AgNW network (Top view with SEM) — *30 nm of ZnO coated AgNW (Taken by TEM)* — *50 nm of ZnO coated AgNWs (Cross-section view with SEM)*

Results

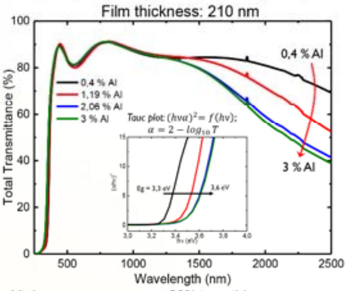
Optimization of AZO films

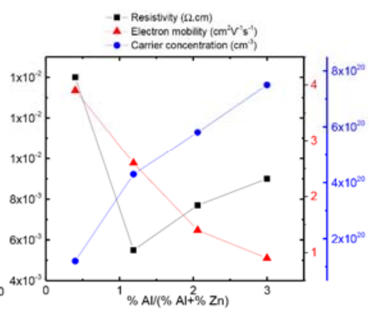


Preferential growth orientation moves from c-axis (002) for low Al content films to m-plane (100) for higher doping level (> 2 %)

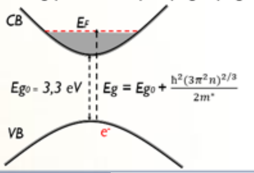


Film morphology also affected by the amount of Al



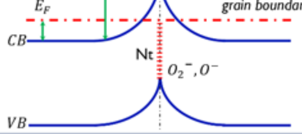


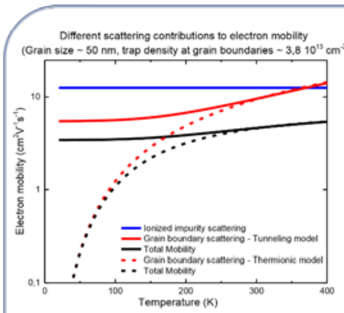
- High transparency up to 90% in visible range
- Optical band gap is tunable by varying doping concentration



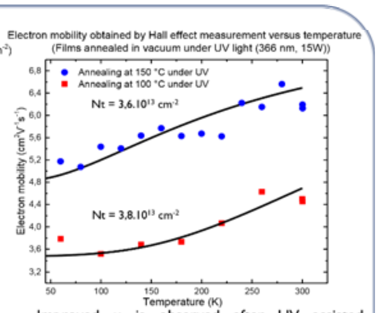
$$\phi_B = -\frac{q^2 N_t^2}{8\varepsilon n}$$

µ in AZO films is mainly limited by oxygen trap scattering at grain boundaries





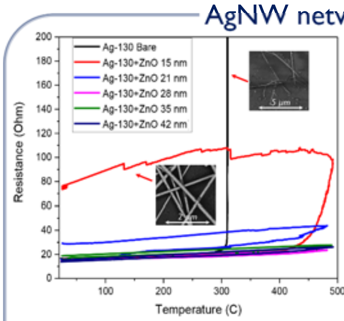
In the case of highly doped AZO (n > 10^{20} cm^{-3}), the conductivity is limited by grain boundary scattering, and the charge transport is dominated by tunneling emission through grain boundaries.



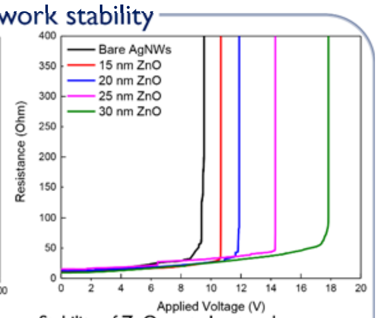
- Improved µ is observed after UV assisted annealing in vacuum which reduces trap density at grain boundaries.
- The tunneling model shows a good fitting with the experimental data from Hall measurement

Film thickness (180 nm)	ρ (Ωcm)	µ $(cm^2V^{-1}s^{-1})$	n (cm^{-3})
As deposited	6,5E-02	1,1	8,5E+19
2h UV treatment/vacuum/150 °C	6,0E-03	6,4	1,6E+20

AgNW network stability



Significant improvement of thermal stability after 28 nm of ZnO coating thickness



Stability of ZnO coated networks goes on increasing with increases of coating thickness and reaches up to 18 volts for 30 nm of ZnO

References

[1] H. Hosono, *Handbook of transparent conductors*, Springer SBM, **2010**.
[2] D. Bellet *et all*, *Materials* **2017**, *10(6)*, 570
[3] D. Muñoz-Rojas & J.Driscoll, *Mater Horiz.*, V1, p314, **2014**
[4] V.H. Nguyen *et all*; *J. Renew. Sustain. Energy* **2017**, 9, 21203.

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