Silicon Surface Passivation by Transparent Conductive Zinc Oxide

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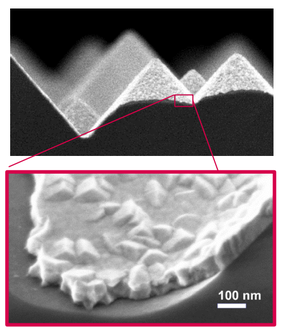
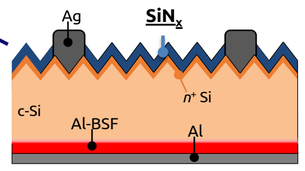
1. A new front surface material for silicon solar cells: atomic-layer-deposited ZnO

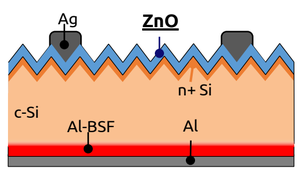


Front surface of silicon solar cells
With anti-reflection coating
Which passivates silicon surface defects

Standard industrial solar cell, front surface with SiN_x:



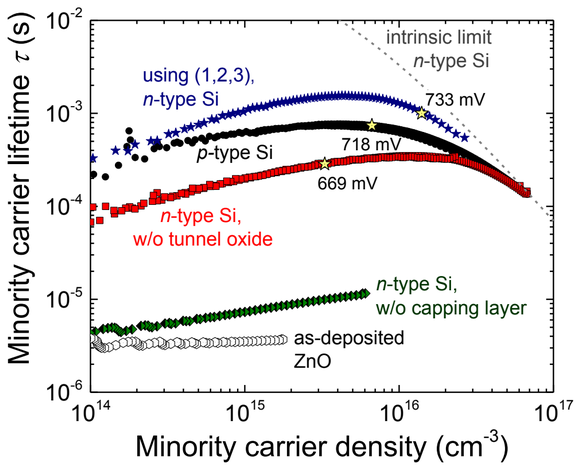
New concept, front surface with **ZnO:**

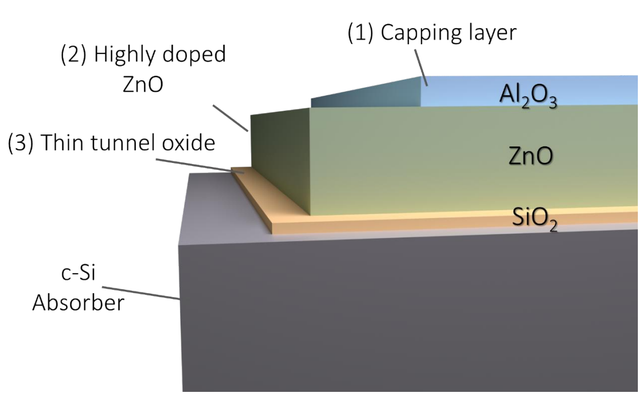


+ Takes care of lateral conduction
+ No need for firing-through contacting
+ Potential to serve as passivating contact

	Industrial standard: SiN_x	Transparent conductors (ITO, ZnO, FTO, SnO_2)	This work: ZnO films
Transparent to solar spectrum	✓	✓	✓
Suitable as anti-reflection coating	✓	✓	✓
Electrically conductive	✗	✓	✓
Provides passivation to c-Si surface defects	✓	✗	✓

2. Key result: enabling surface passivation by ZnO

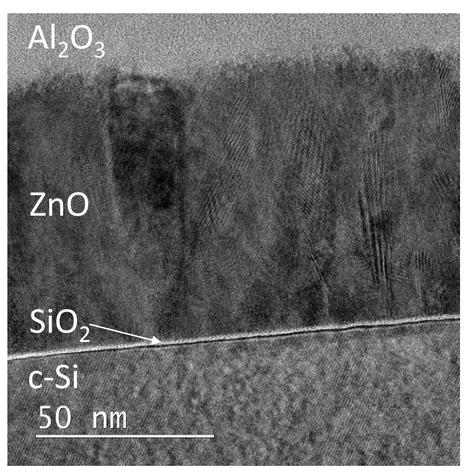


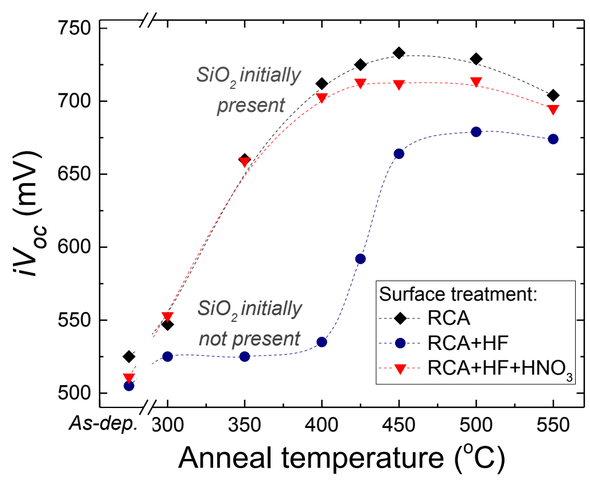


Unique approach to achieve passivation

- **Outstanding Si surface passivation** by ZnO reached, which is conductive (ρ<1 mΩcm) & suitable as anti-reflection coating (J_{sc} >41.6 mA/cm^2)

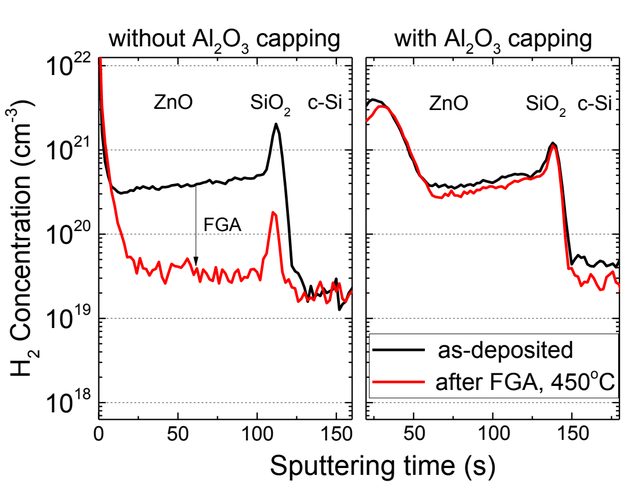
3. A high-quality c-Si/SiO_2 interface

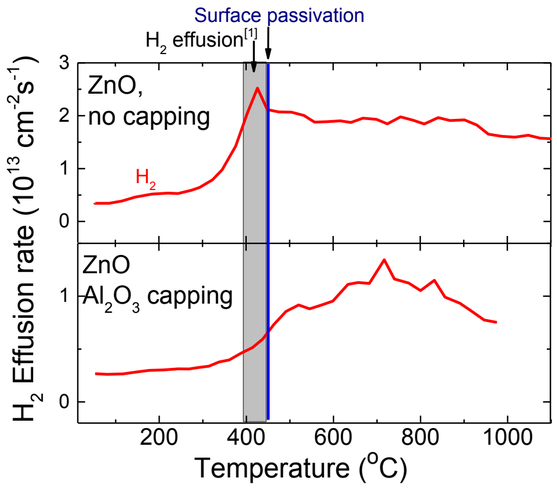




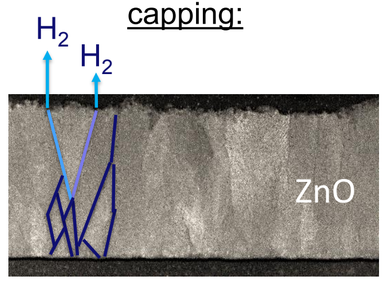
- Thin SiO_2 interface layer (1.5 nm) **key** in achieving passivation
- *A **soft** deposition method* (like ALD) prevents interface damage

4. Al_2O_3 capping layer: hydrogen management at the c-Si/SiO_2 interface



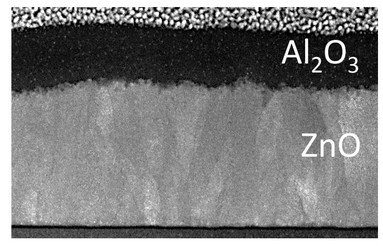


Without Al_2O_3 capping:



Rapid effusion of H_2 at 400 °C through ZnO grain boundaries

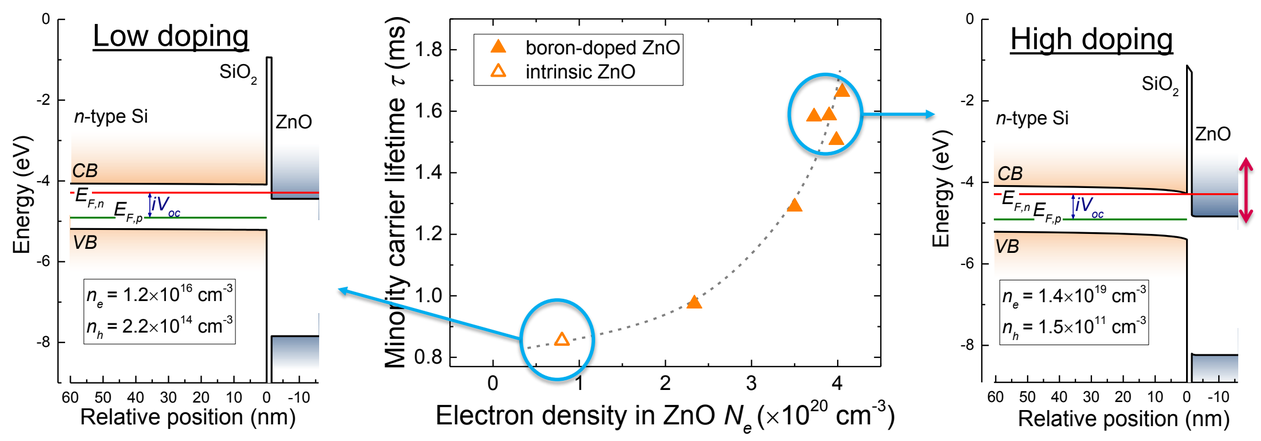
With Al_2O_3 capping:



Effusion of H_2 is blocked: hydrogen remains in ZnO and at c-Si/SiO_2 interface

- A sufficiently high density of hydrogen at the c-Si/SiO_2 interface during annealing **critical** for surface passivation
- Al_2O_3 capping layer prevents effusion of molecular hydrogen through ZnO grain boundaries during anneal. **Can be removed afterwards**!

5. Control over field-effect passivation



- Higher electron density in ZnO improves surface passivation through **downward band bending** of the c-Si

6. Conclusions

- **ZnO can provide outstanding passivation to c-Si surface defects**, when using a high quality SiO_2 interlayer and an Al_2O_3 capping layer.
- The Al_2O_3 capping layer is only required to be present during annealing to prevent H_2 effusion and can be removed afterwards.
- Surface passivation can be improved by adding extrinsic *n*-type dopants to the ZnO, like B or Al.
- **ZnO is now of interest as low-cost, passivating, conductive anti-reflection coating for the front side of common c-Si solar cells.**

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