Recombination and Efficiency Losses

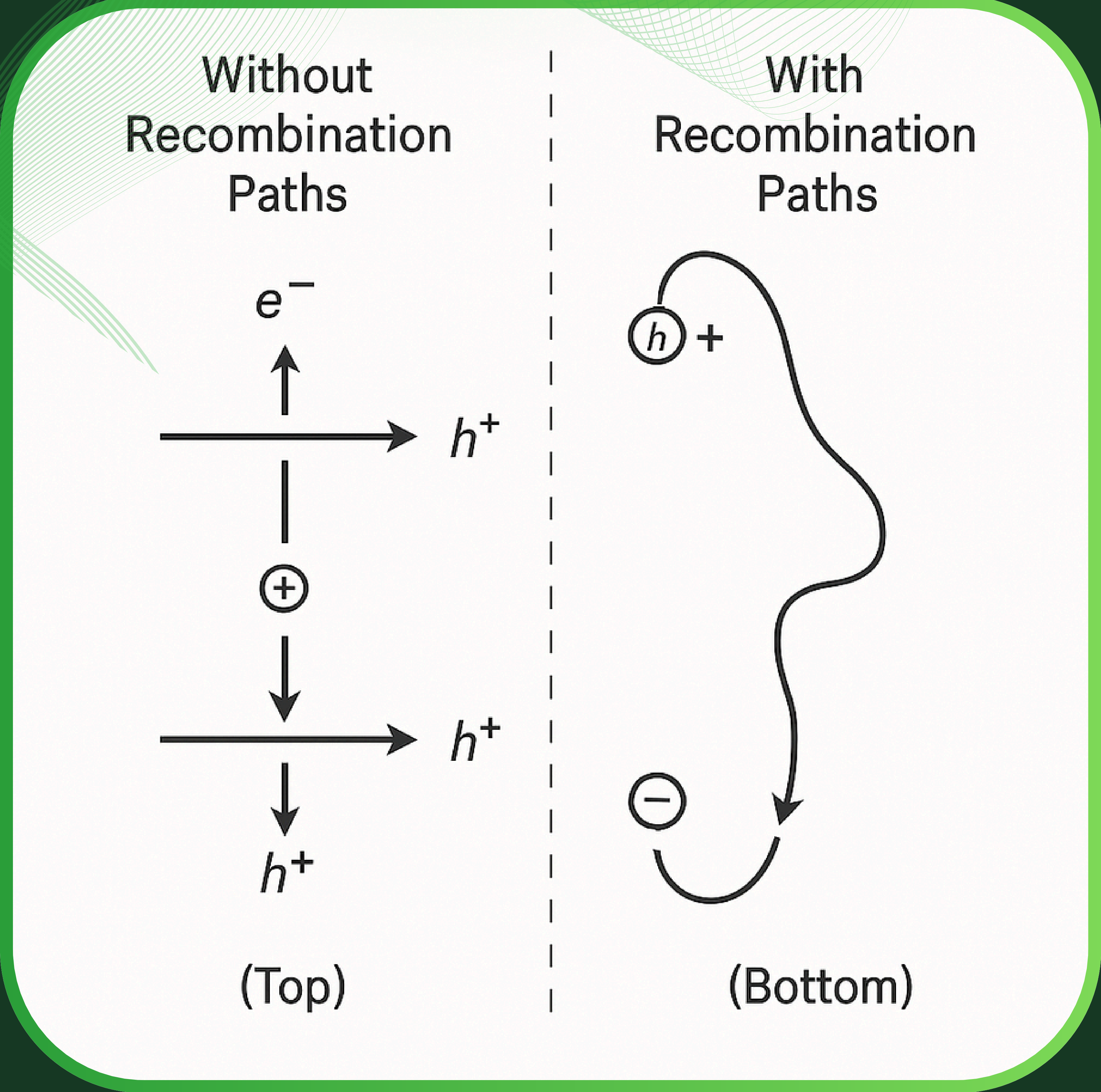
WEEK 2, DAY 2 ››››

Objectives of the Session

- Understand recombination mechanisms: SRH, Auger, surface
- Explore internal losses: series/shunt resistance, optical mismatch
- Learn about theoretical limits: Shockley–Queisser, thermodynamic limits

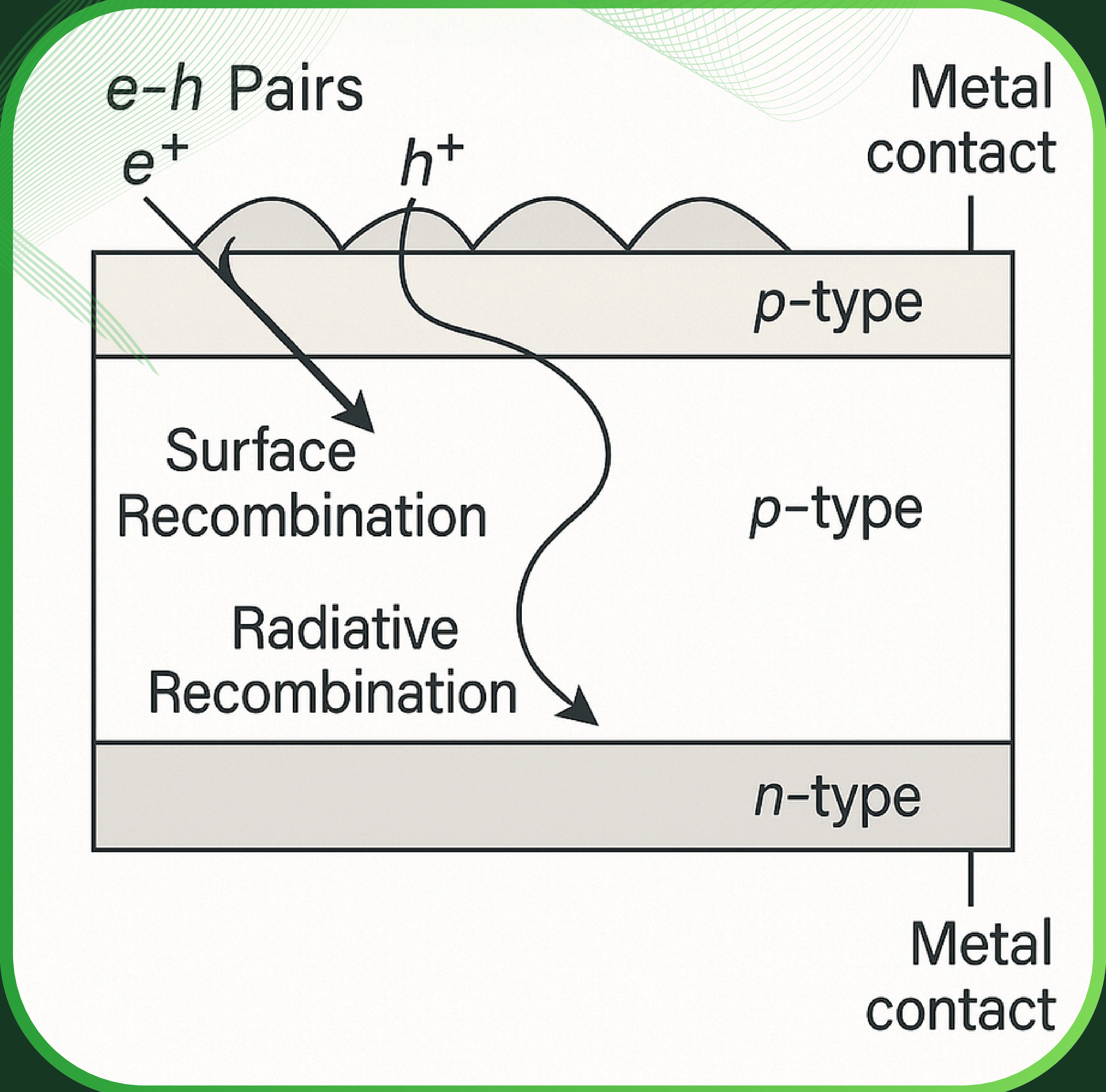
Introduction to Recombination and Losses

- Photovoltaic (PV) cells convert light to electricity, but not all absorbed photons contribute to current.
- Key challenges: Electron-hole (e-h) pair recombination and internal electrical/optical losses.
- These losses reduce power output and overall efficiency of solar cells.
- Understanding recombination and resistance losses is critical to improving performance.



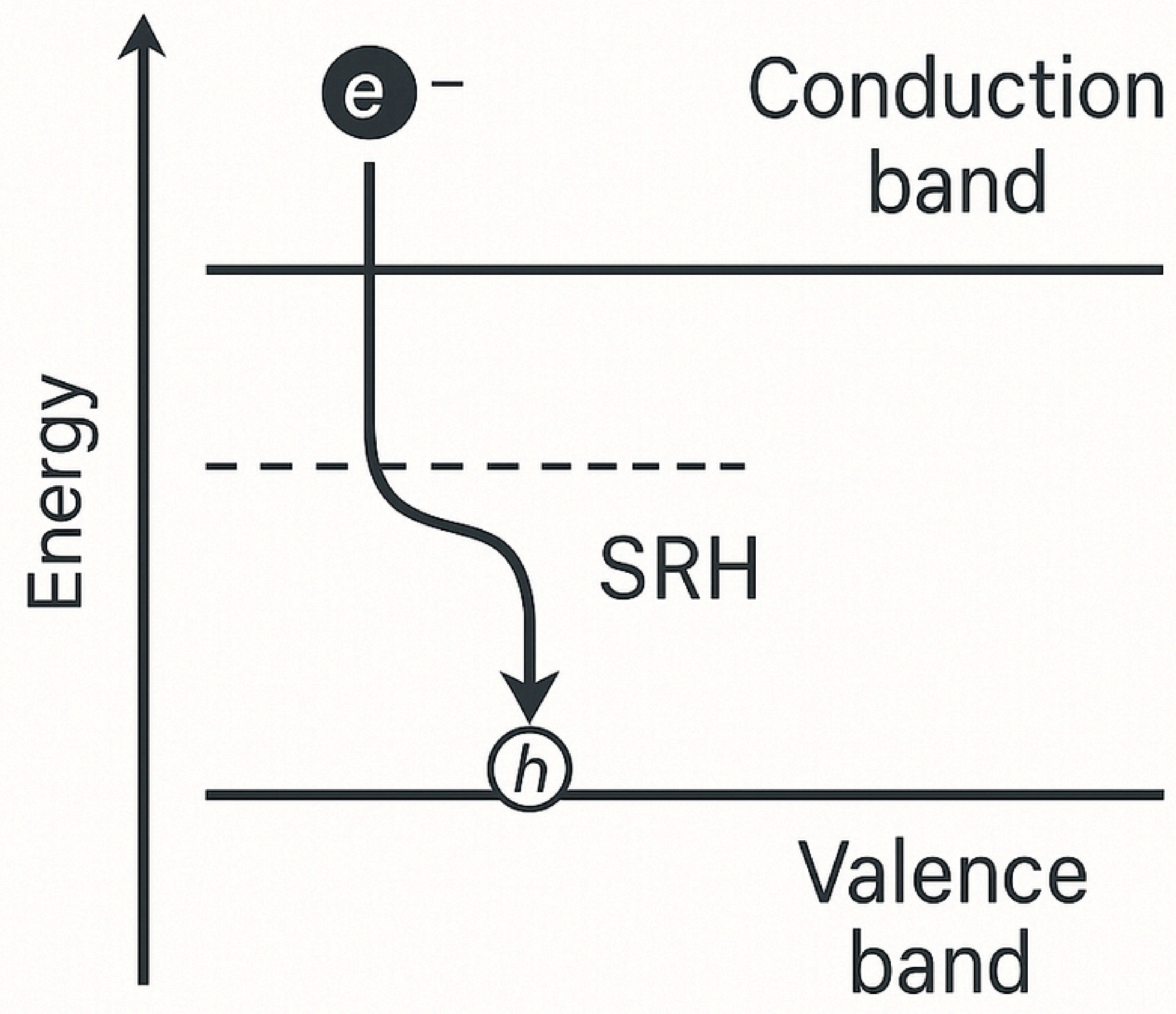
Types of Recombination in Solar Cells

- Shockley–Read–Hall (SRH) recombination (via defects/traps in the bandgap).
- Auger recombination: One carrier loses energy to another (common in heavily doped regions).
- Radiative recombination: Recombination with photon emission; occurs naturally but not useful in PV.
- Surface recombination: Occurs at material interfaces due to dangling bonds or poor passivation.



Shockley–Read–Hall (SRH) Recombination

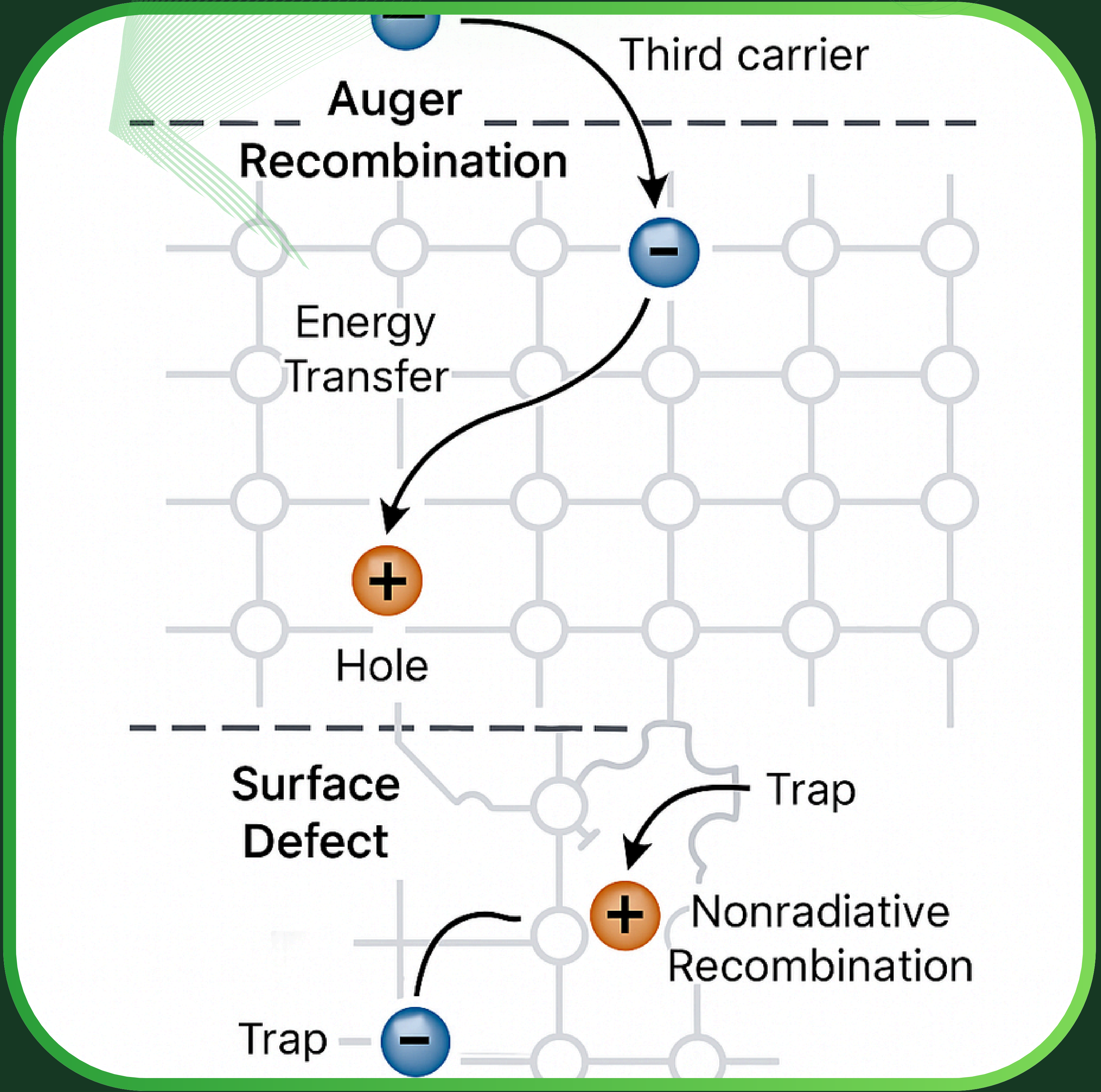
- Dominant in indirect semiconductors like silicon.
- Occurs via defect/trap states within the bandgap.
- Efficiency loss depends on defect density and carrier lifetime.
- Improved by high-quality materials and good passivation techniques (e.g., SiNx layer).



SRH recombination via mid-gap state

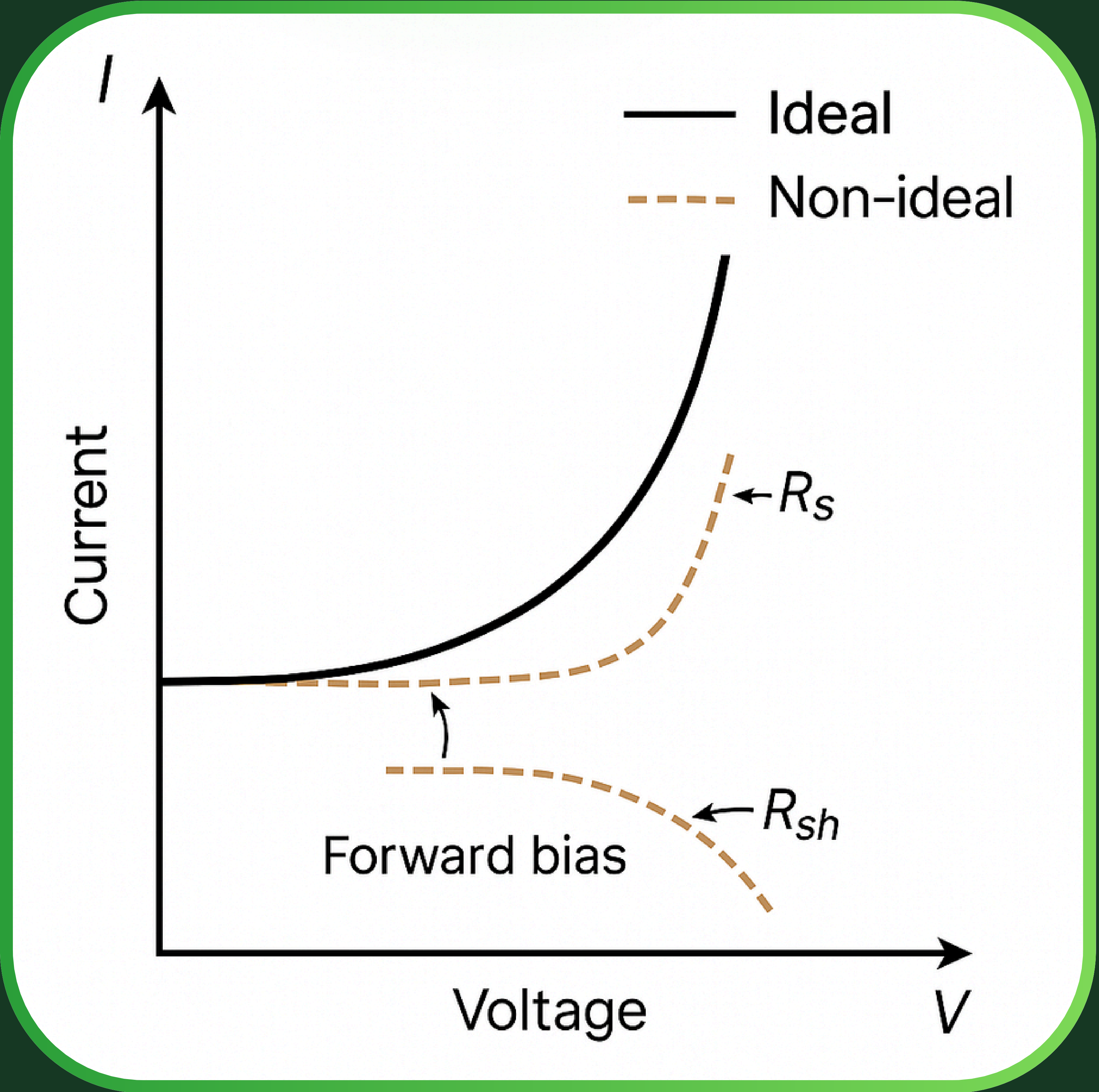
Auger and Surface Recombination

- **Auger recombination** becomes significant at high carrier densities (e.g., concentrated sunlight).
- Causes efficiency drop, especially in heavily doped emitter/base layers.
- **Surface recombination**: Happens at interfaces where dangling bonds trap carriers.
- Reduced using passivation layers like oxide, nitride, or hydrogenation.



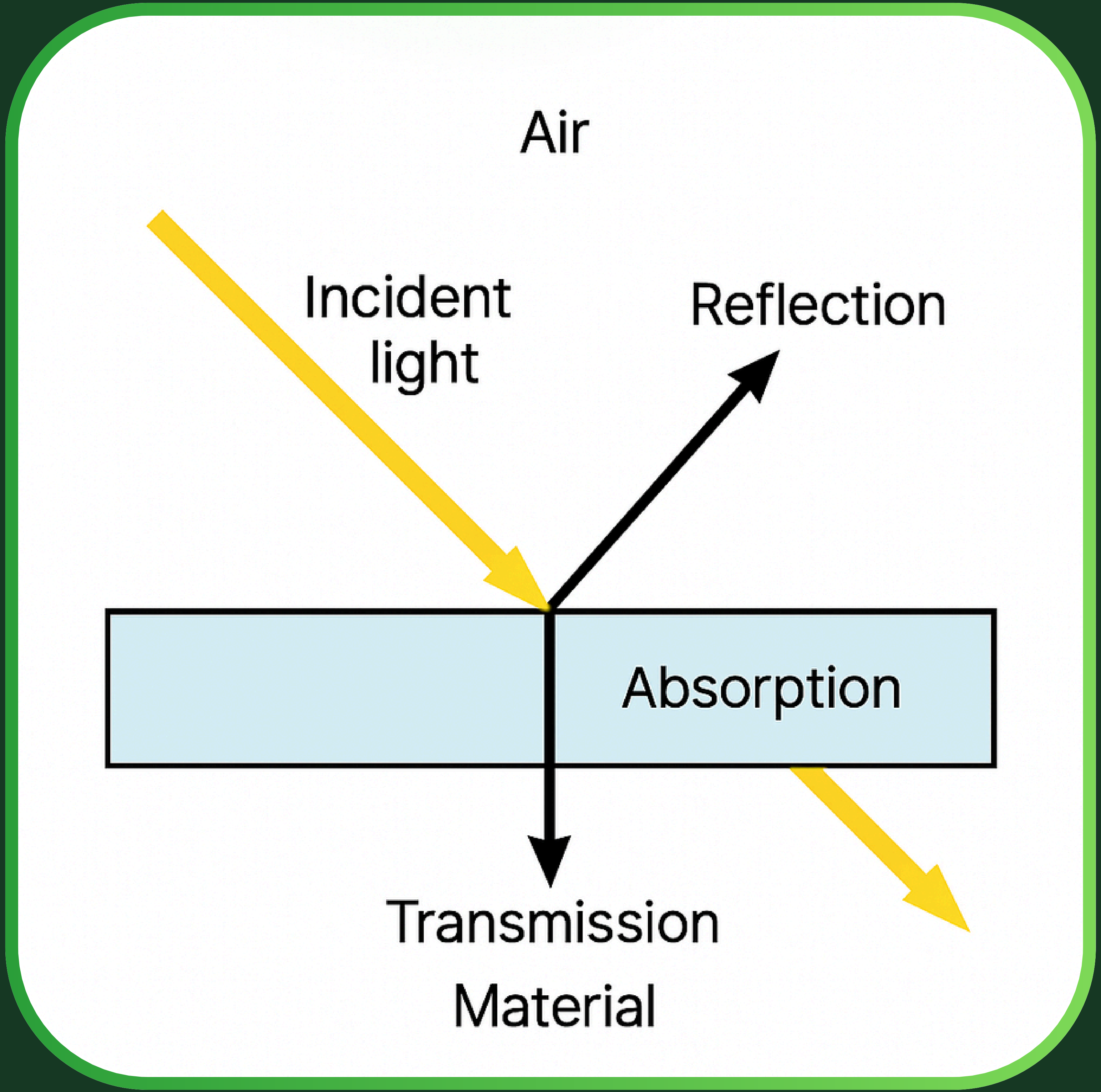
Series and Shunt Resistance

- **Series resistance (Rs):** Resistance in the current path (metal contacts, bulk, interconnects).
- **Shunt resistance (Rsh):** Leakage paths between front and back contacts; drains current.
- Both reduce fill factor (FF) and power output.
- Rs ↑ → voltage drop → lower output.
- Rsh ↓ → unwanted current bypass → power loss.
- Optimizing cell design and material contact reduces these effects.



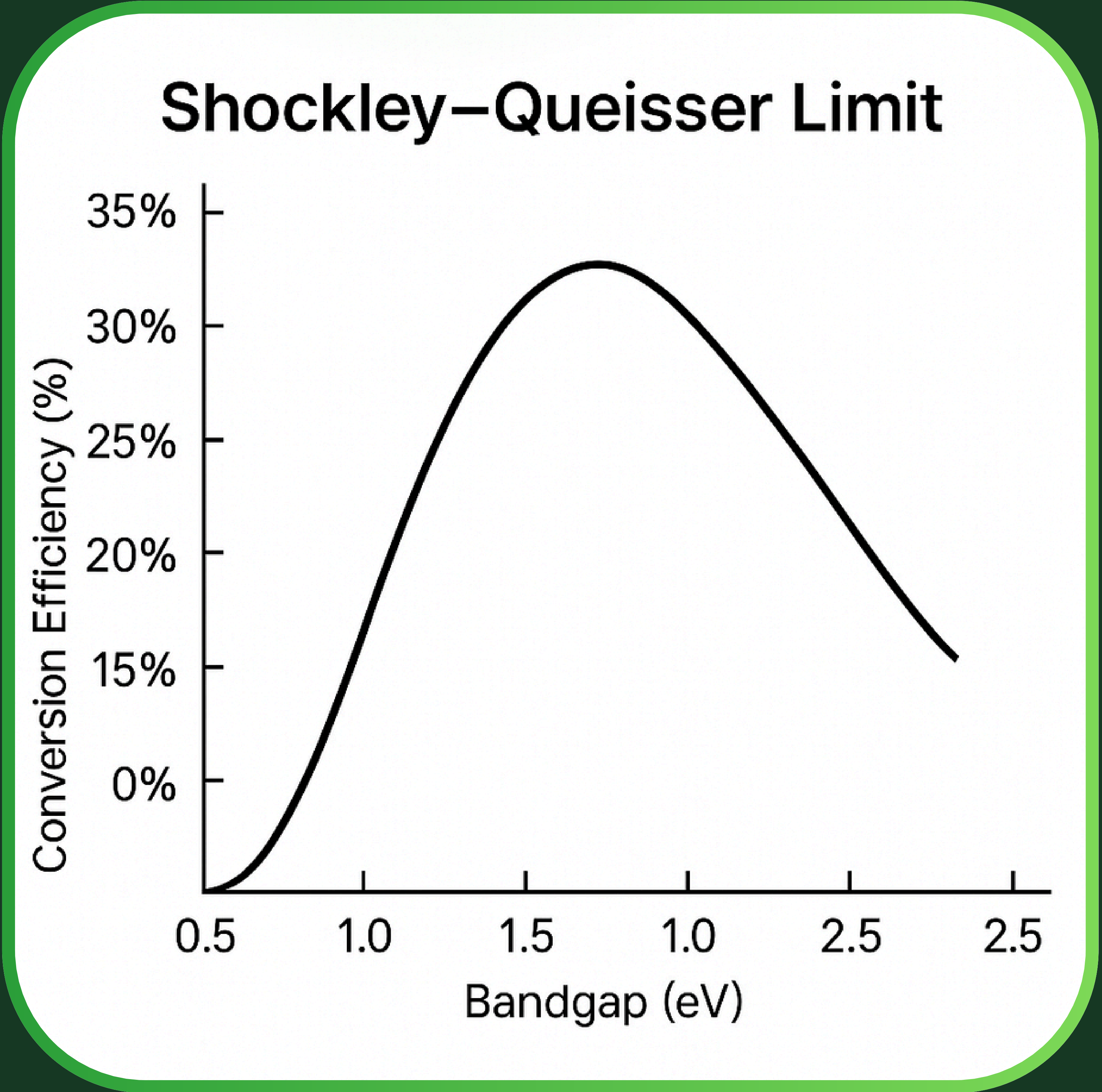
Optical Losses

- Not all incident light is absorbed—reflection, transmission, or parasitic absorption can occur.
- Use of anti-reflective coatings (ARC) and surface texturing reduces front surface reflection.
- Rear side: Back reflectors improve light trapping.
- Losses due to mismatch between solar spectrum and material bandgap also occur.



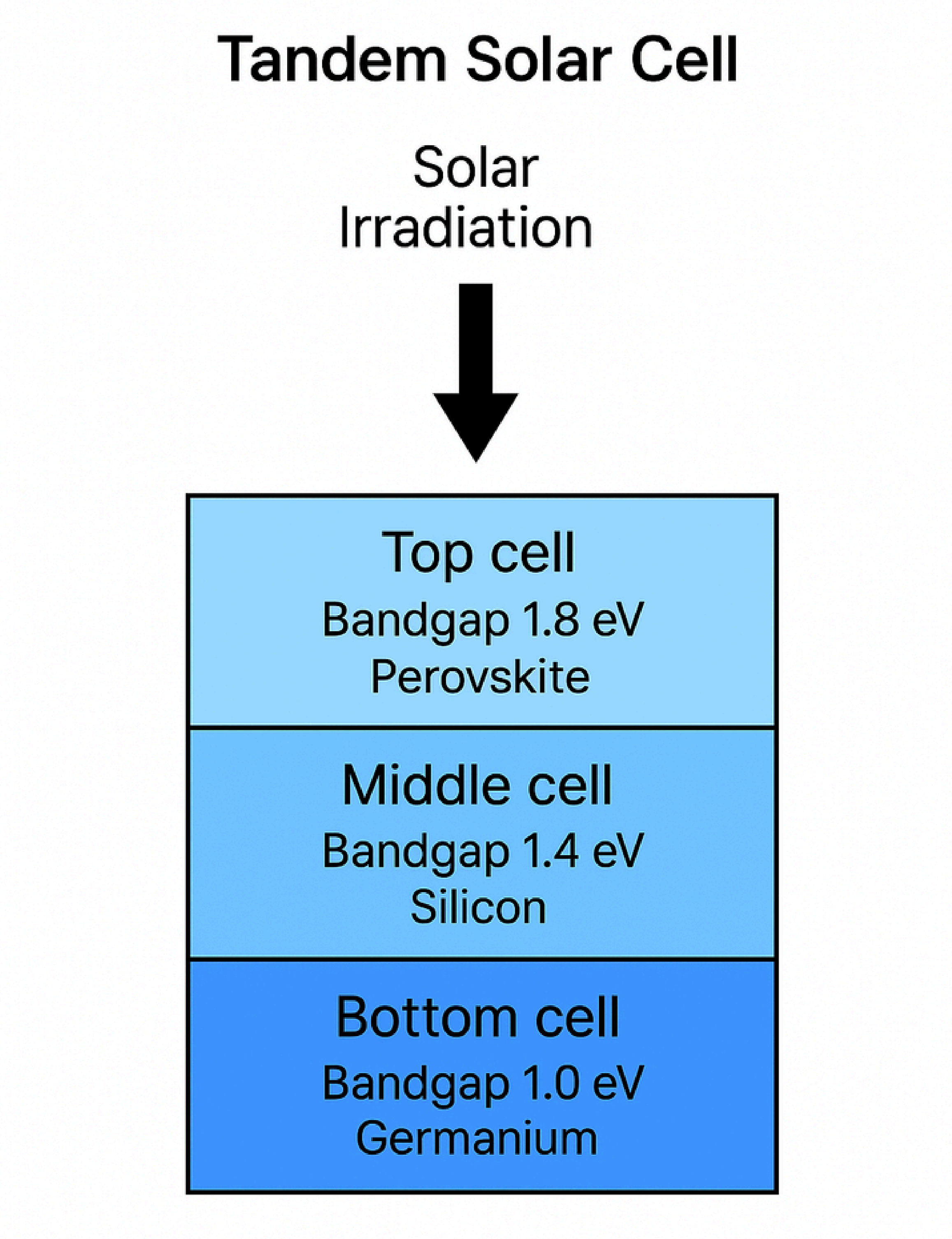
Shockley–Queisser Limit

- The Shockley–Queisser limit defines the maximum theoretical efficiency of a single-junction solar cell (~33.7% for Si).
- Based on detailed balance of absorption vs recombination.
- Trade-off: Bandgap too small → low voltage; too large → fewer photons absorbed.
- Real-world cells fall below this due to practical losses (recombination, resistances, optics).



Thermodynamic and Multijunction Limits

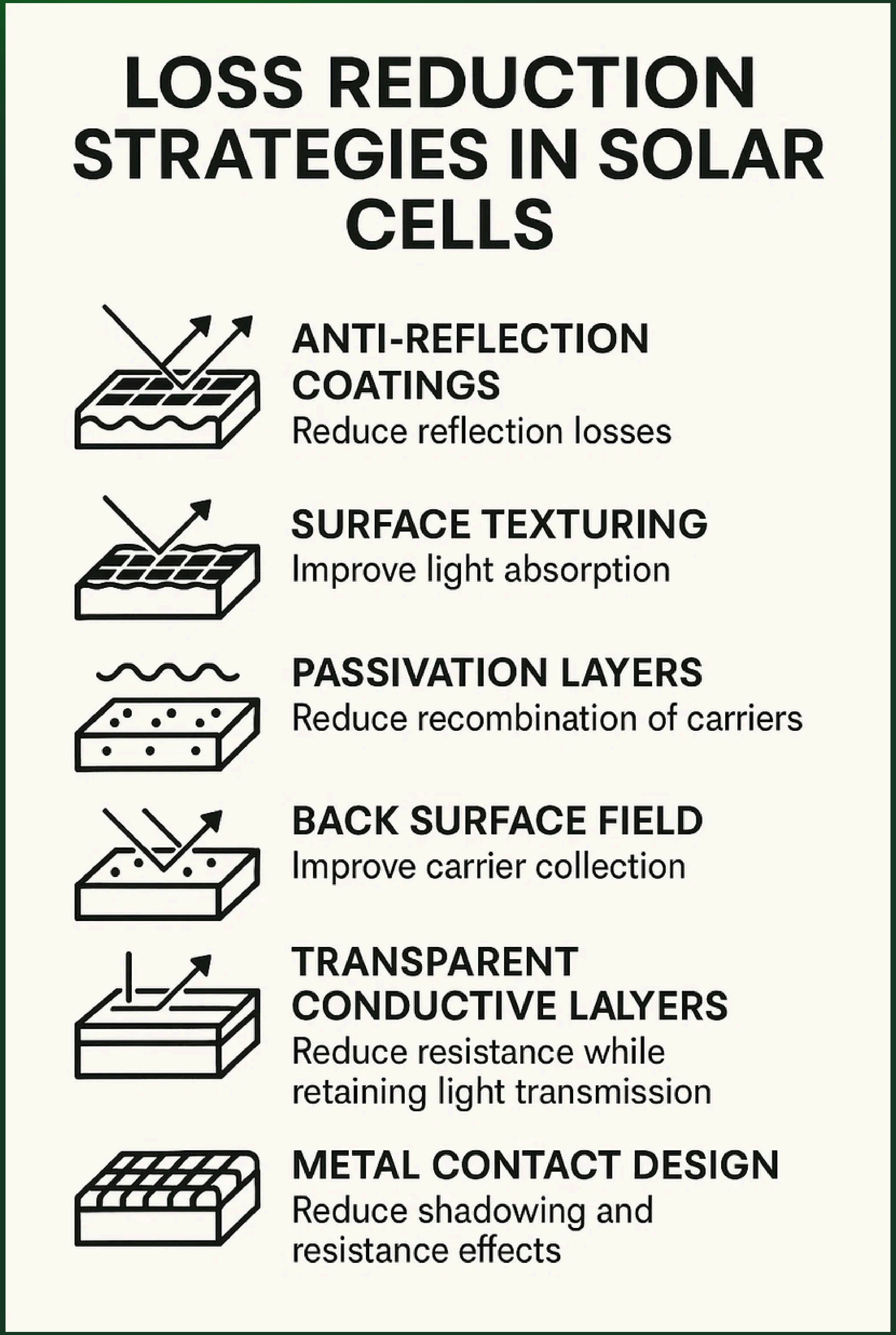
- Thermodynamic limit : Even with perfect absorption, black-body radiation and entropy cause energy loss.
- Multijunction cells (tandem structures) overcome single-junction limits by stacking cells with different bandgaps.
- Lab efficiencies > 45% using III-V multijunctions and concentrator photovoltaics.
- Still expensive and mainly used in space applications.



Tandem Solar Cell

Design Rules to Minimize Losses

- Minimize recombination : High-quality materials, good passivation, optimal doping.
- Reduce Rs and increase Rsh through proper metallization and insulation.
- Enhance light absorption with ARC, surface texture, and back reflector.
- Thermal management : Avoid overheating to prevent higher recombination and resistive losses.



Review Questions :

Q1 : What are the main mechanisms of recombination in solar cells?

Q2 : What are optical losses in solar cells? List at least two strategies to reduce them?

Q3 : What are some design strategies to minimize recombination and resistance losses in solar cells?

Q4 : How do multijunction solar cells enable higher efficiencies than single-junction cells?

got any doubts

regarding the course?

+91 8847603399

samaydora.energiitb@gmail.com

+91 6391 275 528

sushant.energyiitb@gmail.com