NEXT GENERATION SOLAR CELLS WITH TAILORED REDUCED GRAPEHENE OXIDE

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KEY PROBLEMS IN MONO-SI SOLAR CELLS

- Surface Recombination: Electrons and holes recombine at the surface, reducing efficiency.
- Contact Resistance: Metal contacts create resistance, lowering power output.
- Light Reflection: A portion of sunlight reflects instead of entering the silicon layer.
- Series Resistance & Charge Transport: Limits current flow and fill factor.

CURRENT COMPETING TECHNOLOGIES IN SOLAR CELLS SLIDE-1

PERC (PASSIVATED EMITTER AND REAR CONTACT)

- **Overview**
- Combines **crystalline silicon wafer** with **amorphous silicon thin layers.**
- Bifacial by default, high efficiency but costly.
- Requires low-temperature processing → compatible with thinner wafers.
- **Structure**
- **Front:** Transparent conductive oxide (TCO) + a-Si:H (p-layer)
- **Middle:** n-type c-Si wafer
- **Rear:** a-Si:H (n-layer) + TCO + metal grid

CURRENT COMPETING TECHNOLOGIES IN SOLAR CELLS SLIDE-2

TOPCon (TUNNEL OXIDE PASSIVATED CONTACT)

- TOPCon (Tunnel Oxide Passivated Contact)
- Overview
- A next-gen technology developed to overcome PERC's efficiency limit.
- Uses a thin oxide layer + poly-Si layer on the rear to reduce recombination and improve electron passivation.
- Structure
- Front: Similar to PERC
- Rear: Ultra-thin SiO_2 (~1–2 nm) + doped poly-Si layer + metal contact
- Typically uses N-type wafers (better stability and lower LID)

CURRENT COMPETING TECHNOLOGIES IN SOLAR CELLS SLIDE-3

HJT (HETEROJUNCTION WITH INTRINSIC THIN LAYER)

- Overview
- Combines crystalline silicon wafer with amorphous silicon thin layers.
- Bifacial by default, high efficiency but costly.
- Requires low-temperature processing → compatible with thinner wafers.
- Structure
- Front: Transparent conductive oxide (TCO) + a-Si : H (p-layer)
- Middle: N-type c-Si wafer
- Rear: a-Si : H (n-layer) + TCO + metal grid

COMPARISON OF CURRENT COMPETING TECHNOLOGIES

TECHNOLOGY	EFFICIENCY (COMMERCIAL/LAB)	COST & COMPLEXITY	KEY ADVANTAGES	DRAWBACKS & CHALLENGES	MARKET SHARE (2025 ESTIMATES)
PERC	~21–23% (COMMERCIAL), ~24.5% (LAB)	LOWEST CAPEX; HIGHLY MATURE	LOW-COST UPGRADES; BROADLY DEPLOYED	EFFICIENCY CEILING; DEGRADATION ISSUES (LID)	~<30–35%, FALLING RAPIDLY (PMARKET RESEARCH, INFOLINK GROUP, TAIYANGNEWS - ALL ABOUT SOLAR POWER)
TOPCON	~23–25% (COMMERCIAL), ~26%+ (LAB)	MEDIUM CAPEX; UPGRADEABLE FROM PERC	HIGHER EFFICIENCY; LOW LID, BETTER STABILITY	REQUIRES NEW TOOLS; HIGHER INITIAL COSTS	~70–80%, LEADING TECHNOLOGY IN 2025 (TAIYANGNEWS - ALL ABOUT SOLAR POWER)
HJT	~24–26% (COMMERCIAL), ~26.8%+ (LAB)	HIGH CAPEX; SPECIALIZED EQUIPMENT	HIGHEST EFFICIENCY; BIFACIAL; LOW TEMP COEFFICIENT	EXPENSIVE MATERIALS & PRODUCTION; SUPPLY CHAIN CONSTRAINTS	~7–9% OF HIGH-EFFICIENCY CELL CAPACITY (2024–2026 FORECAST) (REUTERS)

WHAT WE HAVE MADE: TAILORED rGO FOR NEXT-GEN SOLAR CELLS SLIDE-1

TAILORED rGO FOR PERC: CONVENTIONAL PERC CELLS STRUGGLE WITH RECOMBINATION LOSSES AT THE REAR INTERFACE DUE TO POOR PASSIVATION AND SURFACE DEFECTS. OUR TAILORED rGO SOLUTION FORMS A SMOOTHER, DEFECT-CONTROLLED REAR SURFACE THAT REDUCES RECOMBINATION, IMPROVES LIGHT TRAPPING, AND INCREASES EFFICIENCY.

WHAT WE HAVE MADE: TAILORED rGO FOR NEXT-GEN SOLAR CELLS SLIDE-2

TAILORED rGO FOR TOPCON: STANDARD TOPCON ARCHITECTURES OFTEN EXHIBIT LIMITED CARRIER SELECTIVITY AND PERFORMANCE DEGRADATION UNDER HEAT STRESS. OUR TAILORED rGO INTERFACE STRENGTHENS ELECTRICAL CONTACT WHILE PRESERVING PASSIVATION QUALITY AND PROVIDES THERMAL STABILITY FOR LONG-TERM RELIABILITY.

WHAT WE HAVE MADE: TAILORED rGO FOR NEXT-GEN SOLAR CELLS SLIDE-3

TAILORED rGO FOR HJT: Heterojunction cells depend on costly transparent conductive oxides (TCOs), which have limited conductivity and increase manufacturing costs. Our tailored rGO-based transparent layer improves conductivity, reduces TCO dependency, and maintains high optical transparency for superior light absorption.

WHERE rGO CAN HELP (BOTH PERC & TOPCON)

- Transparent over-contact / current-spreading layer (front side): reduces lateral series resistance, improves FF and allows Ag paste reduction.
- Ultra-thin rGO interfacial passivation (at metal/Si or SiN_x/metal edges): reduces surface recombination and improves Voc.
- Hybrid front TCO substitute/assist (rGO + AgNW or rGO + thin ITO) — more common for HJT, but can be used on premium TOPCon modules to reduce TCO cost.

rGO INTEGRATION POINTS & THERMAL SEQUENCING FOR PERC

PERC (typical sequence):

- High-temp steps (diffusion, front Ag firing, rear Al firing, ALD/PECVD passivation) are done first.
- Apply rGO after all high-temperature processes and after front metallization is fired. That avoids exposing rGO to >250–300 °C which may be acceptable but can change properties.
- Typical application: spray/slot-die over fired Ag fingers + mild thermal (200–250 °C in N_2) or photoreduction.

rGO INTEGRATION POINTS FOR TOPCON

TOPCon requires tunnel oxide + poly-Si deposition which involves high-temperature processing earlier in the flow.

- Always apply rGO after all high-temperature TOPCon steps and after metallization firing. Do not deposit rGO before or during poly-Si/tunnel oxide processing — it will be destroyed or contaminate tunnel oxide.
- Because TOPCon tunnel oxide is extremely thin (1–2 nm), ensure rGO processing does not introduce contaminants that could later increase recombination — again, apply rGO only after cell finalization

rGO INTEGRATION POINTS FOR HJT SLIDE-1

- **Glass / EVA / encapsulant** — standard module lamination stack.
- **Front cover glass**
- **(Optional) AR layer on glass** — standard.
- **Front TCO hybrid (rGO + AgNW + thin ITO cap)** — *replace or reduce ITO:*
- **AgNW sparse network:** areal density ~0.2–0.4 mg/m^2 (provides highways).
- **rGO film:** 10–20 nm dry (percolated) fills gaps and smooths junctions.
- **Thin ITO cap:** 20–30 nm (protects AgNW, reduces abrasion, improves contact to metal grids) — optional (reduces indium use significantly).

rGO INTEGRATION POINTS FOR HJT SLIDE-2

- Front a-Si:H (p-layer) / intrinsic a-Si:H passivation — standard HJT.
- n-type c-Si wafer (thickness ~150–180 mm) — absorber.
- Rear intrinsic a-Si:H / n-type a-Si:H (doped) contact — standard HJT rear.
- Rear TCO / metal — standard (e.g., ZnO:Al + Ag/Al contacts).
- Backsheet / frame.

rGO INTEGRATION POINTS FOR HJT SLIDE-3

- Where rGO sits and why
- Primary role (front): Hybrid transparent electrode — rGO bridges AgNW junctions, reduces sheet resistance and allows drastic thinning of ITO or full ITO removal in pilot cases.
- Secondary role (contacts): rGO over-contact stripes under the metal grid to spread current and reduce Ag paste usage.
- Tertiary role (primer): Ultra-thin GO primer (1–3 nm) at metal interfaces to improve adhesion and local passivation.

COMPARISON OF HJT VS PERC VS TOPCON WITH PROS AND CONS AND UTILITY OF TAILORED rGO SLIDE-1

Feature / Metric	PERC	TOPCon	HJT	rGO
What it is	Crystalline Si cell with rear passivation	Si cell with tunnel-oxide + poly-Si rear	c-Si + thin a-Si layers + TCO	2D conductive carbon material
Primary domain	Mainstream PV	Next-gen PV	High-efficiency PV	Additive / electrode material
Key strength	Low cost, mature	High efficiency, low LID	Best efficiency, bifacial	High conductivity, tunable
Key weakness	Efficiency ceiling, LID	Higher CAPEX	Very high CAPEX	Integration complexity

COMPARISON OF HJT VS PERC VS TOPCON WITH PROS AND CONS AND UTILITY OF TAILORED rGO SLIDE-3

Aspect	Relevance to PERC	Relevance to TOPCon	Relevance to HJT
Possible role	Additive in silver paste, encapsulant	Back contact conductive additive	Transparent conductive hybrid layer
Challenges	Maintain low-cost structure	Protect tunnel-oxide layer	Match transparency + sheet resistance
Value proposition	Low Ag cost, durability	Contact improvement	Alternative to ITO, mechanical flexibility

COMPARISON OF HJT VS PERC VS TOPCON WITH PROS AND CONS AND UTILITY OF TAILORED rGO SLIDE-3

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COST-BENEFIT OF RGO INTEGRATION IN NEXT-GEN PV (ILLUSTRATIVE EXAMPLE)

Parameter	Without RGO (Conventional)	With RGO Integration	Benefit / Impact
Silver Paste Usage	80–100 mg per cell	50–60 mg per cell (using RGO hybrid ink)	30–40% Ag reduction → significant material cost savings
Cost per Watt (Material)	~$0.015/W	~$0.011/W	~25% lower metallization cost
Module Efficiency Impact	Baseline (e.g., 24% for TOPCon)	+0.1–0.2% (due to improved conductivity)	Extra yield, better ROI
Reliability	Standard	Enhanced (corrosion & thermal cycling resistance)	Longer module life → lower LCOE
Additional RGO Cost	$0	~$0.0008–0.001/W (material + processing)	Negligible vs silver savings
Net Gain per GW Production	–	~$8–10 million savings (based on Ag price $0.7/g)	Huge scalability advantage

GENERATION TECHNOLOGIES LIKE TOPCON, HJT, AND ADVANCED MATERIALS SUCH AS rGO UNLOCKING UNPRECEDENTED EFFICIENCY AND DURABILITY, THE OPPORTUNITY TO LEAD THE CLEAN ENERGY REVOLUTION IS NOW. LET'S COMBINE YOUR VISION WITH OUR EXPERTISE TO CO-CREATE BREAKTHROUGH SOLUTIONS THAT NOT ONLY REDEFINE PERFORMANCE BUT ALSO SET NEW BENCHMARKS FOR SUSTAINABILITY. TOGETHER, WE CAN TRANSFORM INNOVATION INTO IMPACT

PARTNER WITH US TO POWER A BRIGHTER, GREENER TOMORROW."