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The 22nd International Asset, Facility & Maintenance Management Conference

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Solar Panel Optimization Based on Graphene-Silicon-Droplet Integration for Hybrid Solar-RF Energy Harvesting System

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Our Agenda

- **Solar Energy**
- **Solar Panel Optimization**
- **Research Direction.**
- **Proposed System.** Hybrid Solar-RF EH System
- **Results And Discussion .**
- **Conclusion & Future work.**

Solar Energy

- Solar energy is crucial for sustainable and clean energy
- Reliable and lasting energy source but also a very cost-effective and efficient.
- Techniques to generate, use, and store the sun's energy by using different types of solar panels.

Note: A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

Solar Panel Optimization

Ongoing research focuses on "Hybrid Solar Panels" with perovskite, silicon, graphene, and raindrop energy, where:

- Hybrid panels hold promise for reshaping the energy landscape towards sustainability.
- Raindrop energy is an innovative addition for diversified energy sources.

Research Directions

- **Perovskite-silicon hybrid cells:**
  Combine light absorption of perovskite and silicon efficiency.
- **Perovskite Solar Cell Development:**
  Encompasses materials discovery, synthesis, fabrication, optimization, and integration.
- **High-Efficiency Breakthrough:**
  Scientists at KAUST achieve 33.7% efficiency in perovskite-silicon solar cell.

Research Directions

Graphene-perovskite solar cell

Graphene enhances conductivity, improving charge transport and panel efficiency.
Graphene-perovskite solar cell achieved 20.3% efficiency.

Research **Directions**

Droplet Layer:

Transistor-inspired structure introduced new coplanar-electrode which overcomes issues related to parasitic capacitance.
Strip-like droplet energy harvesting panel overcomes challenges, achieving high output voltage.

Raindrop energy harvesting:

Raindrop impact's kinetic energy can supplement solar energy, especially in rainy regions.

Radio Frequency Energy harvesting

energy conversion technique employed for converting energy from the electromagnetic (EM) field into the electrical domain.

Proposed System

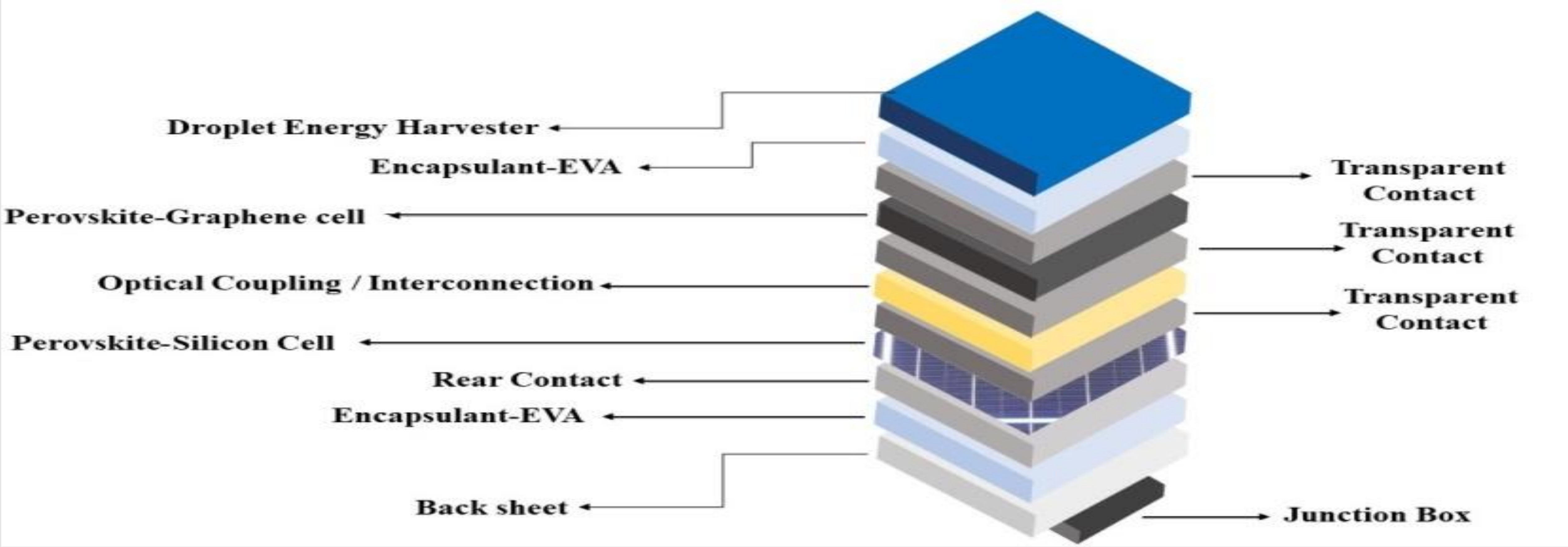
01. Perovskite/Silicon Tandem Solar Cell

02. Graphene in Perovskite Solar Cells

03. Droplet Layer

04. Antenna

Advanced Solar Panel Configuration



Adaptive configuration captures sunlight and raindrop energy.

Proposed System

- **Silicon layer:**

  Enhances charge separation and collection efficiency.

- **Perovskite layers:**

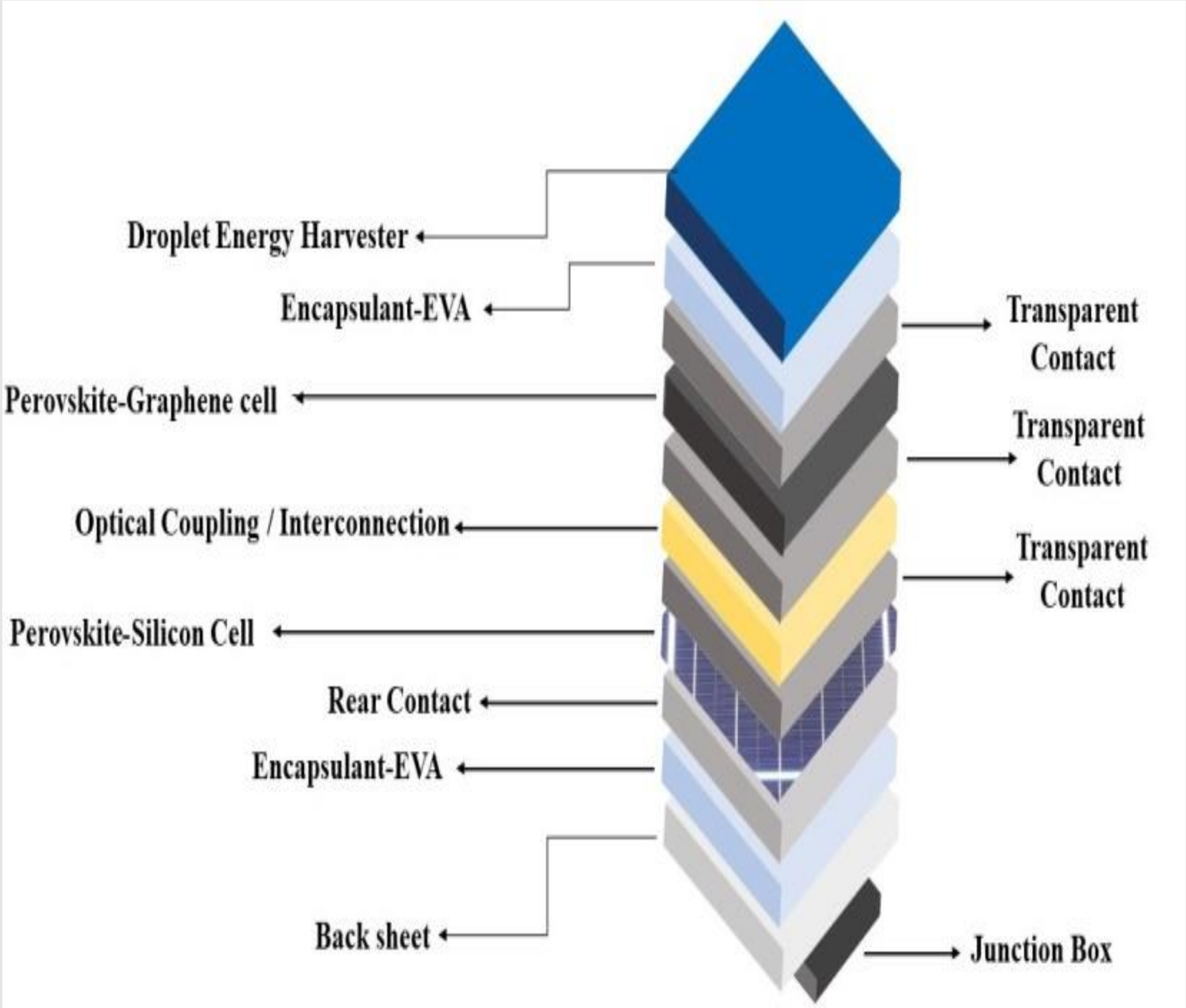
  Excel in light absorption, generating electron-hole pairs.

- **Graphene layer:**

  Acts as a superior conductor, amplifying charge transport.

- **Raindrop Energy Panel:**

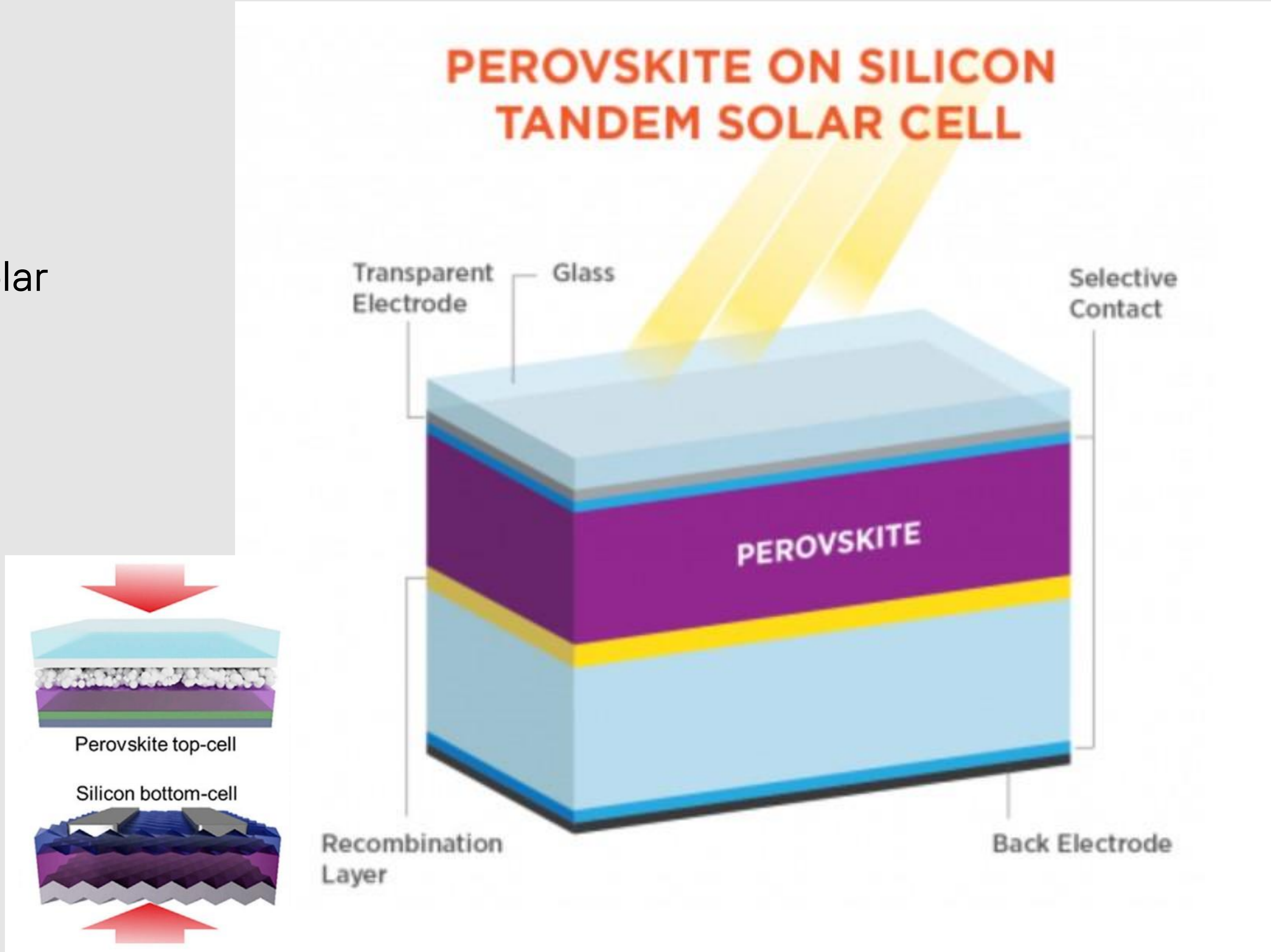
  Raindrop impact generates electrical charge, adding to power generation.



Perovskite/Silicon Tandem Solar Cell Structure

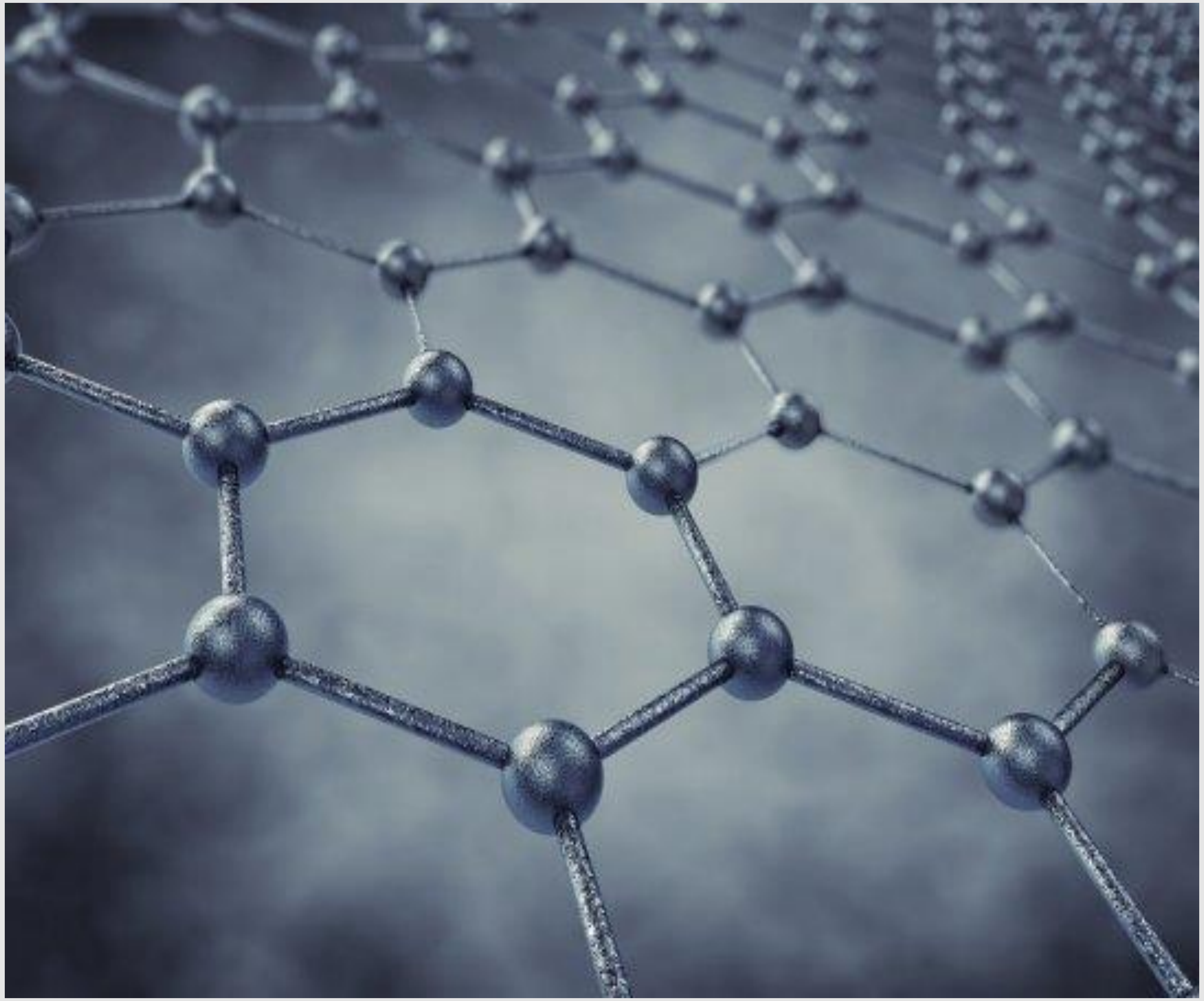
- *Unified Solar Device Integration:*
Merges perovskite and silicon technologies for enhanced solar spectrum capture and higher efficiency.

- *Perovskite Solar Cell Evolution:*
Encompasses material discovery, synthesis, fabrication, optimization, and integration with other solar tech.

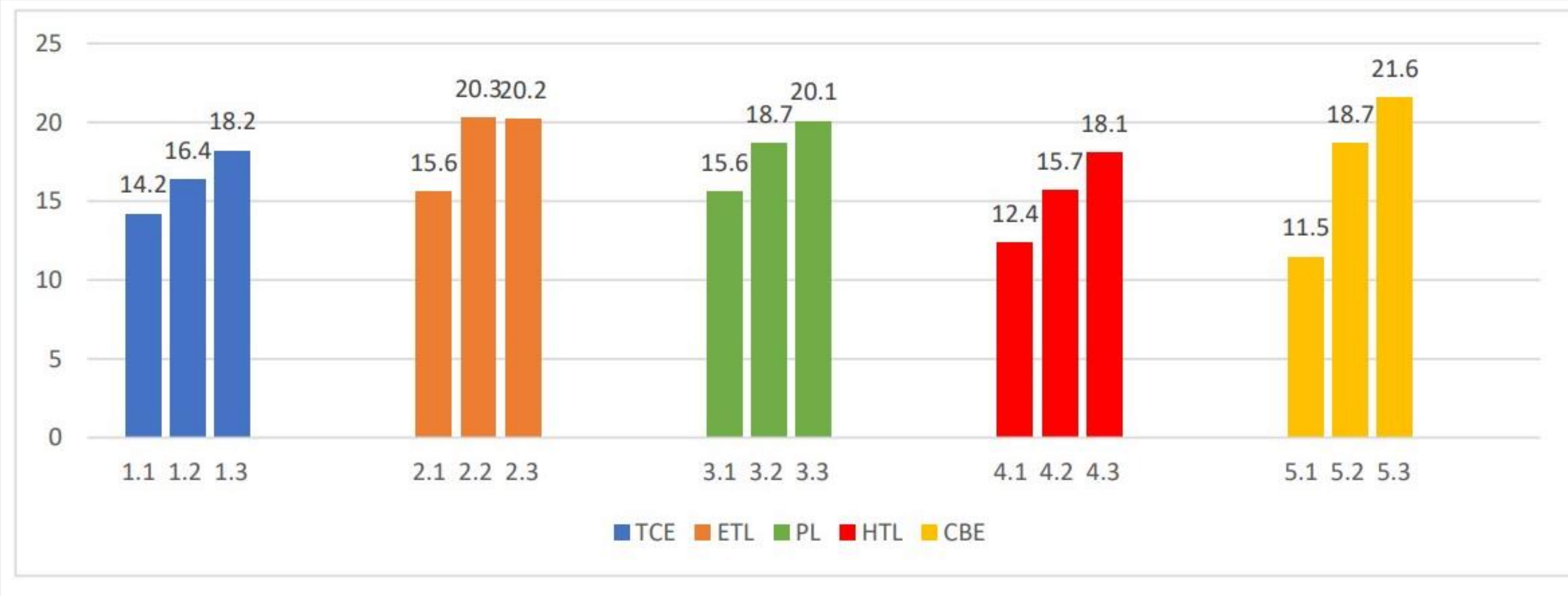


Graphene Features

- *Two-dimensional (2D) material.*
- *Optical Transparency.*
- *Electrical Conductivity*
- *Carrier Transport Properties.*



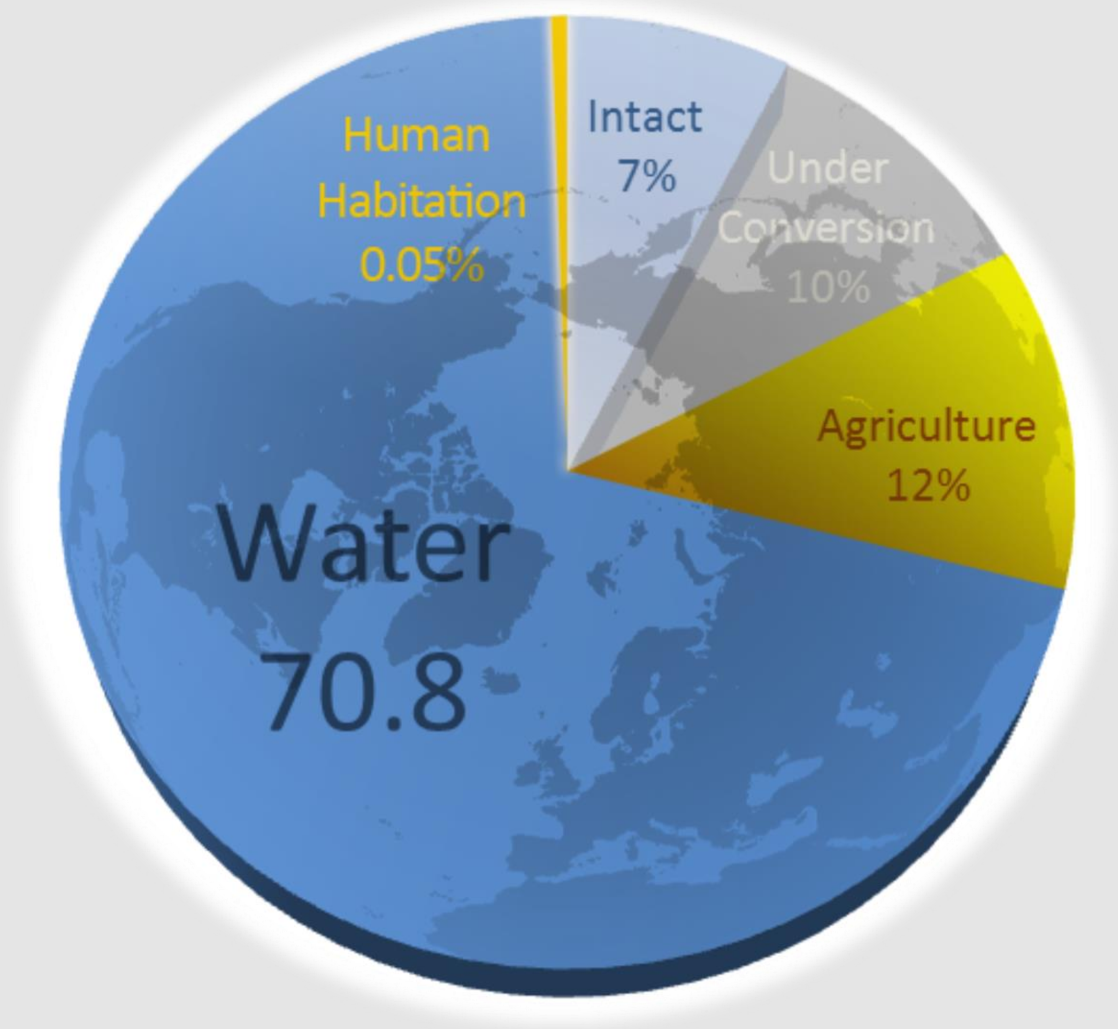
Graphene in Perovskite solar cells:



Performance Impact of Graphene in Perovskite Solar Cell Layers

The position of graphene doping in one of the five layers significantly impacts the performance and efficiency of perovskite solar cells.

Droplet Energy Harvesting



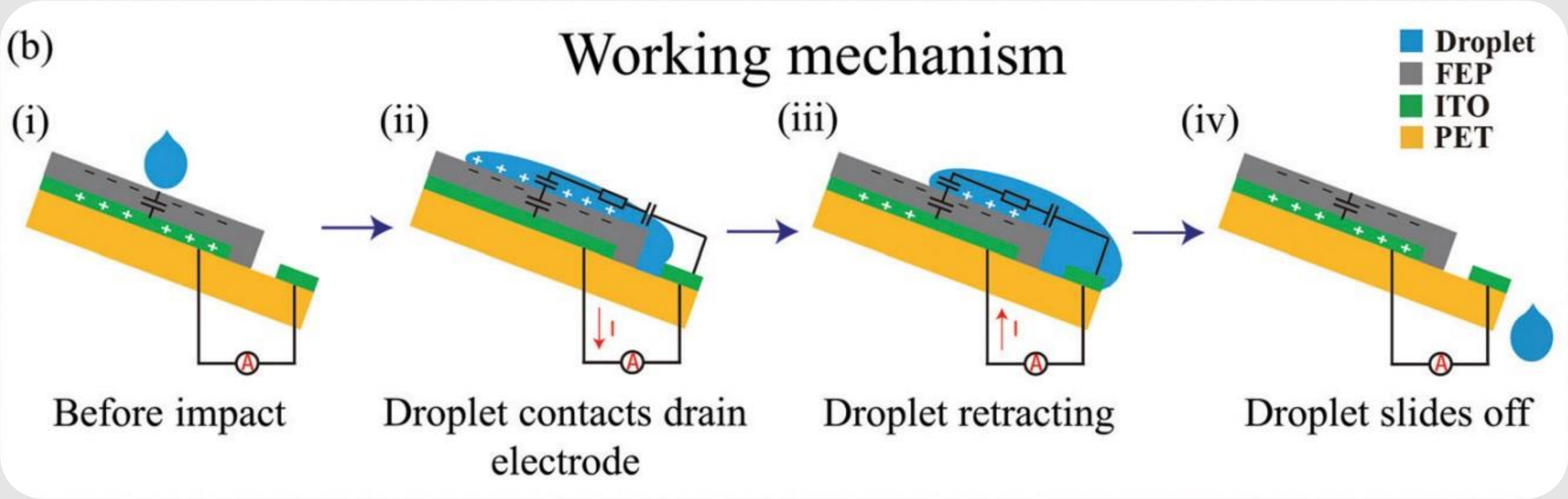
Untapped Water Energy Potential:

- 70% of the Earth's surface is covered by water.
- Earth's water holds substantial energy in various motion forms.
- Raindrops alone possess significant kinetic energy.
- An underutilized resource.

Raindrops Energy Global Impact:

- Raindrops contribute substantial kinetic energy - 3000 TW h annually.
- This energy accounts for 5% of the world's yearly energy consumption.

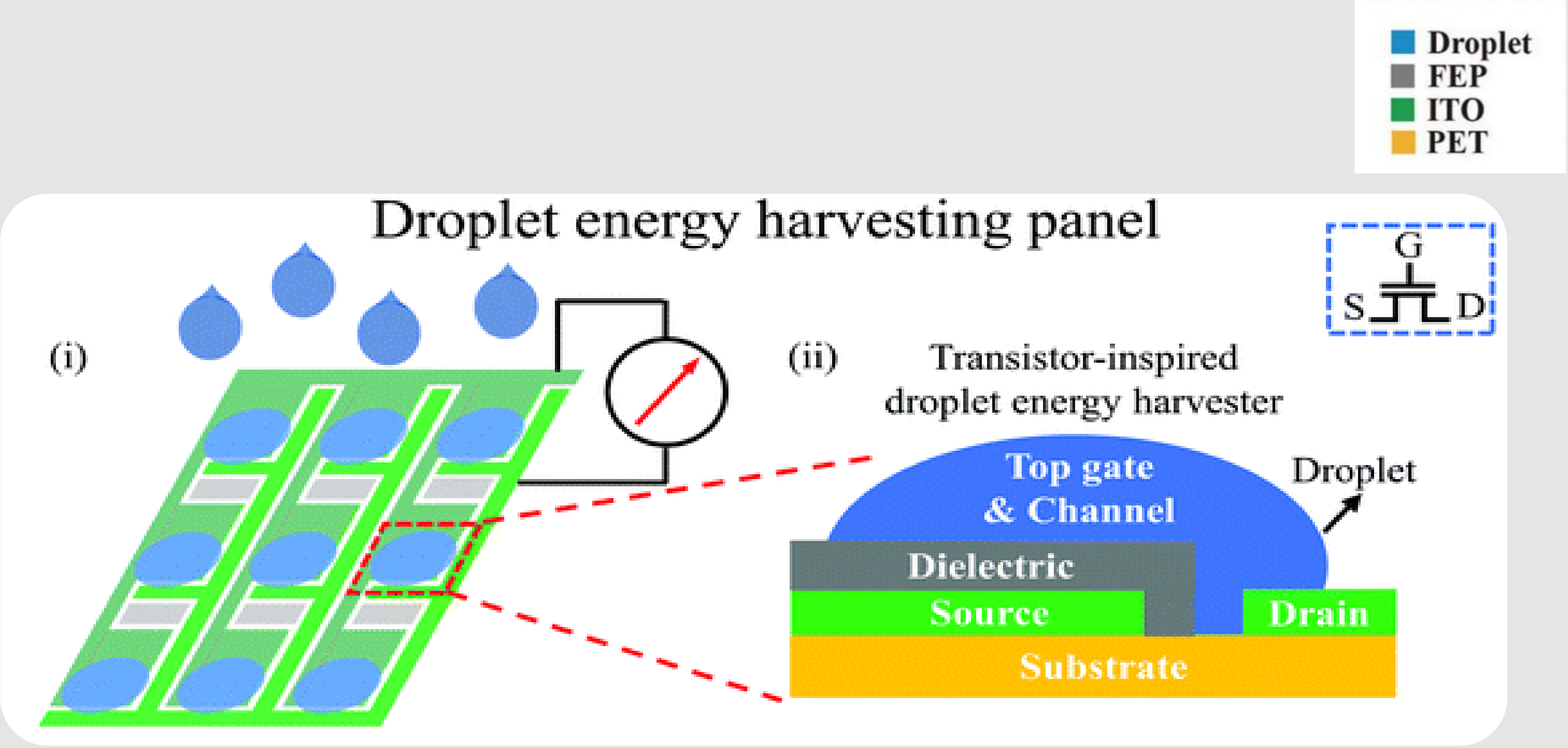
Droplet Mechanism



Droplet Cell Structure

This transistor inspired structure DEH cell consists of 3 layers:

- **FEP:** Transparent Di-electric material, with strong electron-attraction ability.
- **ITO:** Transparent Conductor.
- **PET:** Transparent Hydrophobic Substance.



Transistor inspired structure DEH cell

The coplanar source electrode and drain electrode were separated by etching a gap with a width of 1 mm on the ITO.

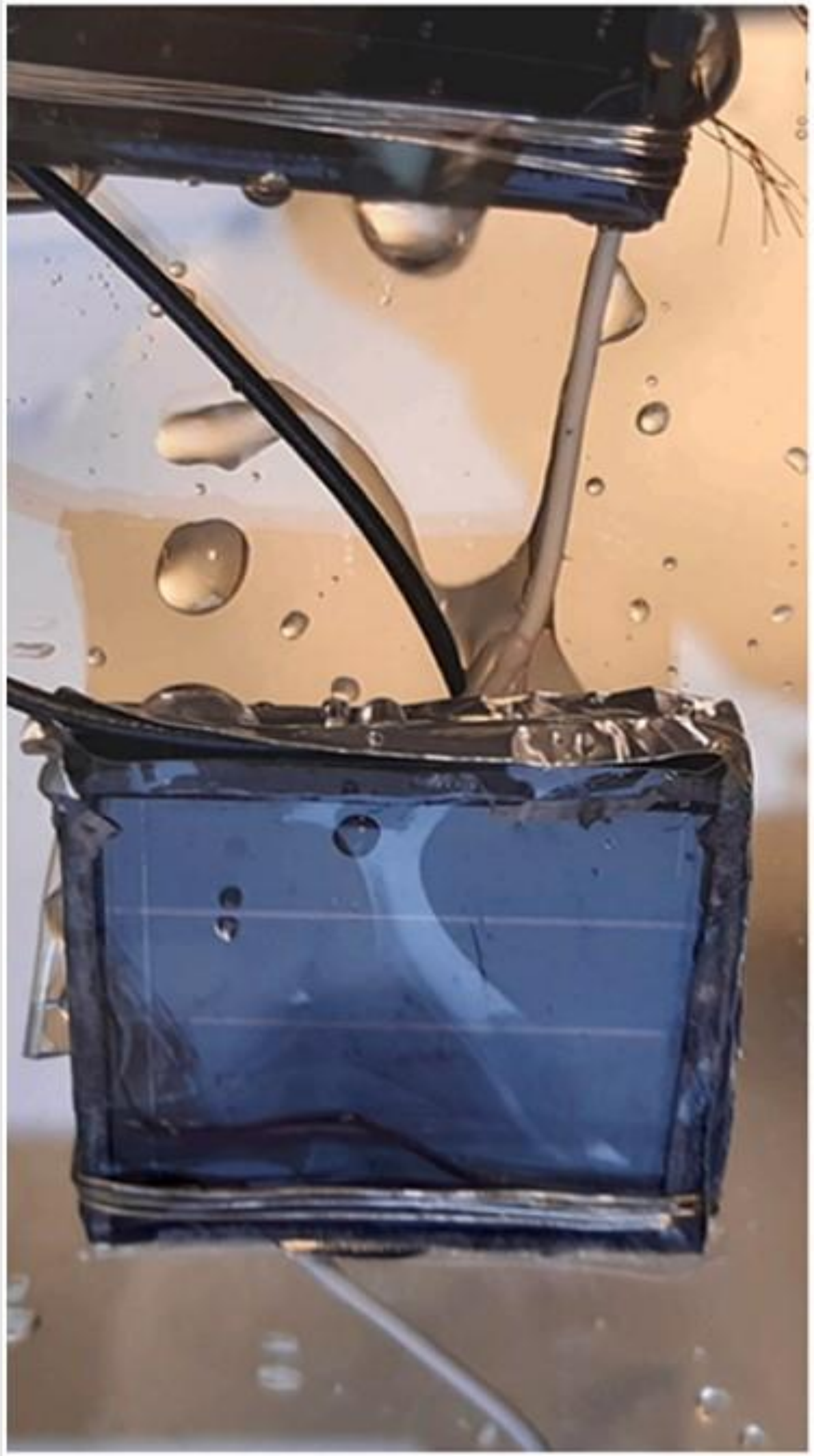
ITO: Transparent Conductor.

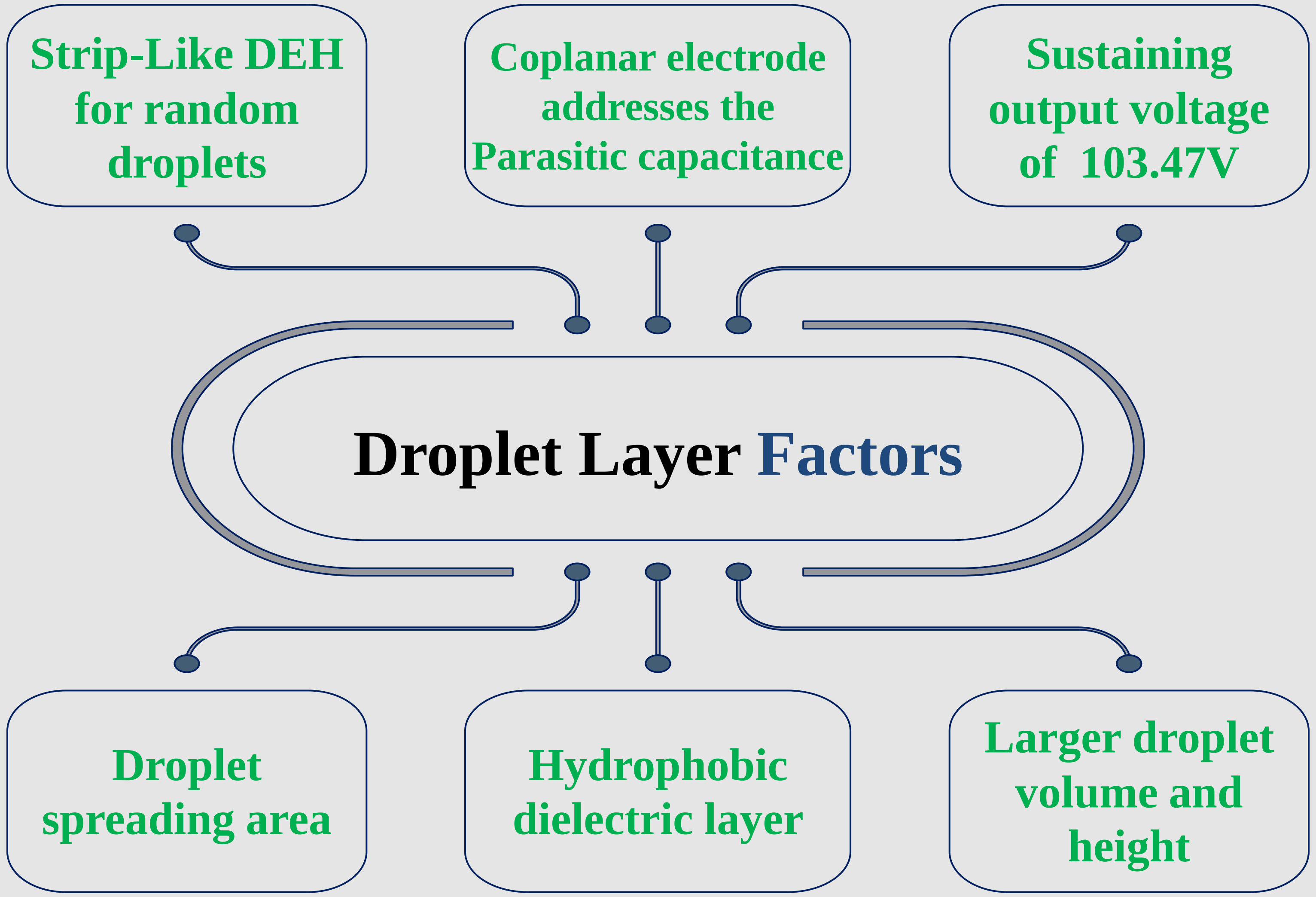
Droplet Cell Features

- Fully Transparent.
- High Performance.
- High-efficiency droplet energy harvesting under multi-position.
- **Robustness:**

1. When the source–drain gap was covered by water, the output performance remained unchanged.

2. After taking out from water, the output voltage gradually recovered and stabilized at about 220 V in 3 min.




Strip-Like DEH for random droplets
Coplanar electrode addresses the Parasitic capacitance
Sustaining output voltage of 103.47V
Droplet Layer Factors
Droplet spreading area
Hydrophobic dielectric layer
Larger droplet volume and height

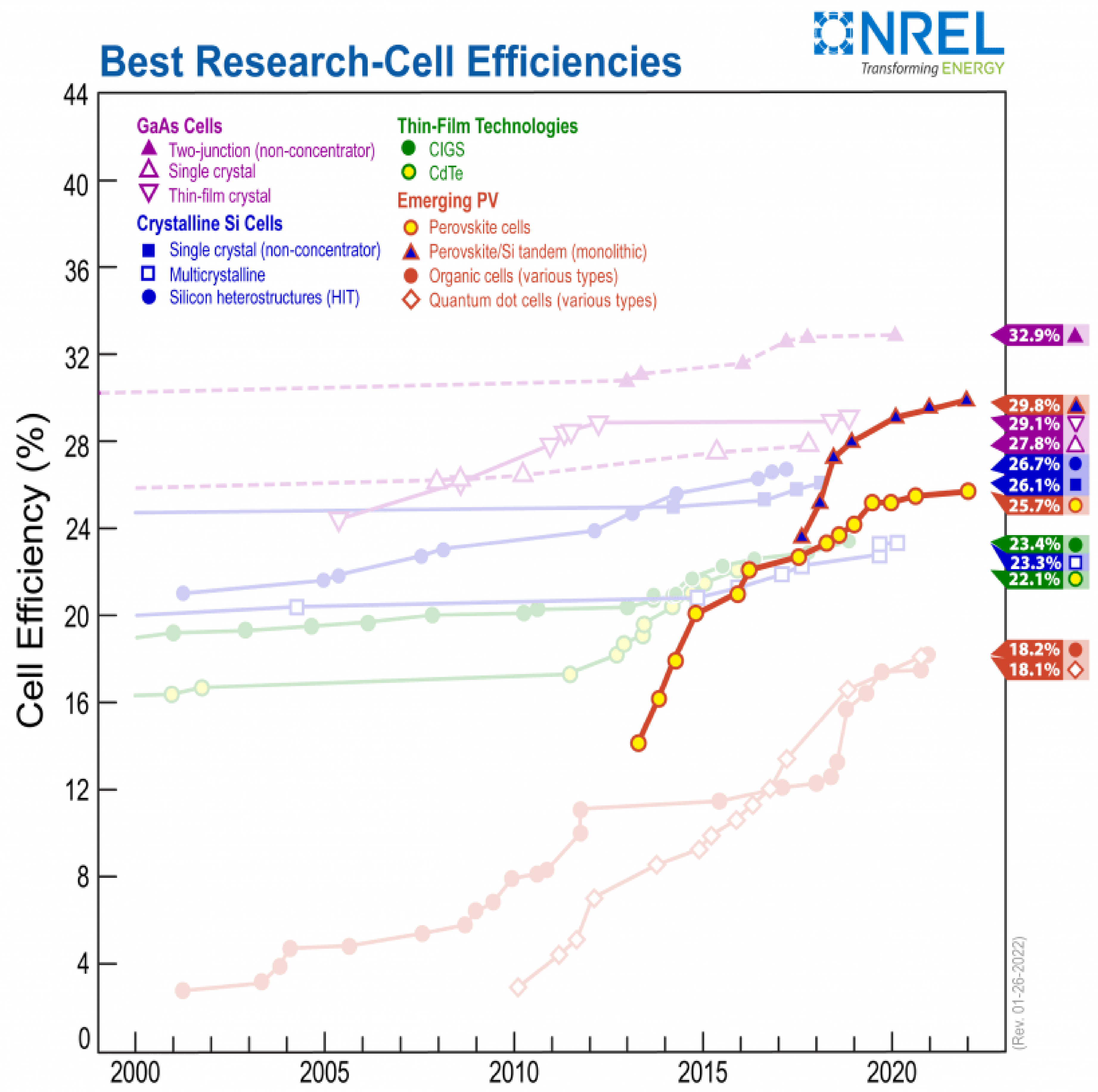
Simulation Results

- Perovskite/Silicon Tandem Solar Cell

The expected theoretical PCE for such a solar cell is around 40%.

- Up to now:

Scientists at KAUST achieved 33.7% efficiency in perovskite-silicon solar cell.



Simulation Results

By using the simulation software (COMSOL) yields the outcome:

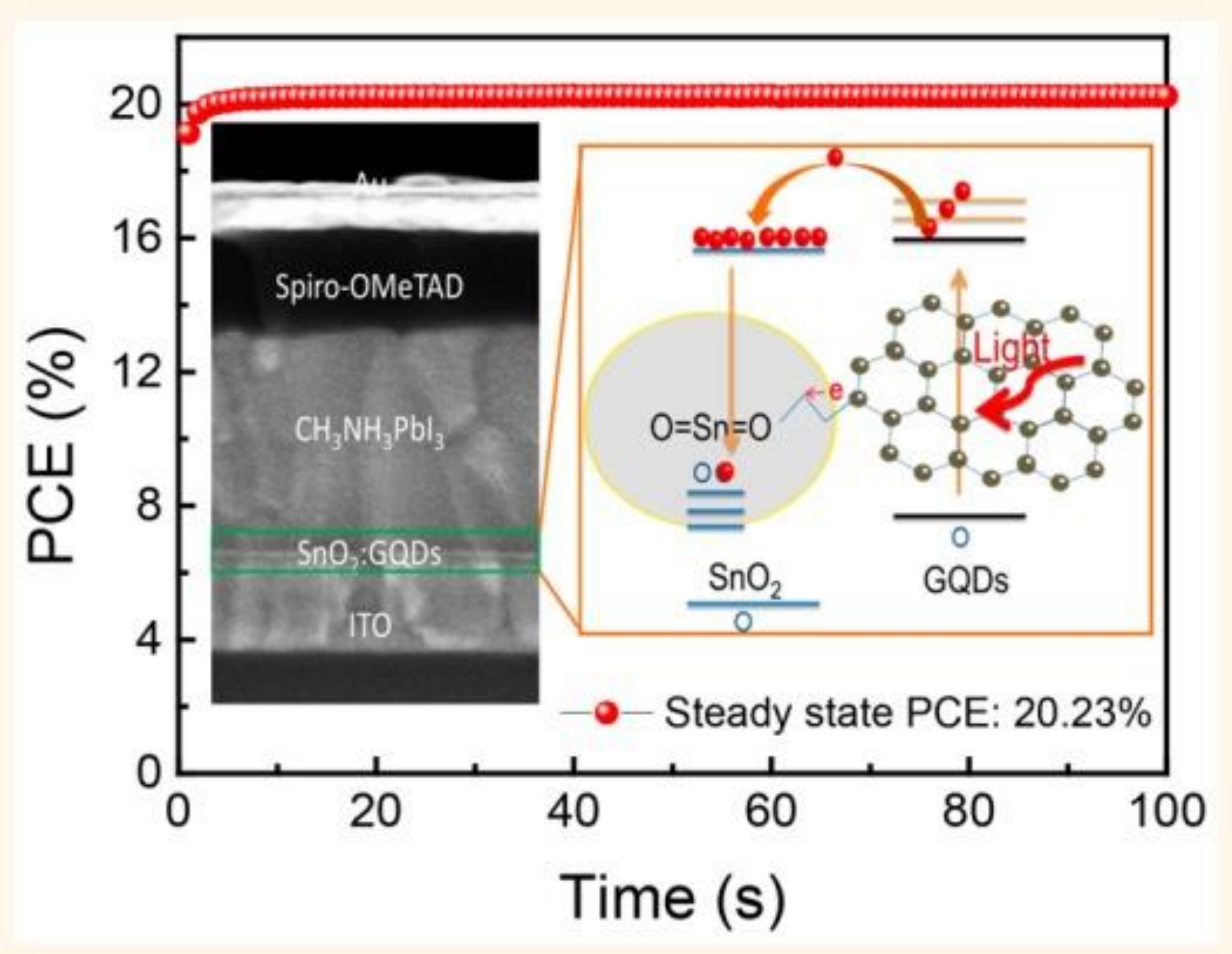
- Graphene in Perovskite solar cells

Enhanced Device Performance with (SnO2:GQDs):

- Achieved average power conversion efficiency (PCE) of 19.2 ± 1.0%.
- Peak steady-state PCE reached 20.23% with minimal hysteresis.

Method for Performance Enhancement:

Enhancing electronic properties of SnO2 effectively boosts cell performance.



Result showcases improved perovskite solar cell performance

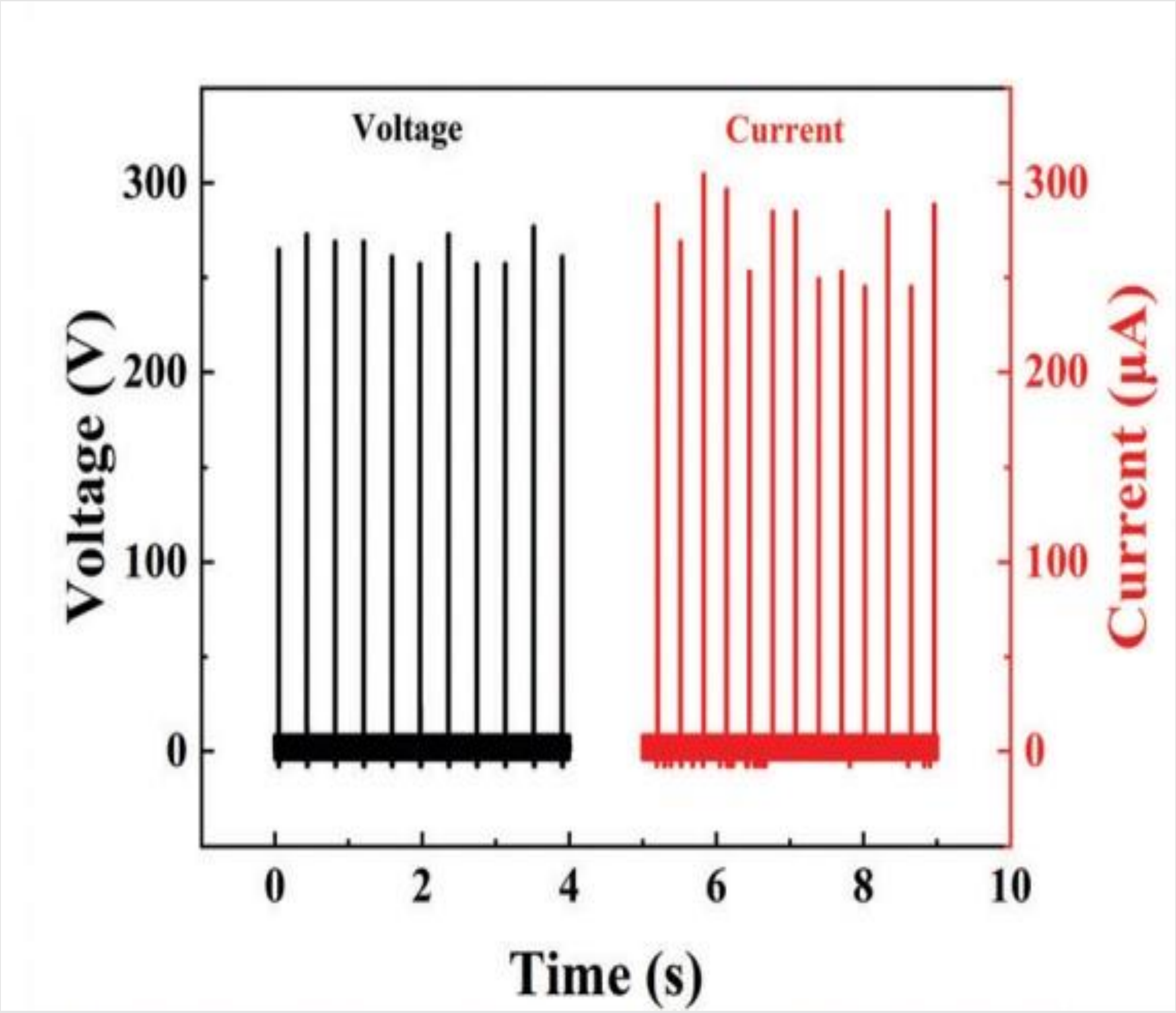
Simulation Results

By using the simulation software (COMSOL) yields the outcome:

- **Droplet Energy Harvester:**

The latest achievement in DEH panel is a strip-like DEH panel to the coplanar-electrode DEH panel can delicately alleviates the parasitic capacitance issue.
Maintaining a high output voltage of 103.47V.

After taking out from water, the output voltage gradually recovered and stabilized at about 220 V in 3 min



Output voltage and current of the DEH cell

RF Energy Harvesting

Radio frequency energy harvesting (RFEH) is an energy conversion technique employed for converting energy from the electromagnetic (EM) field into the electrical domain.

In particular, RF Energy Harvesting is a very appealing solution for use in body area networks as it allows low-power sensors and systems to be wirelessly powered in various application scenarios.

Fig.1. RF Waves Sources

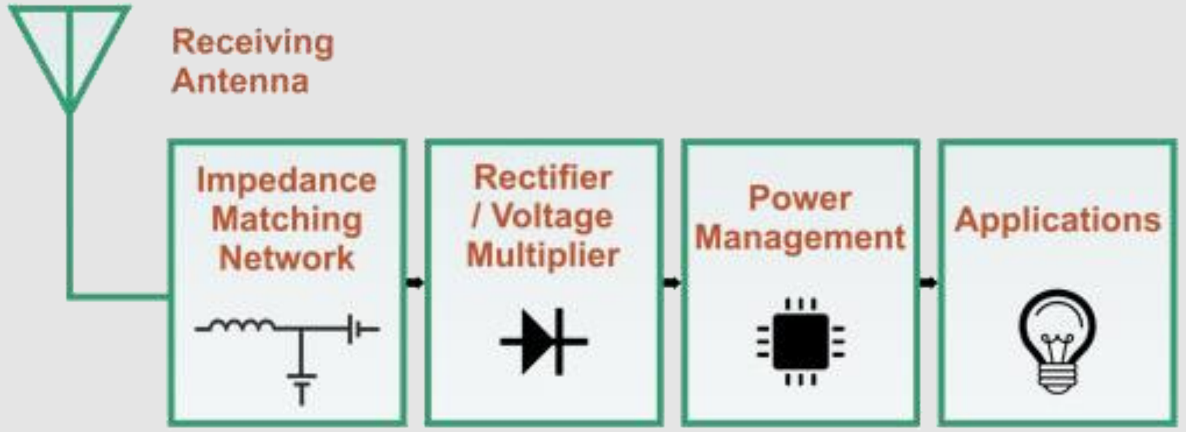


Fig.2. RF Energy Harvesting Block Diagram

RF Energy Harvesting Design Procedure

Band selection

-Local Survey for used bands and frequencies
-Band Usage and Allocation

Design of Antenna

-Patch Shape Selection and Analysis
-Design and Simulation
-Antenna Array Design

Circuit Design

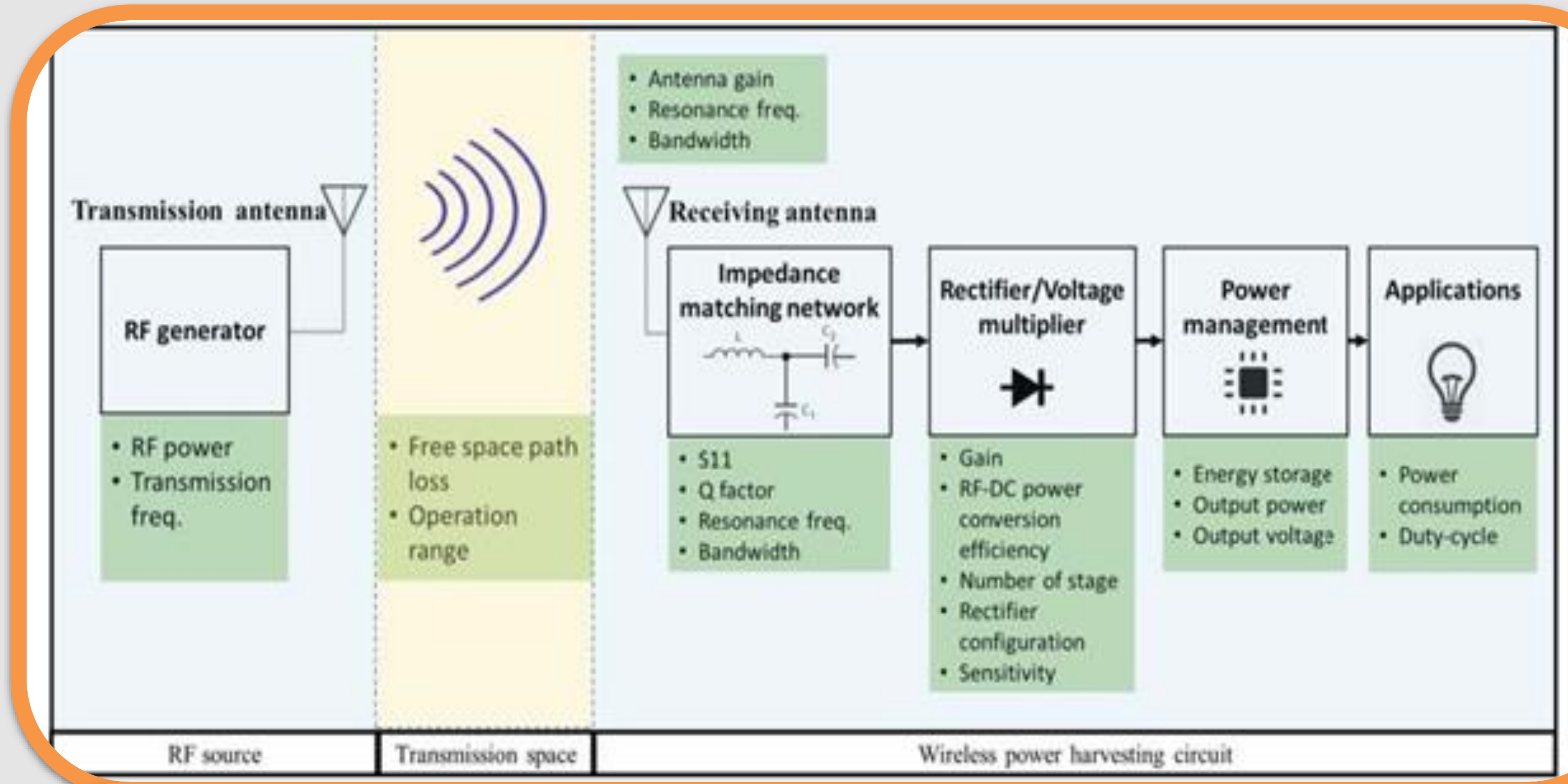
-Combiner circuit design (only for antenna array)
-Rectifier Circuit design
-Matching network design

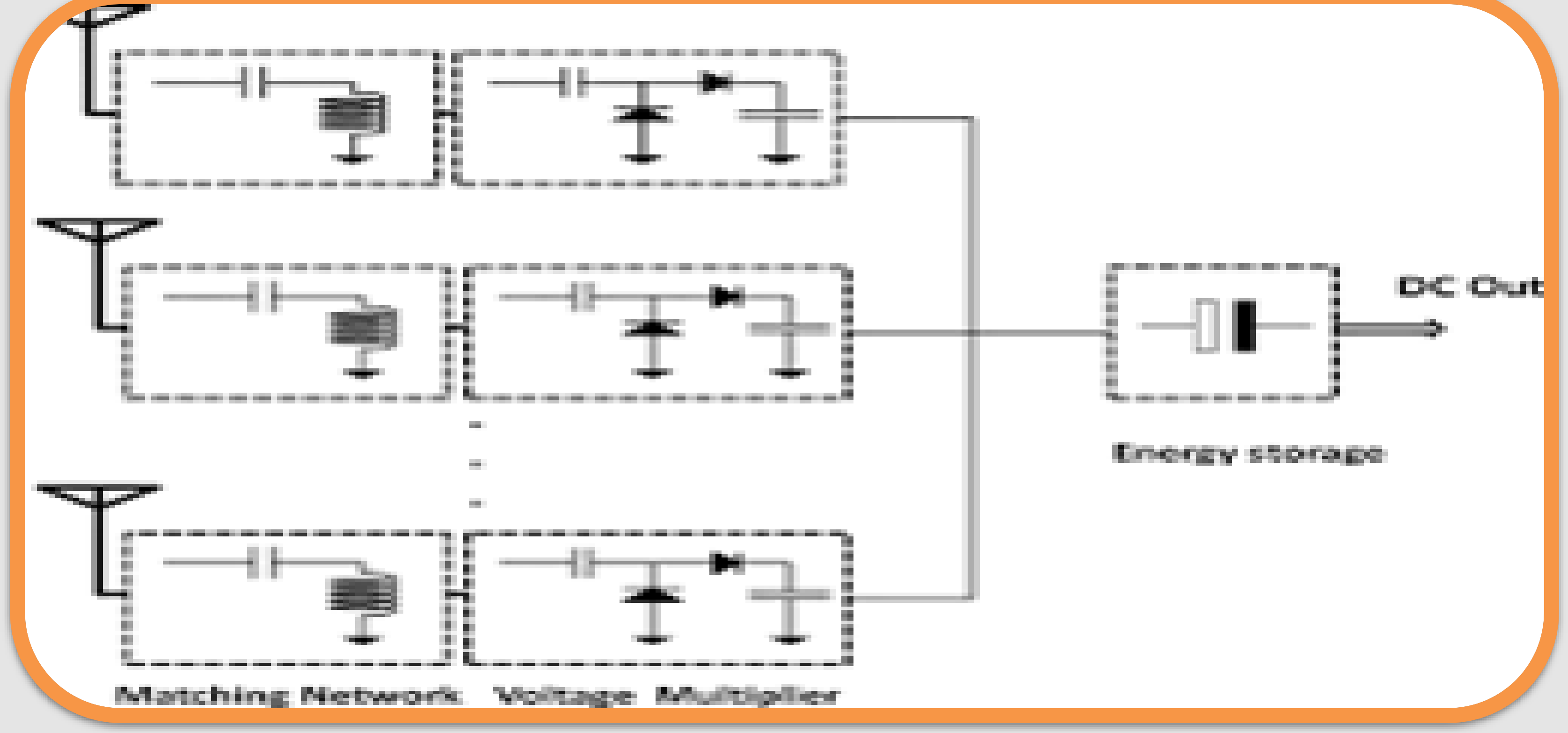
Final Steps

-Fabrication
-Testing
-Assembly

Using Antennas for Energy Harvesting

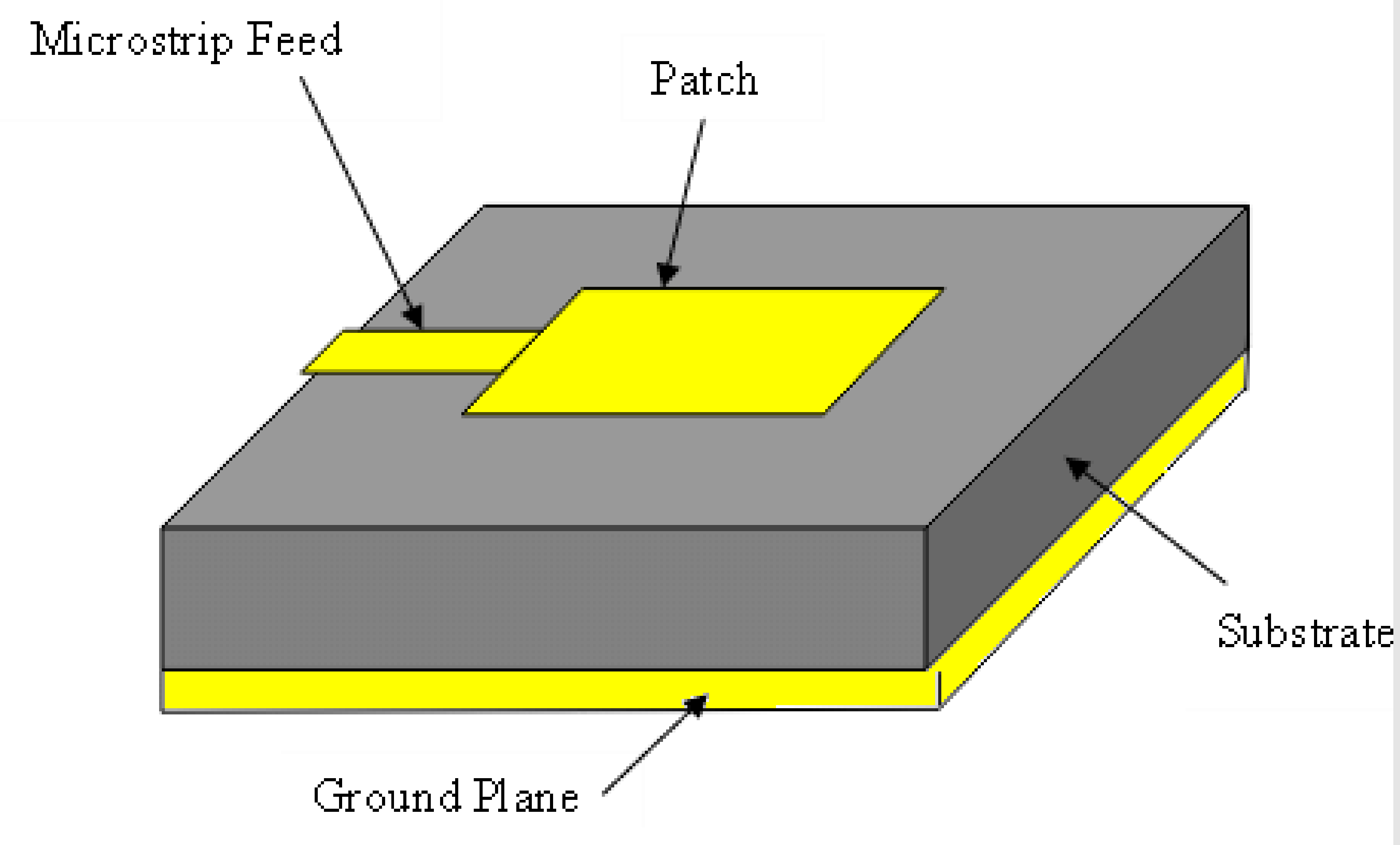
- Nowadays we are surrounded by a lot of electromagnetic waves from different sources such as WIFI, Bluetooth, telecommunication towers, etc. which makes a feasible source for energy harvesting.
- We can use antennas to harvest RF energy from the electromagnetic waves





Microstrip Antenna

- A microstrip patch antenna is a type of low-profile antenna commonly used in modern wireless communication systems, such as mobile phones, satellites, and Wi-Fi routers.
- Structure:
  - A thin metallic patch (radiating element) on a dielectric substrate.
  - A ground plane on the other side of the substrate.
- Key Features:
  - Compact size, lightweight, and easy to integrate into devices.
  - Supports applications with frequencies ranging from MHz to several GHz.
  - Low cost and easy to manufacture.



Microstrip Antenna

Basic Working Principle:

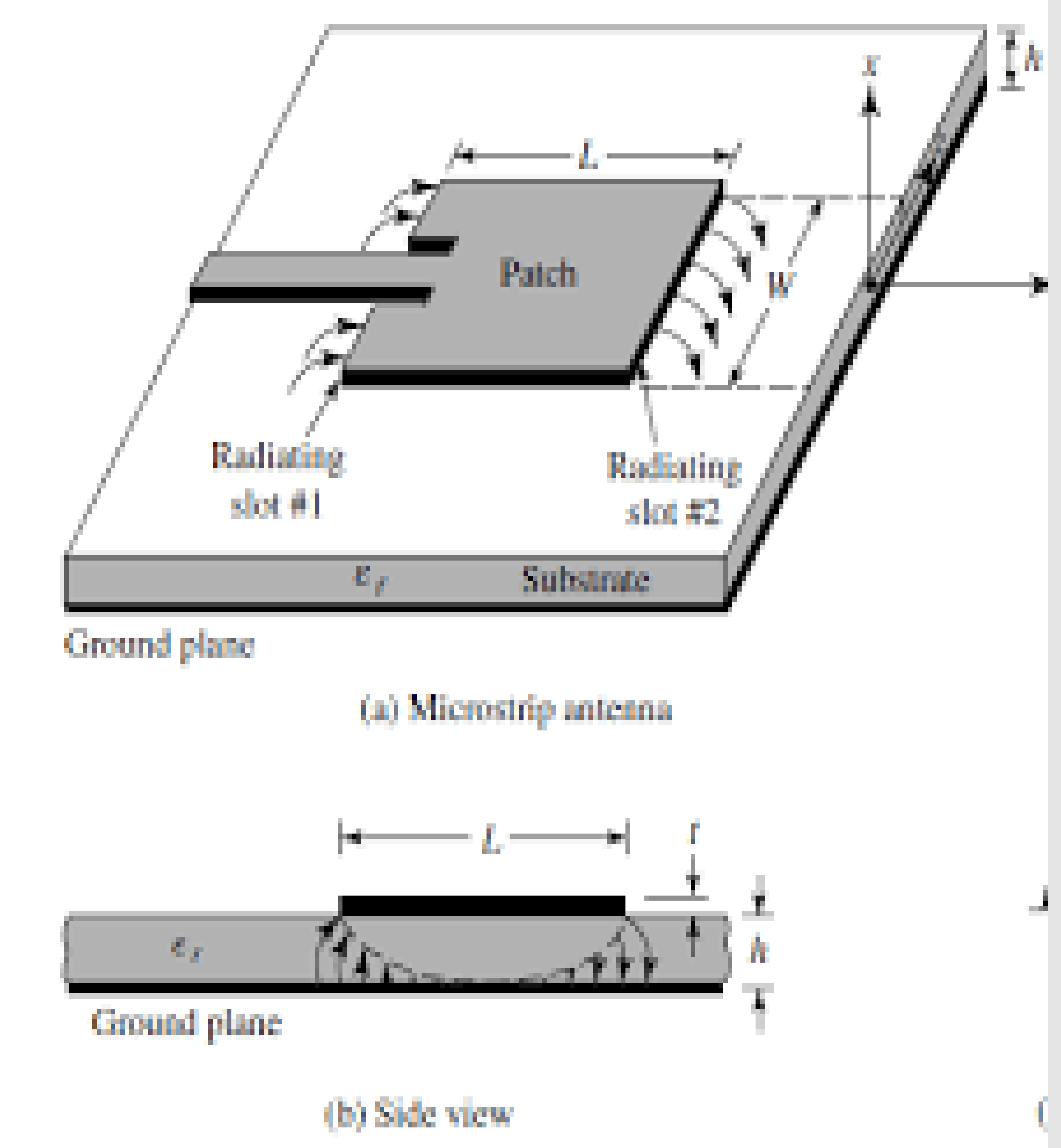
The metallic patch acts as a resonant cavity, radiating electromagnetic waves when fed with an RF signal. Radiation occurs due to the fringing fields at the edges of the patch.

Modes of Operation:

The dominant mode of operation is the TM1010 mode, where the electric field is maximum along one dimension of the patch.

Feeding Methods:

Coaxial feed, microstrip line feed, aperture coupling, and proximity coupling.



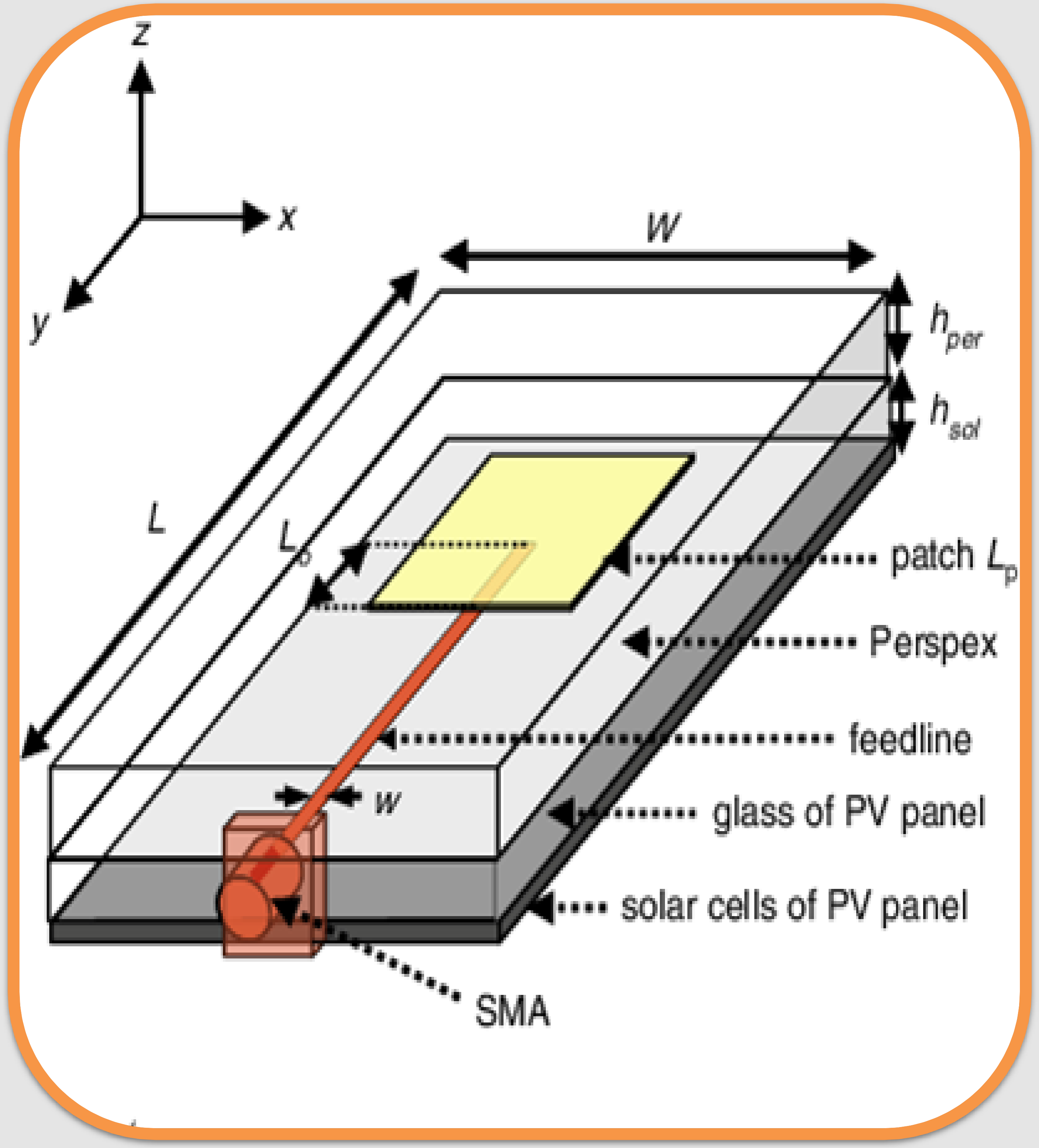
(a) Microstrip antenna

(b) Side view

Construction of Antenna over Solar Cell for Hybrid system

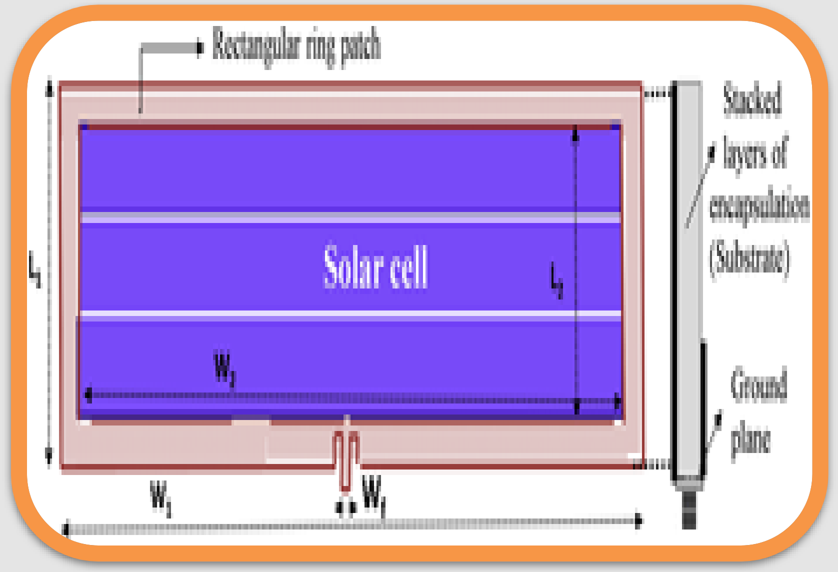
The whole system is constructed of the following parts:

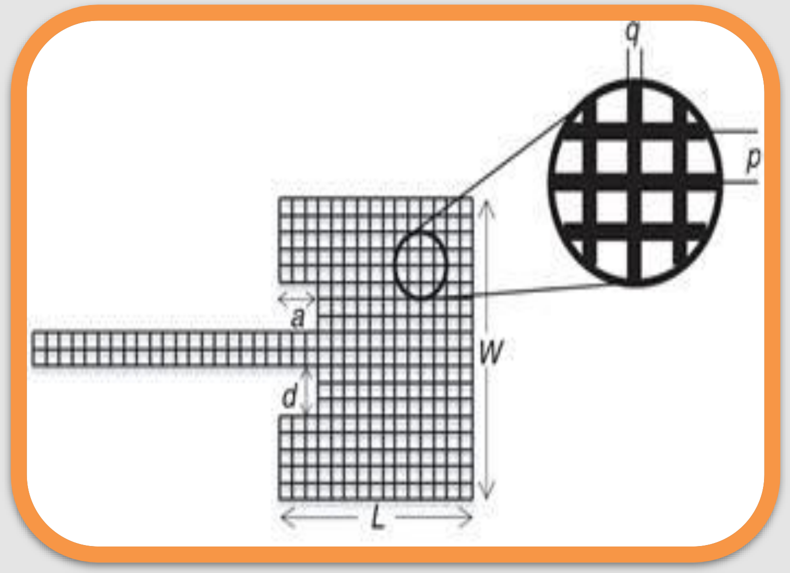
- Patch acting as RF collector using conductive material
- Perspex acrylic substrate for RF Patch
- Feedline for transferring the collected RF power to the SMA connector for energy harvesting and matching the impedance with SMA connector.
- Glass for protecting the solar cell panel
- Solar cell panel
- SMA for terminating the antenna matching to 50ohm

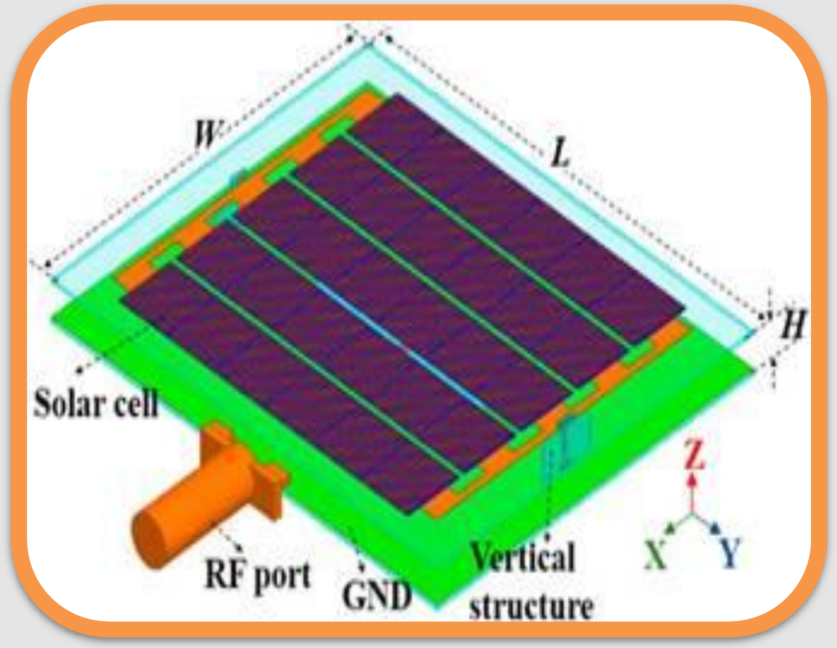


Combining Solar Cell with Antenna

- Building antennas around solar cells
- Interdigitate the Antenna over the solar cells
  - Using Meshed Antenna
  - Using Transparent Conductors

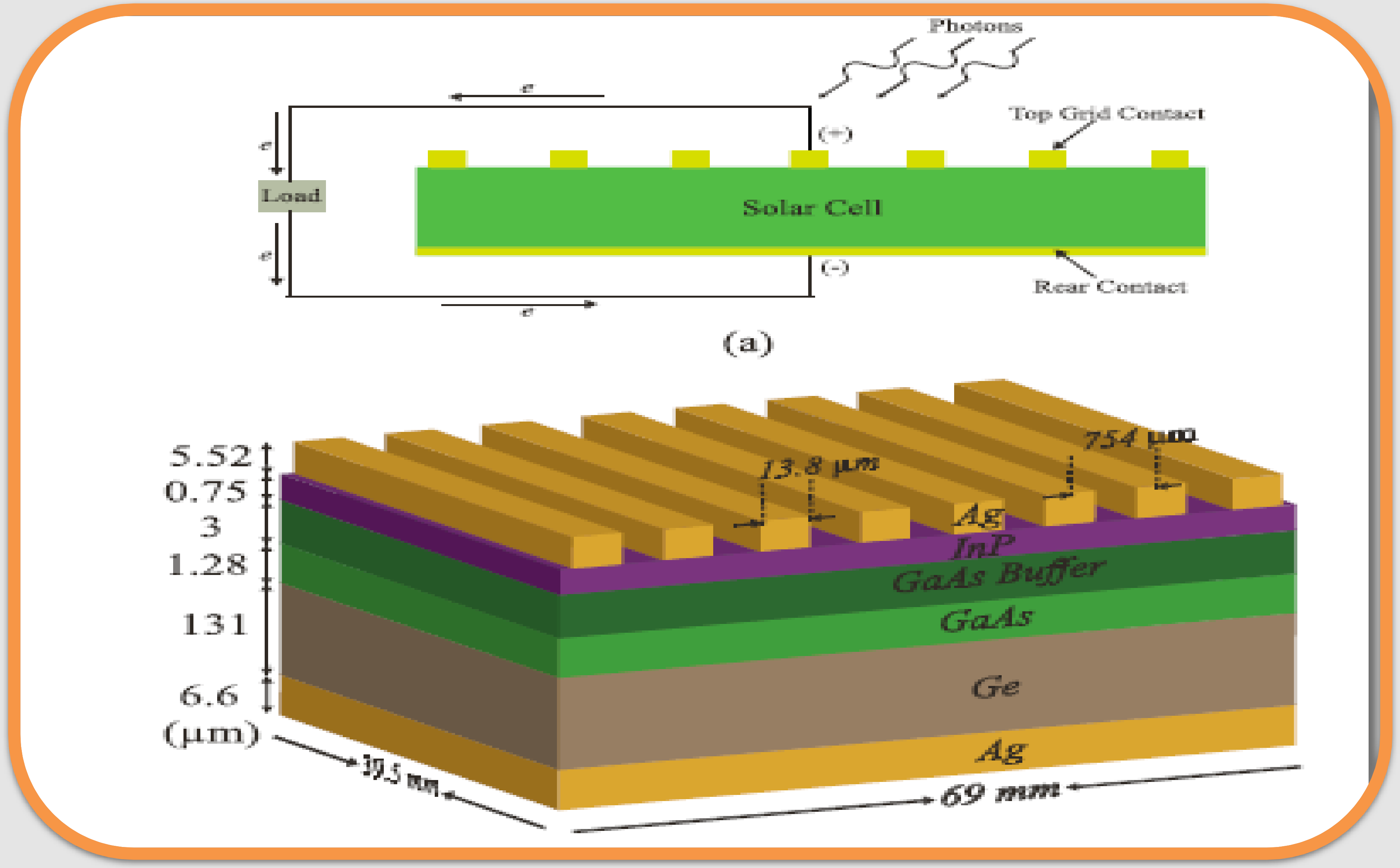


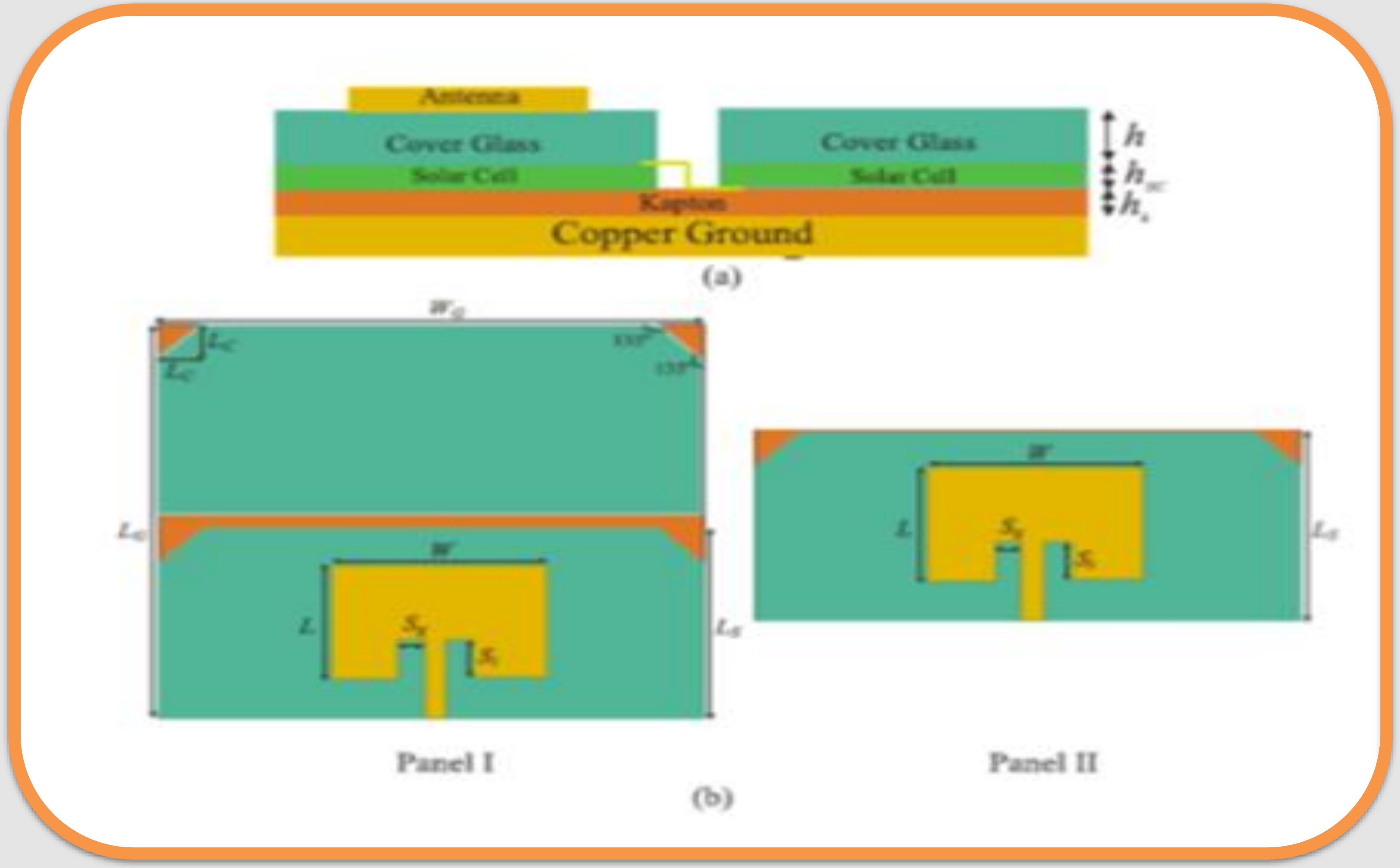




The transparent antenna allows us to utilize the whole solar cell surface to build antenna and/or antenna arrays

Combining Solar Cell with Antenna





Transparent Antenna Concept

- **Transparent antenna could be achieved by:**

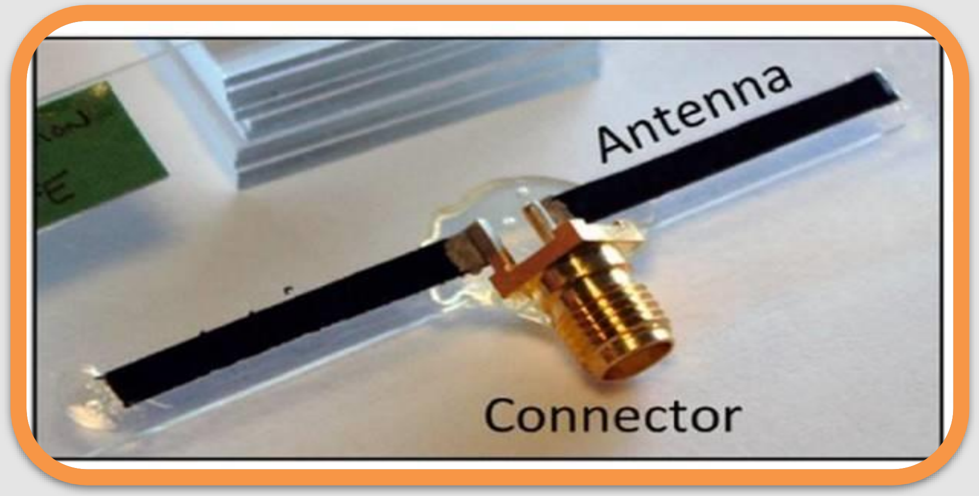
  - Using transparent material
  - Meshing the Antenna Design by using very thin lines

- **Meshing line width effect the peak gain of antenna**

Types of Transparent Conductors

- Nano Carbon
  1. Graphene
  2. Carbon Nano Tubes (CNT)
- Transparent Conductive Oxide (TCO)
- Conductive Polymer
- Nanowires

ITO



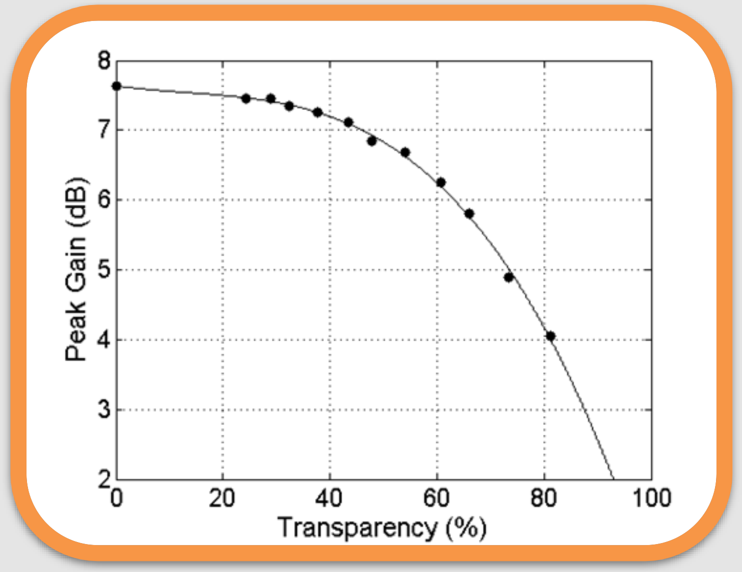
Carbon NanoTunes (CNT)

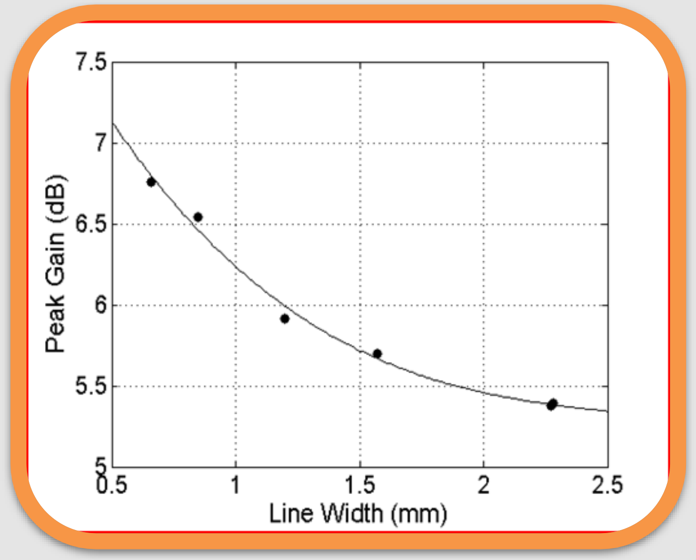
CNT-Silver Nano Tube -Hybrid

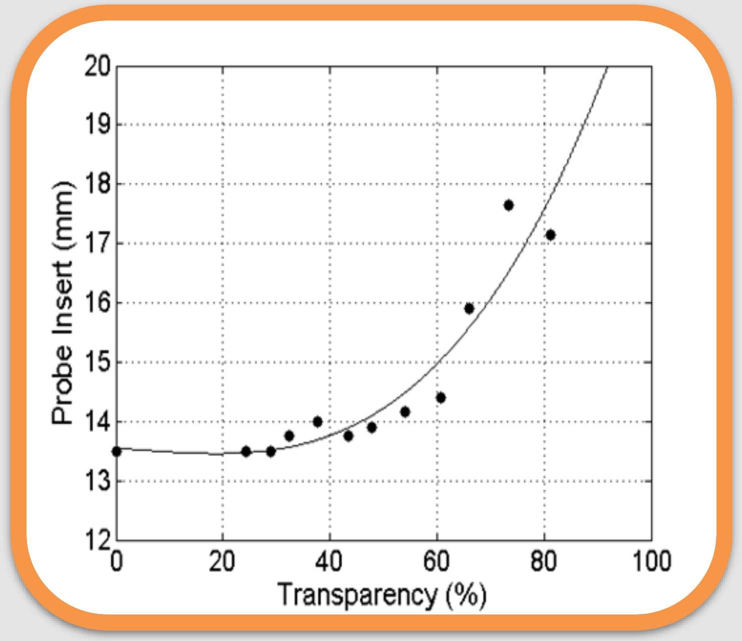
Effect of transparency on antenna gain

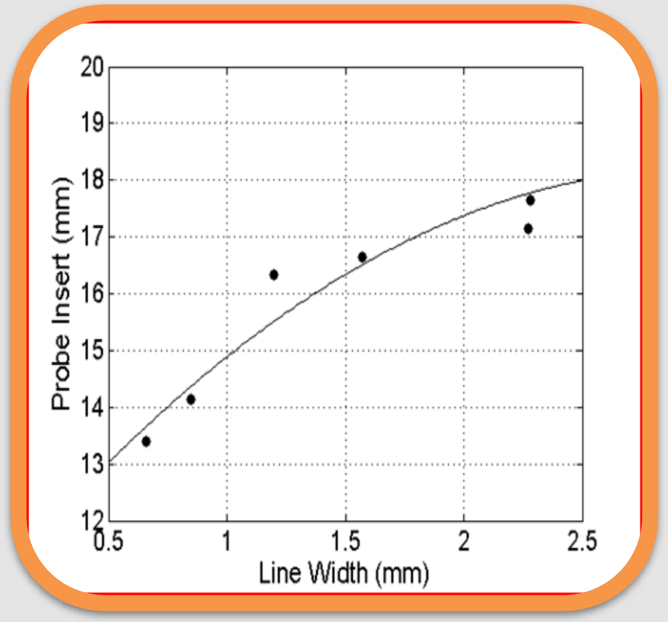
For a fixed line width, higher transparency results in gain reduction,

however, when fixing transperency and optimizing for line width, it is noticiable that the relation between antenna gain and line width is inversely proportional thus the thinner the line results in higher gain.



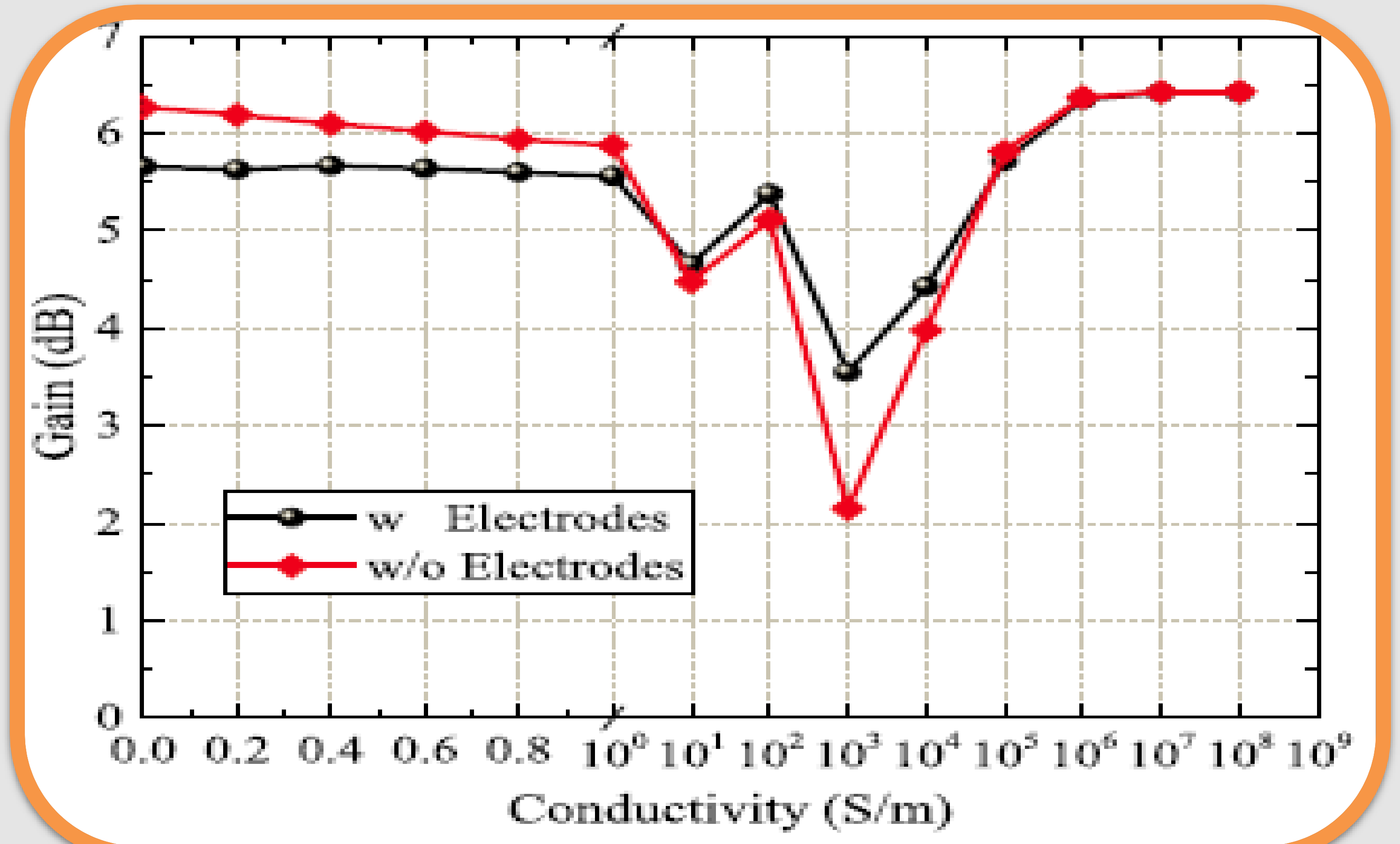


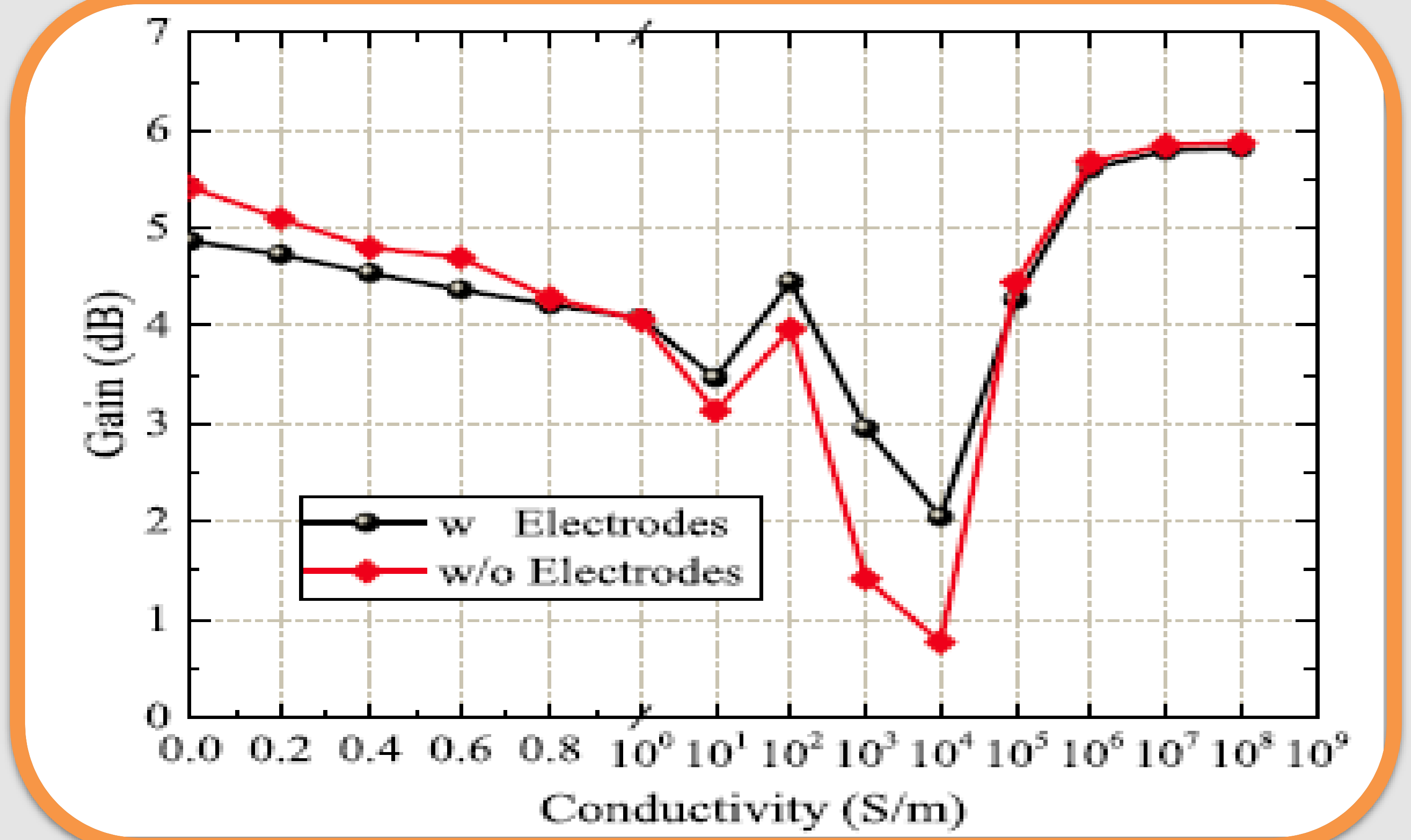




Effect of solar cell on antenna

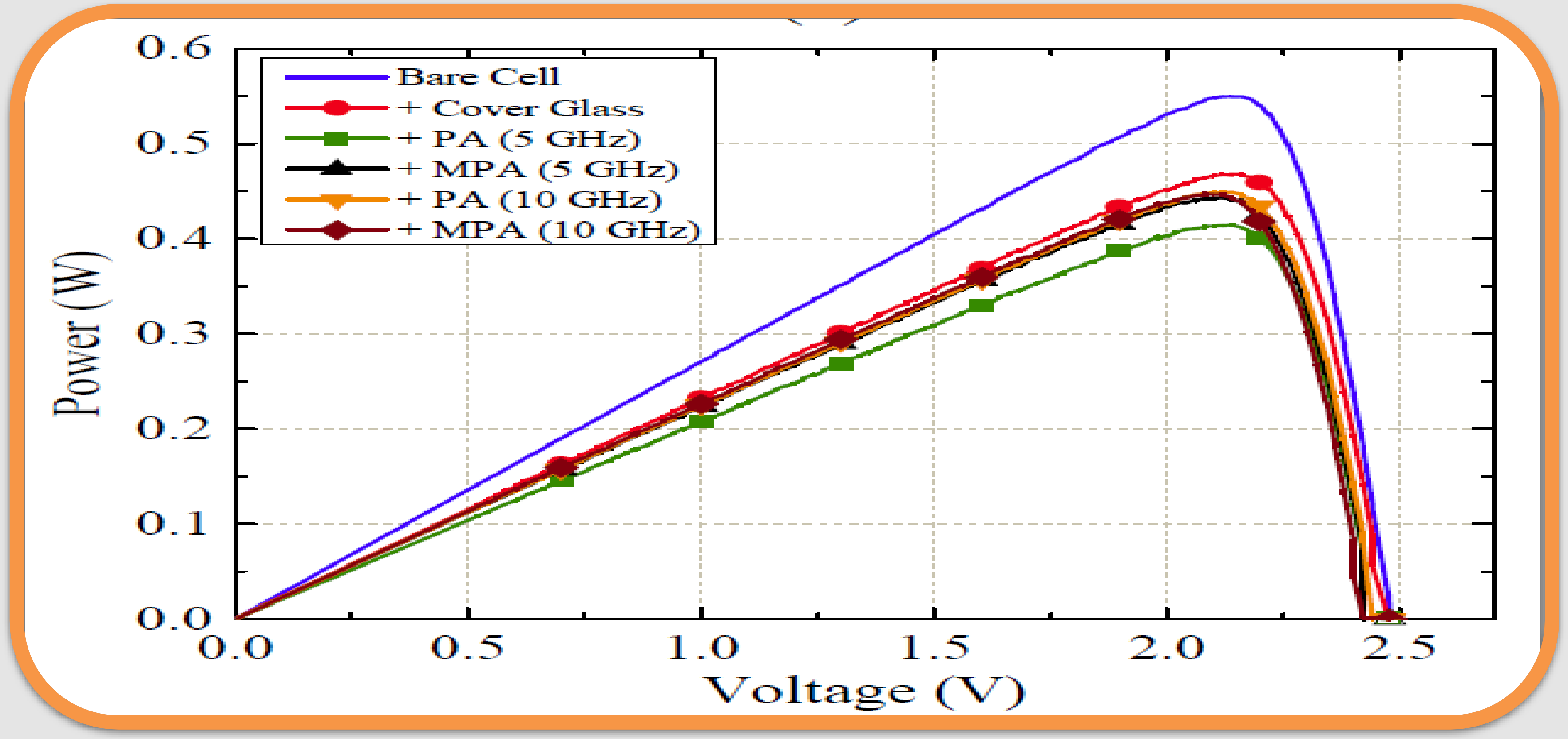
- When solar cells are placed near an antenna, they can cause interference and affect the performance of the antenna
- This interference effect the overall efficiency of the antenna
- The presence of solar cells can also lead to changes in the radiation pattern and polarization of the antenna
- The most noticeable reduction in antenna gain occurs at the conductivity level where solar panel junctions operate

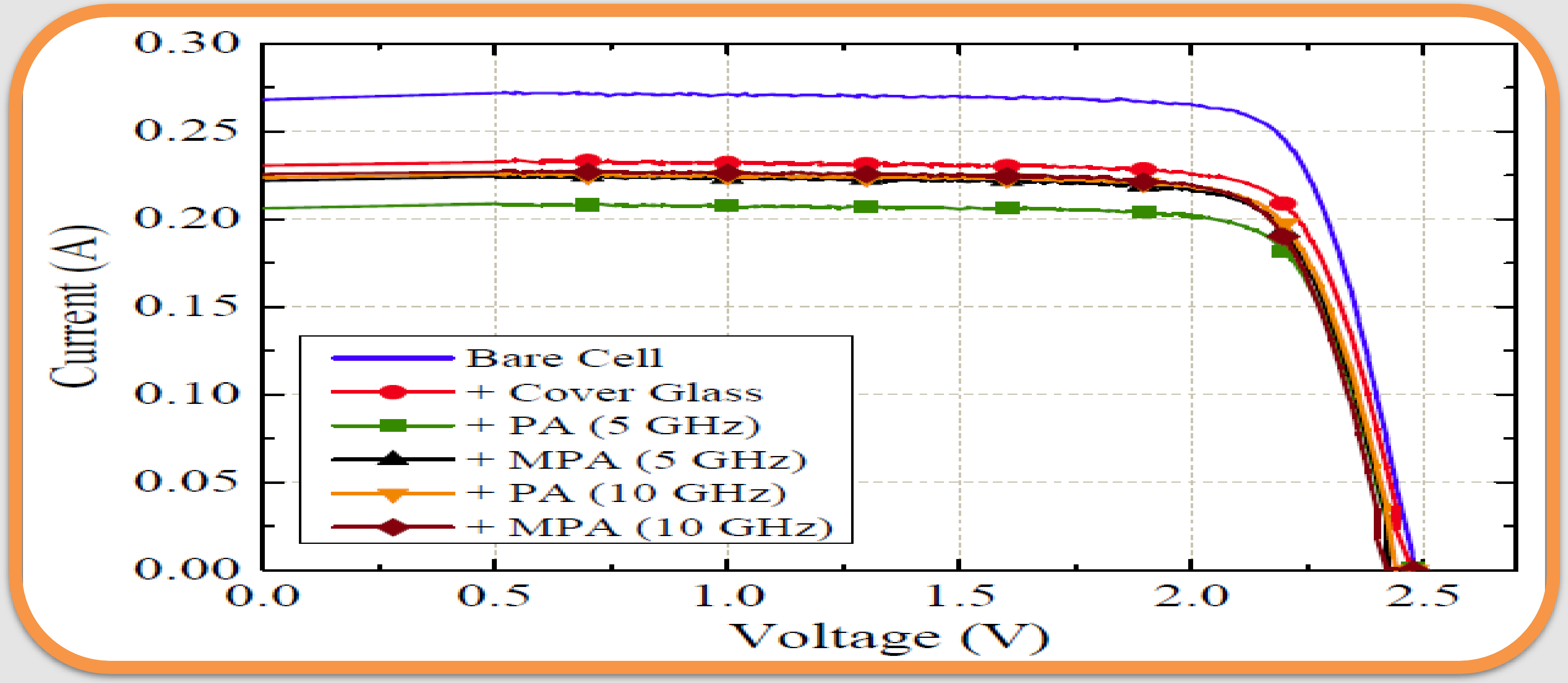




Effect of Antenna on Solar Cell

- Solar cells efficiency is very sensitive to the attenuation in solar energy
- Addition of any materials over the solar cell increase the attenuation
- Conductors easily block light due to it’s nature





Conclusion

- Integration of perovskite, silicon, and graphene layers yields remarkable achievements.
- Efficacy of up to 33.7% (perovskite-silicon) and 23.1% (perovskite-graphene) realized
- Hybrid Energy Source: Combining transparent microstrip patch antennas with solar cells enables dual-mode energy harvesting from both RF and solar sources.
- Transparency Advantage: Transparent antennas offer practical benefits for applications requiring visibility, such as in windows or wearable devices.
- Nanomaterial Enhancements: Using nanomaterial substrates improves the efficiency and compactness of transparent antennas, optimizing energy harvesting.

Future Work

- Study the feasibility of transparent conductive materials suitable for antenna
- Development of suitable conductive ink with low resistivity and can sustained wear and tear.
- Testing more techniques for placing antenna over solar cells for better transparency results.
- Study the feasibility of using graphene solutions to print antenna using ink-jet material printers.
- Adding the new materials to simulation software and simulating the antenna structure using it.
- Study the impedance effect on matching transmission line due to different materials used in antenna and connector electrode.

Thank you

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