Roof integrated thin film Photovoltaic: opportunities and challenges

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Roof integrated thin film Photovoltaic: opportunities and challenges

Outline

- **Flat roof basics**
- **PV Systems for flat roofs**
- **Membrane integrated PV systems (MIPV):**
  - **Technical design aspects**
  - **Key issues**
  - **Validation of durability**
- **Conclusions**

Flat roof basics
Building types and application

- Commercial and industrial buildings
- Health, educational and other public buildings
- Sport and leisure facilities
- Residential buildings

Flat roof basics
Membrane roof systems: overview

Exposed Roofs

- Mechanically fastened systems
- Adhered systems

Waterproofing layer has to withstand all environmental influences

Appropriate for lightweight and solid roof structures

Unlimited design / complex roof geometry

Cost efficient application

Proven technology

Flat roof basics
Membrane roof systems: overview

Ballasted Roofs

- Gravel ballasted systems
- Utility roof decks
- Green roof decks

Waterproofing membrane is protected against environmental and mechanical damage

For solid roof structures only

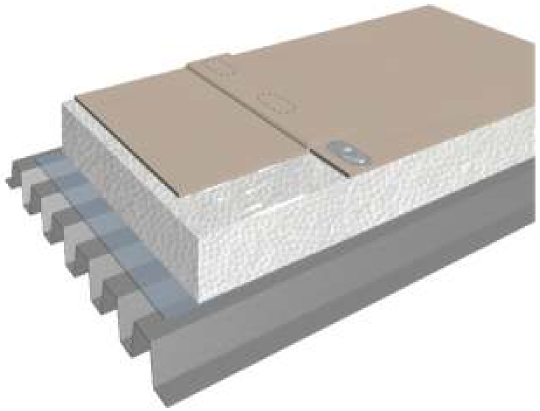
Adequate for additional rooftop load

Improved thermal performance of building

Fire resistant

Low maintenance cost

Flat roof basics
Flat roof assembly



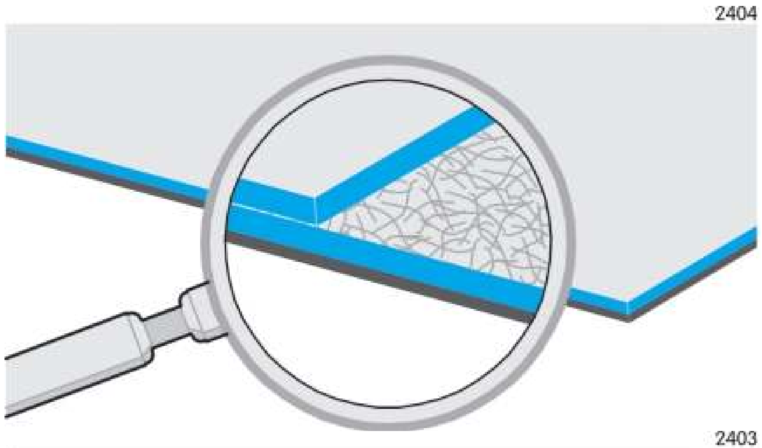
- **Waterproofing layer**
  - Metal panel
  - Bituminous membrane
  - Liquid applied membrane
  - **Single ply roofing membrane**
- **Thermal insulation**

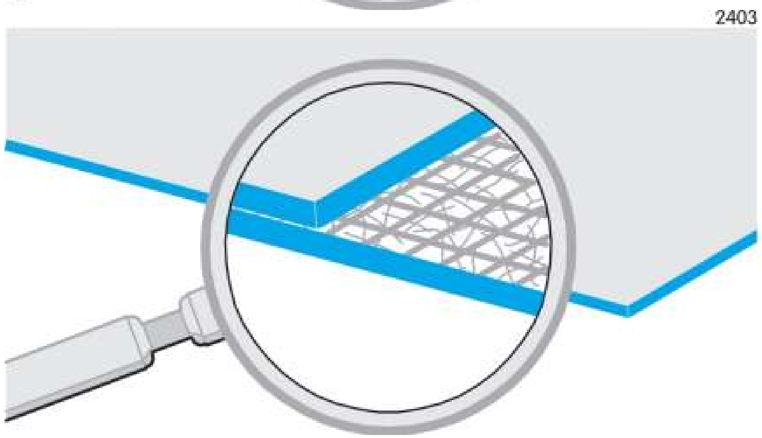
  EPS/XPS, PUR/PIR, mineral fiber, glass fiber, gypsum board, cellular glass, wood fiber
- **Vapor control layer**

  Bitumen, Polyolefin films
- **Supporting structure**

  Concrete, steel, wood

Flat roof basics
Single ply roofing membrane





Composite Material

- **Top layer:** **weather resistance**
  - UV / heat
  - IR reflection
  - Fire resistance
- **Middle layer:** **mechanical properties**
  - Glass nonwoven / glass fabric: dimensional stability (shrinkage)
  - PET fabric: tensile strength (wind load)
- **Back layer**

Polymer base

- **thermoplastic** e.g. TPO, PVC-p
- **elastomeric** e.g. EPDM

Flat roof basics
Multifunctional roof top



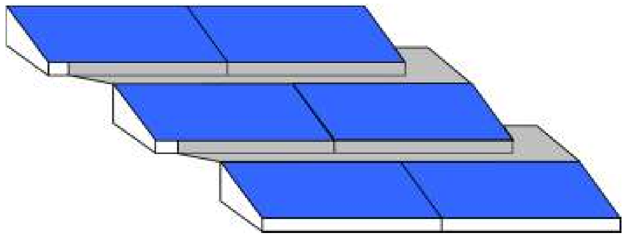

Global challenges (Megatrends):

- Limited resources
- Changing climate
- Short supply of water
- Rising need for efficient infrastructure

Roof tops contribute to sustainable development of our planet:

- **Reducing heat island ("Cool Roofs")**
- **Collecting and retaining rainwater ("Green Roofs")**
- **Generating solar heat or active cooling (Solar thermal)**
- **Producing solar electricity (PV)**

PV Systems for flat roofs
BAPV (Building applied PV)



shadowing

PV Systems for flat roofs
BIPV (Building integrated PV)

PV Systems for flat roofs
Roof parallel installation

Semi integrated design

- high covering rate
- superior wind performance
- natural ventilation
- “out of water solution”

Mounting structure bonded or welded directly to the roofing membrane

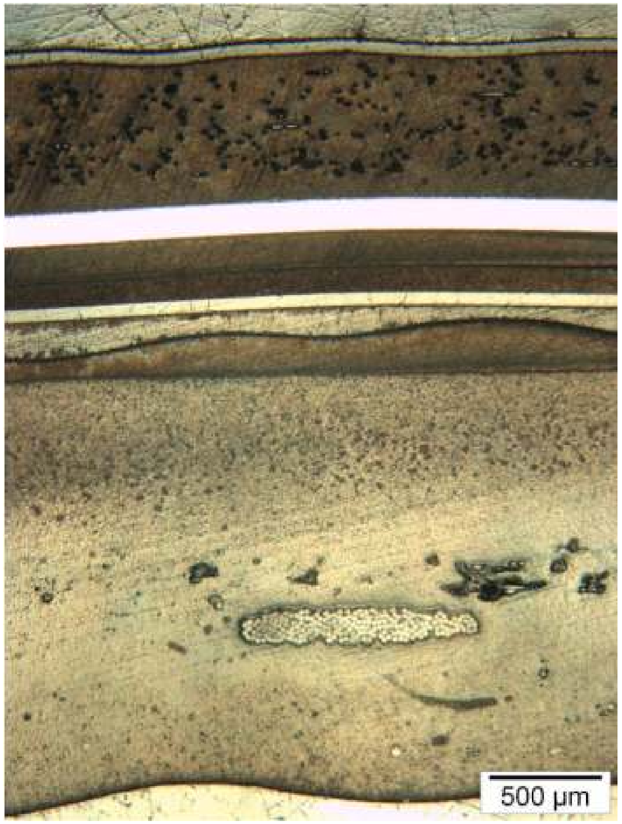
Impact of (wind) load to the roof build-up to be analyzed:

→ static / dynamic uplift and compression load
→ horizontal load

PV Systems for flat roofs
MIPV (Membrane integrated PV)

- **BIPV approach**
- **Two functions combined: generation of electricity and waterproofing**
- **Flexible thin-film technology**
- **Systems:**
  - **Single layer MIPV:** PV and waterproofing layers are applied simultaneously
  - **Double layer MIPV:** PV is applied independent from waterproofing layer

PV Systems for flat roofs
MIPV (Membrane integrated PV)



MIPV: cross-section (optical microscope)

Flexible thin-film technology

- **Composite material, multilayer design**
- **Cell technologies: TF-Si, CIS/CIGS, CdTe, DSSC, OPV**
- **Polymeric packaging materials**

PV Systems for flat roofs
MIPV (Membrane integrated PV)

Strengths

Flexible	Installation to curved roof surfaces is feasible
Lightweight	Additional roof load 2 – 5 kg/m^2
Robust	Glass-free, resistant to hail
No mounting system	Weight and cost savings
Roof parallel installation	Aesthetic solution, high coverage rate
No additional wind loads	
Ease of handling	Supplied on rolls
Ease of installation	Bonding to waterproofing layer by welding or with adhesives
Superior low / diffuse light performance	Compared to conventional c-Si technology

PV Systems for flat roofs
MIPV (Membrane integrated PV)

Challenges

Economy	Higher system cost in comparison to rigid PV technology
Limited long-term experience	Field experience < 20 years (applied to flexible substrates)
Low module efficiency	Large area needed. Higher cost of BOS
Low slope installation	Soiling / dirt build up Standing water → roof slope minimum 3° (5%)
Thermo-mechanical interactions	PV laminate // roof build-up
Chemical interactions	PV laminate // adhesives // waterproofing layer

PV Systems for flat roofs

Roof area required for different PV technologies and arrays

PV technology	Module efficiency	Array	Roof coverage rate	Roof area per unit nominal power (approx.)
MIPV (flexible)	6 %	roof parallel	65 %	**23** m^2/kWp
MIPV (flexible)	10 %	roof parallel	65 %	**16** m^2/kWp
c-Si (rigid)	16 %	roof parallel	85 %	**9** m^2/kWp
c-Si (rigid)	16 %	15° fixed tilt racking	45 %	**15** m^2/kWp
c-Si (rigid)	16 %	30° fixed tilt racking	30 %	**21** m^2/kWp

PV Systems for flat roofs
Market potential of rooftop solar

Flat roof market Europe (all types)

Flat roof area installed (cumulative)	approx. **5’000 Mio m²**
New installed flat roof area per year (new buildings and refurbishment)	min. **360 Mio m²**

Market potential of rooftop solar in Europe (rough estimation)

New installed flat roof area covered with rooftop solar per year	**120 Mio. m²**
New rooftop solar installations per year	**8 GW_p nominal power**

Assumptions:

- **1/3 of new installed flat roof area to be covered with PV installation**
- **Area required per unit nominal power: 15 m^2/kW_p**

Membrane integrated PV system (MIPV): Technical design aspects

A) Design aspects specific to existing flat roofs

Roof assembly to be checked by roofing specialist:

- Is life expectancy of the whole roof assembly minimum 25 years?
- Does fire performance of the system meet local standards?
- Does thermal performance of the insulation meet today's energy saving standards?
- Is function of the thermal insulation o.k.?

Membrane integrated PV system (MIPV): Technical design aspects

B) Design aspects relevant to new and existing flat roofs

Structural capacity of the roof supporting structure

Not relevant for MIPV in general

Roof design

- Site specific shading conditions
- Slope of roof / drainage situation: avoid permanent standing water
- Rooftop features: module array to be adjusted accordingly
- Roof fastening system: avoid negative mechanical interaction with PV modules
- Wind load performance: critical load to waterproofing layer, fastening system or roof-structure?
- Single or double layer MIPV system: feasibility?

Waterproofing layer and thermal insulation

- Materials with proven long-term performance
- Project specific material specification: e.g. thermal resistance / fire performance

Membrane integrated PV system (MIPV): Technical design aspects

B) Design aspects relevant to new and existing flat roofs

MIPV system and BOS

- PV technology: proven long-term performance (durable and robust for min. 25 years)
- BOS: proven long-term performance (e.g. UV exposure)
- Layout of electrical installation (cabling): no restraint to drainage

Other topics

- Compliance to building codes, electro technical codes and other relevant standards
- Lightning protection
- Electrical grounding
- Maintenance concept for waterproofing system and PV installation
- Safety measures at work
- Obligations of each party involved: owner, manufacturer of roof system, roofing contractor, manufacturer of PV system, solar integrator / EPC, electrical contractor
- Warranty conditions and coverage

Membrane integrated PV system (MIPV): Key issues

Real life of rooftop solar

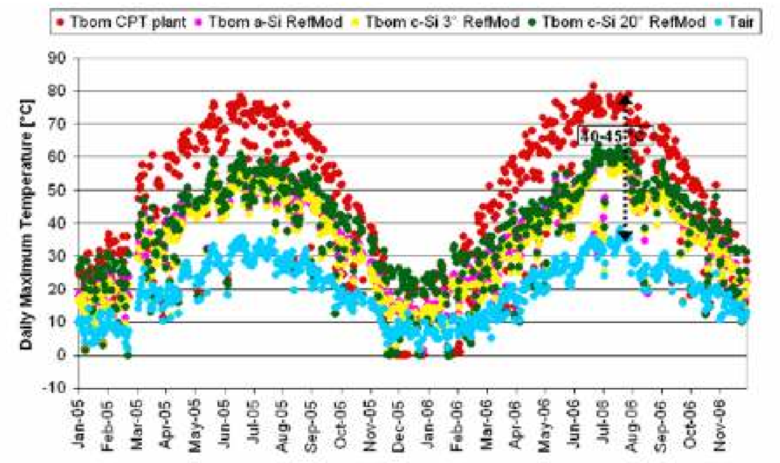
MIPV has to withstand harsh conditions.

Most critical impacts:

- **Service temperature**
- **Humidity**
- **UV radiation**
- **Thermo-mechanical induced stress**

Electrical load gives additional increase of temperature. This effect accelerates potential physical and chemical ageing processes.

Membrane integrated PV system: Key issues
Service temperature



Maximum temperature of PV module: +80 to +95°C
Mean temperature of PV module: 40 to 45°C above ambient temperature

Cause:
- **Solar irradiance**
- **Electrical load**
- **No ventilation** (on backside)

Reliability concerns:
- **Degradation of PV module**
- **Degradation of roofing membrane / insulation**
- **Fire risk**

Measures:
- **PV technology: cell and module design**
- **Roofing material: temperature and fire resistant**

Membrane integrated PV system: Key issues
Humidity

Humidity from environment (rain, snow, dew, standing water)

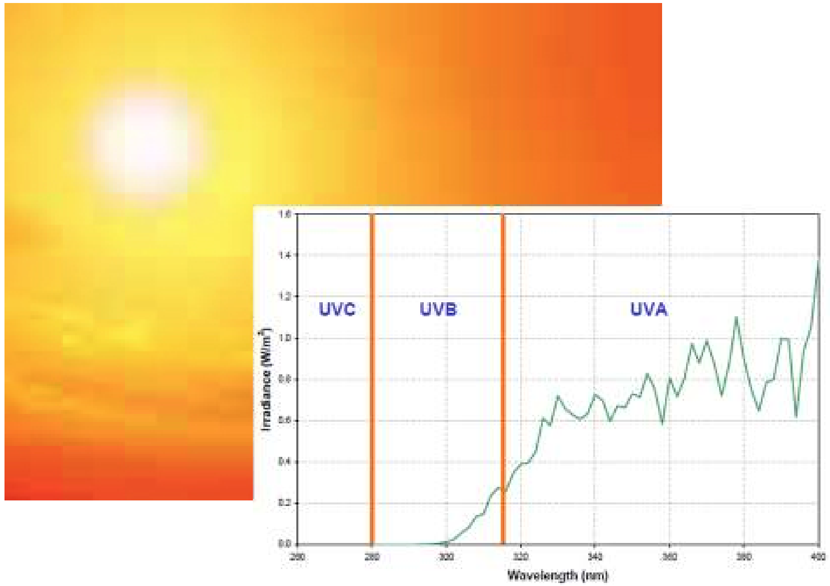
Humidity inside the building envelope (condensate)

Cause:
- **Diffusion of humidity into PV laminate**
- **Migration of humidity along connectors, cabling and electrical termination**

Reliability concerns:
- **Degradation of PV module: corrosion**
- **Weakening of PV module packaging: delamination of layers**
- **Fire risk**

Measures:
- **PV technology: cell design**
- **PV module: packaging material / watertight edges** (e.g. pending patents EP 2 320 479 / EP 2 360 739)
- **BOS: watertight electrical connections**
- **Roofing design and installation**

Membrane integrated PV system: Key issues
UV radiation



Polymeric material show degradation under UV exposure.

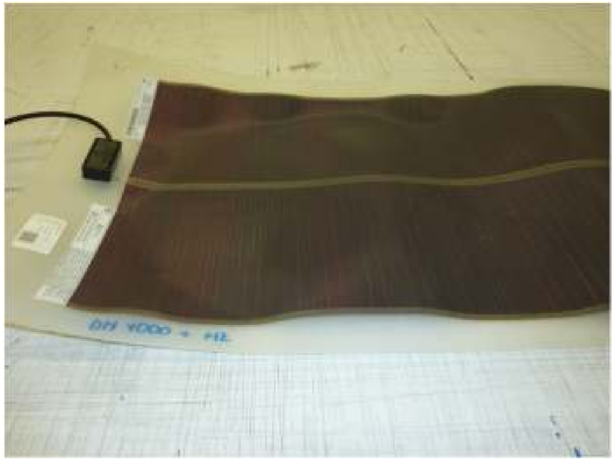
Synergistic effect of UV, temperature and humidity.

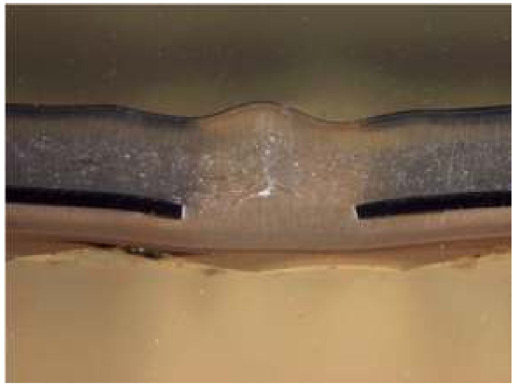
Cause:
- **Solar irradiance (UV)**

Reliability concerns:
- **Degradation of PV cell**
- **Degradation of PV module (polymeric films and adhesives)**
  →discoloration, decline in light transmission
  →weakening of packaging / delamination

Measures:
- **PV technology: material selection**
- **Long-term testing program with adequate ageing exposure**

Membrane integrated PV system: Key issues
Thermo-mechanical induced stress





Cause:

- **Temperature cycling** (day-to-day and seasonal)
- **Multilayer composite material: materials with different coefficients of thermal expansion (CTE) and module of elasticity**

Reliability concerns:

- **PV module: electrical degradation**
- **PV module: waving, buckling / delamination of packaging**
- **Bond between PV module and roofing membrane: weakening / debonding**

Measures:

- **PV module: design an material selection**
- **Roofing membrane: material selection**
- **Buffer layer between PV module and roofing membrane: e.g. foam or low modulus adhesive** (pending patent EP 2 305 746)
- **Finite Element analysis (FEA)**

Membrane integrated PV system: Validation of durability

Situation

- **PV qualification tests according to IEC and UL are not suitable for lifetime and yield prediction under real-world conditions**
- **No established and widely accepted test protocol available for assessment of long-term performance and reliability of PV modules**

Challenges

- **Performance and durability depend on field conditions** (e.g. climatic zones)
- **Diversity of new material technologies in use due to intense cost pressure**
- **Materials are used near their limit** (e.g. polymers)
- **Degradation and ageing mechanisms are not completely understood** (complex chemical and physical processes / cumulative interactions)
- **No scientific model available for module lifetime predictions**
- **Limited significance of test results based on small scale samples** (e.g. thermo-mechanical induced stress)
- **Long test period needed due to limited acceleration factor**

Membrane integrated PV system: Validation of durability
Sika's approach

Step		Test specimen	Information
1	**Qualification testing of PV module**		
1A	**Standard IEC program**	PV module (not integrated)	according to IEC 61646 / 61730
1B	**Complementary test program**		• Extended IEC exposure • Electrical load (+/- voltage bias) • Long-term UV ageing • Static / dynamic mechanical stress (tensile / bending / biaxial)
2	**Qualification testing of MIPV design**		
2A	**Accelerated ageing tests**	PV module integrated in waterproofing layer (reduced size)	Long-term sequential testing (DH / UV / TC / HF)
2B	**Test program specific for rooftop application**		• Wind load • Basic fire safety • PV specific fire safety
3	**Field testing (Outdoor exposure)**	PV modules integrated in roof build-up (full scale)	• Different climatic conditions • PV system electrically operating

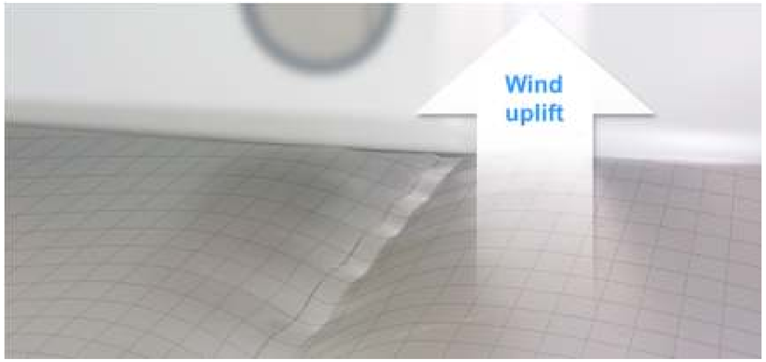
Membrane integrated PV system: Validation of durability
Accelerated ageing tests

Test step	Evaluation
Preconditioning global irradiation (66 kWh/m2)	
▼	
Initial evaluation	Visual inspection, Electrical performance at STC Insulation test Wet leakage test Electroluminescence
▼	
Damp Heat DH **2'000h**	**Intermediate evaluation (VI / WL):** 1'000, 1'500 and 2'000h
▼	
UV exposure **1'000 h** UV-A and UV-B irradiation (48.4 kWh/m2)	**Intermediate evaluation (VI / WL):** 250, 500, 750 and 1'000h
▼	
Temperature cycling test TC **400 cycles**	**Intermediate evaluation (VI / WL):** 200, 300 and 400 cycles
▼	
Humidity Freeze HF **40 cycles**	**Intermediate evaluation (VI / WL):** 10, 20, 30 and 40 cycles
▼	
Final evaluation	Visual inspection, Electrical performance at STC Insulation test Wet leakage test Electroluminescence

Long-term sequential testing

- **Test procedures and requirements are based on IEC 61646**
- **The modules undergo multiple stress tests one after another (sequential)**
- **Test exposures are 2 - 4 times more severe than standard qualification tests**
- **Duration of test program: approx. 10 months**

Membrane integrated PV system: Validation of durability
Test program specific for rooftop application



Wind load

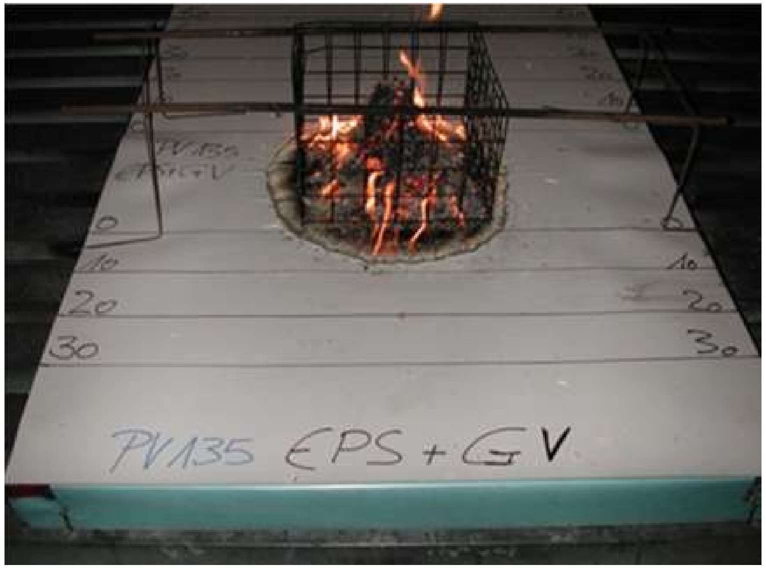
Test procedure according to:

- **ETAG 006**

  Guideline for European Technical Approval: "Systems of mechanically fastened flexible roof waterproofing membranes" or
- **FM Standards** (Factory Mutual, USA)

Sika operates wind load testing facilities in Switzerland, China and USA

Membrane integrated PV system: Validation of durability
Test program specific for rooftop application



Basic fire safety tests

“External fire performance” of exposed roofs according to ENV 1187 (Europe)

- **4 test procedures and classifications: B_{ROOF} (t1) - (t4)**
- **Test results are valid for specified roof assembly and corresponding slope only**
- **Certification of CE- conformity: tests must be performed by an authorized laboratory (third-party)**

Sika operates a fire testing lab in Switzerland

Membrane integrated PV system: Validation of durability
Test program specific for rooftop application

PV specific fire safety tests

Degradation of PV module / components may cause hot-spots and arcing

Energy intensity of DC arcing is higher compared to EN 1187 test procedure

MIPV is in direct contact with roofing material (membrane, thermal insulation)

No established test method available

Test setup for MIPV:

- IR radiation: 1000 W/m^2 (solar irradiation)
- Electrical resistance of e.g. 120 W (serial arcing)

Conclusion: fire risk is minimized by using non-combustible thermal insulation
(e.g. 60 mm of mineral fiber)

Membrane integrated PV system: Validation of durability
Field testing (outdoor exposure)

- **Long-term exposure under realistic outdoor conditions and under full-spectrum solar load.**
- **Modules in full-size, integrated in a real roof assembly**
- **PV system electrically operational**
- **Continually monitoring of system yield**
- **Duration of field testing before market release: minimum 2 years** (5 years is even better)
- **First MIPV test site installed in CH-Sarnen: Feb 2001**

Membrane integrated PV system: Validation of durability
Field testing (outdoor exposure)

Stuttgart

Sarnen

Sika Solar Parks at 5 locations

Stuttgart (DE)

- 9 commercial PV systems
- 150 kW_p nominal power / 2’000 m^2

Sarnen (CH)

- 7 R&D and commercial PV systems
- > 25 kW_p nominal power

Canton (USA)

- 2 commercial PV systems
- 155 kW_p nominal power

Shanghai (CN)

- 2 PV systems

Madrid (ESP)

- 6 PV systems (under construction)

We are very pleased to show you these installations and share our experience.

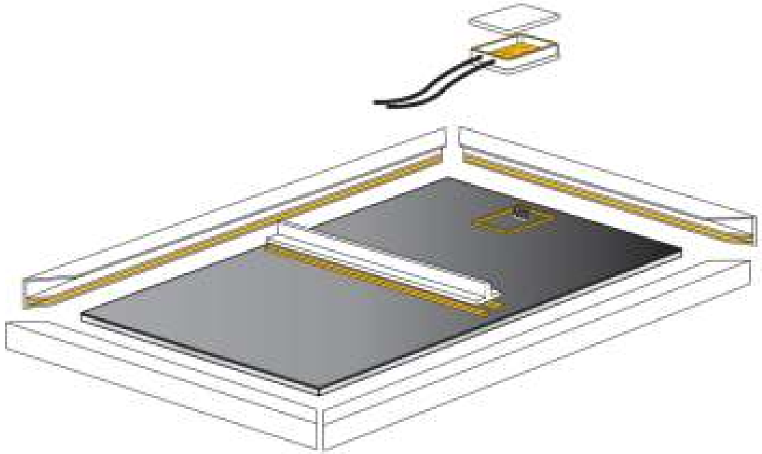
Conclusions
Rooftop solar PV

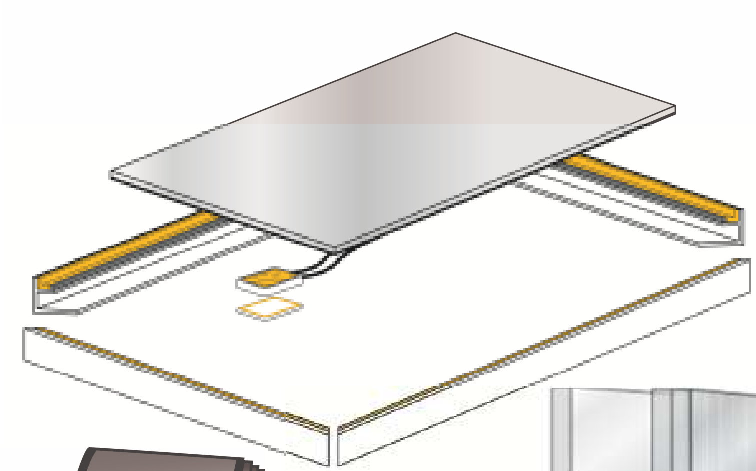
- **Hugh market potential mainly in urban areas**
- **Strong market growth expected**
- **Technology in PV cell, PV module and system integration will continue to evolve**
- **Interdisciplinary teams of experienced and established partners is a prerequisite for successful rooftop solar projects**
- **Technical and commercial risks to be managed carefully**

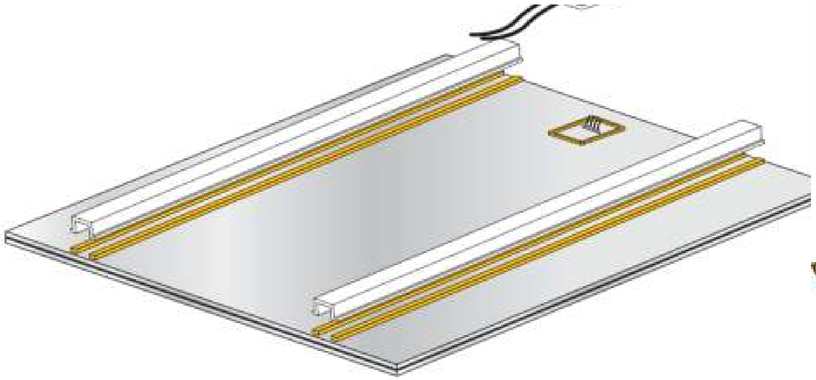
Conclusions
Membrane integrated PV systems (MIPV)

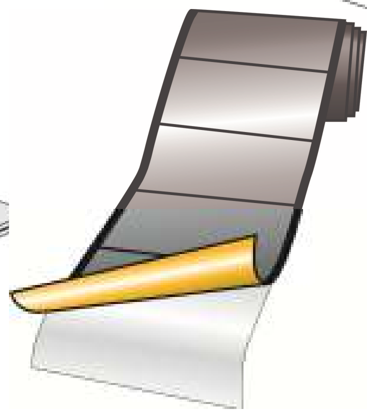
- Flexible PV modules based on thin film technology are qualified for MIPV
- Still an emerging technology due to limited long-term experience
- High system cost and low efficiency
- Most critical impacts are high service temperature, humidity, UV radiation and thermo-mechanical induced stress
- There is need for suitable, real-world test protocols to validate durability and long-term performance
- Long-term testing in the lab does not replace field testing

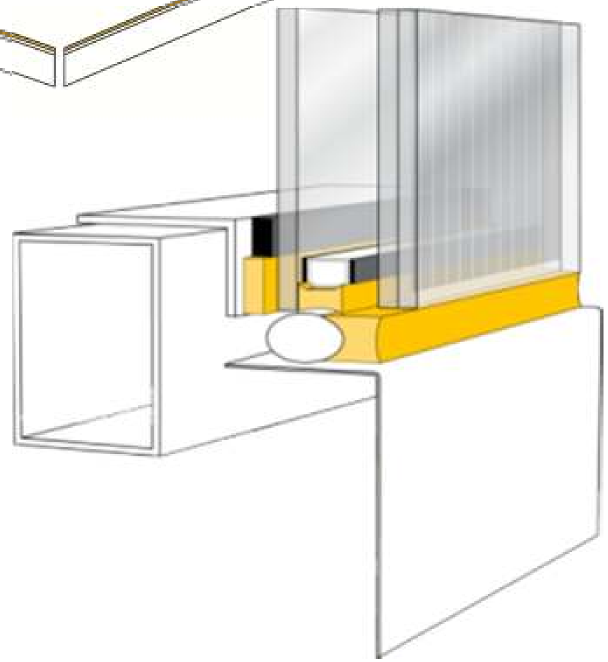
Sika Industry
Sealing and Bonding in PV











- Frame Bonding & Sealing
- Bonding to Mounting Structures
- Junction Box Bonding and Potting
- BIPV Solutions
- Flexible Thin Film Fixation

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