Photovoltaic & Advanced Materials

NOVEMBER 2018

Inspection report

“The Donjon”, Gouda (NL)

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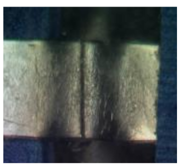
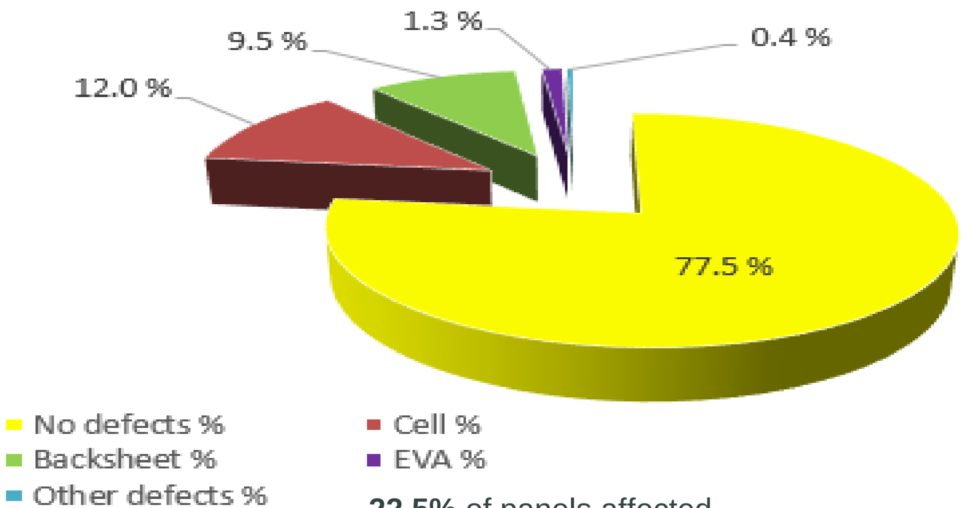
Background

- **DuPont engaged into a field inspection program 5 years ago with the objective to better understand the degradation of solar panels in real life conditions.**
- **To date, DuPont has gathered statistics on a little more than 4 million panels from 2 years old to 30 years old.**
- **The advent of bifacial cells has put some emphasis on transparent panels. DuPont has had particular concerns on glass/glass panels which defect rate is at the moment standing at 12.6% due to glass breakage based on our 4 million statistics.**
- **In order to identify potential suitable candidate for transparent backsheet, DuPont has been particularly seeking data transparent polymeric materials used as backsheets.**
- **“The donjon” has been cited as having used a Tedlar® based backsheet (made of Tedlar® on the outer layer). We inspected this installation to determine the degradation levels and confirm the backsheet type.**

Global DuPont Field Surveys (2017)

- Surveyed: **286** Installations in North America, Europe & Asia Pacific
- Figures reported below: 45 module manufacturers, 1,047 MW > 4.2 MM modules
- Range of exposure: from newly commissioned modules to 30 years in service
- From multiple climates





22.5% of panels affected

Backsheet is one of the main components affected

Source: DuPont Field Module Program 2017 analysis
Note: All percentage numbers are based on MW

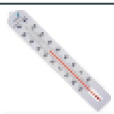
The Backsheet is Critical for Protecting the PV Panel

Stress Environment

Ultra Violet (UV)

- Transmitted
- Reflected

Temperature



- Peak
- Cycling

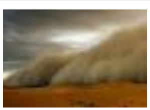
Moisture

- Humidity
- Precipitation
- Condensation

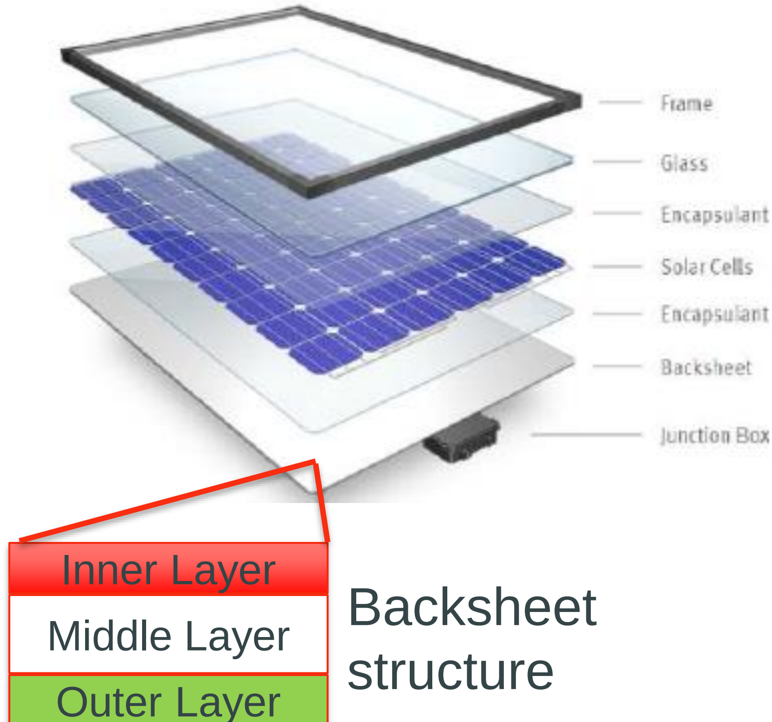
Corrosive Environment

- Atmospheric chemicals
- Ammonia
- Marine environment

Physical Protection



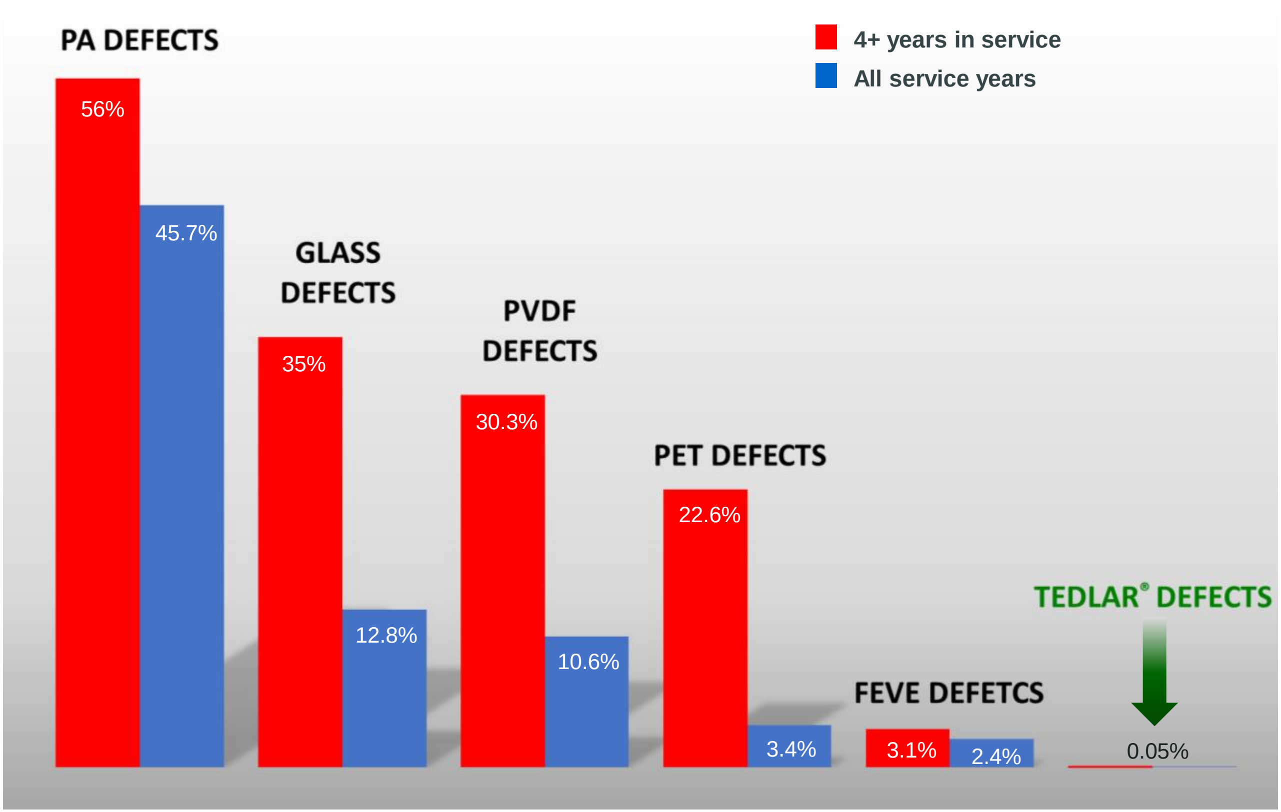
- Abrasion
- Impact



Backsheet structure

Backsheet must provide reliable electrical protection of module over the expected lifetime (and beyond)

Defect rates of backsheets



PA = Polyamide
PVDF = Polyvinylidene Difluoride

PET = Polyethylene Terephthalate
FEVE – Fluoroethylene Vinylether

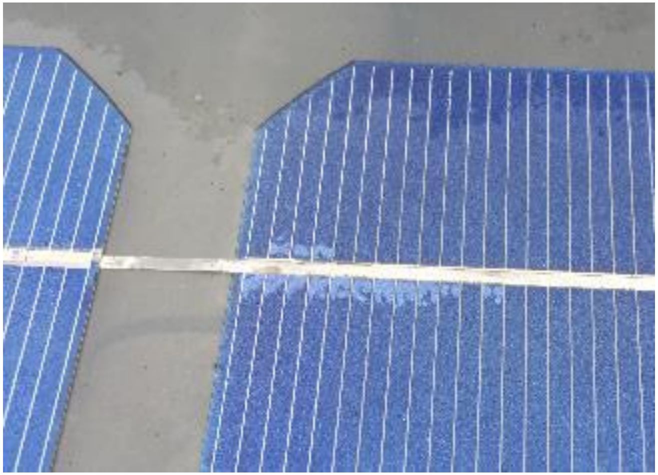
* Data includes installations with minimum of 4 years of service life

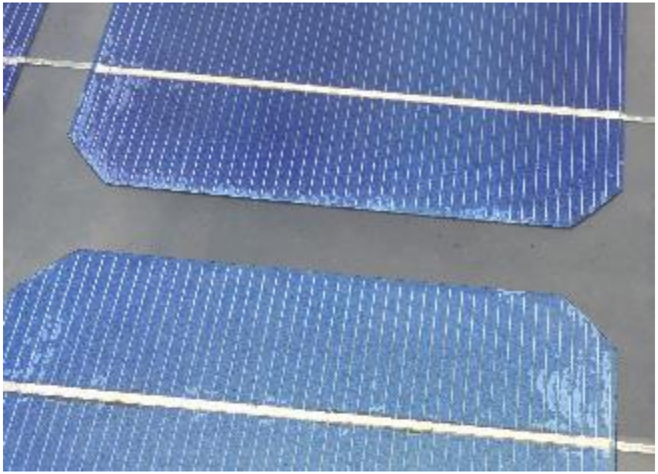
Presentation of “the Donjon” solar plant

- Initial year of operation 2000
- Age 18 years
- Location Rotterdam area
- # of modules 51 full size panels
- # Inspected 51 inspected
- System size 6.228 kWp
- Inverter type & size Fronius Sunrise Midi
- Mounting configuration BAPV
- Photographs Yes
- Date of inspection November 2018
- Racking Metallic structure.
- Module/Backsheet: Tedlar® based
- Technology Polycrystalline
- Backsheet ID: Tedlar® based (confirmed by FTIR)

Cell ARC delamination (slight)

Affects 100% of panels



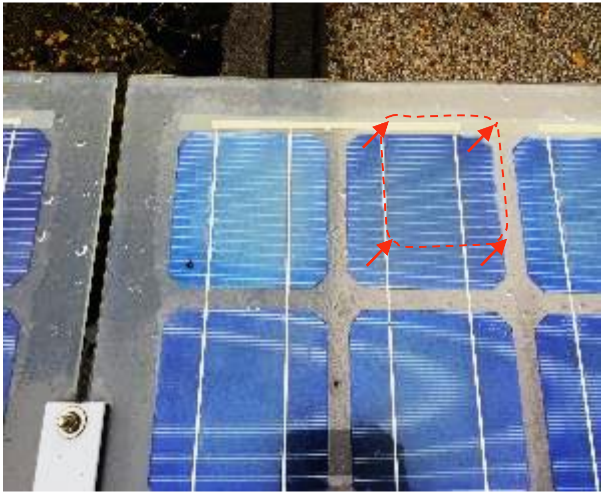


- This defect happens when the antireflective coating (ARC) comes off of the cell silicon surface.
- What does it look like?
  - The ARC makes the cell blue/black. When it comes off, the cell appears whiter/metallic.
- Why does it happen?
  - It can be the result of cell damage by impact or simply be a gradual process of delamination (usually alongside the busbar).
- How serious is it?
  - In itself, this is not a very serious defect unless there is a lot of delamination. But if it comes as a result of impact, then the cell damage itself may induce more serious problems.
- Remediation:
  - If the cells exhibits hot spots above 20°C, the panel should be replaced.
- Prevention:
  - The panel manufacturer should optimize the soldering process in order to avoid ARC delamination in operation.
  - Impact damage should be minimized during installation and maintenance procedures.

EVA yellowing (very slight)

Affects 100% of the panels on this installation

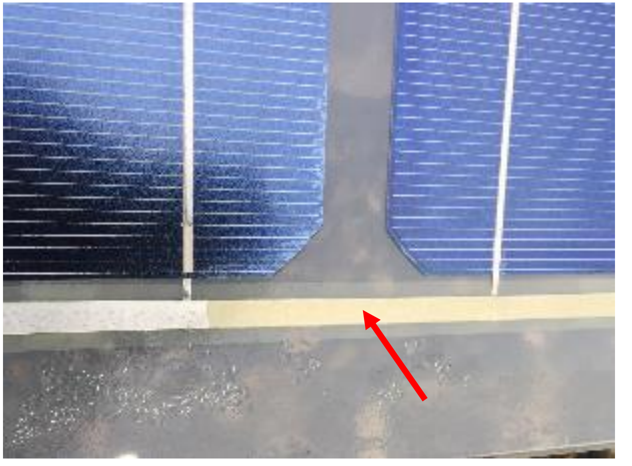
- EVA can be seen to yellow in the field.
- What does it look like?
  - The EVA yellows in front of the cells (rarely on the edges or the open space of permeable backsheets because the yellowing is usually also bleached by oxygen permeating through the backsheet).
- Why does it happen?
  - Poor cross linking.
  - Additives in the EVA formulation.
- How serious is it?
  - It can prevent some light from reaching the panel resulting in slight (maybe not even detectable at system level) power loss. NREL showed up to 5% power loss in very brown panels.
- Remediation:
  - The panels should be monitored for loss of power and signs of delamination.
- Prevention:
  - The panel manufacturer should use a reputable EVA supplier and ensure a minimum gel content of 70% after lamination.



The EVA yellowing here is only very slight. The red outline is a little offset (direction of the red arrows) to show the area of yellowing. Broken cells would become visible because of the oxygen bleaching the yellowing out. We can conclude there are no broken cells on this installation

Backsheet yellowing (very slight)

- Backsheets can become yellow on the front or on the back of the panel (difficult to say which here).
- What does it look like?
  - The backsheet looks yellow over the whole surface of the panel or in specific areas (often hot spots).
- Why does it happen?
  - Some backsheets are UV sensitive and the yellowing is a sign of this sensitive. Temperature can accelerate this degradation.
  - Some backsheets will also suffer yellowing as a result of thermal degradation.
- How serious is it?
  - Yellowing is often associated with worsening mechanical properties. Eventually, the backsheet might delaminate and/or crack.
- Remediation:
  - Continue monitoring the backsheet for cracking and/or delamination.
- Prevention:
  - The panel manufacturer should use backsheet components with high UV and temperature resistance and UV filtering capabilities



The backsheet yellowing here is only visible where there is a double thickness of backsheet, i.e. where a strip of backsheet was used as an insulating insert to fold the solder ribbons back towards the junction box.

Conclusion on state of the installation

- This 18 years old installation is in very good health considering the time of exposure and the fact that it features transparent panels.
- The installation is showing very slight signs of aging such as:
  - Anti Reflective coating delamination on the cells
  - EVA yellowing
  - Insert yellowing (presumed to be the same material as the backsheet but this cannot be confirmed without destructive testing)
- What the installation is not showing which could be expected given its age (and the fact that the panels are frameless):
  - Backsheet delamination
  - Corrosion
  - Cell cracking (would be evidenced by the bleaching of the slightly yellow EVA)
- The production data could not be analysed because the data was not necessarily archived in recent years.

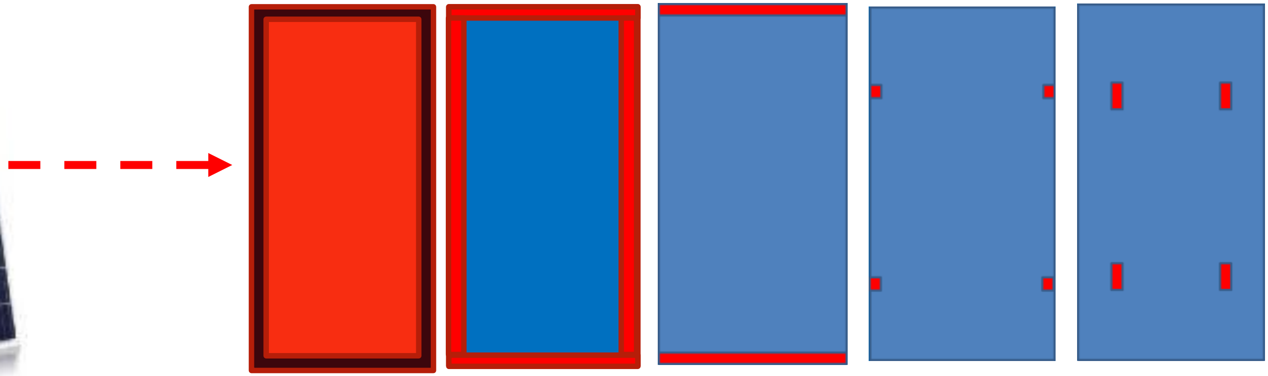
Glass/glass panels

Growing concerns

Preliminary PID Test Results

Commercial framed module with Tedlar® backsheet

Glass/Glass Modules* w/ alternative mounting configurations (foil in red)



ΔP(max) as %	Regulatory Source	G/Tedlar	G/Glass	G/Glass	G/Glass	G/Glass
Stress			4-Edge	2-Edge	Side Clips	Back Clips
50C/85% Foil Face	Pre 2015 IEC Option 1	0	0			
60C/85% RH	Pre 2015 IEC Option 2	-0.5	-6.7			
85C/85% RH						
120 hrs		-1.2	-28.8			
96 hrs	Post 2015 IEC minimum and "China" recommended			-10.6	0	-6.3
192 hrs	2 x "China"			-14.5	-1.9	-17.6

Glass / Glass Modules show power loss and fail PID tests with different mounting configurations

*Commercial Glass/Glass modules with white EVA behind cells. Data sheet claims "PID resistant"

Glass is Heavier, Brittle, and Stiff

Glass adds 5kg

<u>Lighter</u>

- Each G-G module weighs 8kg more than equivalent G-B module
  - 10kW G-G installation will add additional load of ~320Kgs on a roof-top
- Glass is brittle & susceptible to chipping. Extreme care is required during transport.
  - Chipped surfaces are high stress points that can expand into cracks and delamination leading to failures.
  - G-B structures have greater flexibility than G-G structures & stress dissipates by flexing.

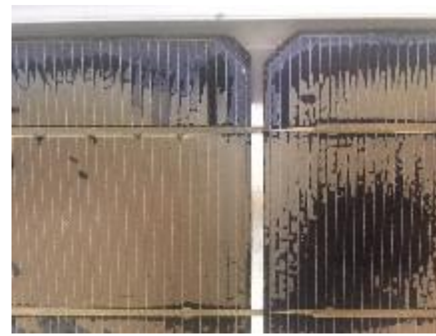
- Higher weight of G-G modules restricts extensive deployment on roof-tops
- Higher care required to prevent cracks during transportation adds additional cost

Glass-glass modules have higher power loss/year (JRC)[1]

Backsheet	Average Power Loss/Year (%)	Years in Field	Source
Glass-Glass	**1.3**	20 - 23	JRC[1] (2008)
All Other Backsheets	**0.5 - 0.8**	5 - 35	NREL[2] (2016)

- Glass traps acetic acid
  - Glass is incapable of preventing moisture ingress from edges[3], acetic acid is generated
  - Acetic acid then corrodes cell interconnects, increases resistance, and reduces power

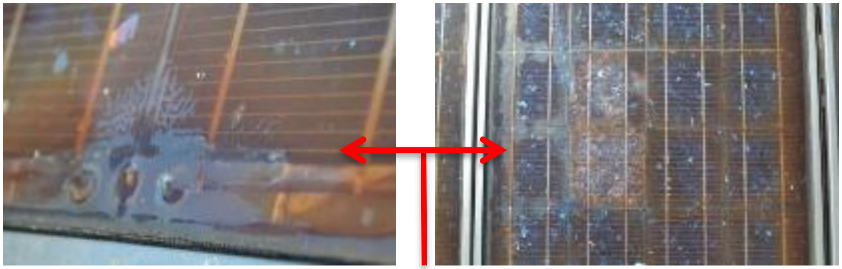
Glass-glass modules with busbar corrosion- Danzhou, China, 15 years



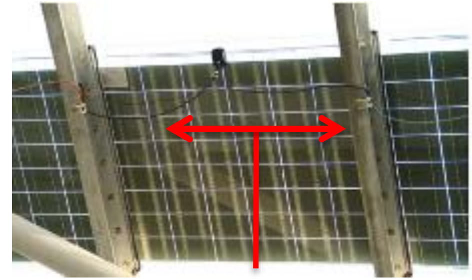
Bus bar corrosion, delamination, and EVA browning in JRC glass-glass modules

1 Skoczek, A., et. al., “The Results of Performance Measurements of Field-Aged Crystalline Silicon Photovoltaic Modules”, Prog Photovolt. Res. Appl. (2008). Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/pip.874
2 Jordan, D. C., et. al., “Compendium of Photovoltaic Degradation Rates”, Prog Photovolt. Res. Appl. (2016). Wiley InterScience (www.wileyonlinelibrary.com) DOI: 10.1002/pip.2744
3 Kempe, M. D., et. al, “Control of Moisture Ingress into Photovoltaic Modules” , 31st IEEE Photovoltaic Specialists Conference (2005)

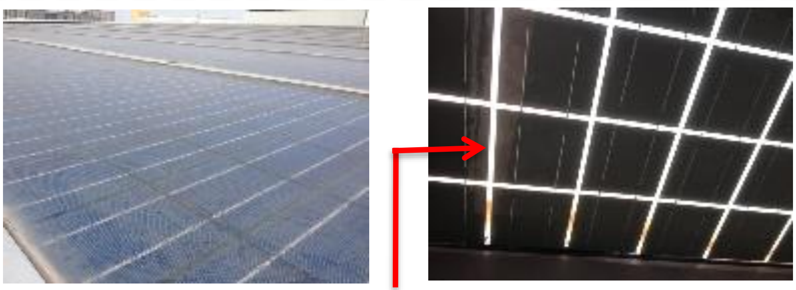
G-G Module Failures Observed in the Field



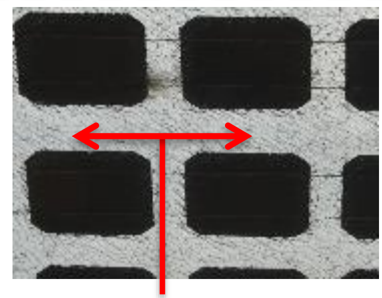
Observation: Bus bar Corrosion, EVA browning
Power loss
Location: Danzhou (China), Time: 15 years



Observation: Bus Bar Corrosion,
Power loss
Location: Okinawa (Japan), Time:11yrs



Observation: Bus bar Corrosion
Power loss
Location: Shanghai (China), Time: 5 years



Observation: Extensive breakage
Location: Yannan (China), Time: 10 yrs

- Multiple failures: Power Loss & Breakages across regions, applications (roof+ground) and tenures
- Believed higher corrosion rates are due to trapping of acetic acid by the glass backsheet

Conclusions on Glass/glass panels

- **Glass-Glass (G-G) modules operate at higher temperature than glass-backsheet (G-B) modules - G-G modules produce less power.**
- **Field studies of Glass-Glass modules show greater power loss/year and degradation than polymer backsheets.**
- **In Dynamic Mechanical Load tests, G-G modules showed delamination from edges, similar to defects seen in the field (more prominent even with frameless panels).**
- **Glass is heavier (thinner glass will not alleviate the problem if used with soft encapsulants), leading to sagging and then breakage.**
- **No advantage of G/G for PID resistance.**

Thank You