Von GRS-A bis JUICE: 62 Jahre Raumfahrtsolarzellen aus Deutschland

PV Dialog, Victor Khorenko

22.04.2026

AZUR SPACE
A 5N PLUS COMPANY

AZUR SPACE – Introduction

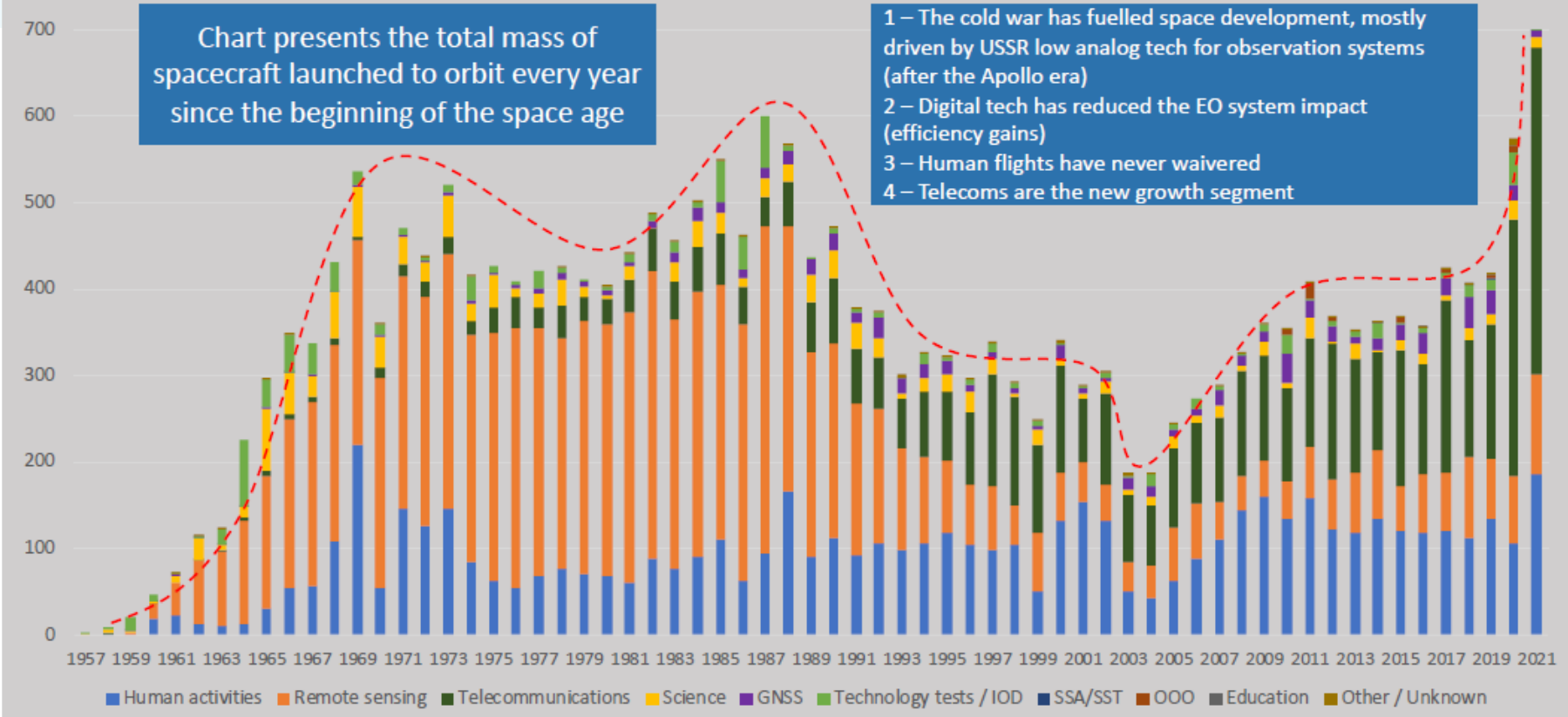
AZUR SPACE

- Located in Heilbronn, Germany
- Production of Space Solar Cells since 1964
- Named after 1st German satellite
- Provides Bare Cells and CICs
- Continuing to grow business worldwide and in USA, including to USA Government customers
- New facility / office space transition completed

AZUR SPACE Highlights

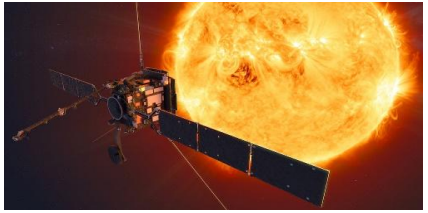
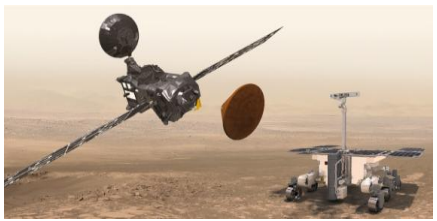
- Production Capacity up to 1MW+ / Year
- ECSS / AIAA Qualified
- ISO / EN / AS Certified among other ISO certifications
- More than 360 current AZUR SPACE associates
- Strong orders backlog

Global space activity since 1957 by mission (tons/year)



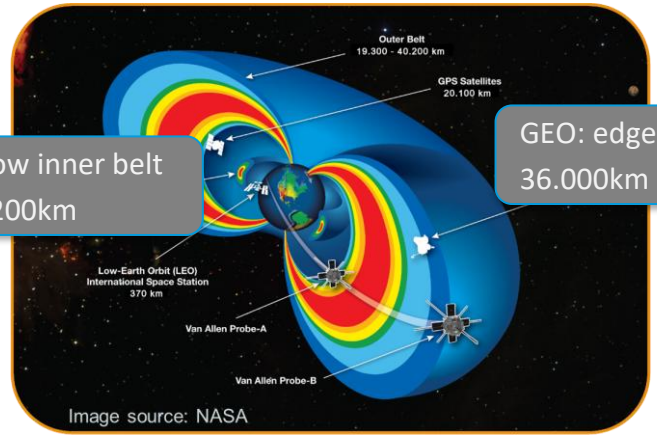
Requirements to Space Solar Cells



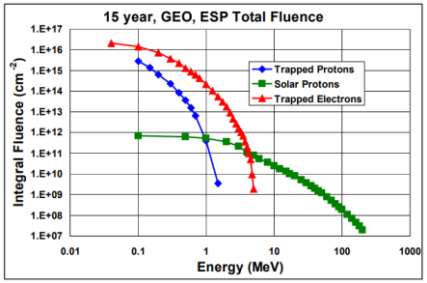

- Resilience against high energy particle radiation (electrons and protons) and plasma (atomic oxygen)
- High efficiency at BOL (Beginning-of-Life) and EOL (End-of-Life)
- Stability in thermal cycles, under UV, resilience against mechanical stress during launch and deployment
- Weight
- „Zero failure“ philosophy
- Operational lifetime >15 years
- + special conditions in exploration and deep space missions

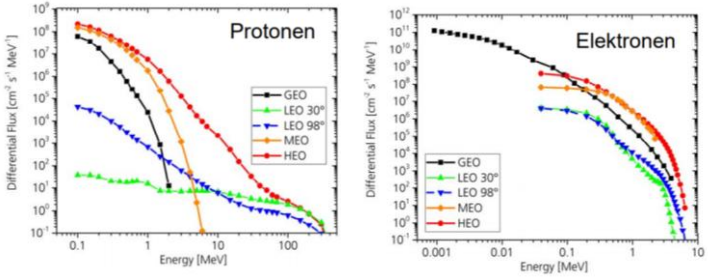
Requirements to Space Solar Cells
High energy particle irradiation



LEO: below inner belt
400 - 1.200km

GEO: edge of outer belt
36.000km



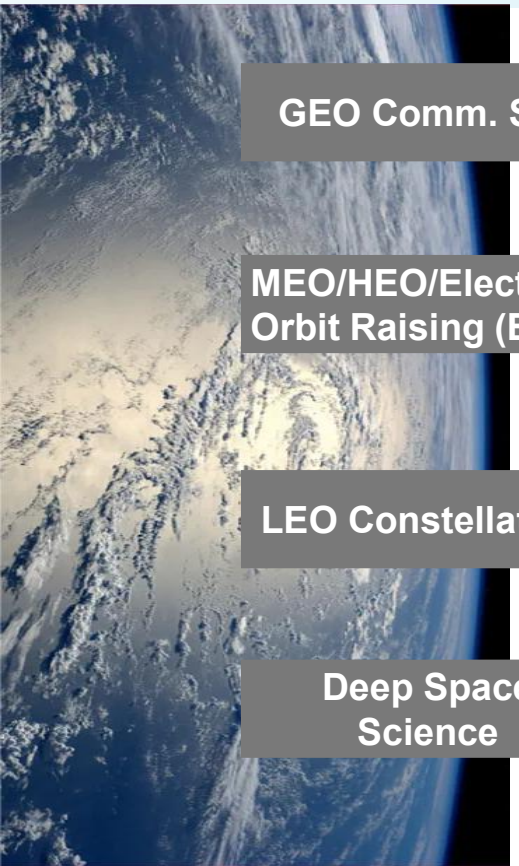


- Electrons and protons -> non-ionizing energy losses -> defects in the cell structure and, thus, degradation of the cell performance. Cells have limited possibilities for radiation shielding;
- Radiation spectrum is orbit dependent;
- Equivalent fluences: GEO - 2E15 cm^{-2} 1MeV electrons, LEO - 2E15cm^{-2}
- Electric orbit raising through van Allen belts results in strong cell degradation additionally

Requirements to Space Solar Cells
Environment temperatures and insolation levels

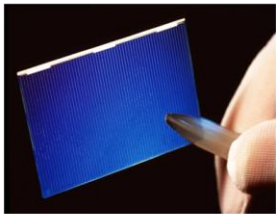
	GEO	LEO	Mercury	Jupiter
Orbital period	24 hr	90 min (ISS) 110 min (OneWeb)		8 yr transfer 3 yr operation
No of cycles	5000 /15 yrs	5000 /1 yr	-	-
Temperatures	-170°… +100°C	-120°… +160°C	up to +200°C	+160°C (Venus fly-by) -120°C (Jupiter)
Sunlight intensity	1361 W/m^2 (AM0 spectrum)	1361 W/m^2 (AM0 spectrum)	max. 14500 W/m^2 (11AM0)	50 W/m^2 (0,05AM0)

Requirements to Space Solar Cells
Mission dependent



GEO Comm. Sats	**very high power demand** radiation stabilitiy 15-20 years in orbit
MEO/HEO/Electric Orbit Raising (EOR)	**Highest radiation stability** high power demand
LEO Constellations	high BOL power **Cost efficiency in €/W** volume production
Deep Space Science	**reliability** very specific mission requirements

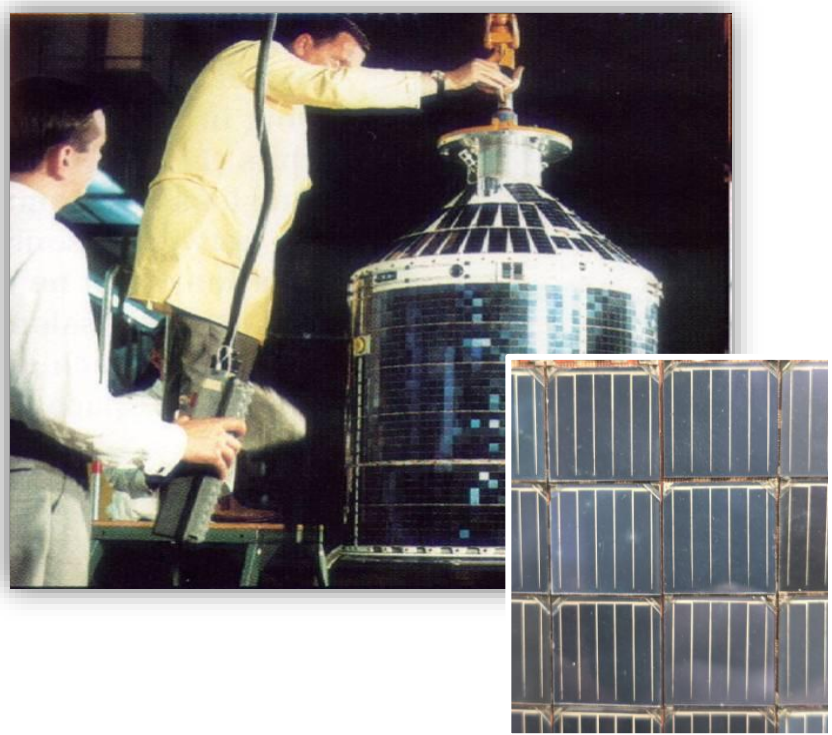
How a solar cell works
Internal photoeffect



The first solar panel in space
1958, the American satellite Vanguard 1

1 Watt solar panel

History
First german satellite GRS-A (AZUR)



Launch:
08. November 1969

Bundesministerium für Bildung und Forschung

Mission:
7 experiments for the study of the Van Allen belt, solar particles and aurorae

AEG TELEFUNKEN

Solar array:
39W by 5300 pcs 2×2 cm^2
Si cells with TiAg contacts

History of AZUR SPACE

From powering the first German satellite
to best in class PV supplier.

ESA JUICE

Rosetta Mission

Venus Express

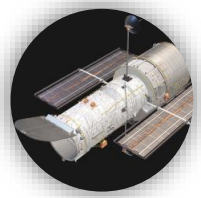
Touwsrivier, South Africa,
@ Soitec Solar 44.2 MWp,

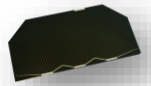
Globalstar

ATV

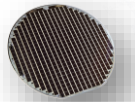
Galileo Sats

Mildura Australia,
@ RayGen 4 MWp and storage,





Space MJ-PV



Terrestrial MJ-CPV

1964
AEG
Telefunken

1969
Satellite
AZUR

1974
World first multi-crystaline silicon solar cell

1982
Telefunken
Electronic

End 1980th
Hubble Space Telescope

1989
Daimler Chrysler
Aerospace

In the 80th and 90th
Terrestrial Si-PV-cell production

1994
ASE Angewandte
Solarenergie

2000
RWE
Solar

Beginning 2000
New technology of high efficiency MJ-PV-cells

2002
RWE
SSP

about 2003
New CPV technology with high efficiency MJ-PV-cells for terrestrial applications

2007
AZUR SPACE Solar Power GmbH

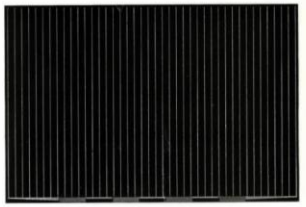
2022
Becomes part of 5N Plus

AZUR SPACE
A 5N PLUS COMPANY

2025:
- >100 M€ Umsatz
- 360 Mitarbeiter

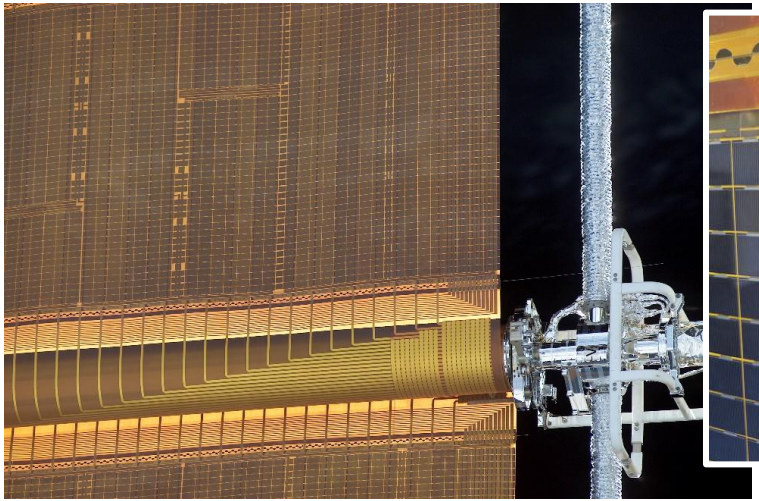
TECHNOLOGISCHE ENTWICKLUNG DER RAUMFAHRT-SOLARZELLEN AM BEISPIEL INTELSAT	VE2 E222 Schilling/gä 25.02.92

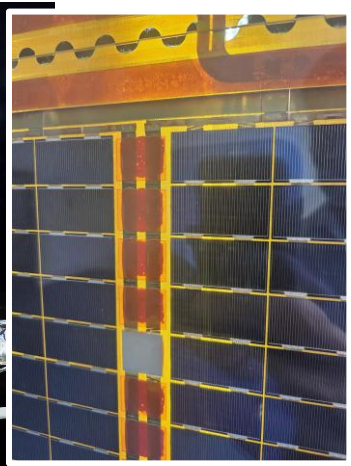
Leistungssteigerung und Flächenzuwachs

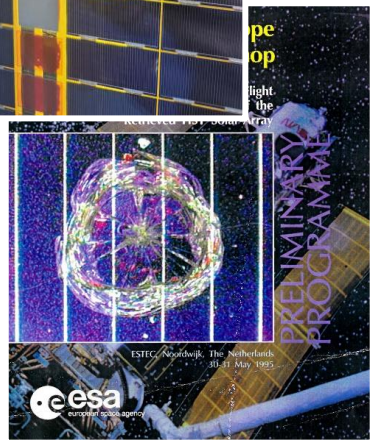
INTELSAT IV	2 cm x 2 cm Löttechnik	TiAg-Kontakt	1969	= 10,5 %	
INTELSAT V	2 cm x 4 cm High Efficiency Technologie Schweißtechnik	TiPAg-Kontakt	1977	= 11,5 %	
INTELSAT VI	2 cm x 6 cm Back Surface Reflector Multielementtechnologie		1984	= 11,8 %	
INTELSAT VII	4 cm x 6 cm glanzgeätzte Oberfläche 2 Ωcm-Zelle Multi-AR-Schicht		1989	= 13,7 %	

1988 Erste Weltraumsolarzelle aus Silizium mit 18%

History
Missions: Hubble Space Telescope







Launched in 1990 with Discovery Space Shuttle

- Largest flexible solar array (4800 W) with extremely high numbers of sun/eclipse transitions (30k cycles)
- 2002 – Service and replacement of the solar array by a new one with GaAs cells

History
Missions: Rosetta

Angewandte Solarenergie – ASE GmbH

TESSAG Solar

Solar Cell Data Sheet
10THI-ETA2/200-6239(1)

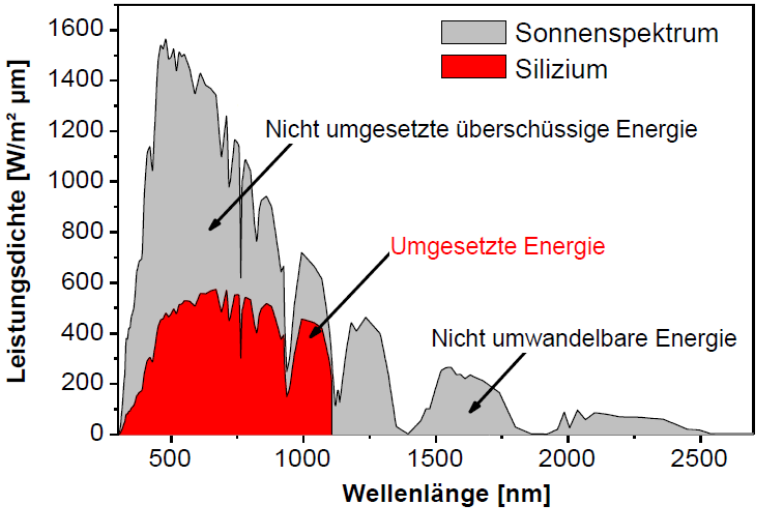
1. Type	:	10THI-ETA2/200-6239 (n⁺pp⁺ structure) 2 cells out of round 100 mm wafer cropped corners / cosmetic defects allowed(2)
2. Status	:	space qualified
3. Size	:	62.51 mm x 39.07 mm
4. Cell area	:	24.4 cm²
5. Thickness	:	200 ± 30 µm
6. Resistivity	:	p (B) 10 ± 3 Ωcm
7. Base Material	:	CZ ₛ < 1-0-0 >
8. Ag – Thickness	:	≥ 3.5 (partly pre-soldered)
9. Grid Design	:	grid system with 3 contact pads
10. AR- coating	:	TiO_x / Al_2O_3
11. Shadow Protection	:	no
12. Electrical data(3) (Engineering data)	:	(25°C, AM1.5, GLS SWS, 100.0 mW/cm²)

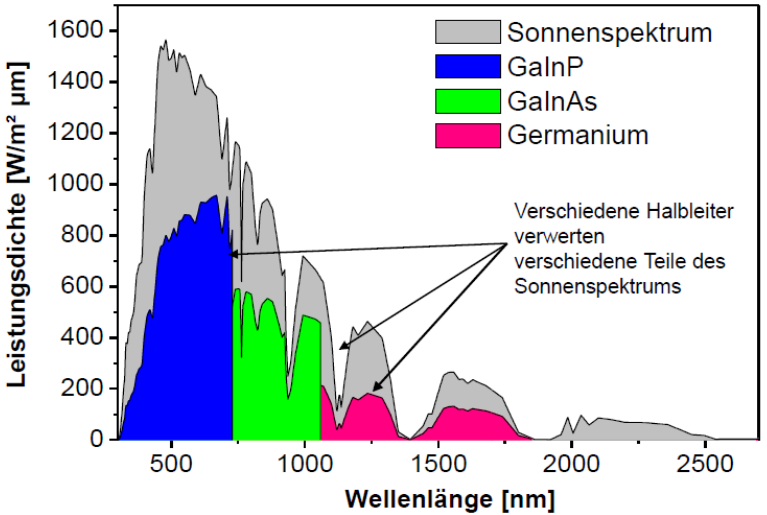
		BOL	1E14	3E14	1E15	3E15
V_{OC}	[mV]	620				
I_{SC}	[mA/cm²]	37.3				
V_{pmax}	[mV]	520				
I_{pmax}	[mA/cm²]	34.7				
P_{max}	[mW/cm²]	440				
η_{bare}	[%]	18.0				
$I_{op(515mV)}$	[mA/cm²]	35.0				

Launched in 2004

- Solar generator with two 14m-long solar array wings and a total area of 64m²
- Special Si Hi-ETA solar cell for adapted for Low Intensity Low Temperature conditions (3.6% AM0, -130°C) and delivering 400W power.
- 2014 – successfull arrival at 67P/Churyumov–Gerasimenko comet

Limits of the cell efficiency
From Si single junction to tandem solar cells





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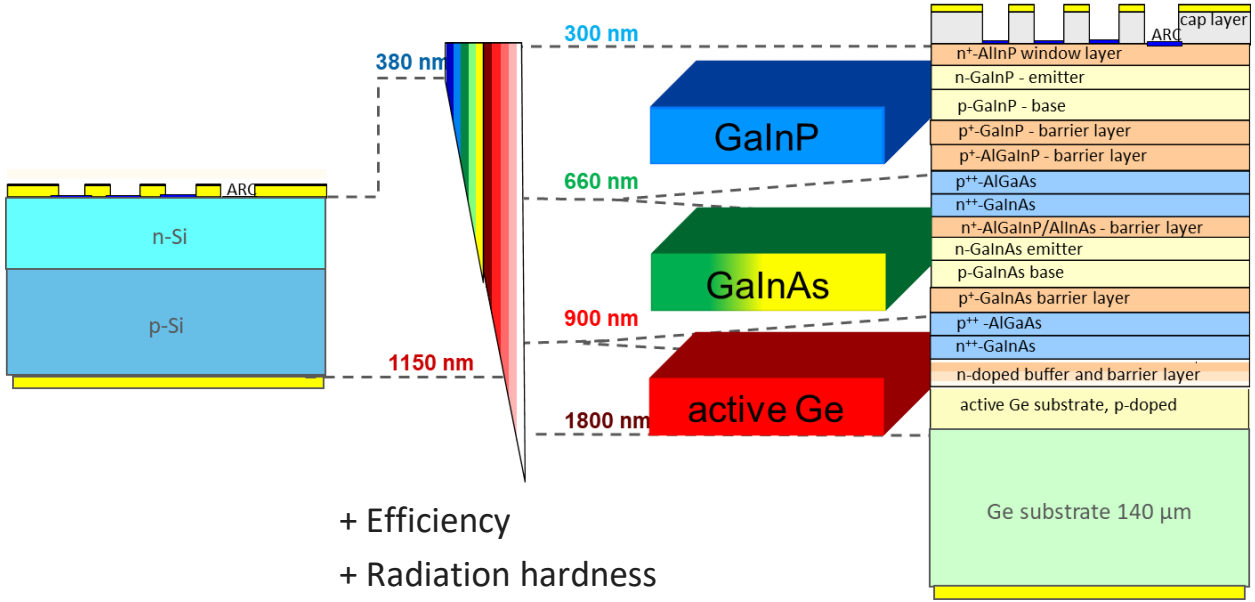
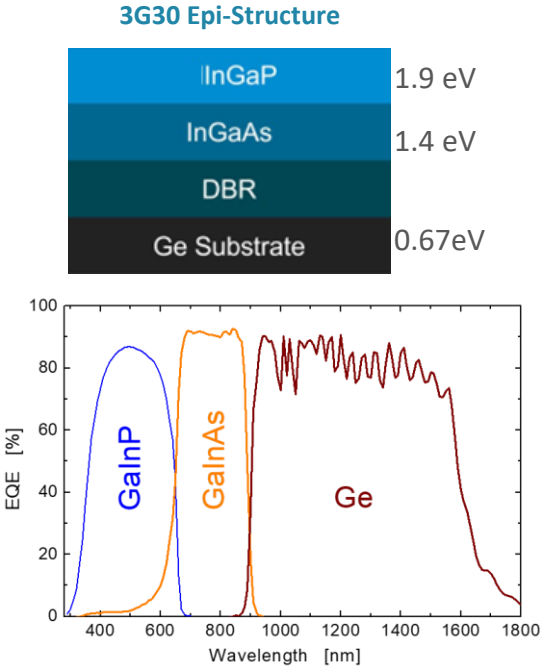


+ Efficiency
+ Radiation hardness
+ Higher voltage
+ Lower temperature coefficients
- More complex structure and technology

Stand der Technik
3G30-Advanced Dreifachsolarzelle

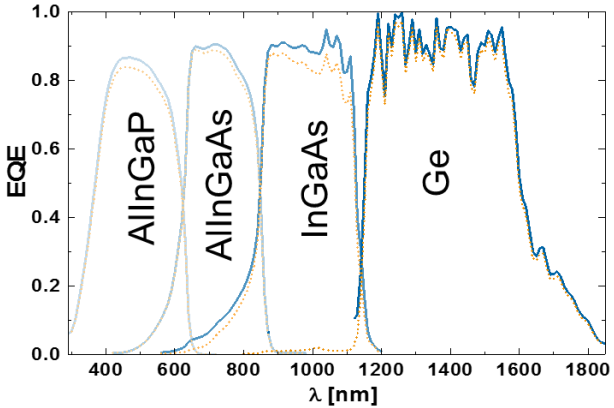
- Gitterangepasste 3-fach Solarzelle
- InGaP- und Ge-Teilzellen sind sehr strahlungshart
- InGaAs-Teilzellen zeigen eine hohe Degradation im Weltraum
- Durch den Braggreflektor konnte die Dicke der GaAs-Teilzellen auf die Hälfte reduziert werden daher effektives Trennen von Minoritätsladungsträgern am pn-Übergang (End-of-Life)



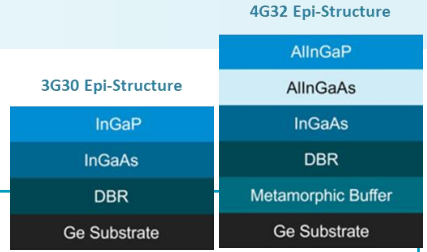
Nächste Generation
4G32-Advanced Vierfachsolarzelle

- 4-fach Solarzelle
- Übergang von gitterangepasstem zu metamorphem Wachstum
- Bandlücken-Anpassung mit Al-Verbindungen
- Verbesserte Lichtausnutzung, Strahlungshärte und höhere Spannung

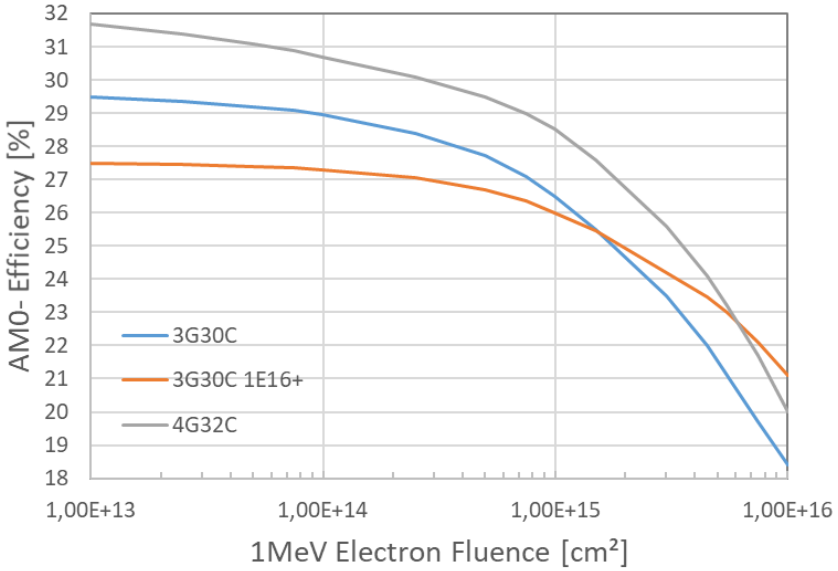
4G32 Epi-Structure



Electrical performance
3G30 vs 4G32



Efficiency [%]:	3G30 Epi-Structure	4G32 Epi-Structure
Begin of Life	29.9	31.8
5 yrs in LEO	28.6	30.0
15 yrs in GEO	26.5	28.7



Current Missions
Science and Deep Space

Bepi Colombo

Launch – October 2018

- 42m^2 solar array for the Mercury transfer module (MTO) with 15kW power generation
- Special 3G30 based solar cells adapted to HIHT environment: up to 200°C, 11 Suns (14 500 W/m^2)

Jupiter Icy Moon Explorer JUICE

Europa Clipper

Launch – 2023

- Solar array 85m^2 for 800W power generation
- Special 3G28 based solar cells adapted to LILT environment: -120°C, 0.04 Suns (50W/m$^{2)}$

Key development areas
€/W performance and productivity

Reduced usage on raw materials

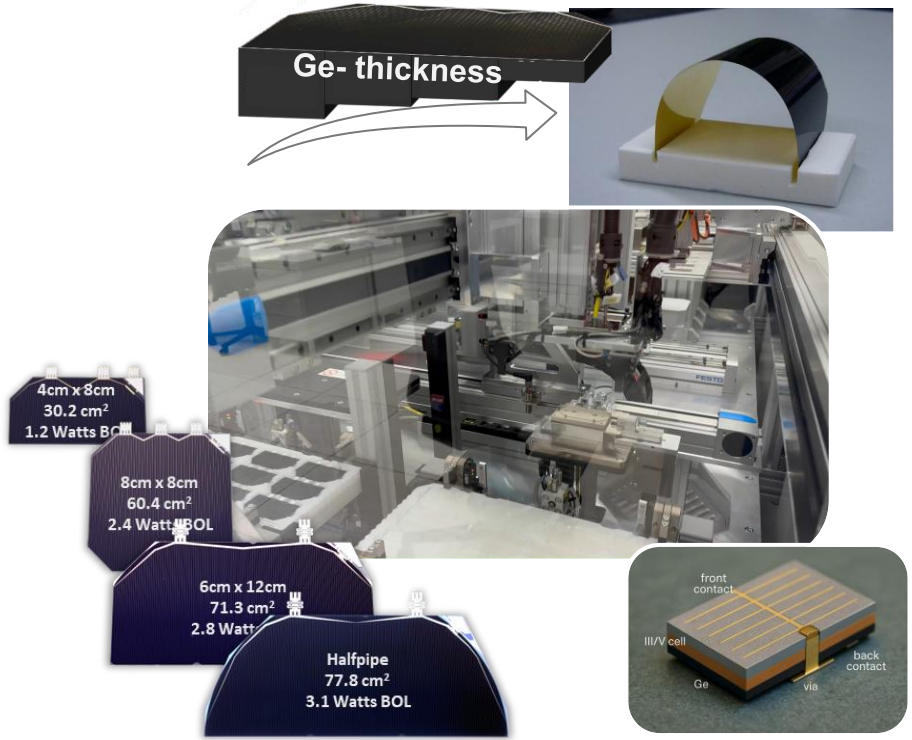
…by thinner cells and innovative cell architectures up to complete Ge substrate release

Innovative manufacturing processes

…including automation, reduced consumption of chemicals, use of more ecological raw materials

Cell design development and adaption

…for imporved performance in diverse mission environments



Bundesministerium für Wirtschaft und Klimaschutz

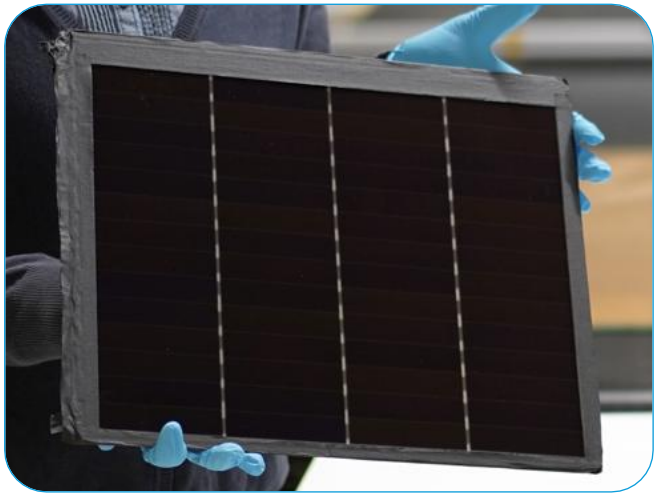
Highest Performance with 3G30 Design

Fraunhofer ISE · Gochermann Solar Technology · temicon micromana solutions

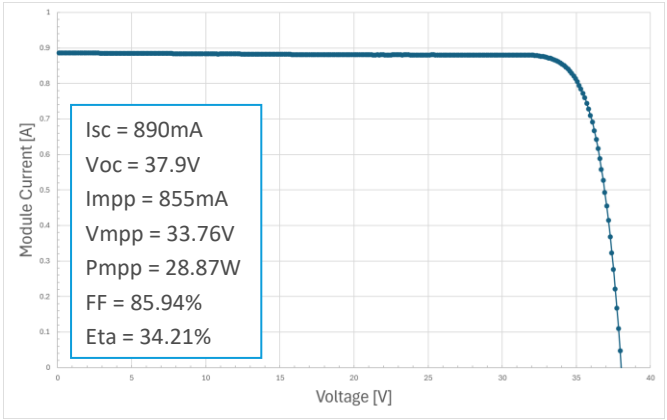
34.2% efficiency absolute –

AZUR's Solar Cells enabled New World Record module made by project partners

15 cells per module



World Record: 34.2% AM1.5 on module level



Area = 844cm²; T = 25°C; AM1.5 = 996.1W/m²

3G30 design adapted on terrestrial solar spectrum (AM 1.5)

Optimized glass surface structure to minimize reflection losses

https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2026/fraunhofer-ise-erzielt-rekordwirkungsgrade-fuer-tandem-photovoltaikmodule.html

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Gestalten Sie die Zukunft der Raumfahrtphotovoltaik – mit einer Karriere bei AZUR SPACE

->> **https://www.5nplus.com/de/karriere/jobliste/**