Research Center for Photovoltaics

High speed MOVPE for InGaP/GaAs multijunction solar cells

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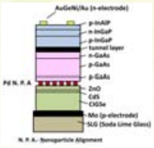
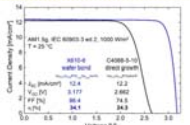
REASERCH BACKGROUND

To decrease cost of III-V semiconductor solar cells

- Substrate cost: substrate reuse and epi-growth on inexpensive substrates

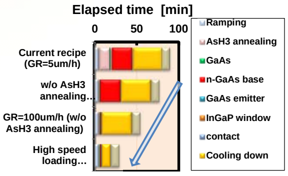


K. Makita et al., 32nd EU-PVSEC, 4CV.1.3, p. 1390, 2016.



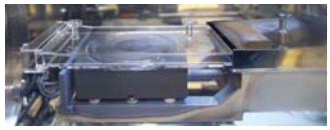
https://www.ise.fraunhofer.de/en/press-media/press-releases/2019/fraunhofer-ise-sets-two-records-for-the-efficiency-of-silicon-based-monolithic-triple-junction-solar-cells.html

MOVPE growth time for a GaAs cell



- Epitaxial cost: high speed MOVPE and improve material utilization

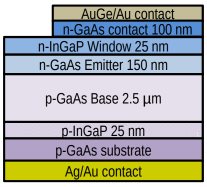
METHOD



- **Taiyo Nippon Sanso, HR3335**
  - Horizontal MOVPE reactor
  - Standard precursors
  - Narrow flow channel to enhance the growth rate (GR)

- **Standard growth conditions: in this work**
  - Total gas flow: 10 SLM
  - Reactor pressure: 15 kPa
    - Our recent study indicates that a slightly high pressure is good for InGaP growth.

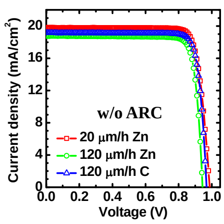
OPTIMIZTION OF 120-μm/h GROWN GaAs 1J SOLAR CELLS



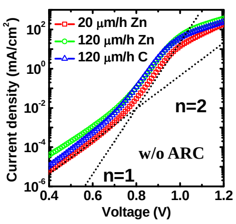
Schematic and details of GaAs 1J

- A reference GaAs cell grown with GR of GaAs base layer at 20 μm/h
  - V/III ratio 20 using Zn dope
- 2 samples of 120 μm/h grown cells
  - V/III ratio 20 using Zn dope
  - V/III ratio 3 using carbon auto-dope

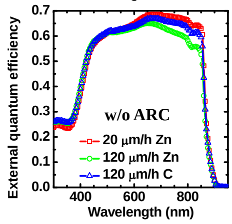
I-V (AM1.5G)



Dark I-V



EQE

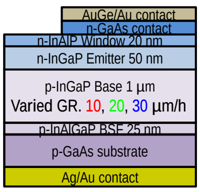


GR (μm/h)	V_{oc} (V)	J_{sc} (mA/cm²)	FF	η (%)	J_{01} (mA/cm²)	J_{02} (mA/cm²)
20	0.99	19.82	0.836	16.35	4.49×10^{-16}	1.41×10^{-9}
120 (Zn)	0.94	18.76	0.852	15.08	1.70×10^{-15}	1.64×10^{-8}
120 (C)	0.97	19.15	0.853	15.82	6.38×10^{-16}	1.28×10^{-9}

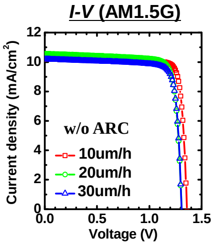
- Increase of J_{01} and J_{02} with GR from 20 to 120 μm/h
  - reduce both V_{oc} and J_{sc} because of increase in defect density
  - C dope (low V/III) better than Zn dope for 120 μm/h grown cells
  - Native defect in p-GaAs = As antisite → decrease defect by lowering V/III ratio

EFFECTS OF GROWTH RATE ON InGaP SOLAR CELLS

Schematic of InGaP 1J



I-V (AM1.5G)



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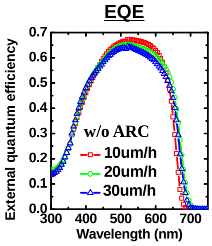
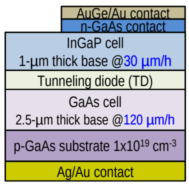


- Increase of W_{oc} with GR
  - Degradation of InGaP quality
- Shunt-like *I-V* characteristics
  - Not exist in DIV measurement
  - Issue of poor carrier extraction

GR (μm/h)	V_{oc} (V)	W_{oc} (V)	J_{sc} (mA/cm²)	η (%)
10	1.36	0.518	10.20	11.92
20	1.31	0.529	10.57	11.43
30	1.31	0.543	10.19	11.13

HIGH SPEED GROWN InGaP/GaAs 2J SOLAR CELLS

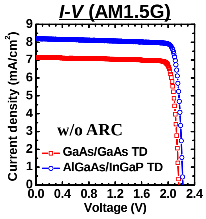
Schematic of 2J



- Two combinations of TD used in this work
  - p^+GaAs(Zn)/n^+GaAs(Si) and p^+AlGaAs(C)/n^+InGaP(Si)

	Layer	V/III	T_g (°C)	Dopant	[Carrier] (cm⁻³)
TD1	p^+GaAs	20	550	Zn	9.2×10^{19}
	n^+GaAs	20	650	Si	8.7×10^{18}
TD2	p^+AlGaAs	3	550	C	1.07×10^{20}
	n^+InGaP	50	650	Si	1.55×10^{19}

I-V (AM1.5G)



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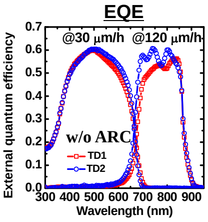

TD	V_{oc} (V)	J_{sc} (mA/cm²)	η (%)
TD1	2.16	7.15	13.49
TD2	2.22	8.19	15.91
TD2 w/ARC	2.26	11.36	22.30

- Sufficient loss in TD1
  - Absorption loss decreased J_{sc}.
  - Voltage drop across TD1 > TD2

CONCLUSIONS

- For n-on-p GaAs single junction solar cell, low V/III ratio during high speed grown GaAs base is beneficial for low defect density and allowing carbon auto-doping.
- For both GaAs and InGaP, high speed growth results in decreasing of cell efficiency, which defects and dislocations are responsible.
- InGaP/GaAs 2J solar cells were successfully fabricated with GR of 1-μm thick InGaP and 2.5-μm thick GaAs base layers at 30 and 120 μm/h respectively.

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A part of this study was supported by NEDO project: the research and development of ultra-high efficiency and low-cost III-V compound semiconductor solar cell modules.