NREL
Transforming ENERGY

Remote epitaxy of III-V solar cells via hydride vapor phase epitaxy

Dennice Roberts[1], Hyunseok Kim[2], Elisabeth McClure[1], Anna Braun[1], Kevin Schulte[1], Aaron Ptak[1], Jeehwan Kim[2], John Simon[1]

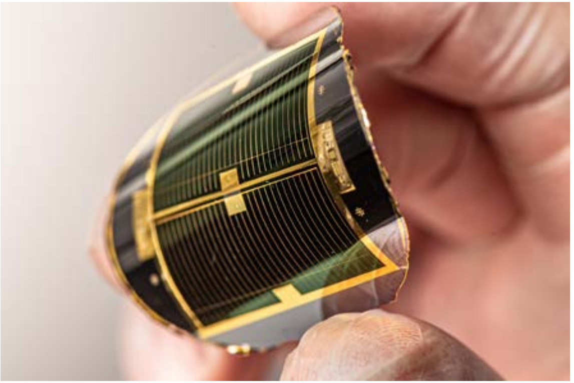
[1]National Renewable Energy Laboratory

[2]Massachusetts Institute of Technology

Session EQ02.11: Epitaxy of Mixed Dimensional Structures IV

dennice.roberts@nrel.gov

Advantages of III-V solar

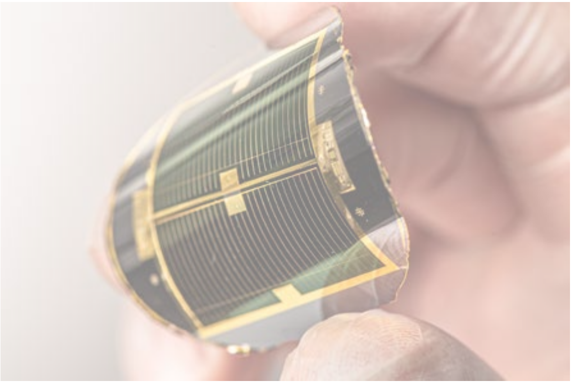


- Record efficiencies
  - 29.1% single junction GaAs (one-sun)
  - 47.1% multijunction (concentrated)
- Thin, flexible, radiation hard – robust in harsh environments

Geisz et al 47.1% Nature

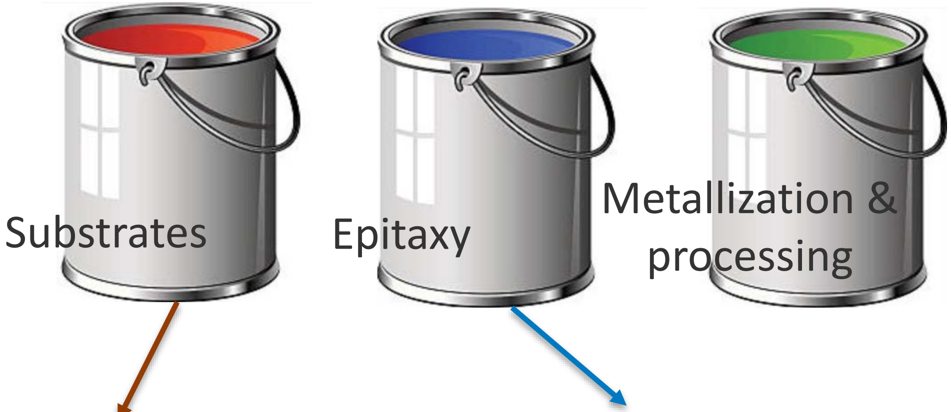
*M. A. Green, et al., Prog. in Photovoltaics **28** (2020)*

Advantages of III-V solar



- Record efficiencies
  - 29.1% single junction GaAs (one-sun)
  - 47.1% multijunction (concentrated)
- Thin, flexible, radiation hard – robust in harsh environments

Major costs in III-V solar:

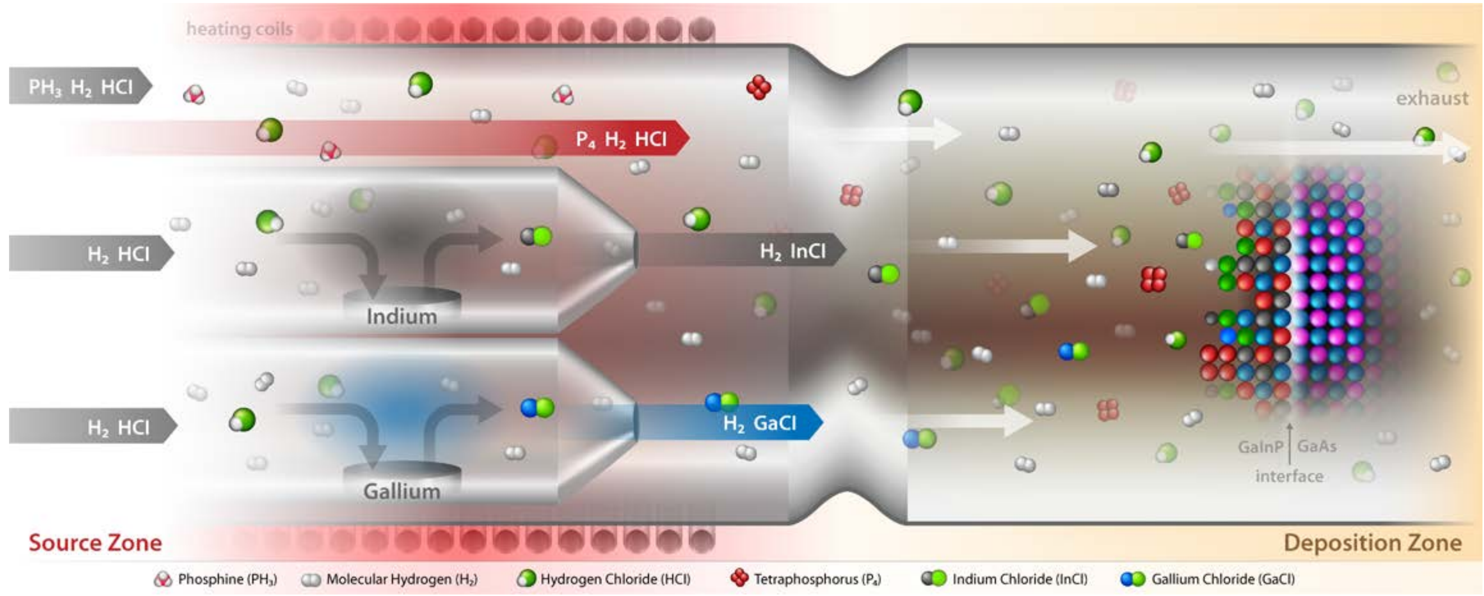


Address via remote epitaxy

Address via hydride vapor phase epitaxy (HVPE) growth

K.A. Horowitz, et al., NREL Technical Report NREL/TP-6A20-72103

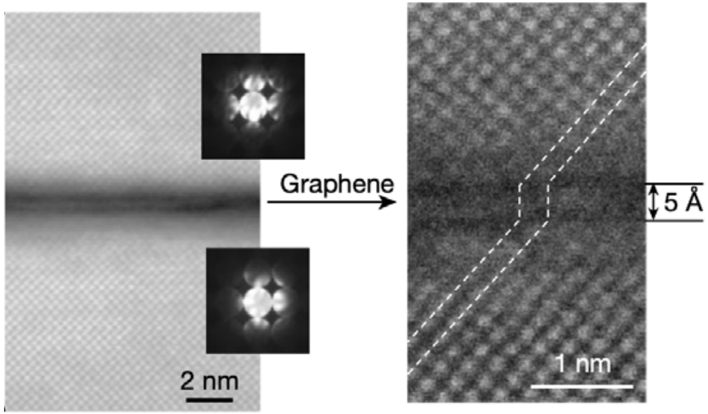
Hydride vapor phase epitaxy (HVPE) growth



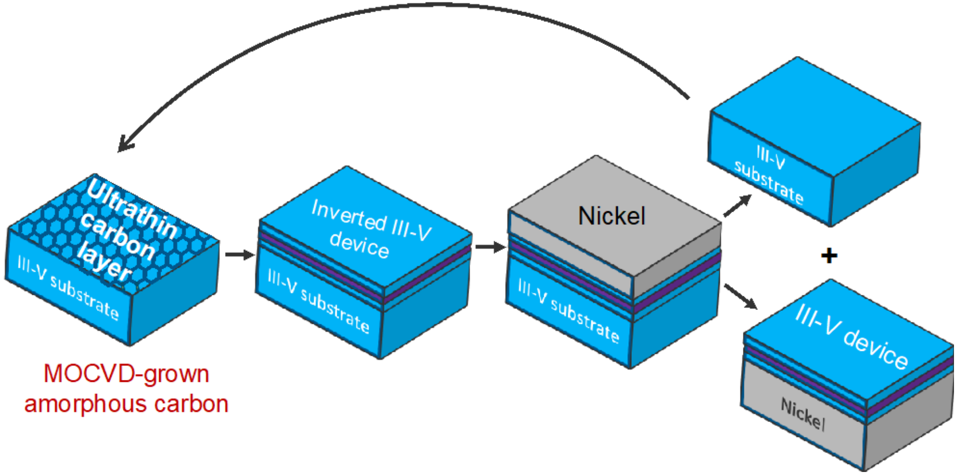
- Atmospheric pressure process
- Less expensive precursors than incumbent OMVPE growth method
- Higher precursor utilization
- Extremely fast growth rates up to 528 µm/h

McClure *et al* Appl. Phys. Lett. 116 (2020)

Combining HVPE growth and remote epitaxy



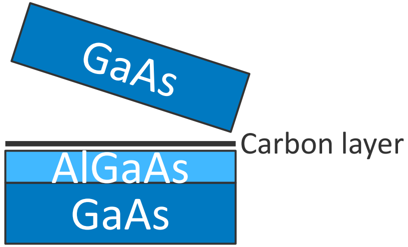
Remote epitaxy of GaAs on GaAs demonstrated by MOCVD

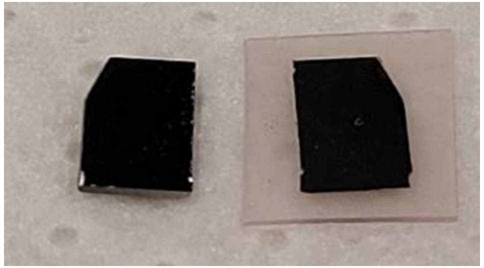


For more on 2D layer fabrication and optimization, check out talks by Jeehwan Kim and Hyunseok Kim in this session

Kim *et al* Nature 544 (2017)

Exfoliation of HVPE-grown GaAs layer

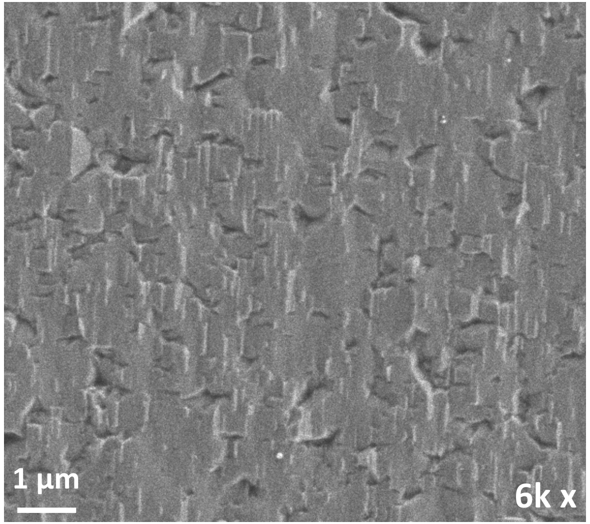




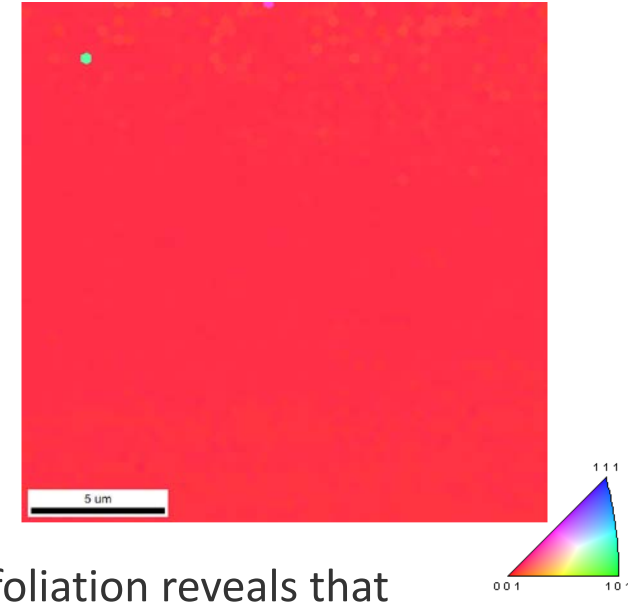
Substrate

Released GaAs layer

SEM of top surface, pre-exfoliation



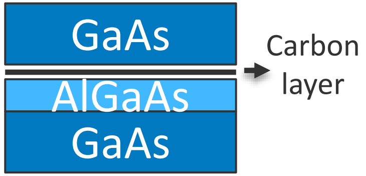
EBSD map, layer at wafer interface

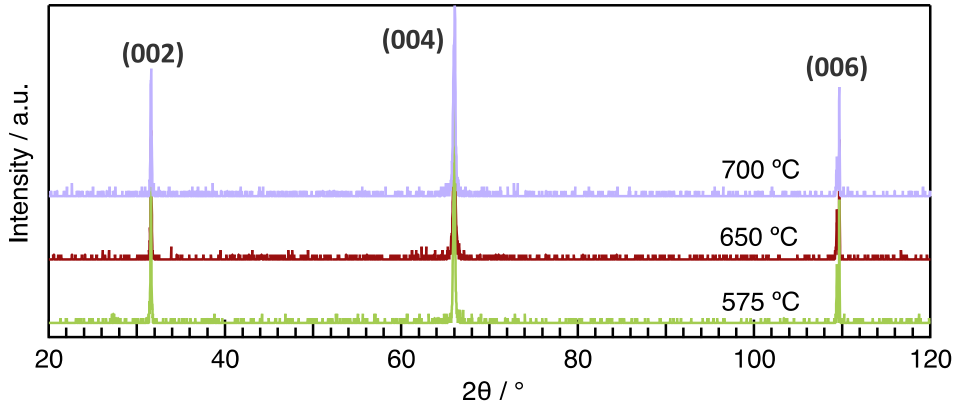


Despite rough surface, exfoliation reveals that all nucleation proceeded along (001) face

Data and images courtesy of Hyunseok Kim

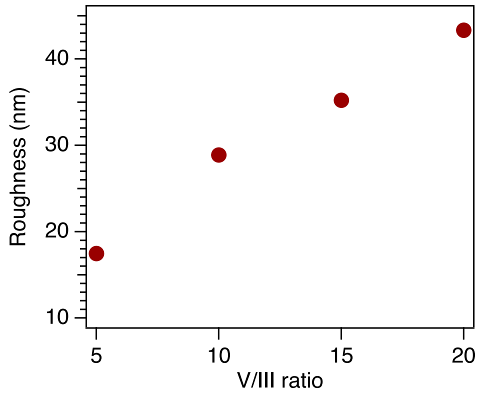
Nucleation of GaAs on amorphous carbon

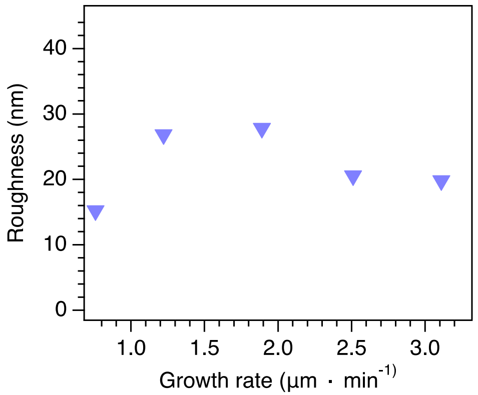




Single crystal films oriented along (001) at temperatures between 575 and 700 °C

650 °C, V/III = 5, growth rate = 0.76 µm/min



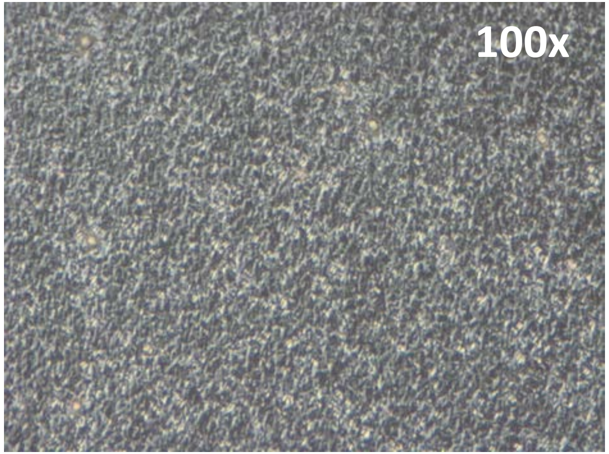


Among coalesced films: film roughness has dependence on V/III, some dependence on GR

Planarizing film surfaces

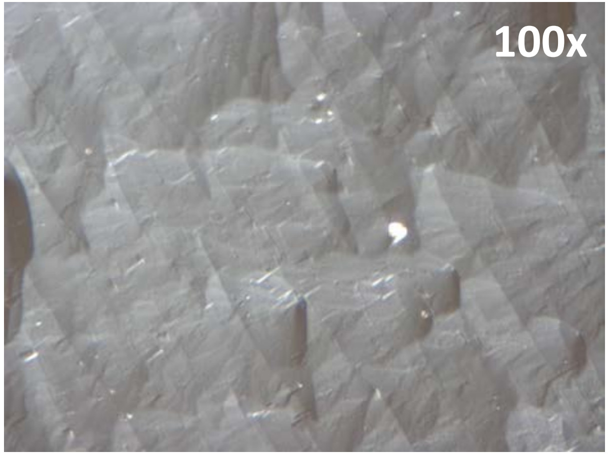
Improve surface morphology and reduce roughness by introducing layer with high carrier flow and high GaCl generation

500 nm nucleation under N_2



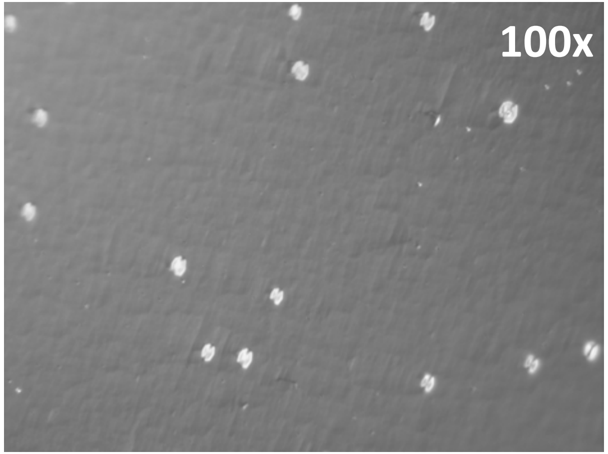
R_a = 15.2 nm

500 nm under N_2 + 3 μm high flow layer under H_2



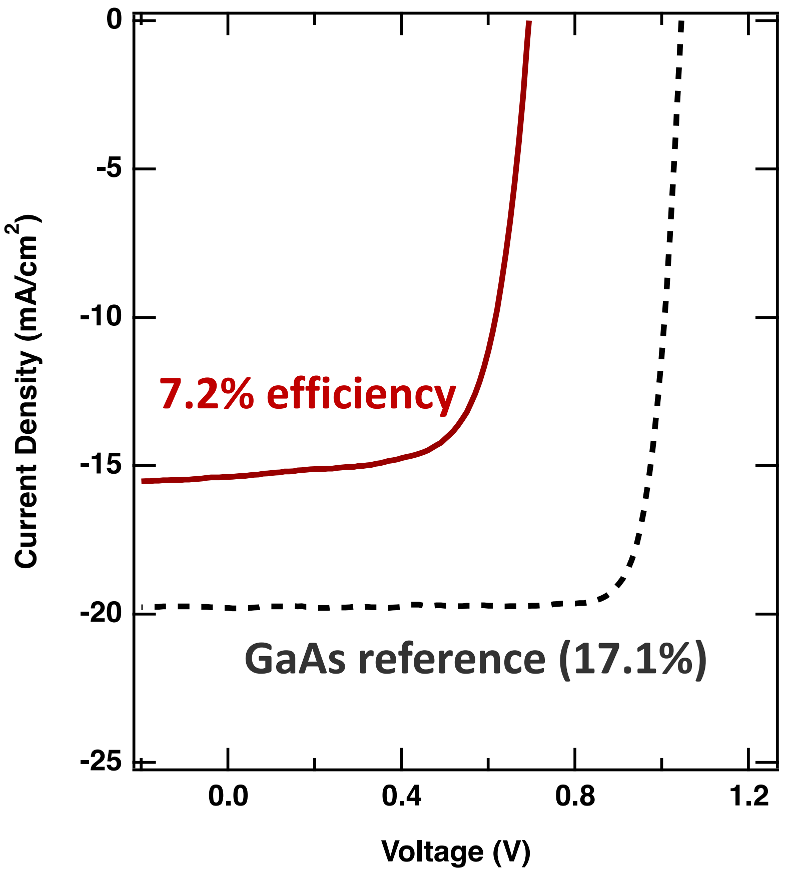
R_a = 10.6 nm

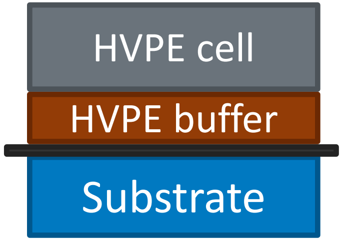
3 μm high flow layer under N_2



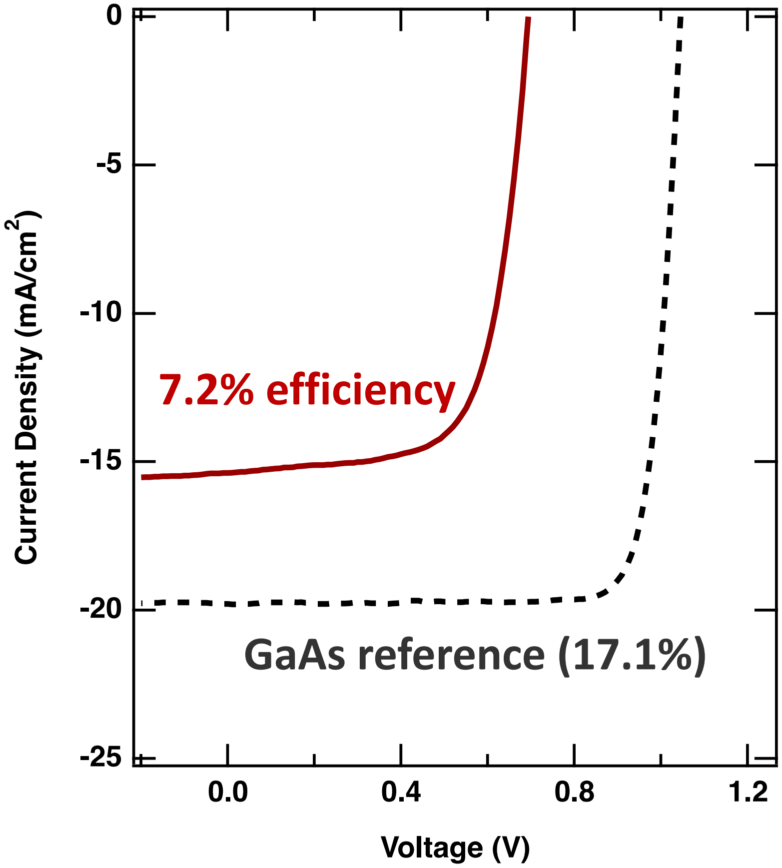
R_a = 2.2 nm

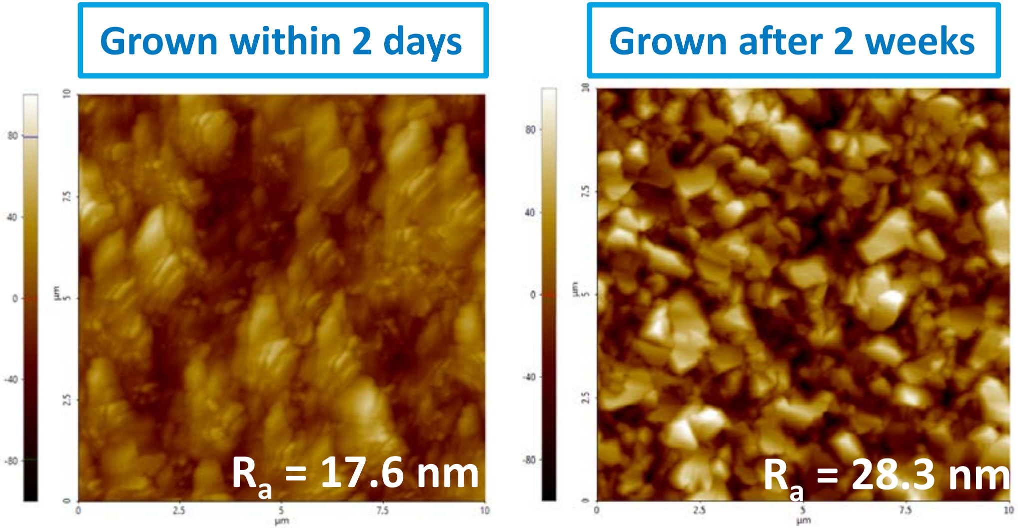
Growth of III-V solar cells





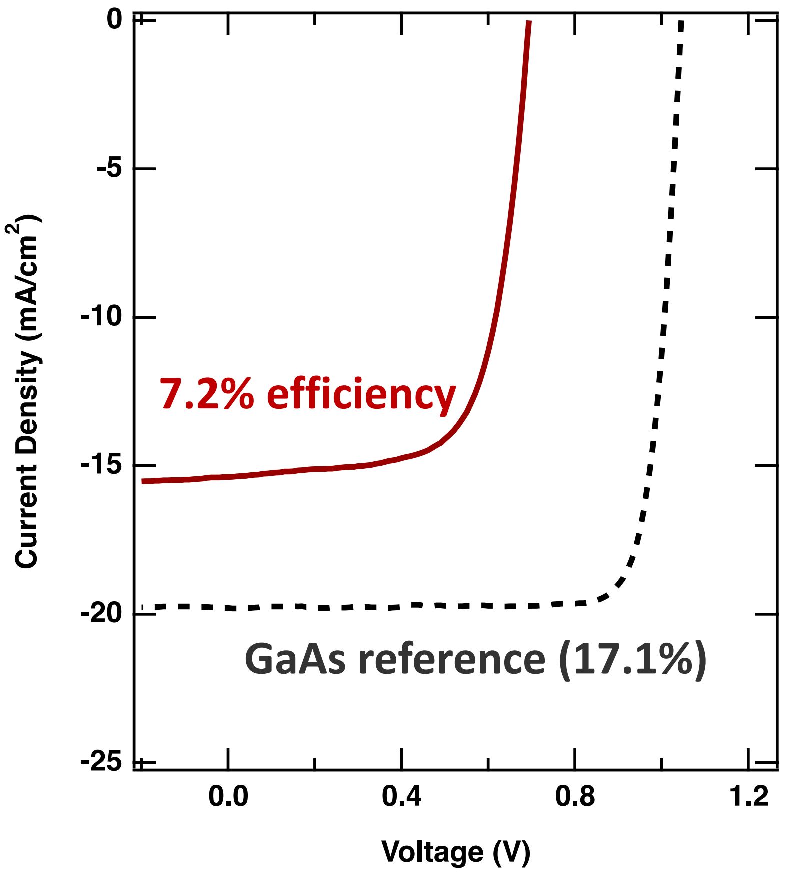
Growth of III-V solar cells

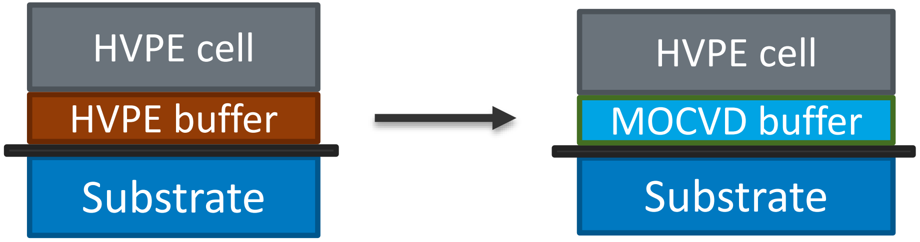




Surface degradation of carbon substrates over time results in increased film roughness and regions of no growth

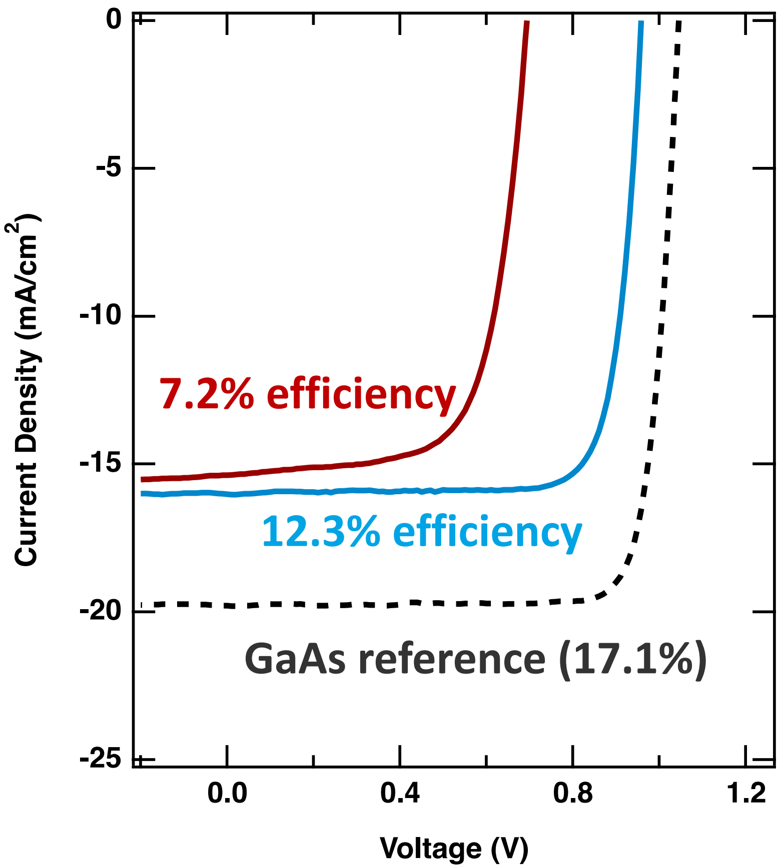
Growth of III-V solar cells





To negate the effects of surface degradation, MOCVD buffer is grown before shipping to NREL

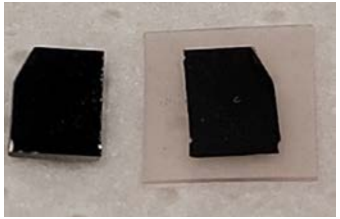
Growth of III-V solar cells



- Cell efficiency of 7.2% for all-HVPE grown cell
- Using MOCVD-grown buffer to offset carbon degradation, see cell with 12.3% efficiency

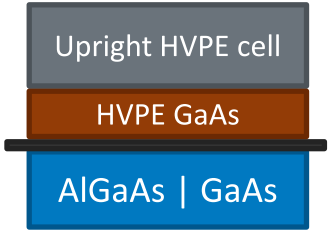
- After applying anti-reflective coating, cell efficiency is >19%!

Conclusions



Investigated conditions for remote epitaxy of GaAs on amorphous carbon layer via HVPE and show proof of exfoliation

Explored planarization conditions to improve film surface and morphology



Developed remote-epitaxial GaAs cell with promising path for substantial improvements

Thank you!

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dennice.roberts@nrel.gov

NREL/PR-5K00-81669

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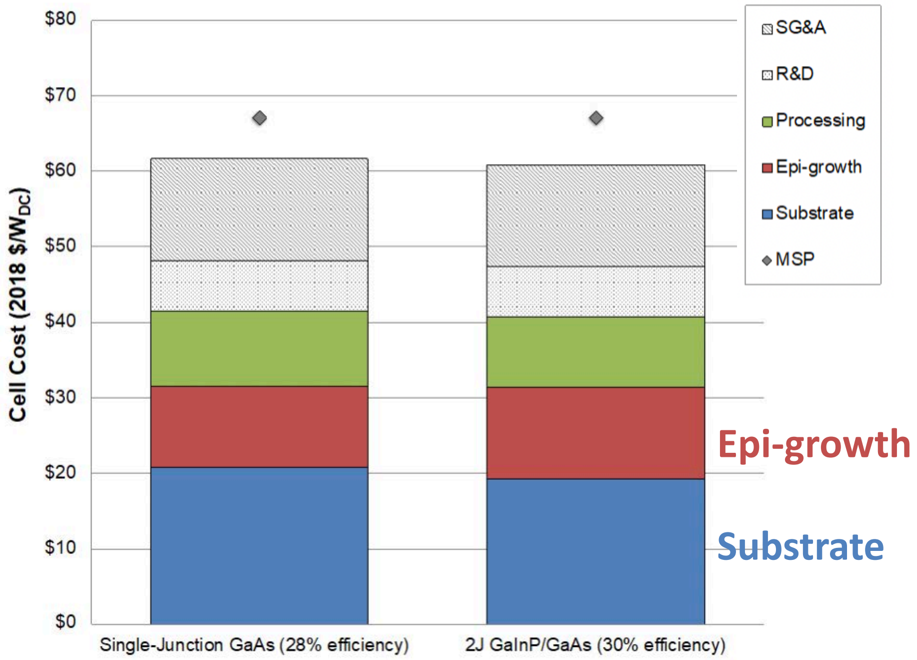
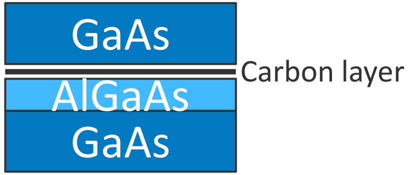
Large-scale deployment of III-V solar limited by cost

K.A. Horowitz, et al., NREL Technical Report NREL/TP-6A20-72103

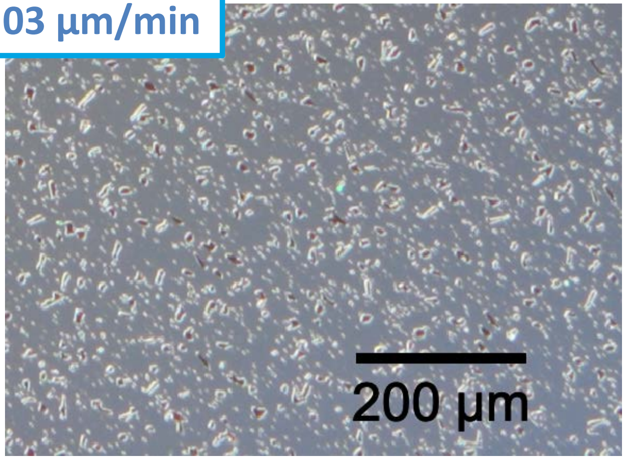


Cost breakdown for III-V cells by OMVPE

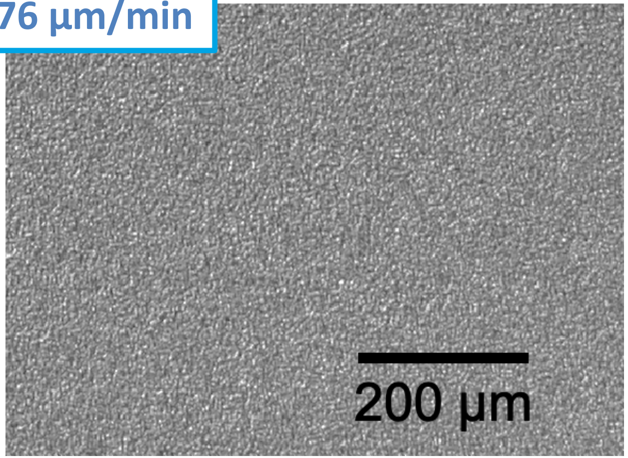
Nucleation of GaAs on amorphous carbon



.03 µm/min



.76 µm/min



Island growth at very slow growth rates; coalesced films at higher GRs