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On the Relation Between Growth, Quantum-Dot Morphology, Optoelectronic Properties, and Performance in InAs/GaAs Quantum Dot Intermediate Band Solar Cells

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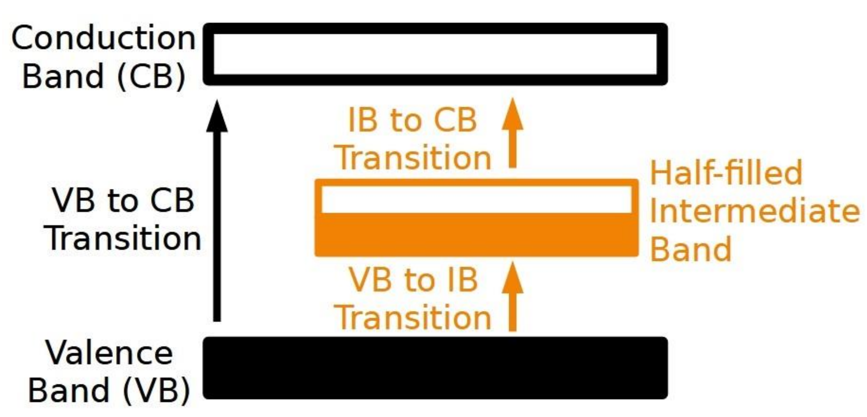
Introduction

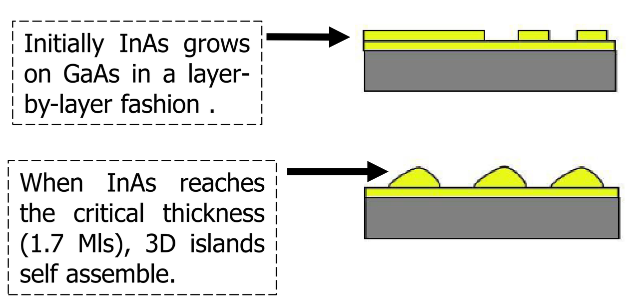
- Intermediate band solar cells take advantage of nanostructures to allow absorption sub-bandgap photons.

Intermediate Band Solar Cell

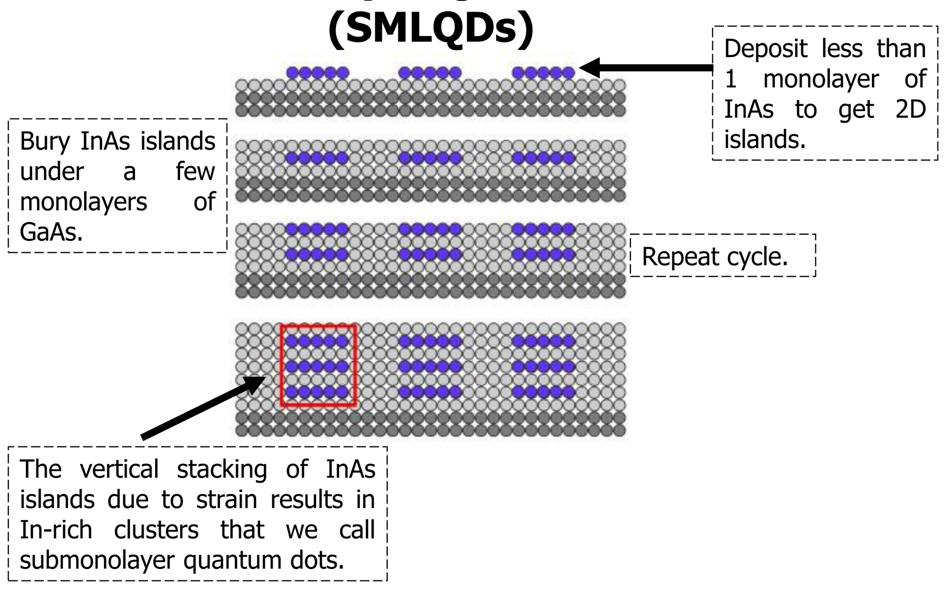


- We used two types of InAs/GaAs quantum dots to create intermediate bands in GaAs-based solar cells grown by molecular beam epitaxy.

Stranski-Krastanov Quantum Dots (SKQDs)



Submonolayer Quantum Dots (SMLQDs)



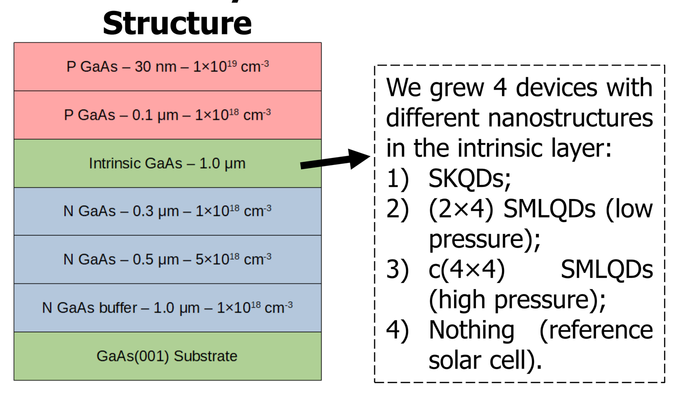
Objective

- Can InAs/GaAs SMLQDs yield better intermediate band solar cells than InAs SKQDs? Why?
- Can InAs/GaAs SMLQD intermediate band solar cells perform better than conventional GaAs solar cells? Why?

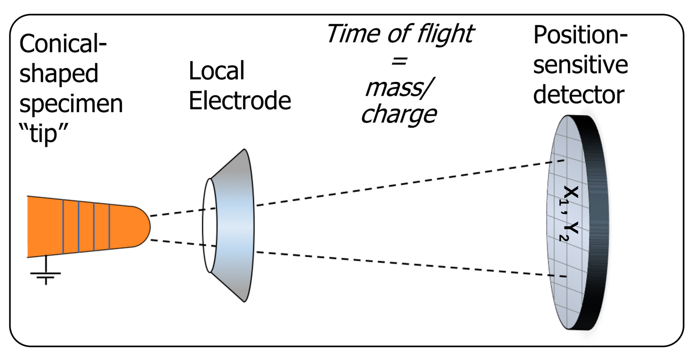
Materials and Methods

- Growth → solid source molecular beam epitaxy.
- Device processing → Photolithography
- Device contacts → E-beam evaporation + rapid thermal annealing
- Optoelectronic characterization → photoluminescence + external quantum efficiency
- Nanomorphology and composition → cross-sectional scanning tunneling microscopy + atom probe tomography
- Device performance → illuminated current-voltage curves (AM1.5G standard).

Device Layer Structure

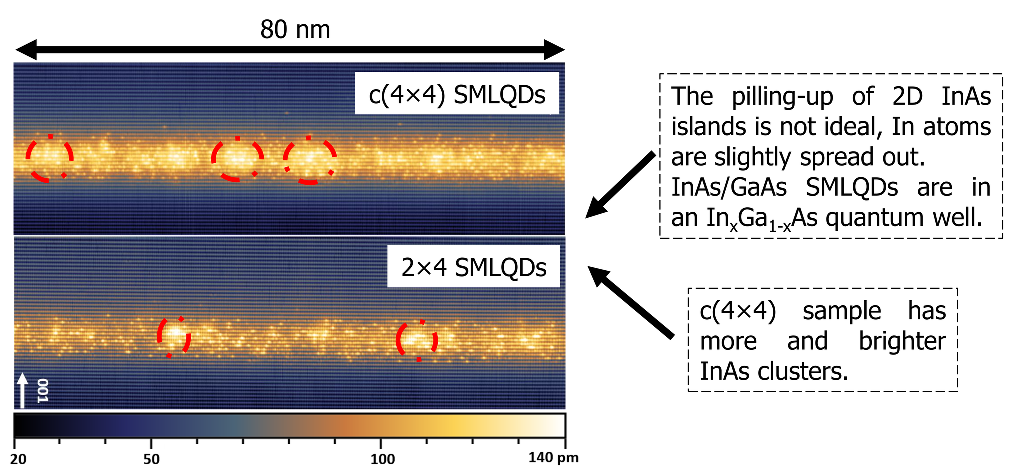


Local Electrode Atom Probe Tomography[1]

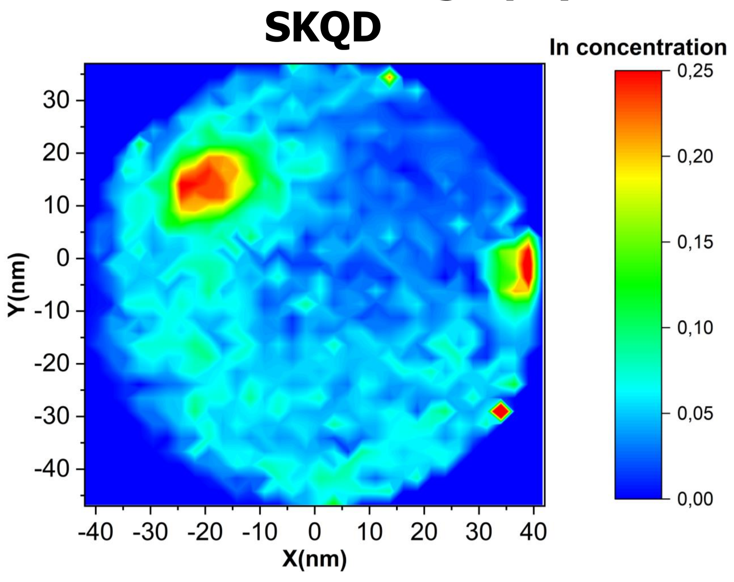


Results

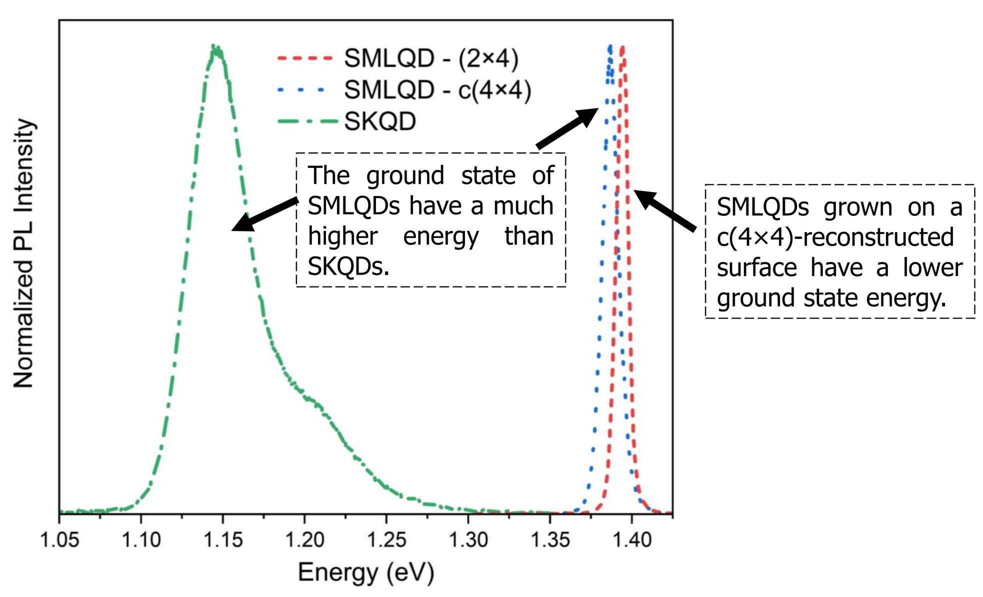
Cross-sectional Scanning Tunneling Microscopy



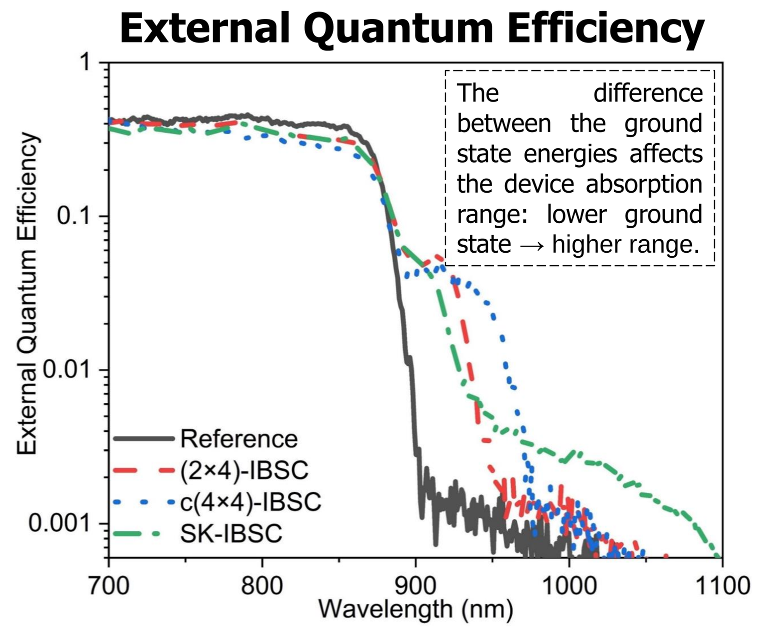
Atom Probe Tomography SKQD



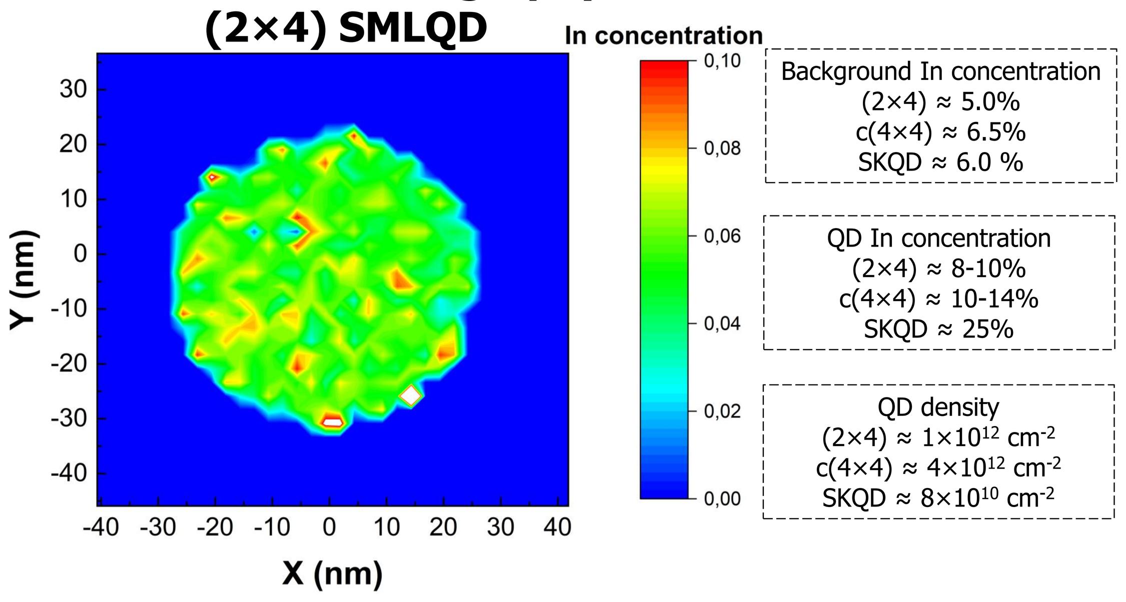
Photoluminescence



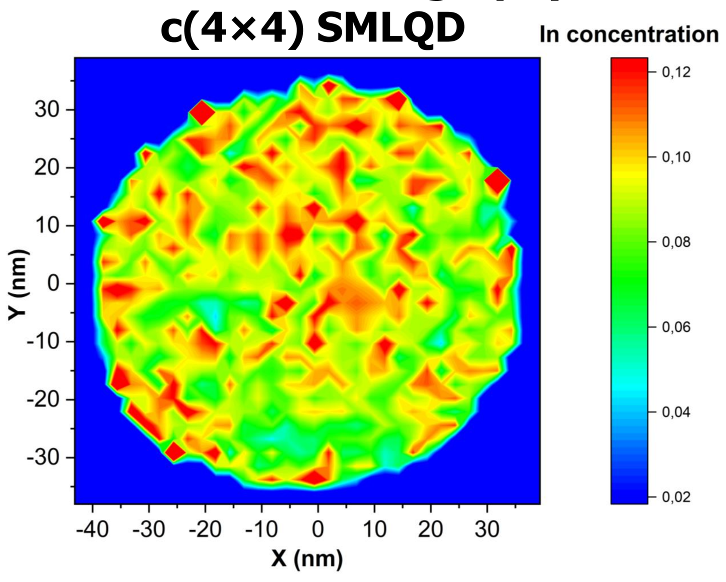
External Quantum Efficiency



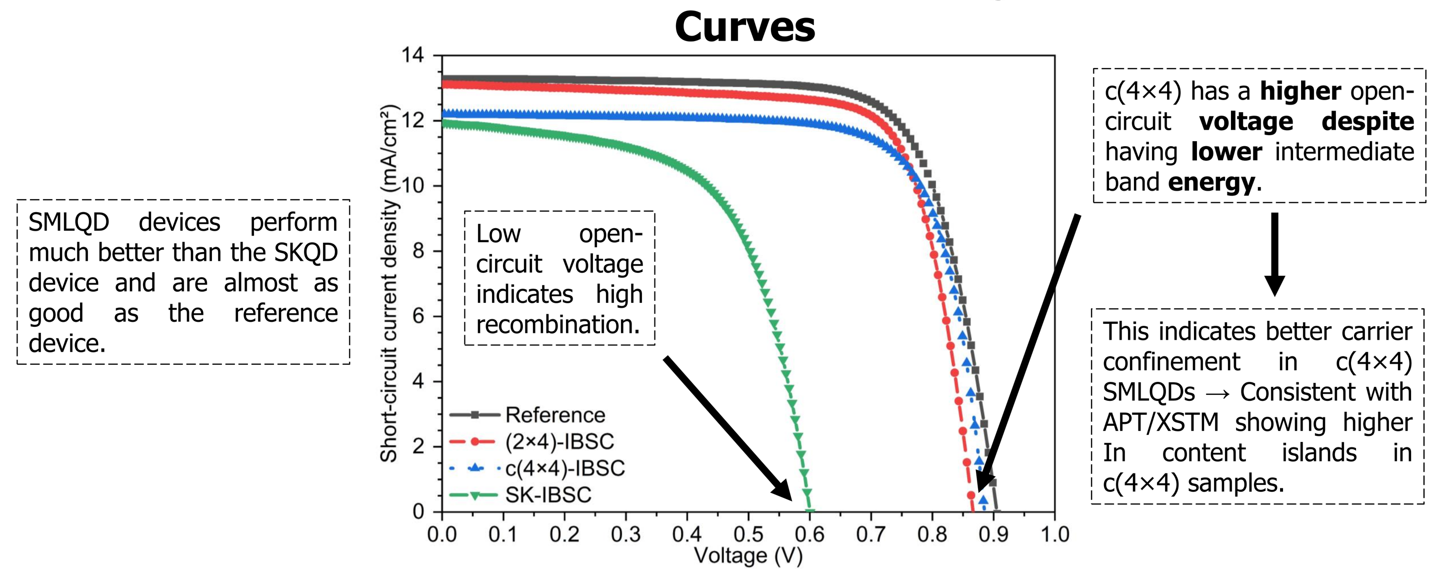
Atom Probe Tomography (2×4) SMLQD



Atom Probe Tomography c(4×4) SMLQD



Illuminated Current-Voltage Curves



Conclusion

- Can InAs/GaAs SMLQDs yield better intermediate band solar cells than InAs SKQDs? Why?
  - Yes, SKQD solar cells have much lower open-circuit voltage (i.e., high recombination) due to defects that result from strain.
- Can InAs/GaAs SMLQD intermediate band solar cells perform better than conventional GaAs solar cells? Why?
  - Not yet. The c(4×4) solar cell has a higher open-circuit voltage than the (2×4) solar cell despite the c(4×4) SMLQDs having a lower ground state energy, which indicates better carrier confinement. An optimization process to maximize the short-circuit current could lead to high-efficiency SMLQD solar cells in the near future.

Acknowledgments

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References

- [1] C. Greenhill, Influence of Composition and Morphology on the Electronic Properties of Semiconductor Nanostructures and Alloys, PhD thesis, 2021.
- [2] R. S. R. Gajjela et al., Cross-sectional scanning tunneling microscopy of InAs/GaAs(001) submonolayer quantum dots, Phys. Rev. Materials 4, 114601, 2020.