

Compound semiconductor photovoltaics optimised for artificial lighting conditions

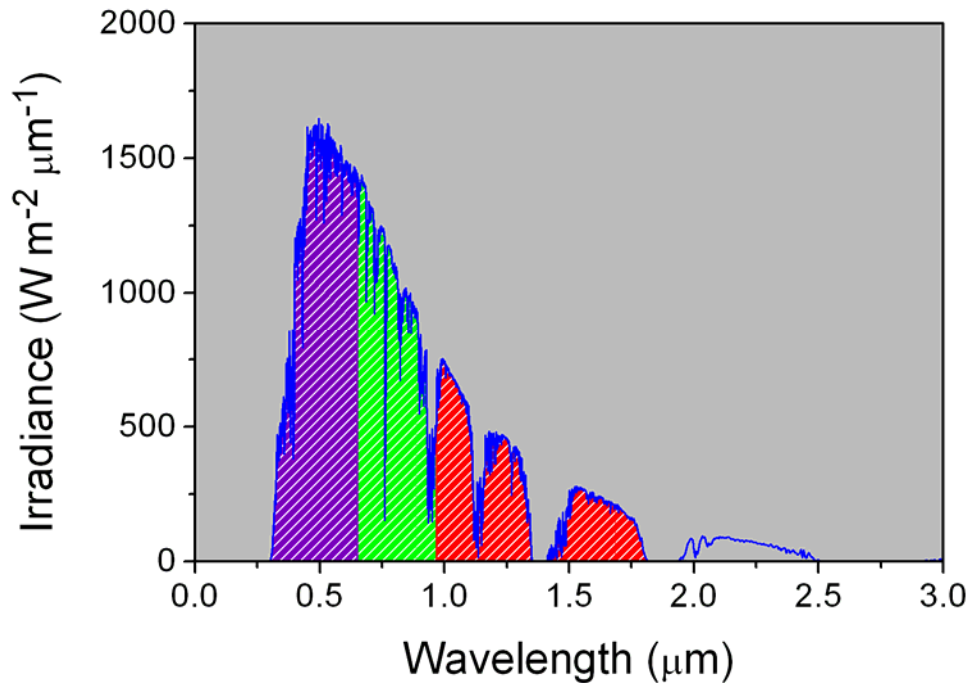
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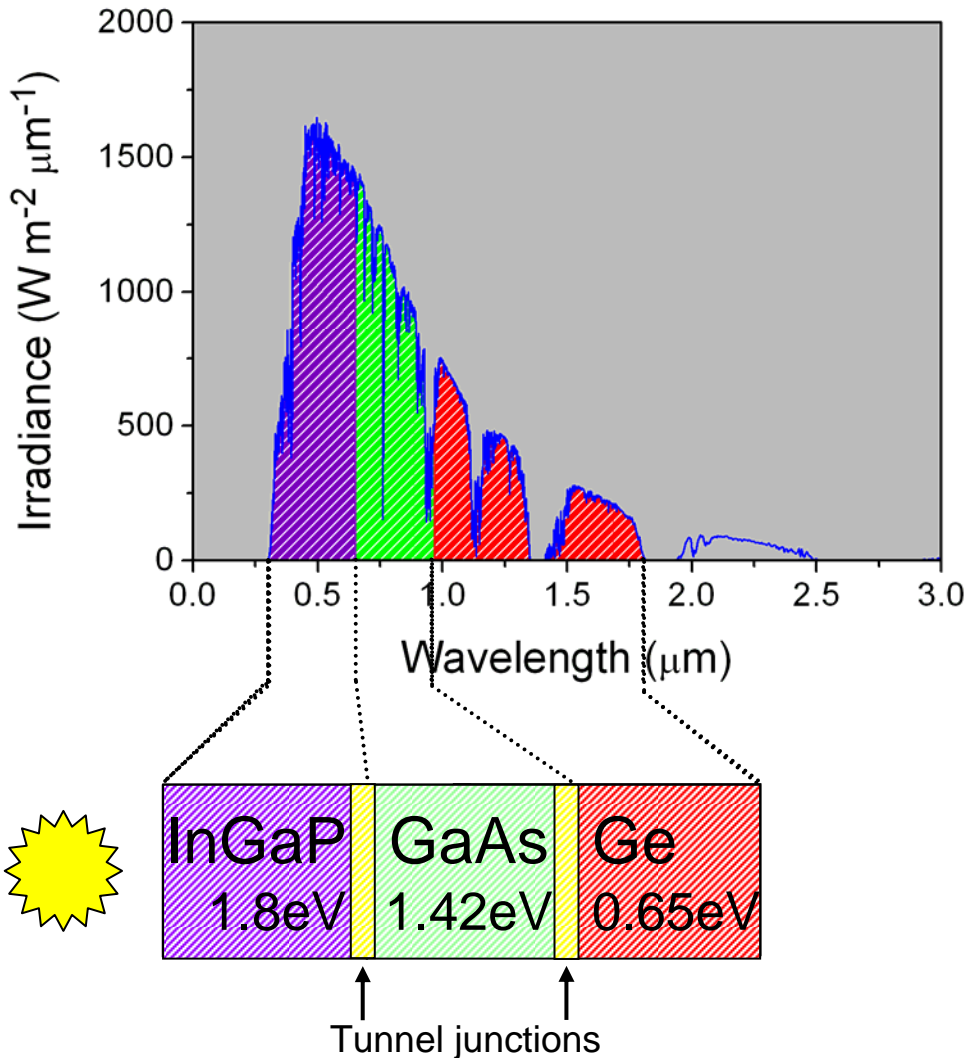


Aims

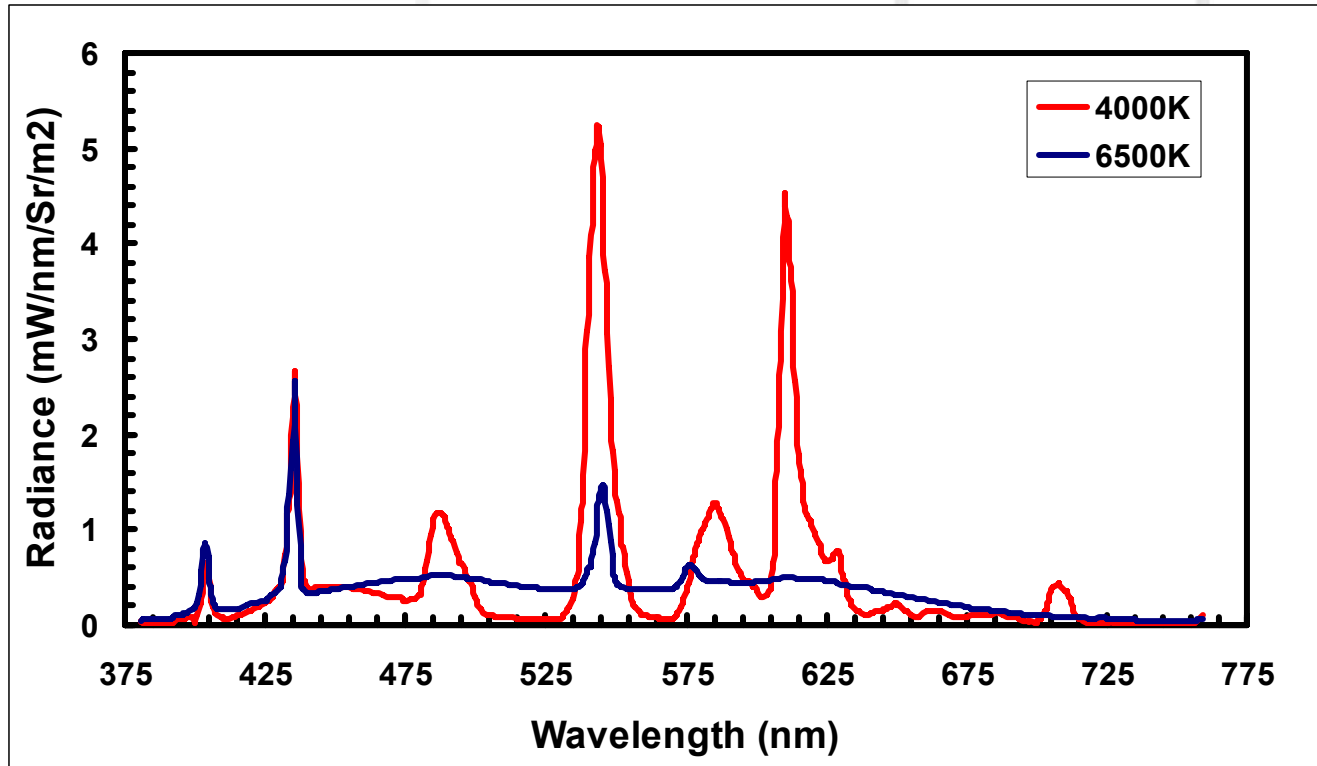
- To produce a Photovoltaic Cell optimised for fluorescent lighting conditions.
- Harvest as much energy as possible from ambient lighting to provide power for an energy neutral device.
- To grow III-V semiconductors on Ge and GaI substrates to allow devices and power supply to be integrated onto a common Si substrate.



- Blackbody radiation
- Peak power in the visible
- Large fraction of light is in the infrared $>750\text{nm}$
- Conventional Si Solar cells capture most of these photons
- Energy in excess of $(hf - E_g)$ is lost as heat, reducing conversion efficiency.



- Multi Junction Solar cells greatly increase efficiency
- Photons in different parts of the spectrum absorbed by semiconductors with bandgaps closer to the photon energy.
- Less energy is lost from photons that have energies above the bandgap.
- Careful design required to ensure each cell contributes a similar current.

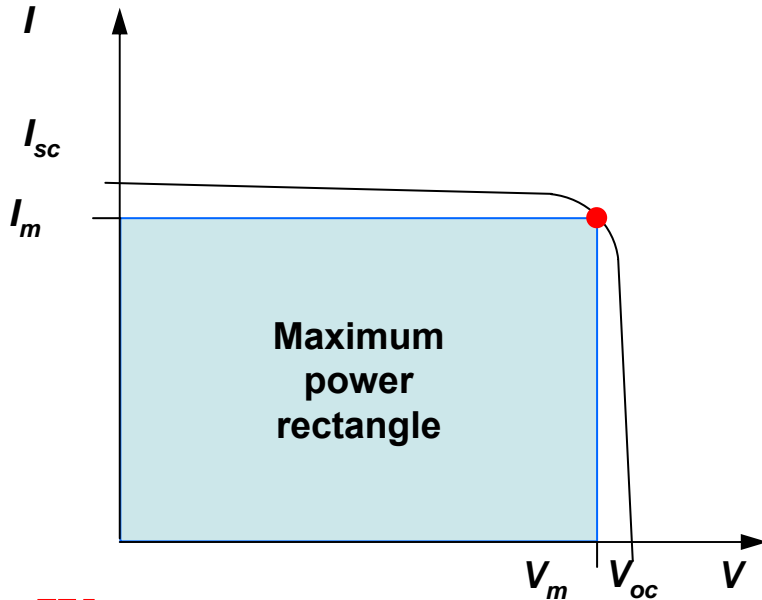


- Typical Fluorescent Tube Spectra for 2 different colour temperatures
- Reference: “**Diffraction parameric colors**”, J. Orava et al, JOSA A, Vol. 25, Issue 12, pp. 2901-2907, 2008

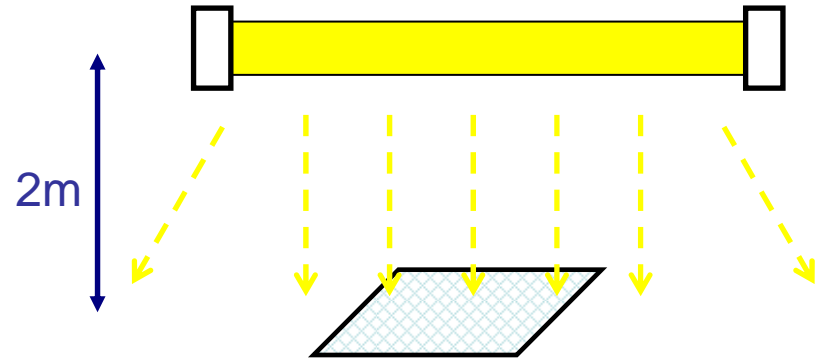
Speck

PV cell design considerations

Research Consortium in Speckled Computing



Fluorescent Tube



PV Cell

Absorption layer thickness $\sim 1\mu\text{m}$

Surface area 1cm^2

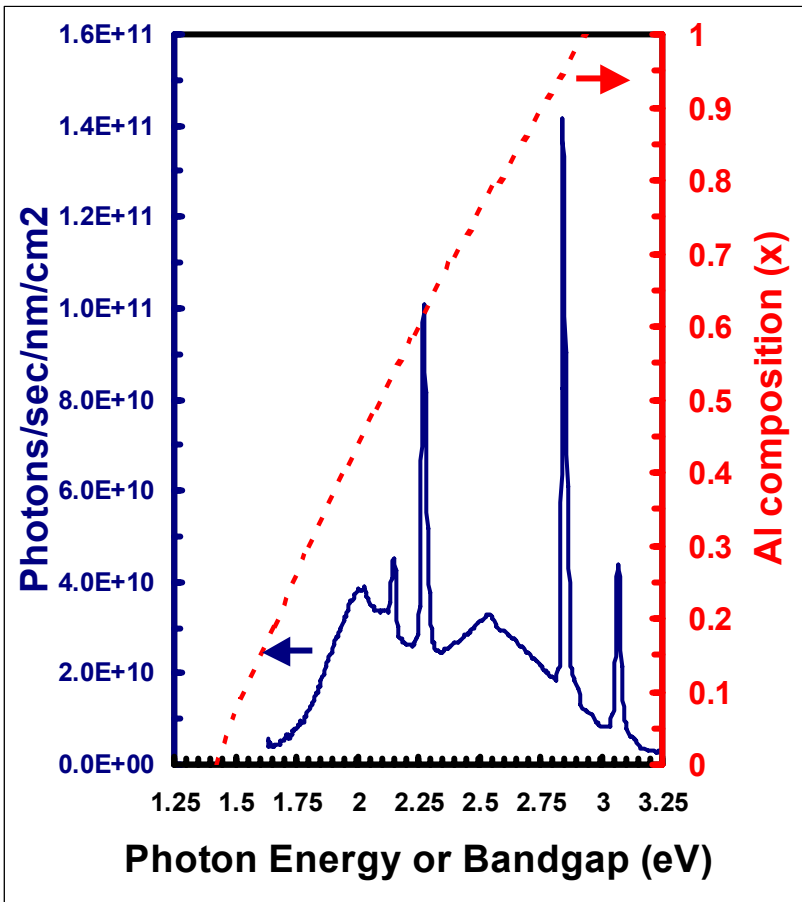
$P=IV$

$I \propto$ Absorbed Photons

$V \propto$ Bandgap (E_g), typically $V \sim 0.75 * E_g$

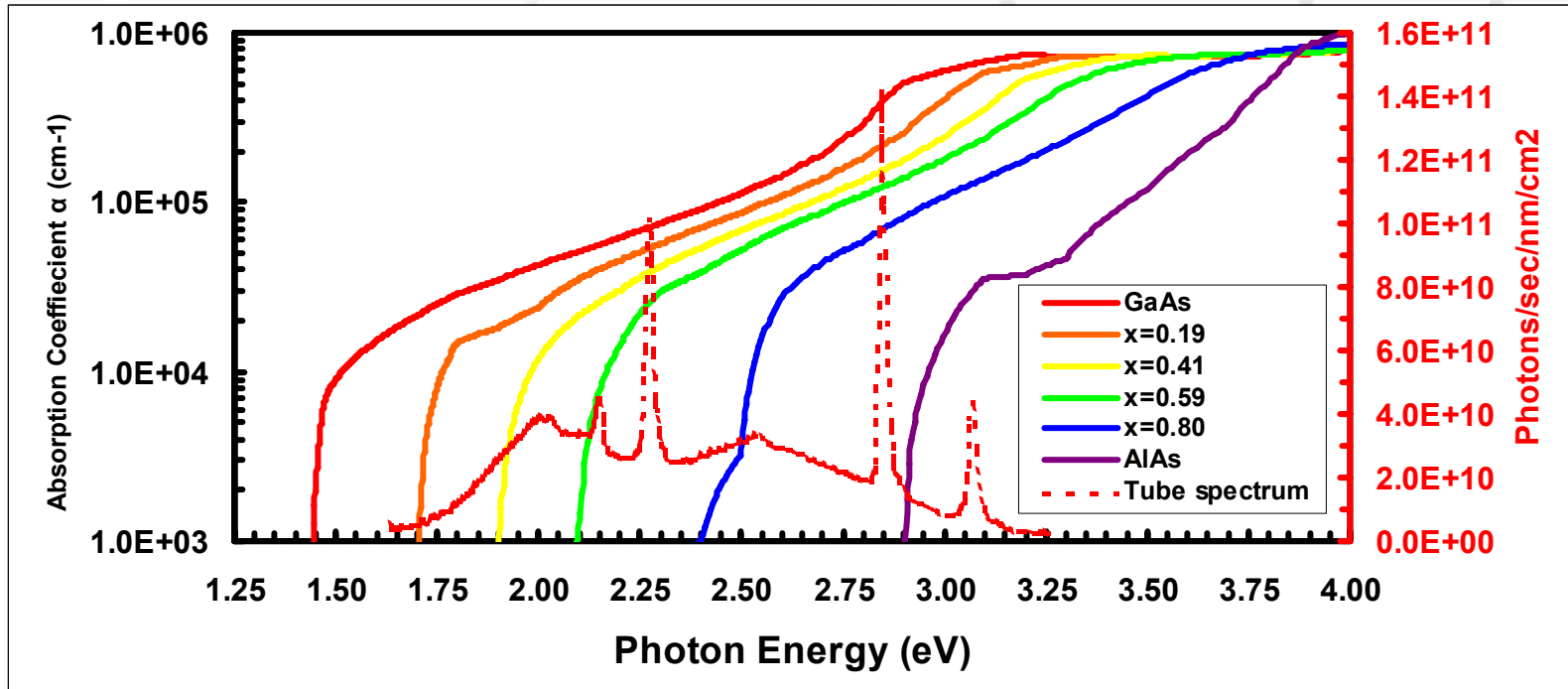
Maximise the product of bandgap and absorbed photons





- **6500K Fluorescent Tube Spectrum**
- **Estimated tube output ~450 lumen**
- **Distance from source = 2 meters**
- **Total photon flux $\text{cm}^{-2} = 9 \times 10^{12} \text{s}^{-1} \text{cm}^{-2}$**

- **$\text{Al}_{(x)}\text{Ga}_{(1-x)}\text{As}$ Bandgap varies from 1.42eV-2.95eV which covers the visible spectrum**
- **Closely lattice matched to Ge and GaAs Substrates**

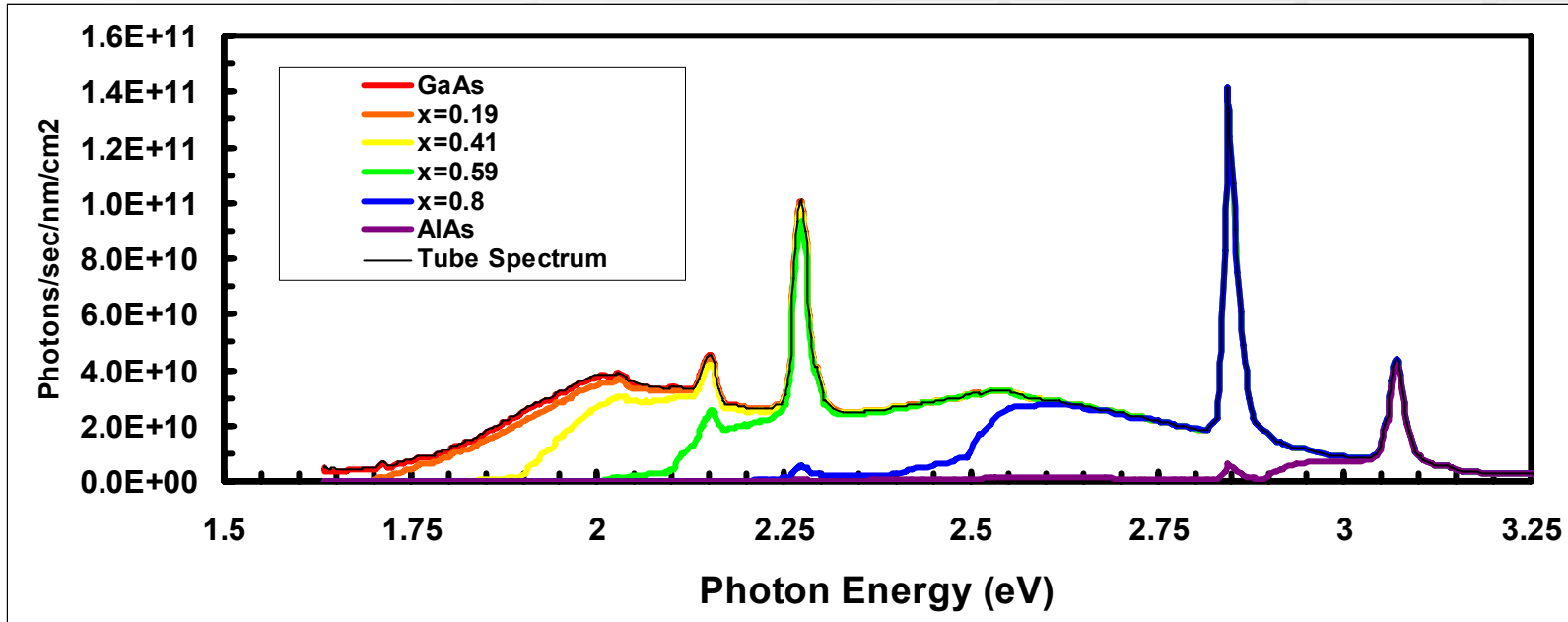


• Number of absorbed photons $I_{abs} = I_0(1 - e^{-\alpha t})$

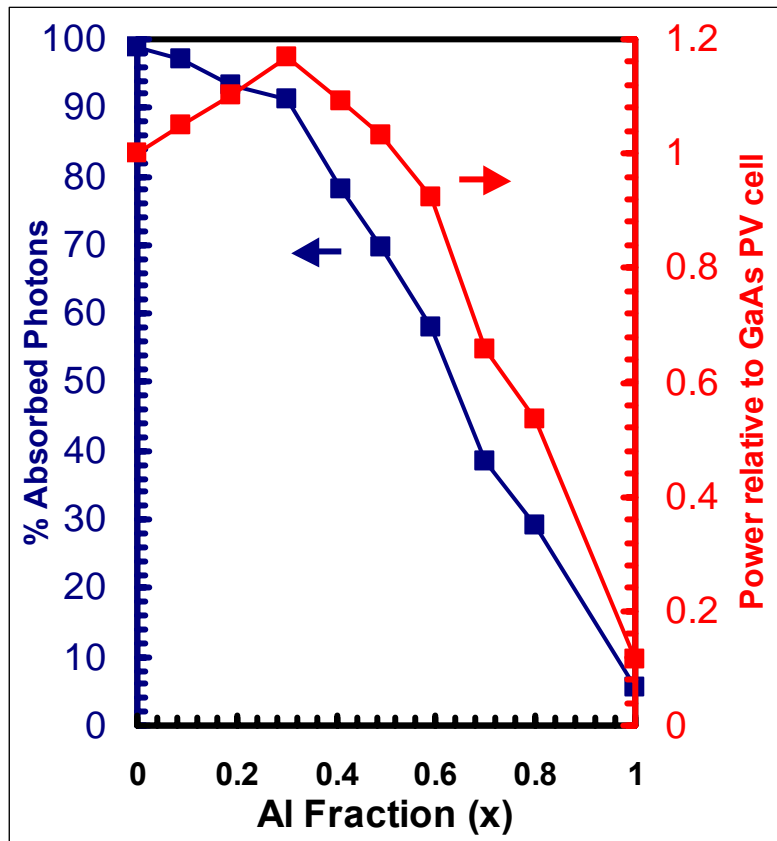
• t = thickness of absorption region $\sim 1 \mu\text{m}$

• α = absorption coefficient

• I_0 = Incident Photon Flux



- Spectral distribution of absorbed photons for various $\text{Al}(x)\text{Ga}(1-x)\text{As}$ compositions.
- Photons with energies below the bandgap are not absorbed
- As bandgap increases, number of absorbed photons decreases

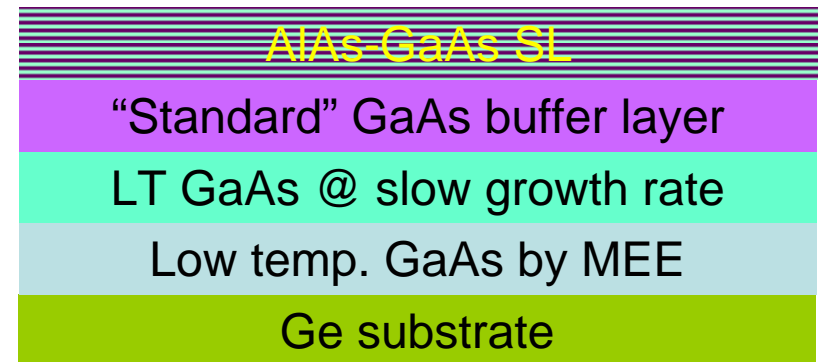


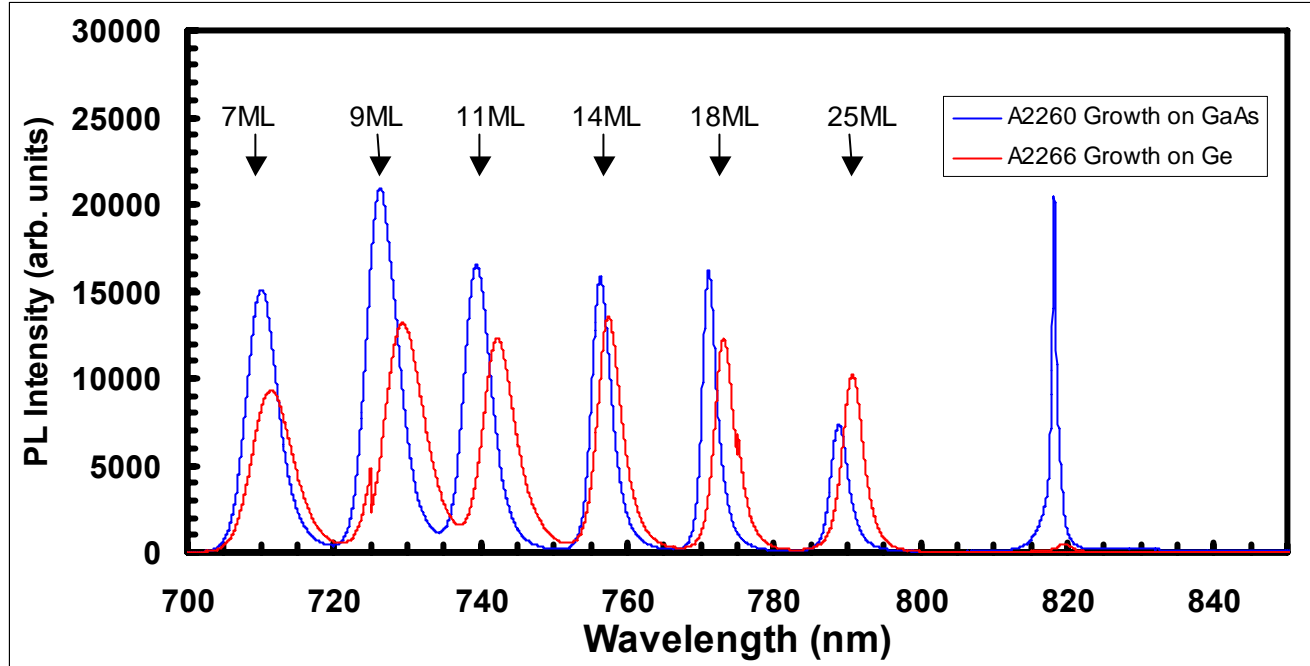
- Normalised to GaAs Cell which has a similar performance to a conventional poly-crystalline Si cell
- Maximum ~30% Al composition
- ~18% improvement compared to GaAs cell
- Small gains could be made by increasing the absorption layer thickness above 1 μm
- Estimated power ~1 $\mu\text{W}/\text{cm}^2$ for this example

Percentage of absorbed photons

Product of absorbed photons and bandgap

- Substrate degassed and Ge oxide(s) removed by a 20 min anneal at 640°C.
- 120s exposure to Arsenic flux
- Migration Enhanced Epitaxy of 10 monolayers (ML) GaAs at ~350°C and a growth rate of ~0.1 ML/s.
- ~0.1 μm of GaAs at ~500°C and a growth rate of ~0.1 $\mu\text{m/hr}$
- ~0.5 μm of GaAs at ~580°C and a growth rate of ~1 $\mu\text{m/hr}$
- AlAs-GaAs superlattice may be required to provide electrical isolation of III-V device structure from Ge substrate, can also reduce interface roughness.





- Multiple Quantum Well structure
- AlGaAs/GaAs Quantum wells
- Good test of material quality and morphology

- Photovoltaic cell design has been optimised to work with an artificial light source.
- There are gains to be made by tuning the bandgap of the material to the spectrum of the light source.
- Not necessarily advantageous to maximise the number of absorbed photons
- Growth of III-V material on Ge substrates has commenced, further optimisation is required to improve material quality.
- Initially we can grow an optimised PV cell on a GaAs substrate to test the design and compare it with GaAs or poly-Si based PV cells.