Triple-junction InGaP/GaAs//InGaAs Solar cell for Mobile Devices

Karen Yang
ECE 443 Final Project

ILLINOIS
Electrical & Computer Engineering
COLLEGE OF ENGINEERING
Motivation

- Widespread dependence on mobile devices
  - Emergency services
  - Navigation

- Limited surface area
  - Silicon: $\eta \sim 20\%$ [1]
  - InGaP/GaAs/Ge: $\eta \sim 32\%$ [2]
  - InGaP/GaAs/InGaAs: $\eta \sim 34\%$ [3]

- Decrease cost
  - Mechanically bonded InGaP/GaAs to InGaAs cell
  - No buffer region needed

Fig. 1 Solar irradiation spectrums (AM1.5G in Green) [4]

Fig. 2 QE of InGaP/GaAs/InGaAs structure [5]

Background

▪ Current Matching
  – InGaP/GaAs/Ge: too much bottom cell current
  – InGaP/GaAs/InGaAs: larger bandgap = larger $V_{OC}$

▪ Lattice Matching
  – $a_{GaAs} = 5.65 \text{ Å}$; $a_{InGaAs} = 5.77 \text{ Å}$ % → Difference: 2.1%
  – Strained structures: altered band structure
  – Misfit dislocations: recombination sites

▪ Graded buffer: extra fabrication, extra expense
▪ Mechanical bonding: transparent layers between cells

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### Device Structure

- **Window:** prevent electrons from recombining at front surface
- **BSF:** prevent holes from recombining at back surface
- **Tunnel junction:** enable tunneling between cells without reverse current (reverse pn junction)

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**Fig. 4a** Structure of optimized dual junction InGaP/GaAs cell with layer functionality, composition, thickness, and doping levels (left)

**Fig. 4b** Structure of optimized single junction InGaAs cell (top)
Parameter Optimization

- **Effect of Doping on J_{MPP} and Efficiency on DJ**
  - **GaAs Base Doping (cm^{-3})**
  - **J_{MPP} (mA/cm^2)**
  - **Efficiency (%)**
  
- **Effect of Base Thickness on J_{MPP} and Efficiency on DJ**
  - **GaAs Base Thickness (um)**
  - **J_{MPP} (mA/cm^2)**
  - **Efficiency (%)**

- **Effect of Base Doping on V_{MPP} and Efficiency on InGaAs**
  - **InGaAs Base Doping (cm^{-3})**
  - **V_{MPP} (V)**
  - **Efficiency (%)**

- **Effect of Base Thickness on V_{MPP} and Efficiency on InGaAs**
  - **InGaAs Base Thickness (um)**
  - **V_{MPP} (V)**
  - **Efficiency (%)**

**Fig. 5a** Effect of GaAs base doping concentration on J_{MPP} and efficiency

**Fig. 5b** Effect of GaAs base thickness on J_{MPP} and efficiency

**Fig. 5c** Effect of InGaAs base doping concentration on J_{MPP} and efficiency

**Fig. 5d** Effect of InGaAs base thickness on J_{MPP} and efficiency
Simulated Results

Fig. 6a Band diagram for InGaP/GaAs
Fig. 6b Band diagram for InGaAs

Fig. 7a JV curve and power output for InGaP/GaAs
Fig. 7b JV curve and power output for InGaAs
Fig. 7c JV curves for InGaP/GaAs and InGaAs

$J_{MPP} = 12.17 \text{ mA/cm}^2$
$V_{MPP} = 2.787 \text{ V}$
$P_{MPP} = 14.8 \text{ W}$
$\eta = 34\%$
Application and Next Steps

Financial Feasibility

- iPad 8th Gen: 5.2V; 2.4A [7]
  - Two cells in series: 5.57V; 2.65A [8]
  - $1031 at 200kW/yr production level [9]

- iPhone 13: 5V; 1A [7]
  - One iPhone-sized cell: 2.787V; 1.276A [10]
  - $250 at 200kW/yr production level [9]

Next Steps

- MOCVD optimization for theoretical efficiencies
- Widespread adoption of technology: ↓ Cost

Conclusions

- Mobile devices: limited surface area
  - High efficiency: InGaP/GaAs//InGaAs
- Vary parameters
  - GaAs base thickness and doping
  - InGaAs base thickness and doping
  - Highest current density of GaAs
  - Highest voltage for InGaAs
  - $J_{MPP} = 12.17 \text{ mA/cm}^2; V_{MPP} = 2.787 \text{ V}$
- 34% efficient, good match to iPad charging
- Expensive: $1031 \text{ iPad}/$250 iPhone