School of Photovoltaic and Renewable Energy Engineering

Can Copper be an alternative strategy of front contact for GaAs-based III-V solar cells?

Mengdi Liu, Udo Roemer, Alison Lennon, N.J. Ekins-Daukes

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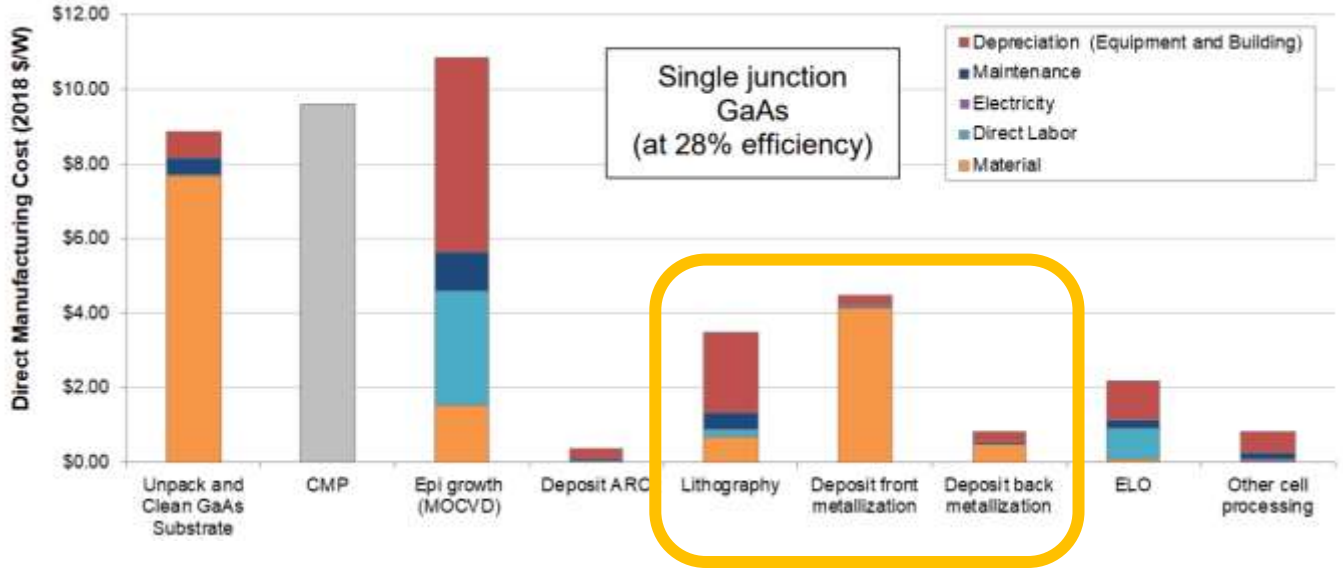
Background

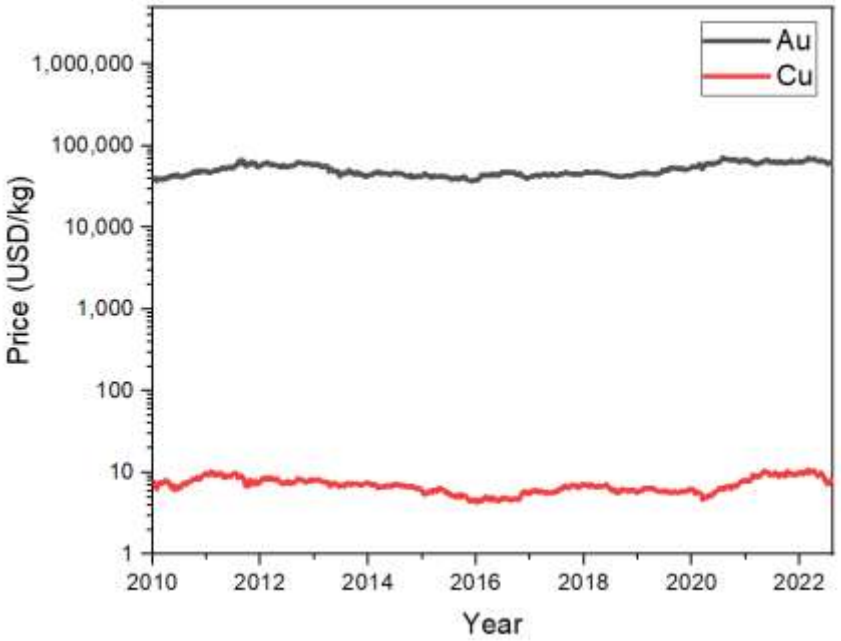
CMP: chemo-mechanical polishing



- Front metallization costs: about US$ 4/Wdc, **10% of total costs**.
- Prevailing metallization approaches have prioritized performance over cost.

[1] K. A. Horowitz, T. W. Remo, B. Smith, and A. J. Ptak, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2018.

Copper?



- **High conductivity** (5.8×10^7 S m^{-1}) **;**
- **Low material cost**（below US$10/kg ）**;**
- **Low processing cost** (plating);
- US$**4.00**/ Wdc ➡ US$**0.07**/ Wdc

- **Fast diffuser** in GaAs (diffusion coefficient 10^{-9} cm^2/s at 100℃);
- Introduce **trap levels** in the bandgap;
- **Limited** researches on Cu-plating technology for III-Vs;

[2] "Gold Prices - 100 Year Historical Chart." macrotrends.
[3] "Copper Prices - 45 Year Historical Chart." macrotrends.
[4] M. Woodhouse and A. Goodrich, National Renewable Energy Lab (NREL), 2013.

Motivation

Reducing the **metallisation costs** of III-V solar cells but without sacrificing efficiencies

- Improved understanding of the metallurgy associated with the different interfaces in Cu-plated contacts;
- Demonstrations of industrially-feasible Cu-plated metallisation processes.

Outlines

I. Copper diffusion barrier layer investigation;

II. Copper plating development.

Accelerated Ageing Test

- Temperature-depend diffusion $\left(D = D_0 \exp(-E_a/kT)\right)$

- Temperature accelerated tests: $\frac{t_{op}}{t_{acc}} = \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{op}} - \frac{1}{T_{acc}}\right)\right]$

➢ Arrhenius law

➢ Activation energy Ea ranging from 0.9-1.5eV for CPV III-V solar cells

Ea=0.9eV

T_{acc}	t_{acc}	T_{op}	t_{op}	If assuming 5h per day
300 ºC	0.5 h	80 ºC	42559.3 h	23.3 years
300 ºC	0.5 h	110 ºC	4200.9 h	2.30 years

acc: accelerated condition op: operating condition

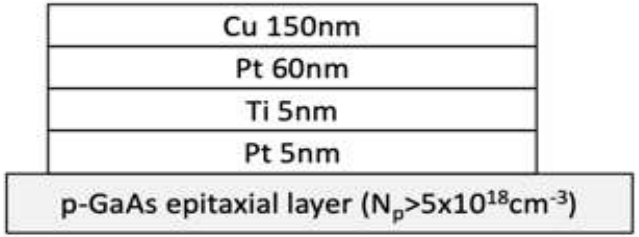
[5] N. Núñez, J. González, M. Vázquez, C. Algora, and P. Espinet, Progress in Photovoltaics: Research and Applications, 2013.
[6] N. Nuñez, M. Vazquez, V. Orlando, P. Espinet-González, and C. Algora, in Progress in Photovoltaics: Research and Applications, 2015.
[7] P. Espinet-González et al., in Progress in Photovoltaics: Research and Applications, 2015.

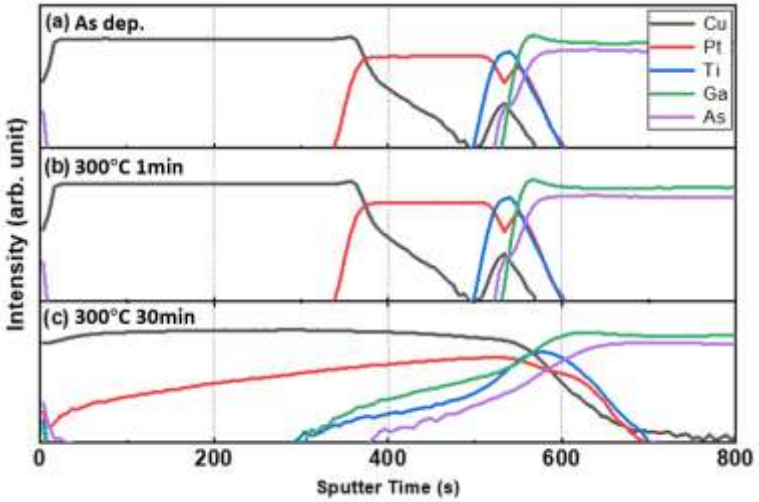
Copper Barriers

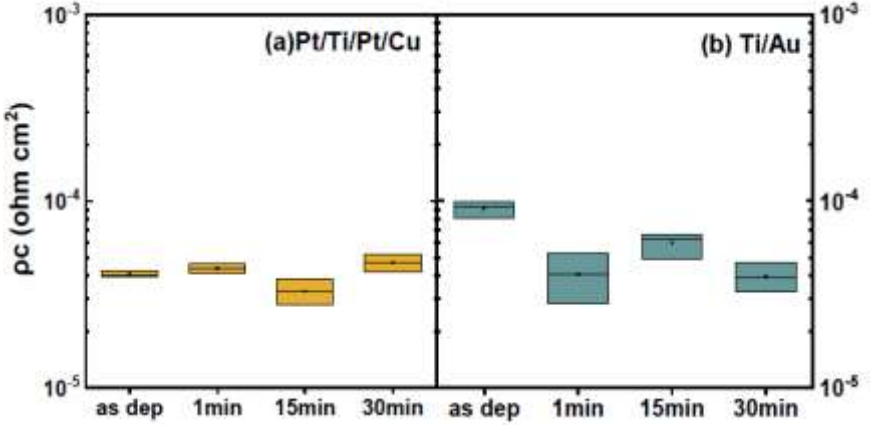
- Barrier performance qualification conditions: no heavy Cu penetration after annealing at 300 ºC for 30min;
- Deposition method: e-beam evaporation.

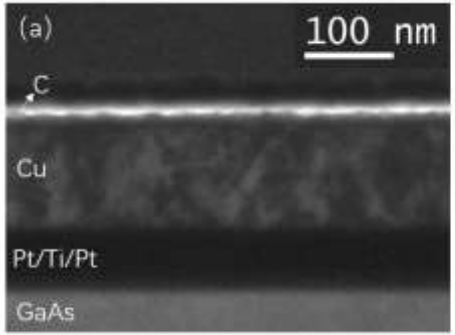
	Structure
n-GaAs	Pd10nm/Ge150nm/Cu 150nm
p-GaAs	Pt 5nm/Ti10nm/Pt 60nm/Cu 150nm

For p-GaAs

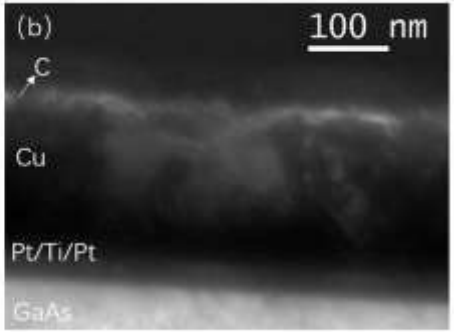






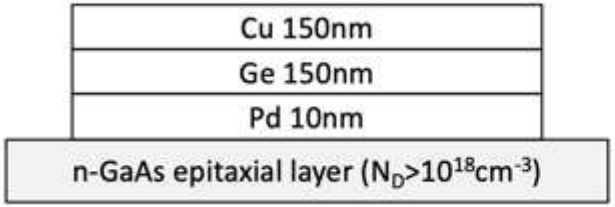


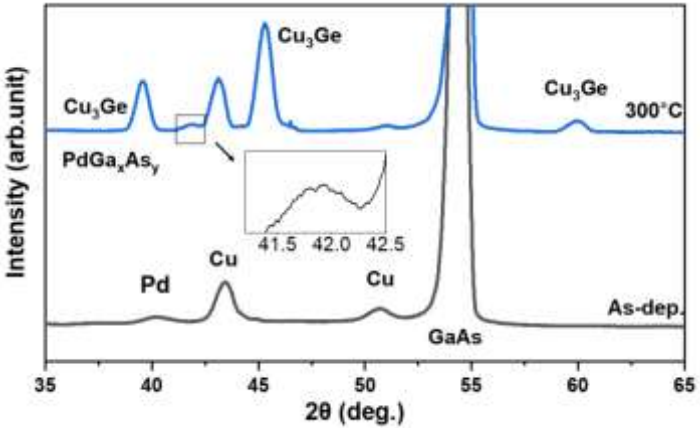
300℃ 1min

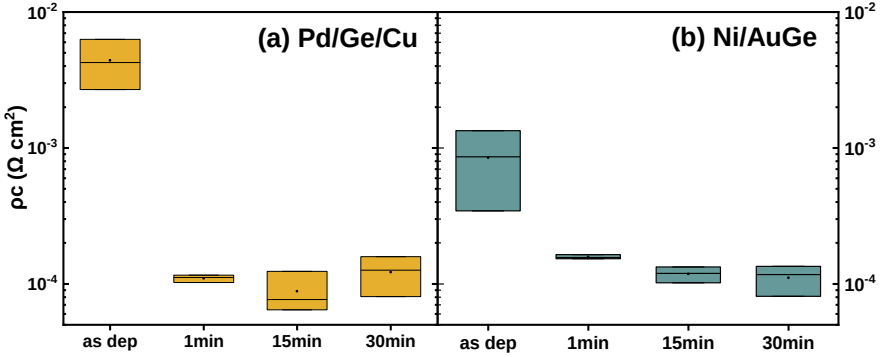


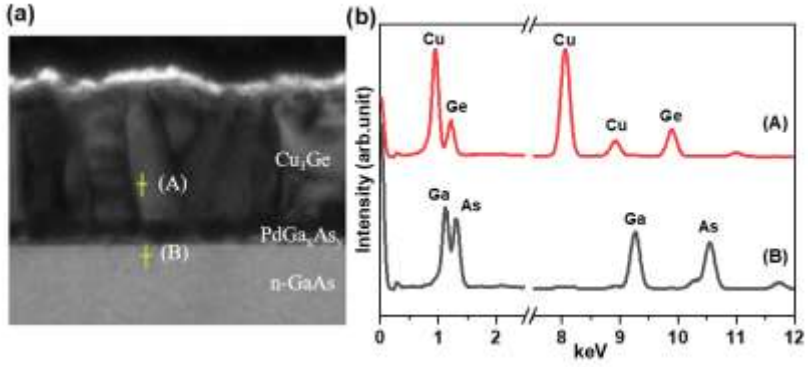
300℃ 30min

For n-GaAs

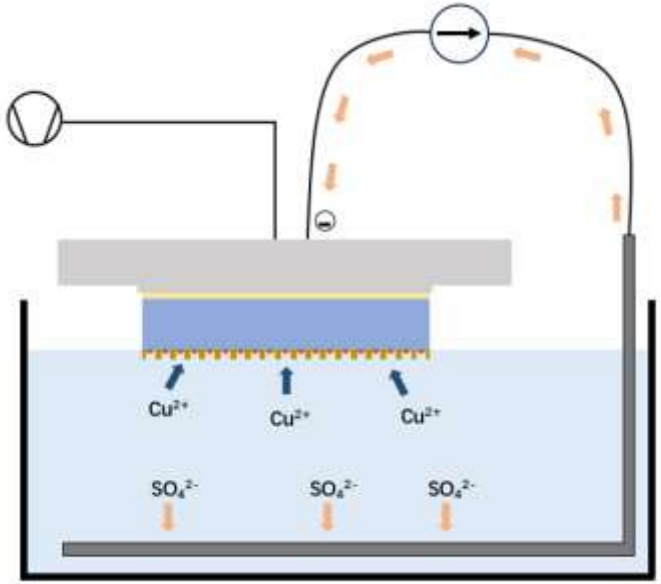

Cu 150nm
Ge 150nm
Pd 10nm
n-GaAs epitaxial layer (N_D>10^{18}cm^{-3})


Intensity (arb.unit)
Cu3Ge
Cu3Ge
Cu3Ge
300°C
PdGaxAsy
41.5 42.0 42.5
Pd
Cu
Cu
GaAs
As-dep.
35 40 45 50 55 60 65
2θ (deg.)

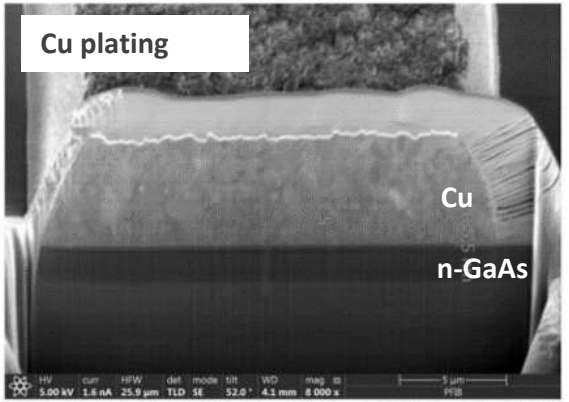

(a) Pd/Ge/Cu
(b) Ni/AuGe
ρc (Ω cm²)
10-2
10-3
10-4
as dep
1min
15min
30min

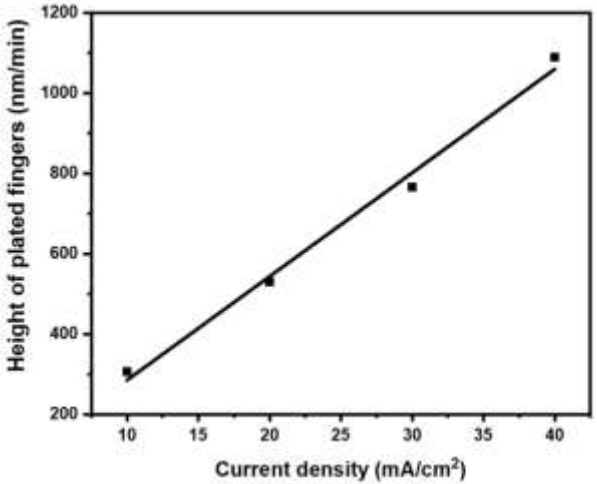

(a)
(b)
Cu3Ge
(A)
PdGaxAsy
(B)
n-GaAs
Intensity (arb.unit)
Cu
Ge
Ga
As
(A)
(B)
0 1 2 8 9 10 11 12
keV

Copper Plating

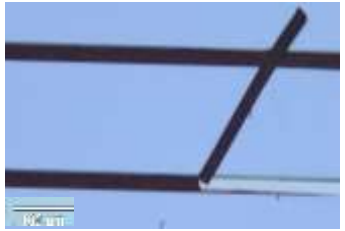


Cu anode
Cathode (ohmic contact layer)
Photoresist
III-V
Rear side metallization
Holder
Vacuum pump





Voids Control

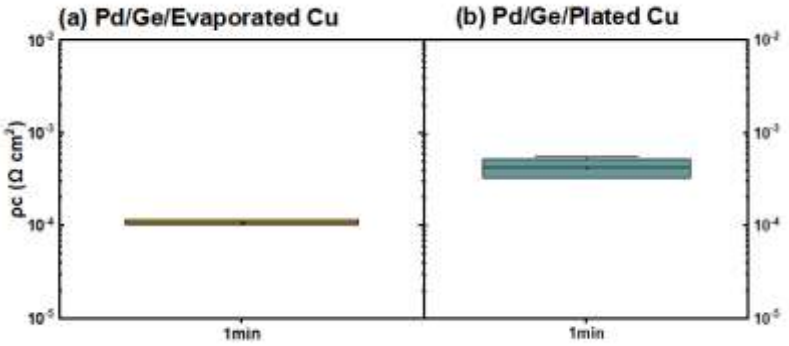


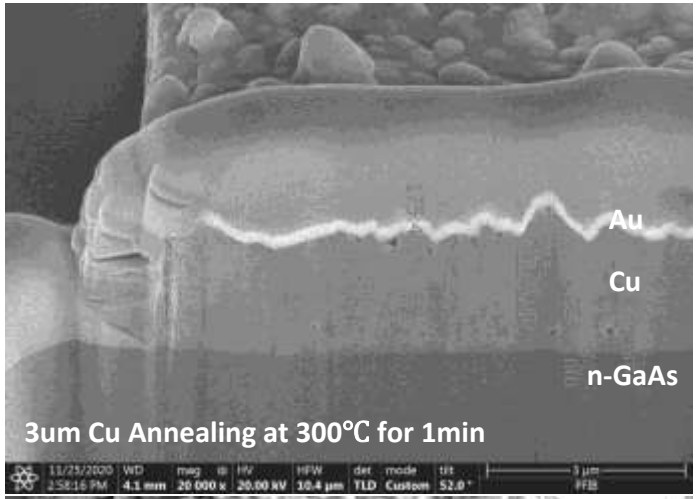
Possible reason:

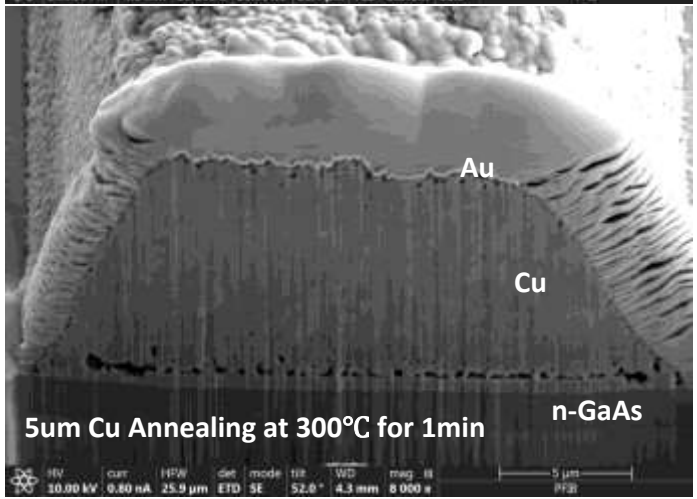
- ➢ Defects ➡ Fast route

❌ Additional cleaning process

(wet chemical cleaning, plasma etching)



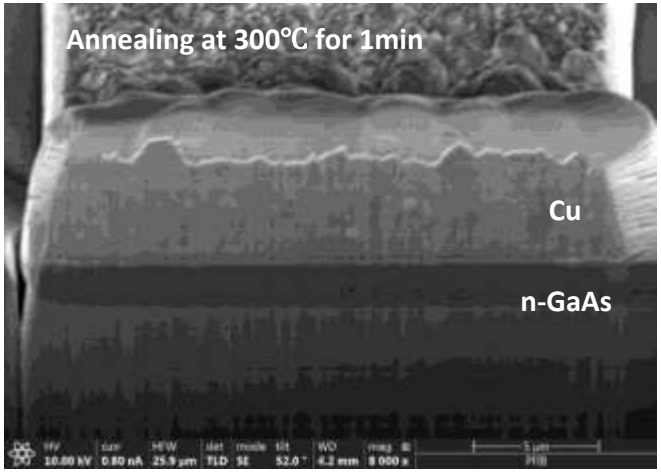


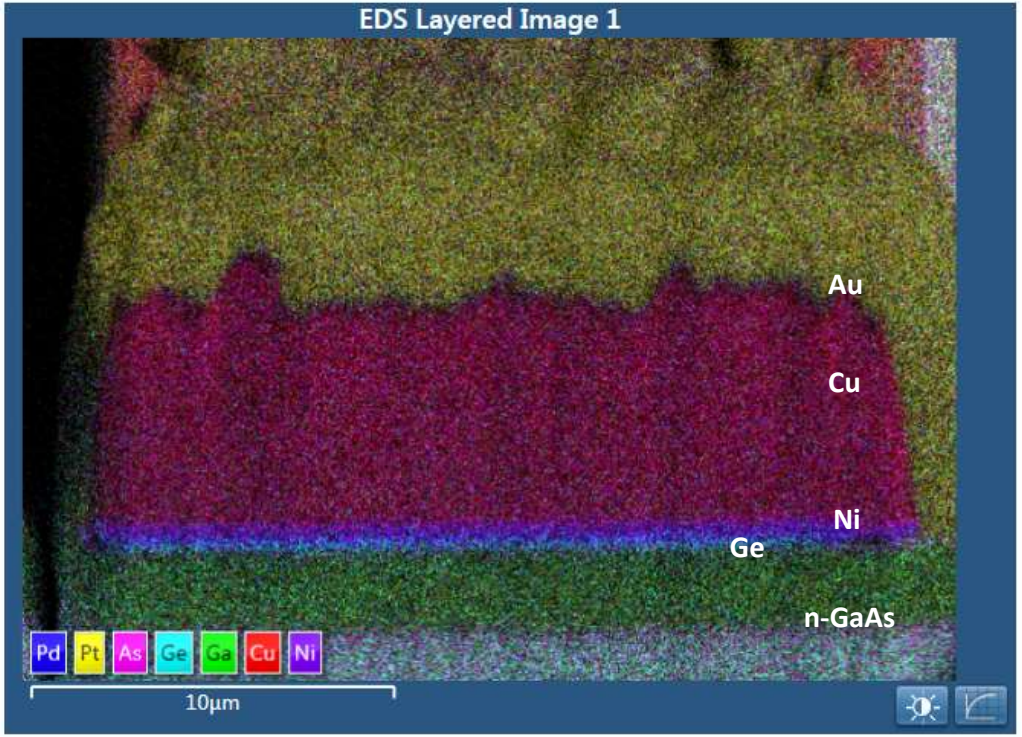


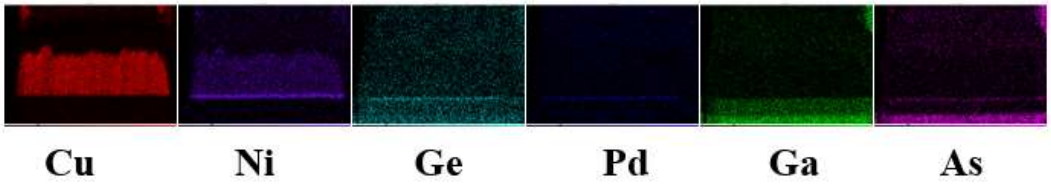
Voids Control

Possible reason:

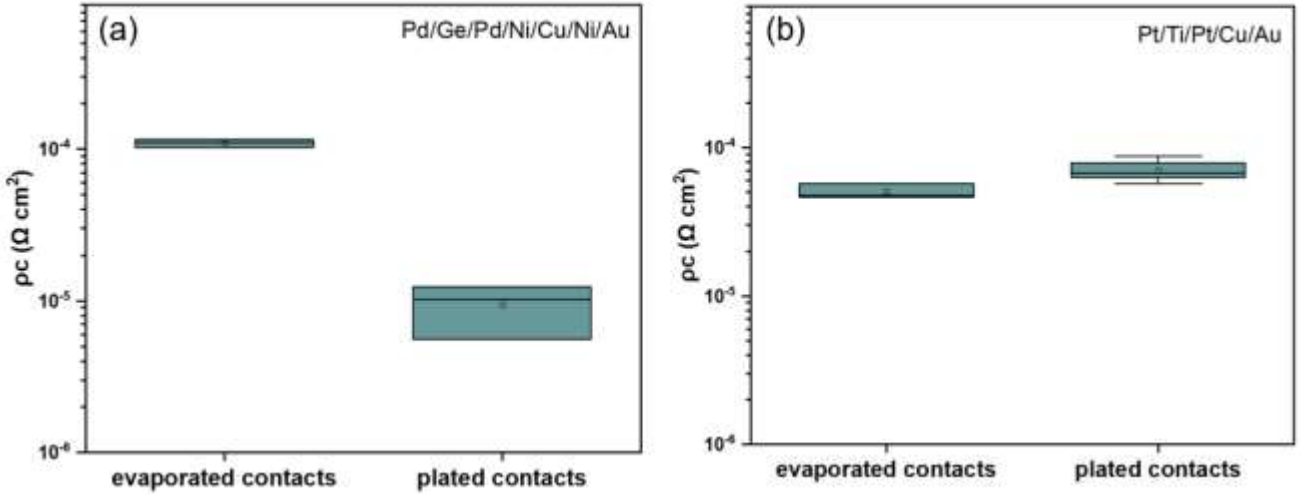
- ➢ Kirkendall effect
- • Ni seed layer







Specific Contact Resistance



n-GaAs

p-GaAs

Conclusion

Copper can be front contact for GaAs-based III-V solar cells:

- **Pd/Ge/Cu** and **Pt/Ti/Pt/Cu** evaporated metal schemes can achieve a low specific contact resistivities in the order of **10^{-5} Ω cm²** and prevent penetration after 30 min tests.
- Unbalanced diffusion rate between Cu and adjacent metal ➡ voids, and Ni can reduce Kirkendall effects;
- Specific contact resistance for the **plated contacts** were found similar to or lower than those of the comparative **evaporated contact** structure.

Questions?

Mengdi Liu

mengdi.liu@unsw.edu.au

UNSW SYDNEY

ACAP

Australian Government
Australian Renewable Energy Agency
ARENA

Preliminary results for cells