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Effect of forming gas annealing on screen-printed Ag metallization of silicon solar cells

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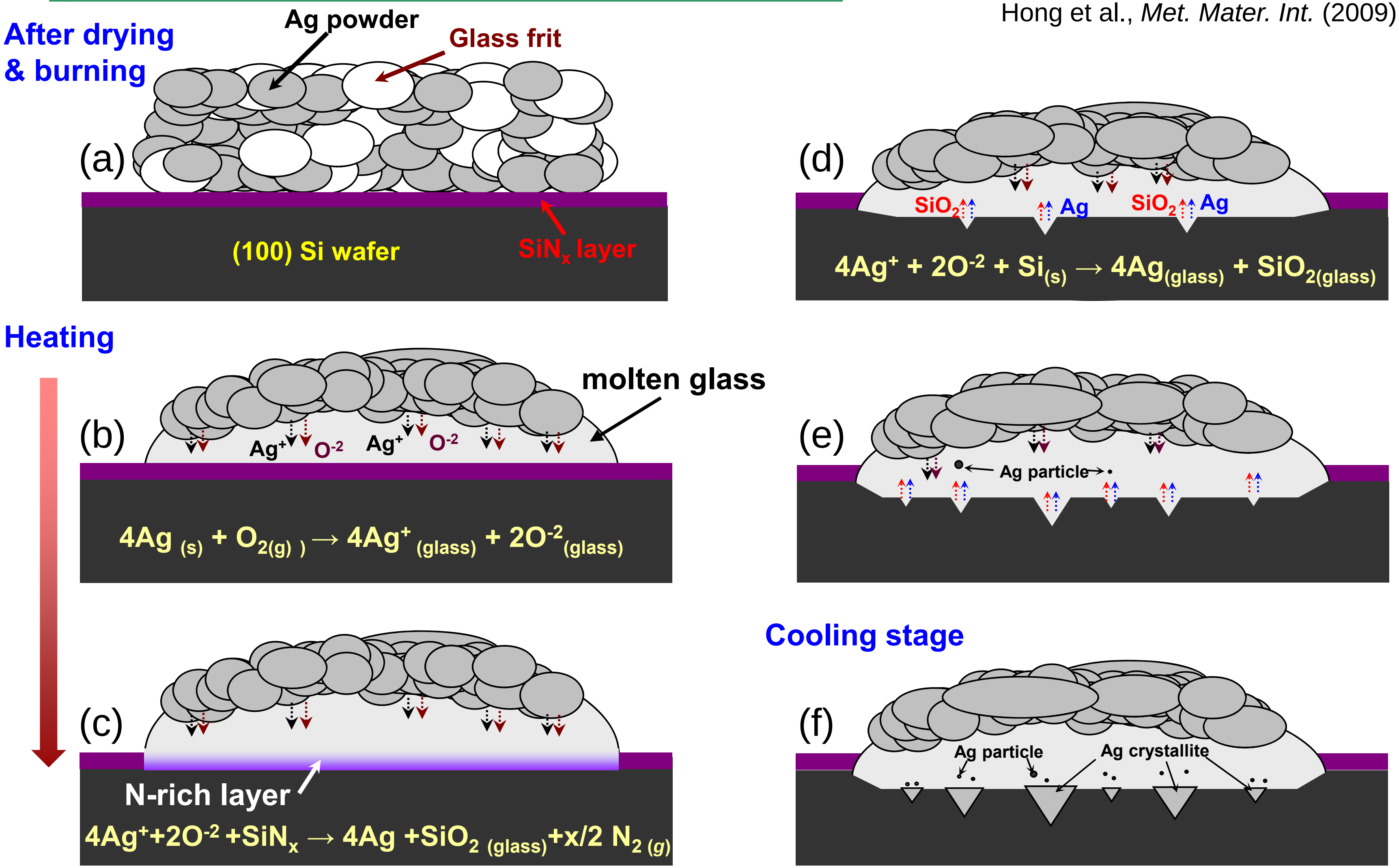
Outline

- **Motivation & Objectives**
  - Mechanism of screen-printed Ag contact formation
- **Experimental procedure**
  - FGA of cells optimally fired at 800°C and over-fired at 850°C
- **Results**
  - Specific contact resistance measurement
  - Contact microstructures before and after FGA
  - FGA of Ag-containing glass on Si wafer
- **Conclusions**

Proposed Ag contact formation mechanism

Hong et al., *Met. Mater. Int.* (2009)



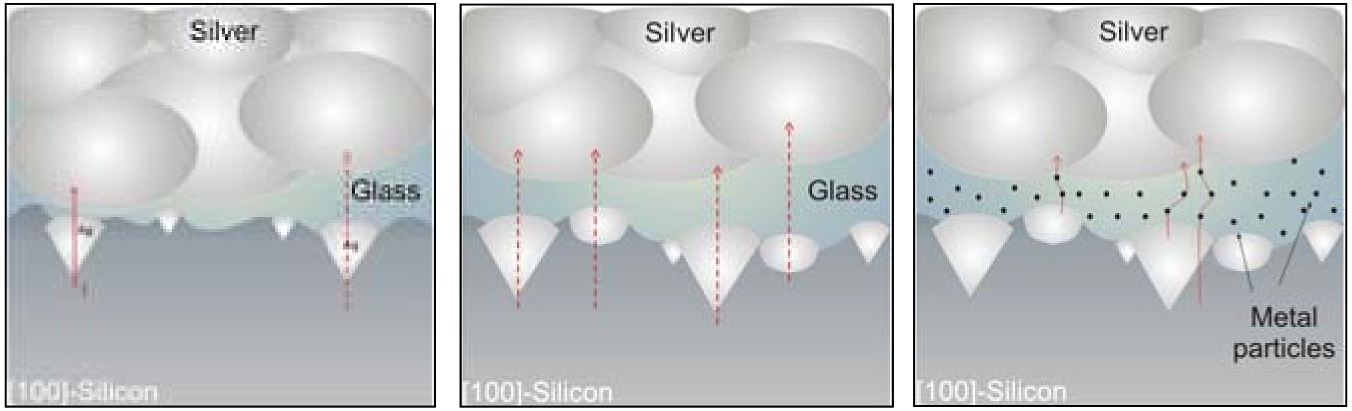
Motivation & Objectives

*In over-firing condition

	R_s ($\Omega\cdot cm^2$)	FF
As-fired	**11.02**	**0.585**
After FGA	**0.749**	**0.766**

Ebong A et al., *Proc. 21st EU PVSEC,* 2006

Optimally fired | **Over-fired** | **After FGA**



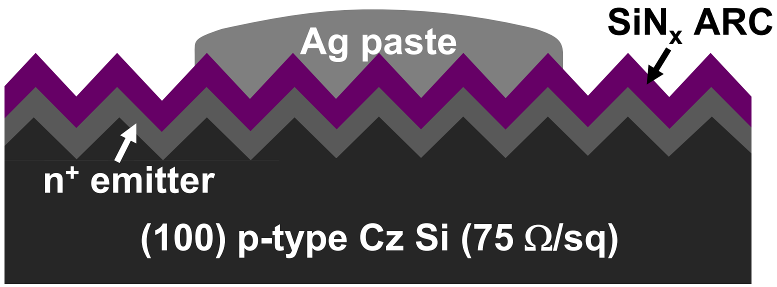
G. Schubert et al., *Proc. 21st EU-PVSEC*, 2006

- Over-fired contact has more Ag crystallites and a thicker glass than optimally fired one.
- Current transport at the over-fired contact is limited by the thick glass layer.
- It has been postulated that the beneficial effect of FGA is attributed to the reduction of metal oxide in glass.

❑ **To clarify the mechanism of the beneficial effect of FGA on the contact resistance of the screen-printed Ag front contacts of Si solar cells.**

Experimental procedures

- ρ_c and contact microstructures before and after annealing



Screen-printing & drying

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Spike-firing at 800°C & 850°C

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TLM measurement (ρ_c)

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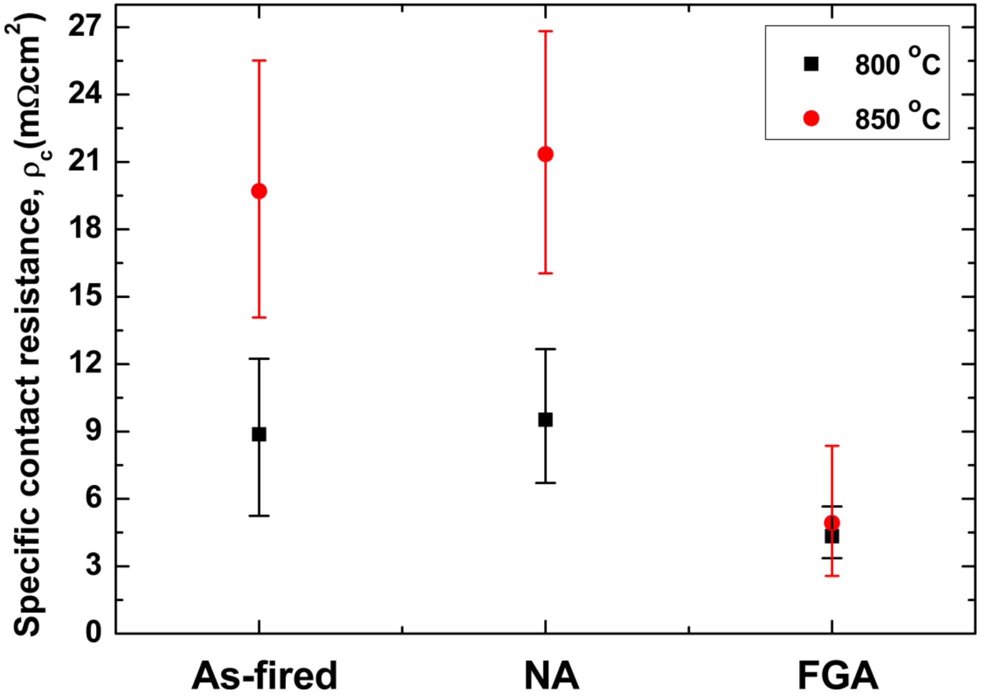
Annealing at 400°C for 30 min in N_2(NA) and N_2+10%H_2(FGA)

↓

TLM measurement (ρ_c)

- Analyses
  - Microstructure : UHR-SEM (Hitachi S-5500)
  - Contact resistance : transfer length method

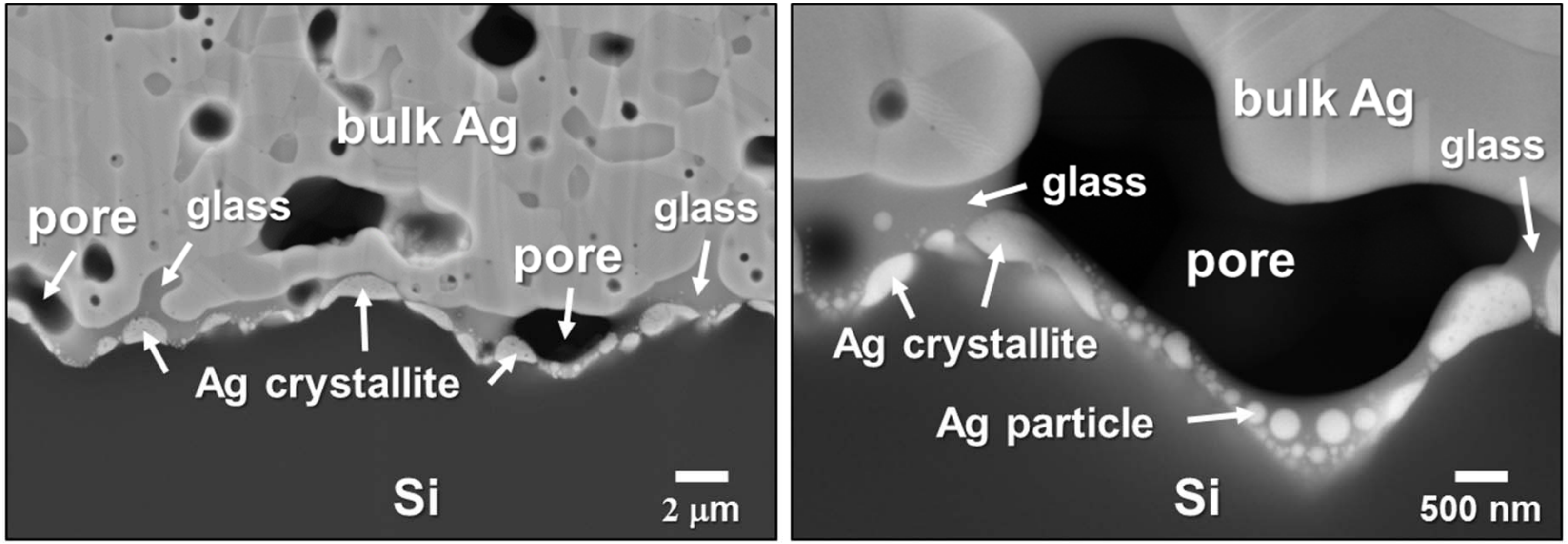
Effects of FGA and NA on contact resistance



- Before post-annealing, contacts fired at 850°C exhibited higher ρ_c than those fired at 800°C.
- NA had no beneficial effect on ρ_c.
- FGA resulted in an improvement in the contact resistance especially in over-fired case.

Interface of over-fired contact before FGA

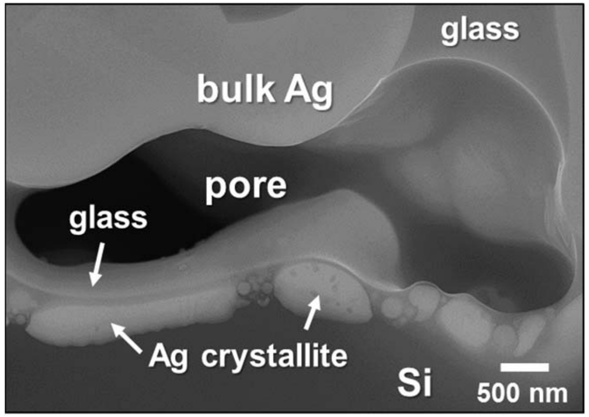
- After spike-firing at 850^{o}C



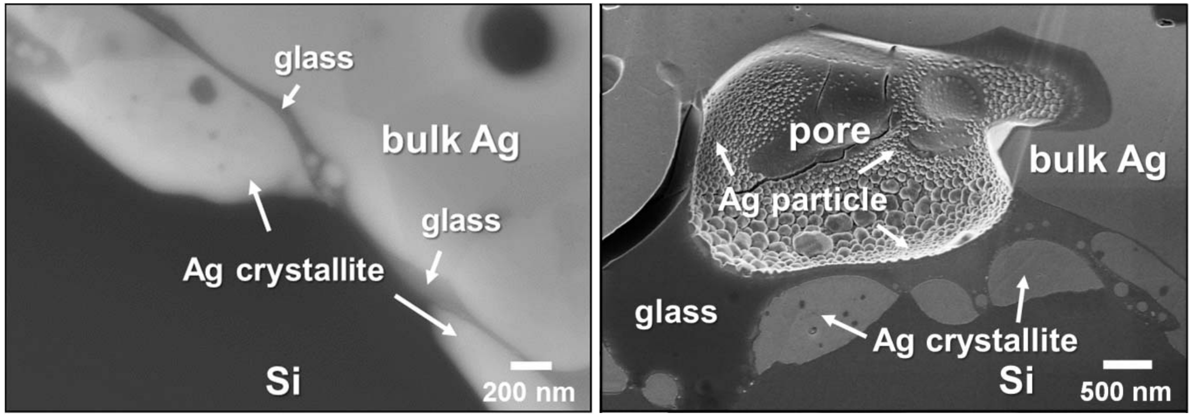
- Contact interface contained Ag crystallites grown into the Si emitter, a glass layer, and large pores.
- Ag crystallites were separated from the porously sintered Ag bulk by a glass layer.
- Ag crystallites grown onto the emitter surface underneath the large pores were covered by a thin glass layer : no contribution to the current conduction from the emitter Si to the bulk Ag.

Contact interfaces after annealing at 400°C

- After NA



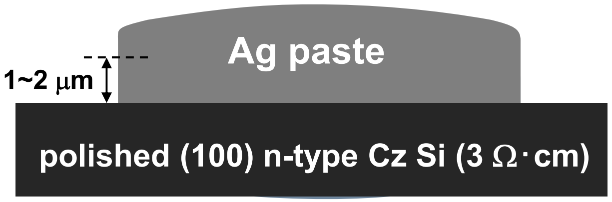
- After FGA



- After NA, no noticeable changes observed on pore surface and similar with as-fired state.
- After FGA, interfacial region away from the pores were little influenced by FGA.
- Dense layer of Ag particles were formed on the surfaces of interfacial pores.

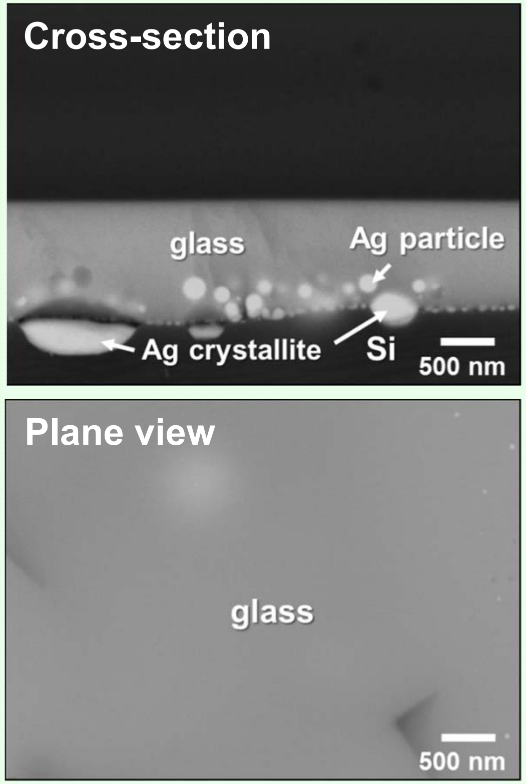
Effect of FGA on surface of glass layer

- Sample preparation

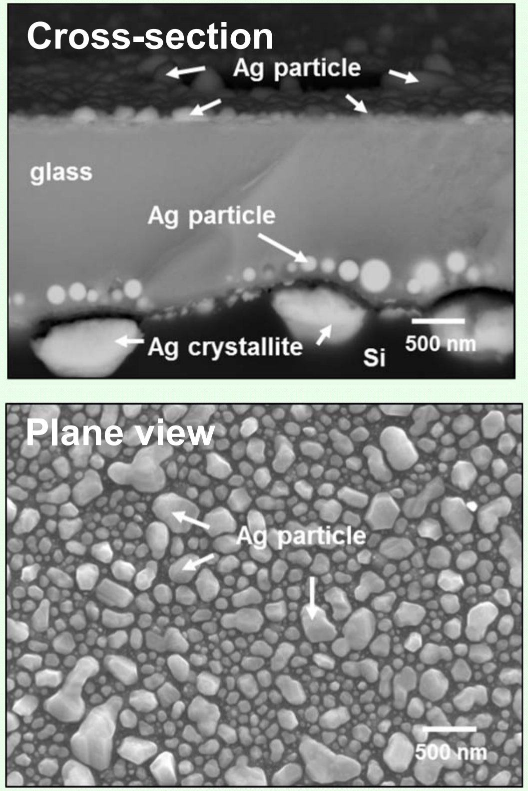


  - Thick screen-printing
  - Firing : 800 °C for 5 min

As-fired



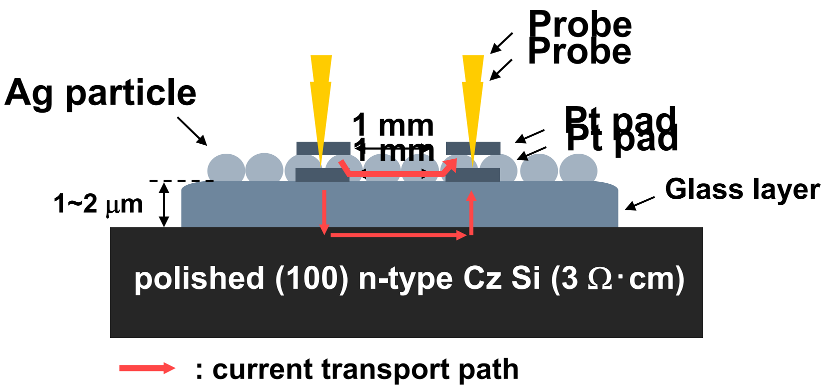
After FGA

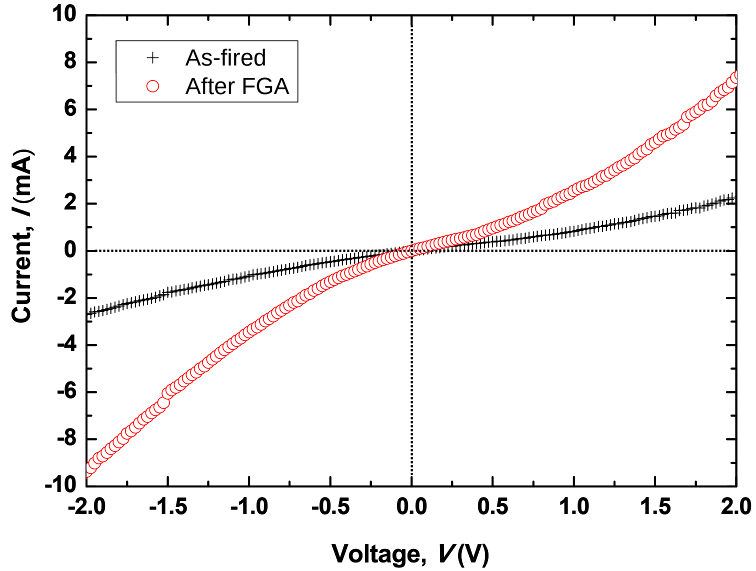


- After NA, no changes were observed.
- FGA had minor influence on glass/Si interface.
- After FGA, dense layer of Ag particles were precipitated on the surface of glass.

Effect of FGA on surface of glass layer

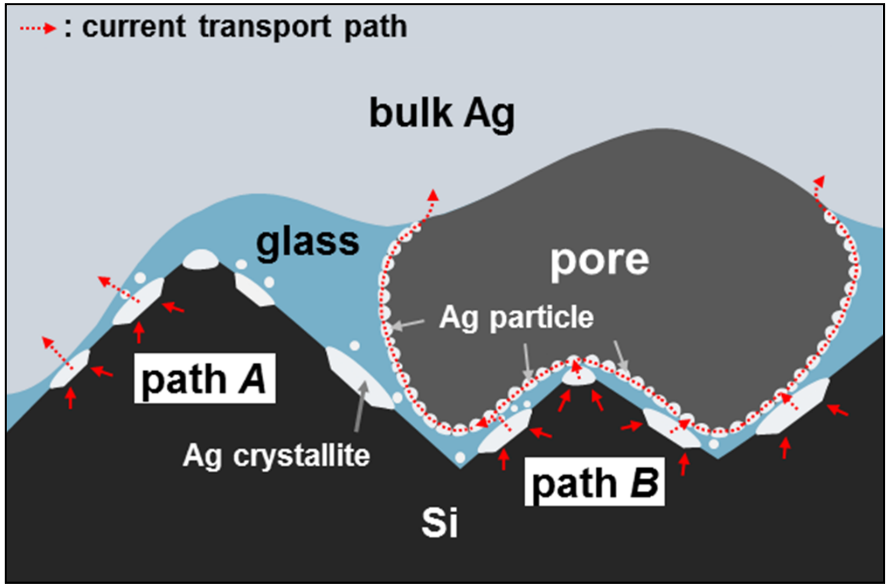
- Measuring conductance between Pt pads





- 1.12×10^{-3} S in as-fired case and 3.67×10^{-3} S in after FGA.
- The formation of Ag particles on glass surface contributed to the difference between two value.
- High density of Ag particles on glass provide an extra path for current transport.

Current transport paths after FGA



- At the as-fired state, the current conduction occurs only through path *A* away from the pores.
- After FGA, the pore surface decorated with dense layer of Ag particles provides another path for the current conduction (path *B*).
- The Ag particles were formed by out-diffusion of Ag^{+} ions contained in the glass layer and then by reduction by H_2 in the forming gas to precipitate as Ag particles.

Conclusions

- The **glass layer at the as-fired contact** interface **already contains amount of Ag^+ ions that can be reduced to form fine Ag particles during FGA.**

- During FGA, the **permeation rate of H_2** molecules into the glass layer **is negligible, compared to the out-diffusion rate of Ag^+** ions toward the pore surface that is in contact with the forming gas.

- The **beneficial effect of FGA** on the over-fired Ag contacts of Si solar cells is attributed to the pore surfaces **decorated by Ag particles, acting as an additional conduction path** for the current flow.

Thank you for your attention !