Effects of constituents in paste on low light performances of silicon solar cells

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Outline

Motivation

- Why are low light performances necessary for solar cells ?
- Previous studies
- Aim of this study

Approach

- Floating contact method

Results and Discussion

- I-V characteristics at low light intensities
- Dark I-V characteristics

Conclusion

Why are low light performances necessary ?

Module STC (Standard Test Condition) efficiency vs Final yield

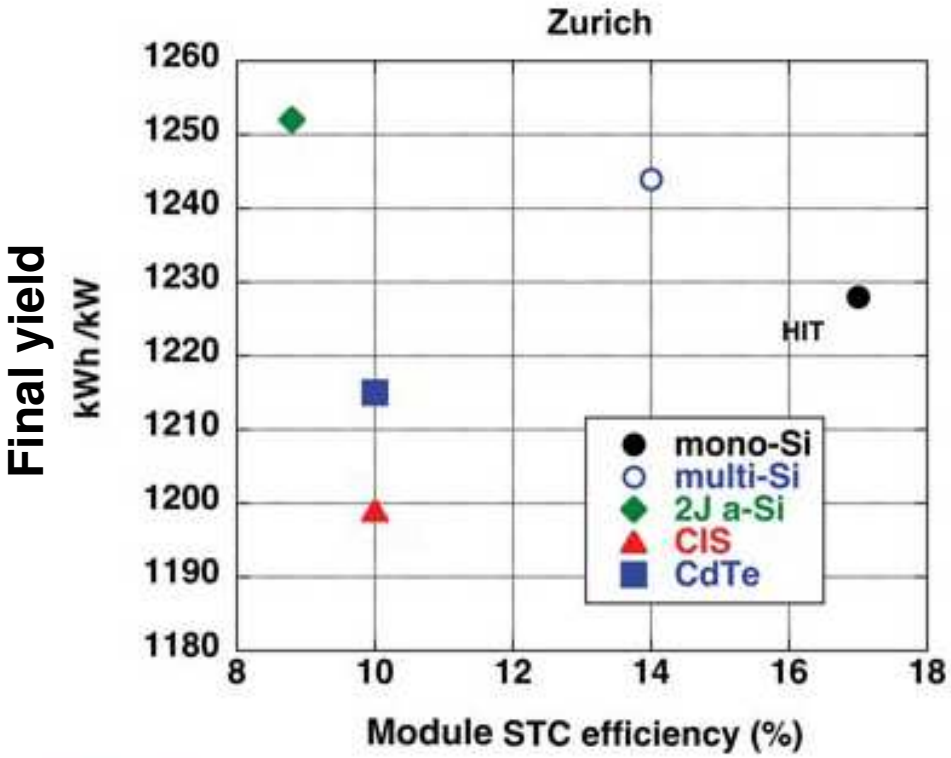


FIGURE 2 | DC Y_F (kWh/kW) for five systems ~1.8 kW in Zurich obtained over 12 months. (Created using data from Ref 14.)

Steven Hegedus, WIREs Energy Environ 2012.
doi: 10.1002/wene.61.

Final yield (YF) =

$$\frac{\text{Measured PV energy in kWh}}{\text{kW power rating under STC}}$$

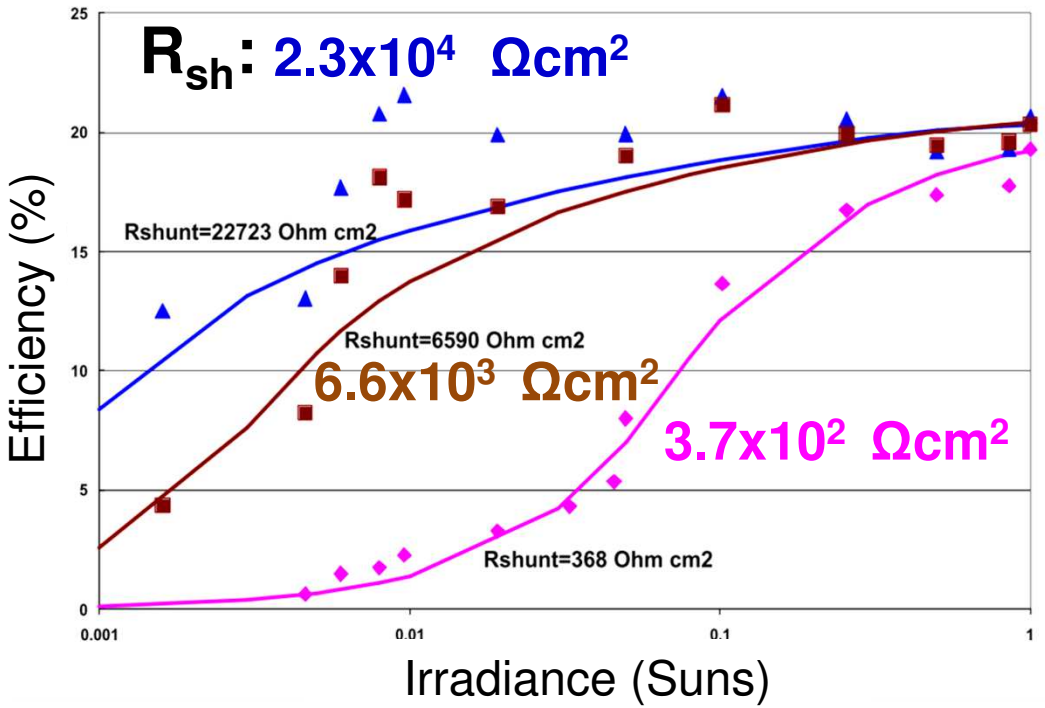
: "Effective" energy yield

High efficiency modules don't necessarily generate high energy yield.

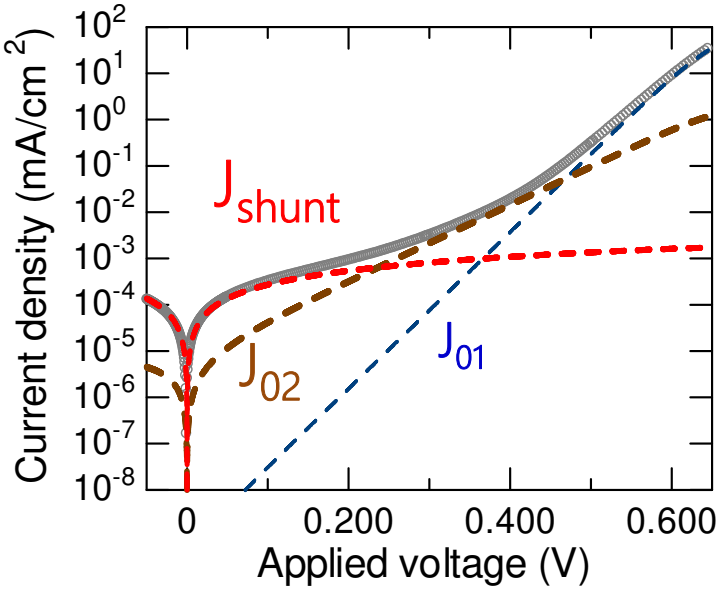
Low light performances are practically important.

Review for low light performance

Shunt resistance, R_{sh} strongly affects low light performances.



Gabriela E. Bunea et al., in Proc. 4th WCPEC, 2006, p. 1312.



J_{shunt} is dominant current loss at low voltage.

Current losses at low voltage are important for low light performances.

“Our” Previous studies

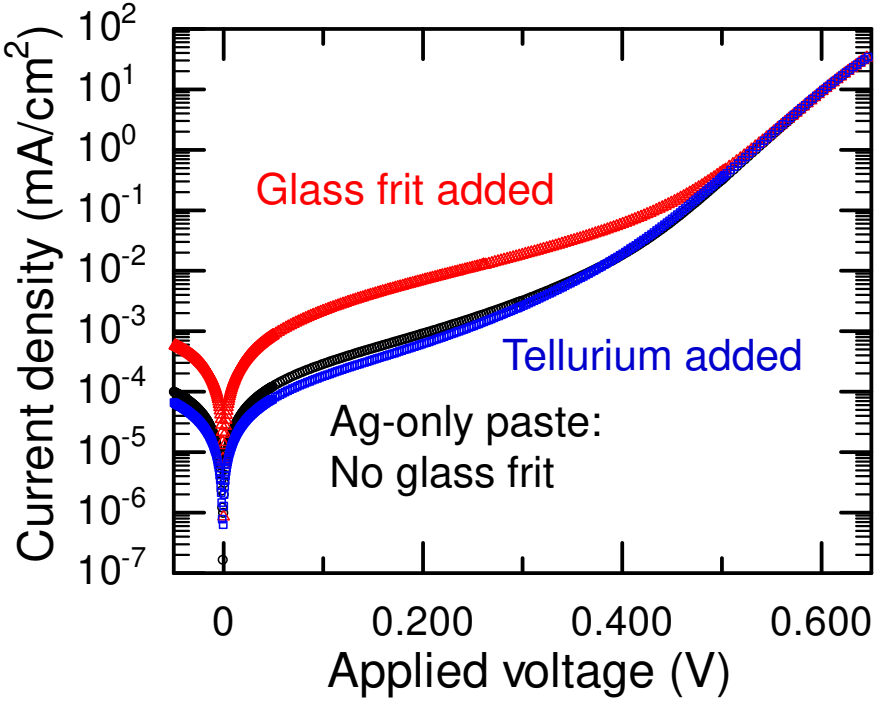
Effects of paste constituents on current losses: shunts and recombination have been demonstrated.

Paste constituents ⟺ **Shunts, Recombination**

- ✓ Ag powder
- ✓ Glass frit
- ✓ Aluminum
- ✓ Tellurium

etc.

- ✓ Some constituents cause shunts and recombination.
- ✓ some can mitigate these losses.



Aim of our work

Paste constituents

- Ag powder
- Glass frit
- Aluminum
- Tellurium

etc.

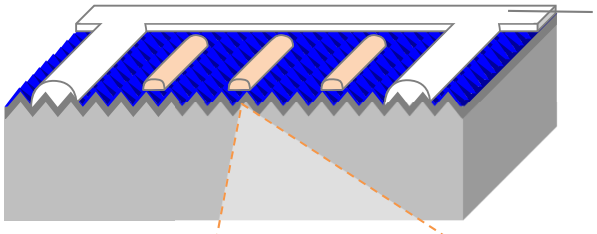
Solar cell performances at low light intensity

Aim of our work:

Investigating “each effect” of paste constituents on low light performances of solar cells

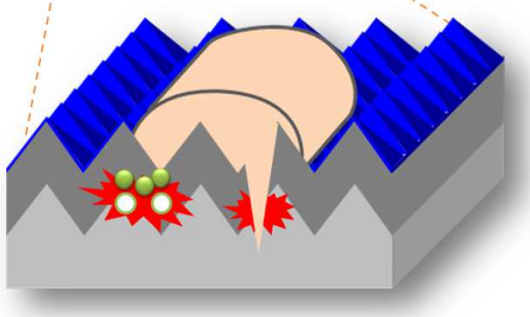
<u>Effective method: Floating contact method</u>

Approach-Floating contact method



Standard H-pattern "grid-contact"

- For "only" measuring cell parameters
- Paste is fixed throughout experiments

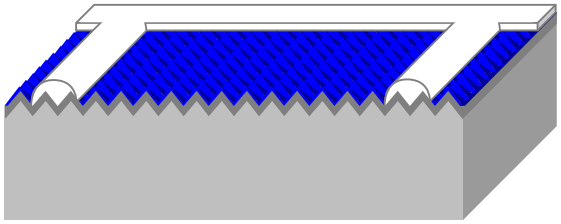


"Floating contacts (F.C.)"

- Electrically and geometrically isolated
- Any constituents can be used

✓Conductive ✓Nonconductive ✓Non-contact

Effects of F.C.

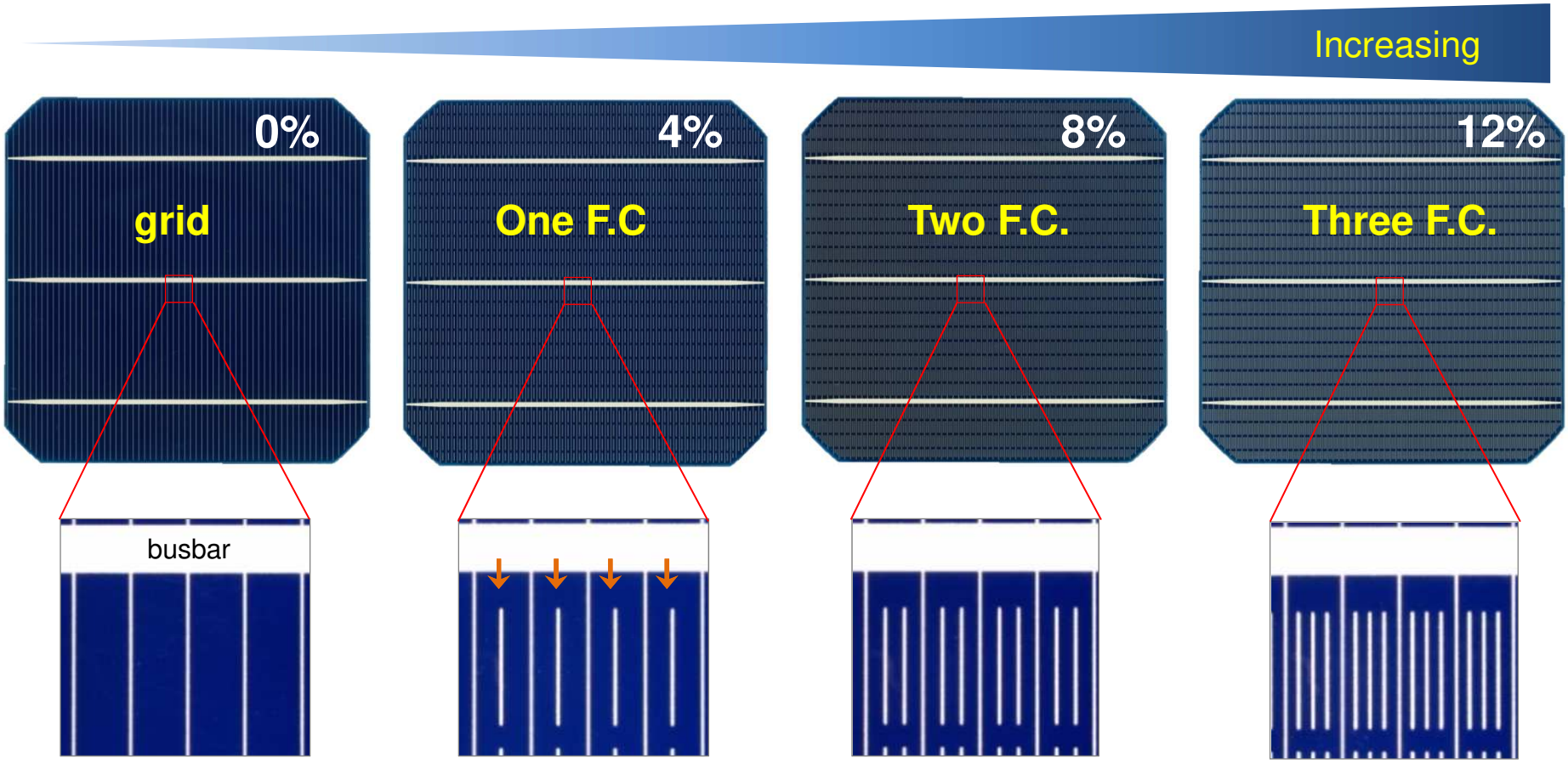


Dark → Shunts, Recombination

Light intensities → Low light performance

Approach-Floating contact method

Floating contact area “fraction”



Effects of F.C. can be clearly shown by the fraction change.

Experimental setup

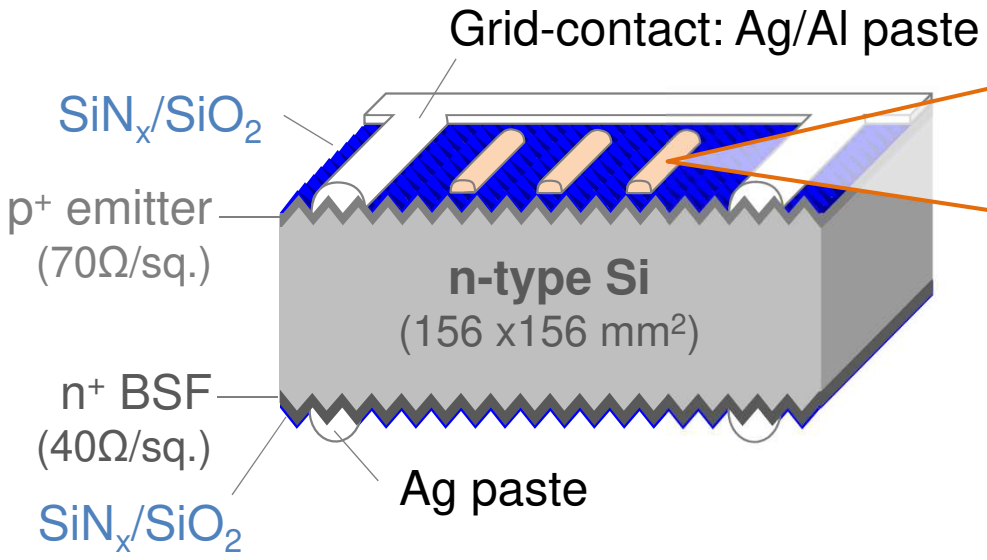
Focus of this study

An indispensable constituent;
Contact formation by firing-only

Glass frit "itself"

Characteristics of glass frit itself has been unclear.

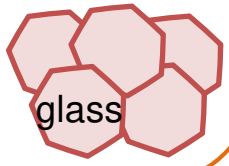
Low light performance ⟷ **Shunt, Recombination**



Floating contacts:
homemade test pastes

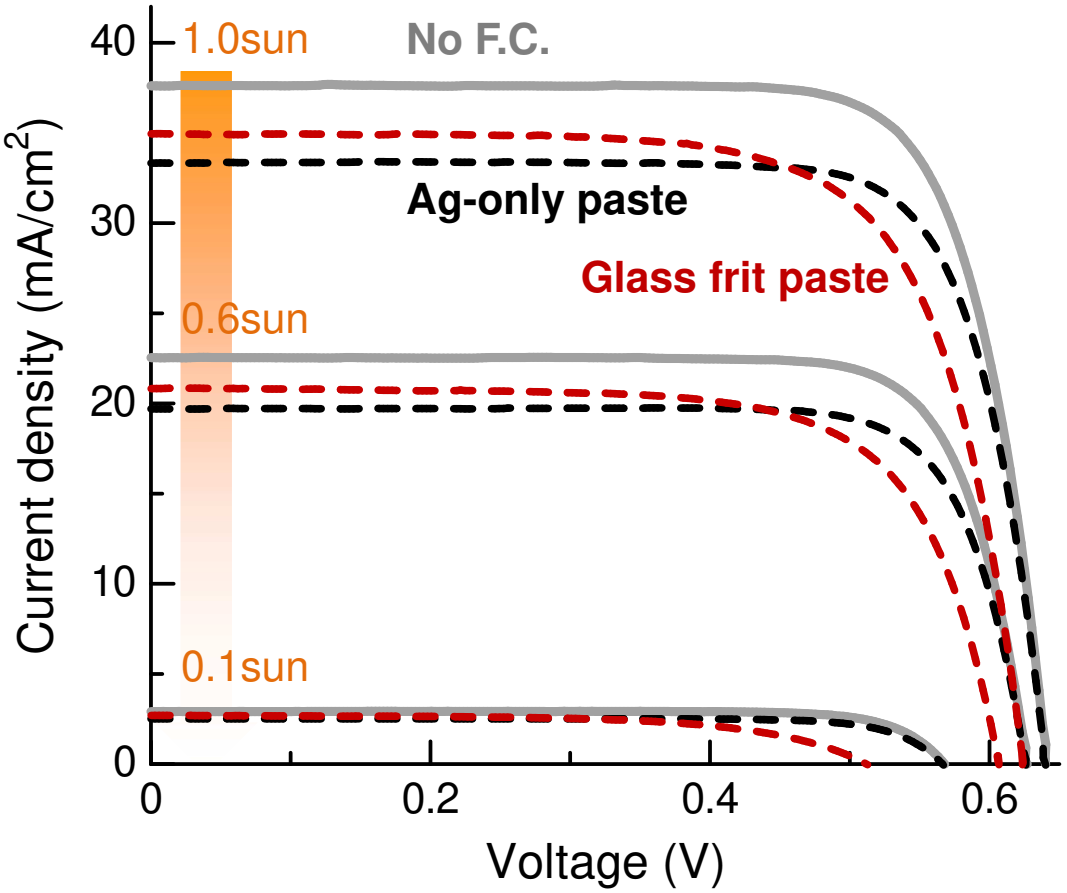
- Ag-only paste
  - No glass frit

- Glass frit paste
  - Frit only



T. Aoyama, et al" *IEEE J. Photovolt.*, vol.7, p. 1313, 2017.

Illuminated I-V curves at lower intensities



- ✓ **Light intensity affects cell parameters:**

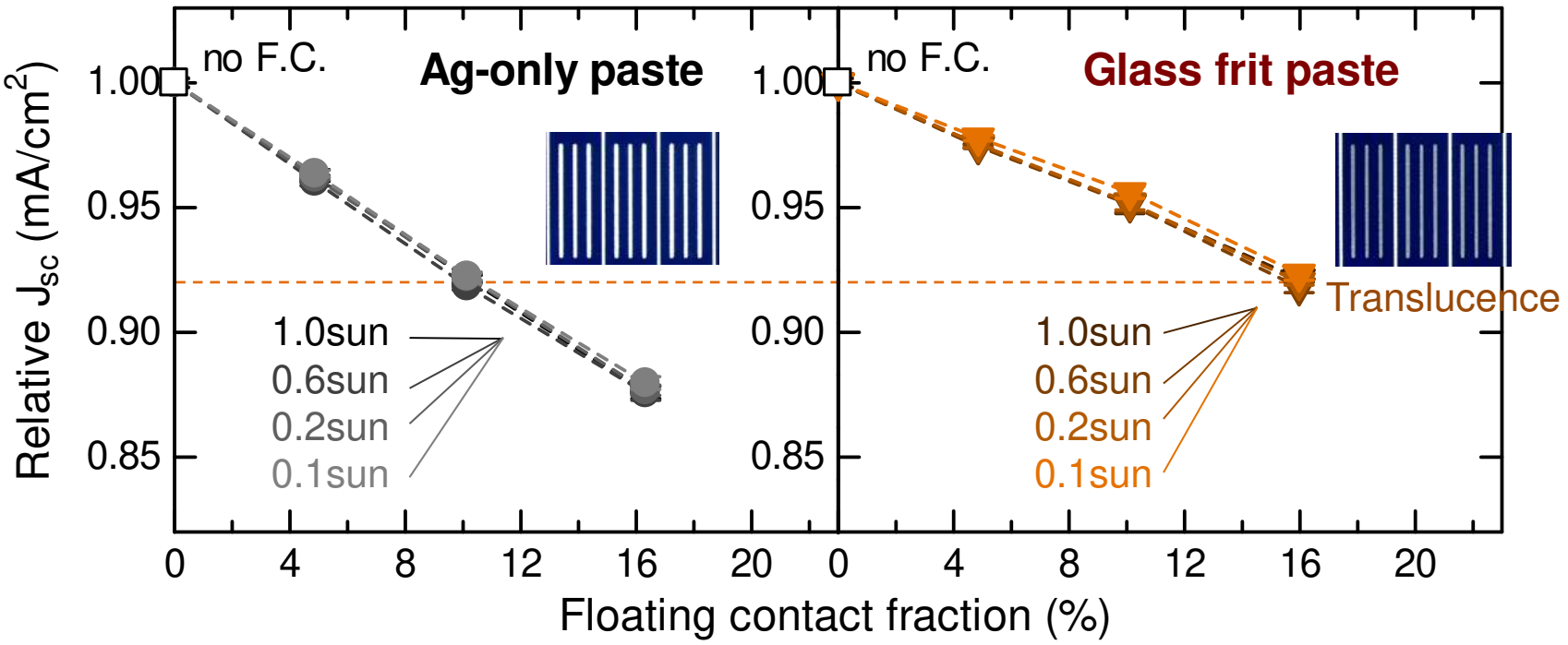
  J_{sc}, V_{oc}, FF, and R_s.

- ✓ **Cell parameters at low light intensities depend on paste of F.C.**
  - Ag-only paste; J_{sc}
  - Glass frit paste; J_{sc}, V_{oc}, FF, and R_s

$$\text{Relative cell parameter} = \frac{\text{cell parameter with F.C.}}{\text{cell parameter with no F.C.}} \text{ at each light intensity}$$

Low light performances: J_{sc}

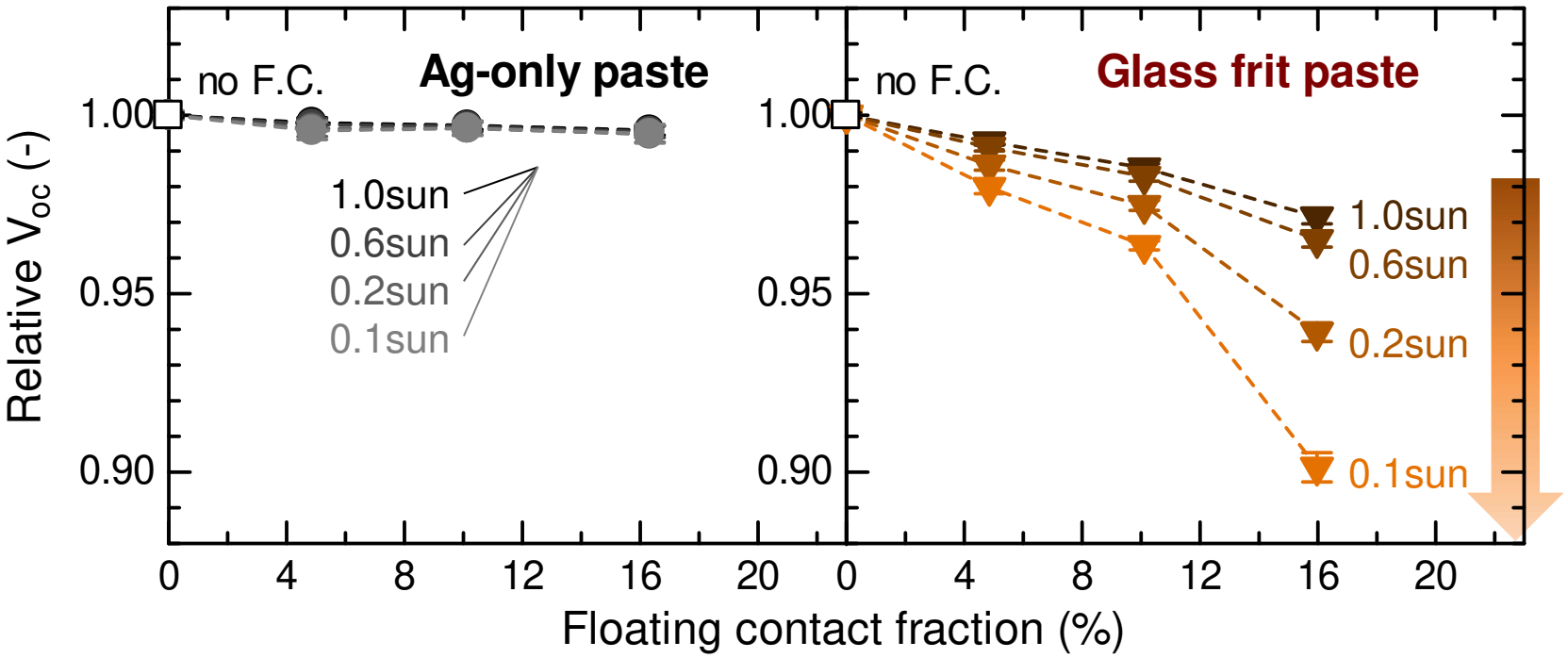
Relative-J_{sc}



- ✓ Relative-J_{sc} decreases with increasing the fraction due to shadowing.
- ✓ The decreasing rate has no dependence on the light intensity.

Low light performances: V_{oc}

Relative-V_{oc}



Ag-only paste

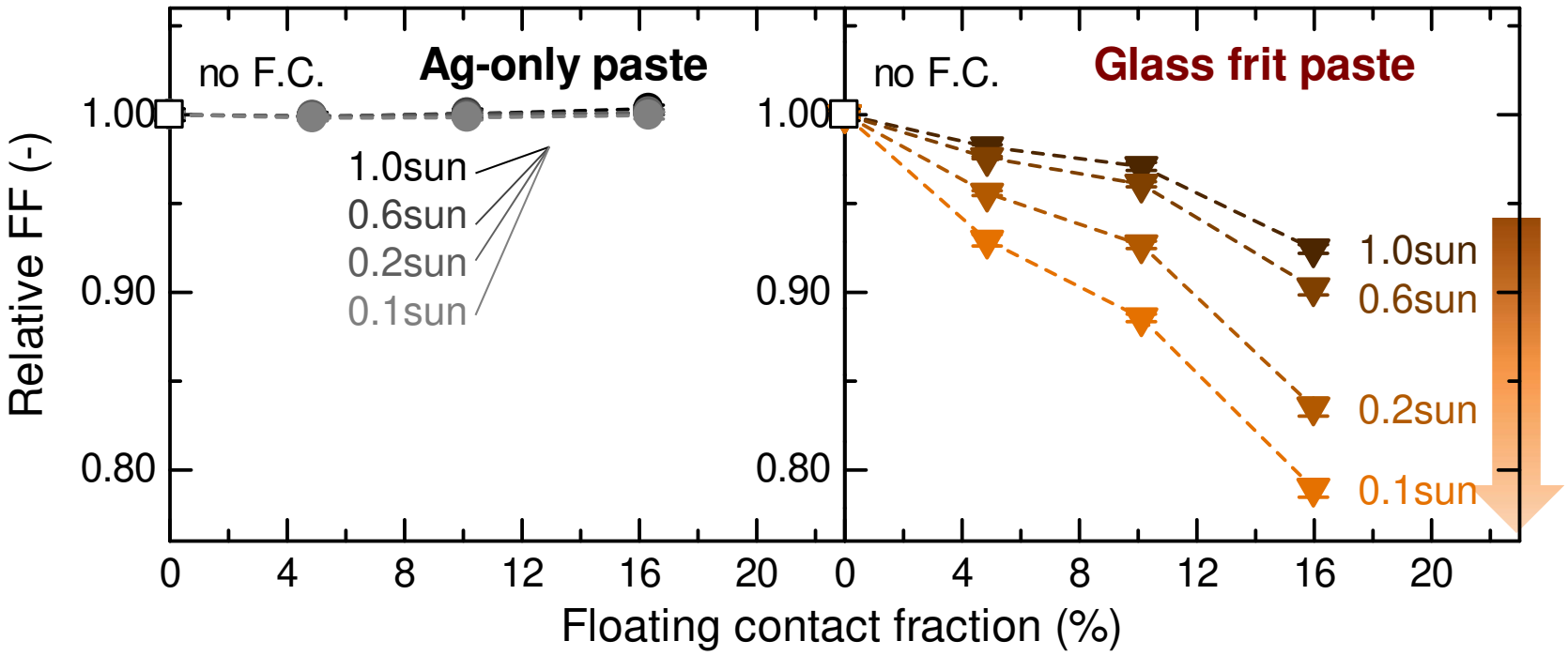
- ✓ Relative- V_{oc} slightly decreases with increasing the fraction.

Glass frit paste

- ✓ Relative-V_{oc} significantly decreases.
- ✓ The decreasing rate is enlarged at the lower light intensities.

Low light performances: FF

Relative-FF



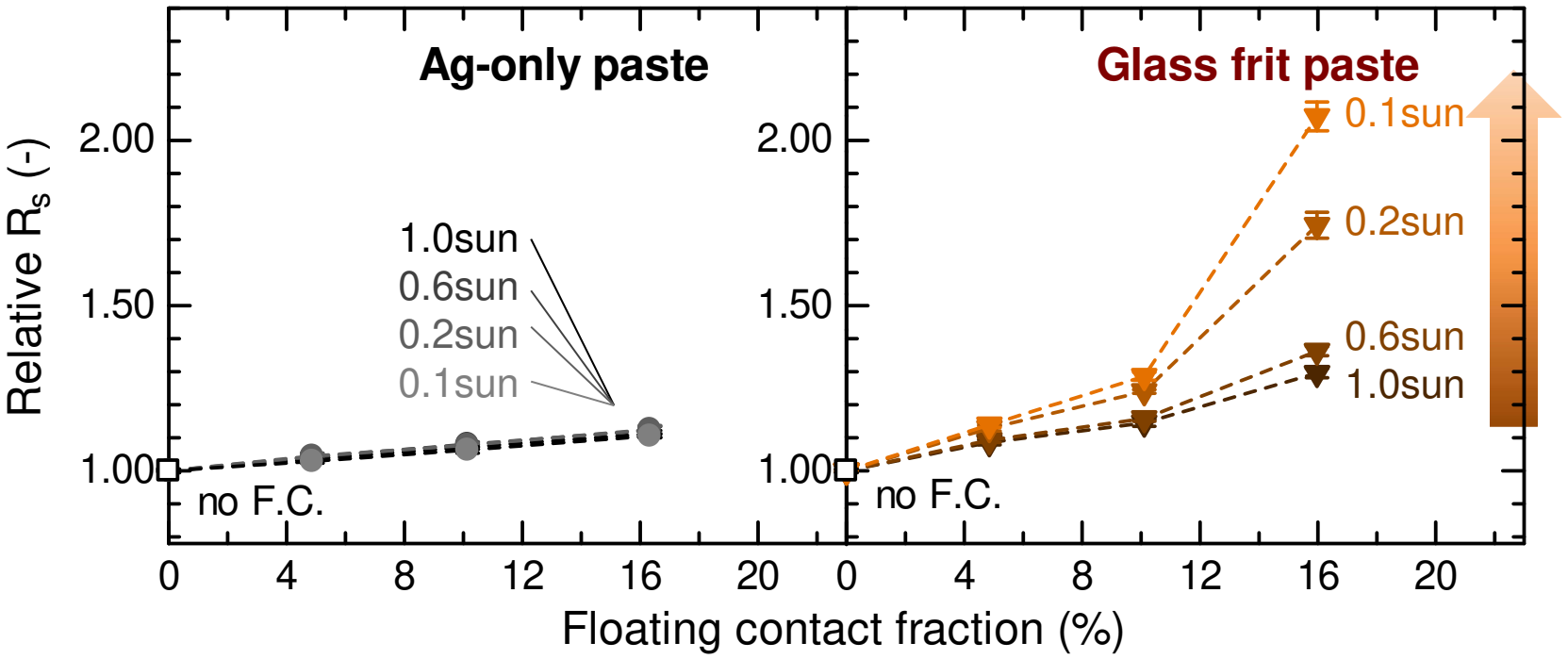
Relative-FF shows similar tendency to relative-V_{oc}:

- ✓ Glass frit paste decreases relative-FF.
- ✓ The decreasing rate becomes larger with increasing the intensity.

Effects of the frit on R_s.

Low light performances: R_s

Relative-R_s



Ag-only paste

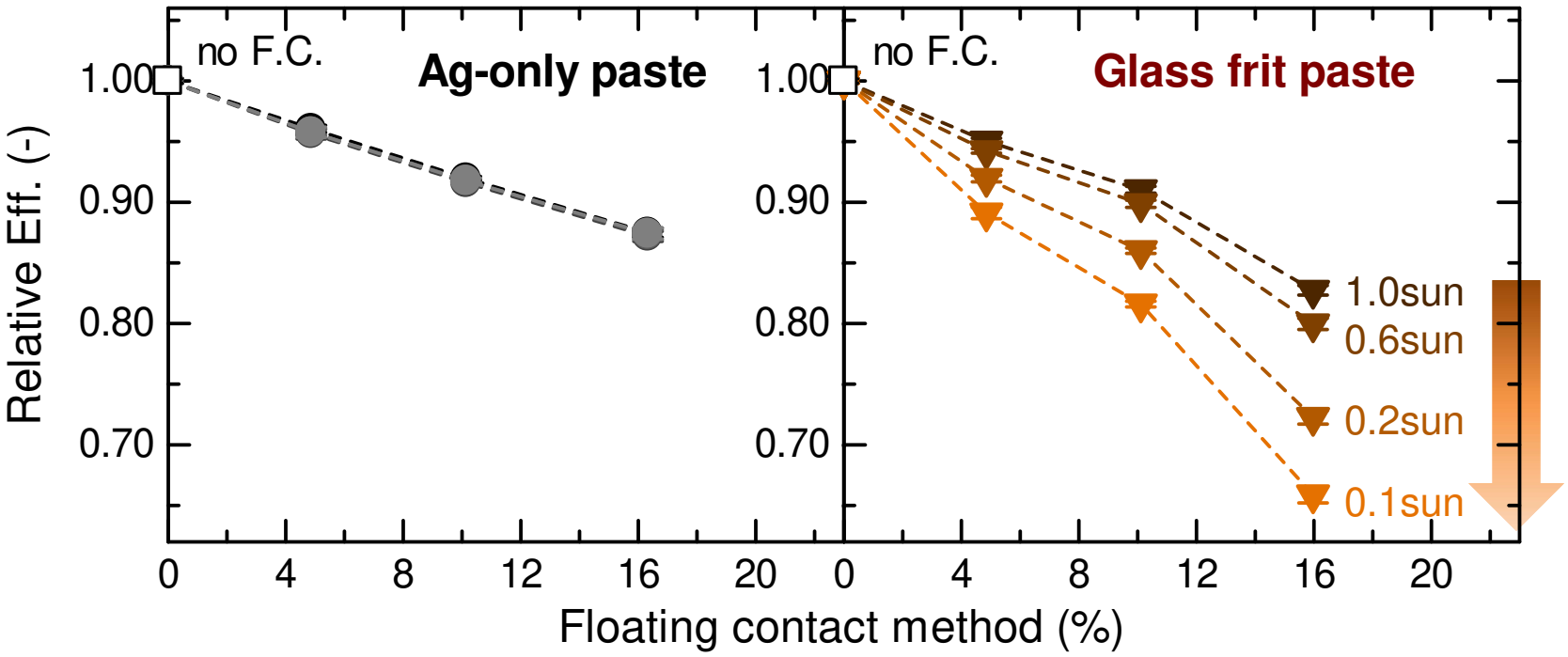
- ✓ Relative-R_s slightly increases, but does not depend on light intensity

Glass frit paste

- ✓ Relative-R_s significantly increases.
- ✓ The increasing rate is enlarged at the lower light intensities.

Low light performances: Eff

Relative-Eff.

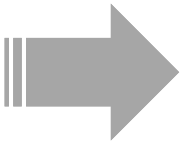


Glass frit drastically decreases relative-Eff especially at low light intensities due to V_{oc} and FF decrease.

Low light performances: summary

Effects of paste constituents on low light performances

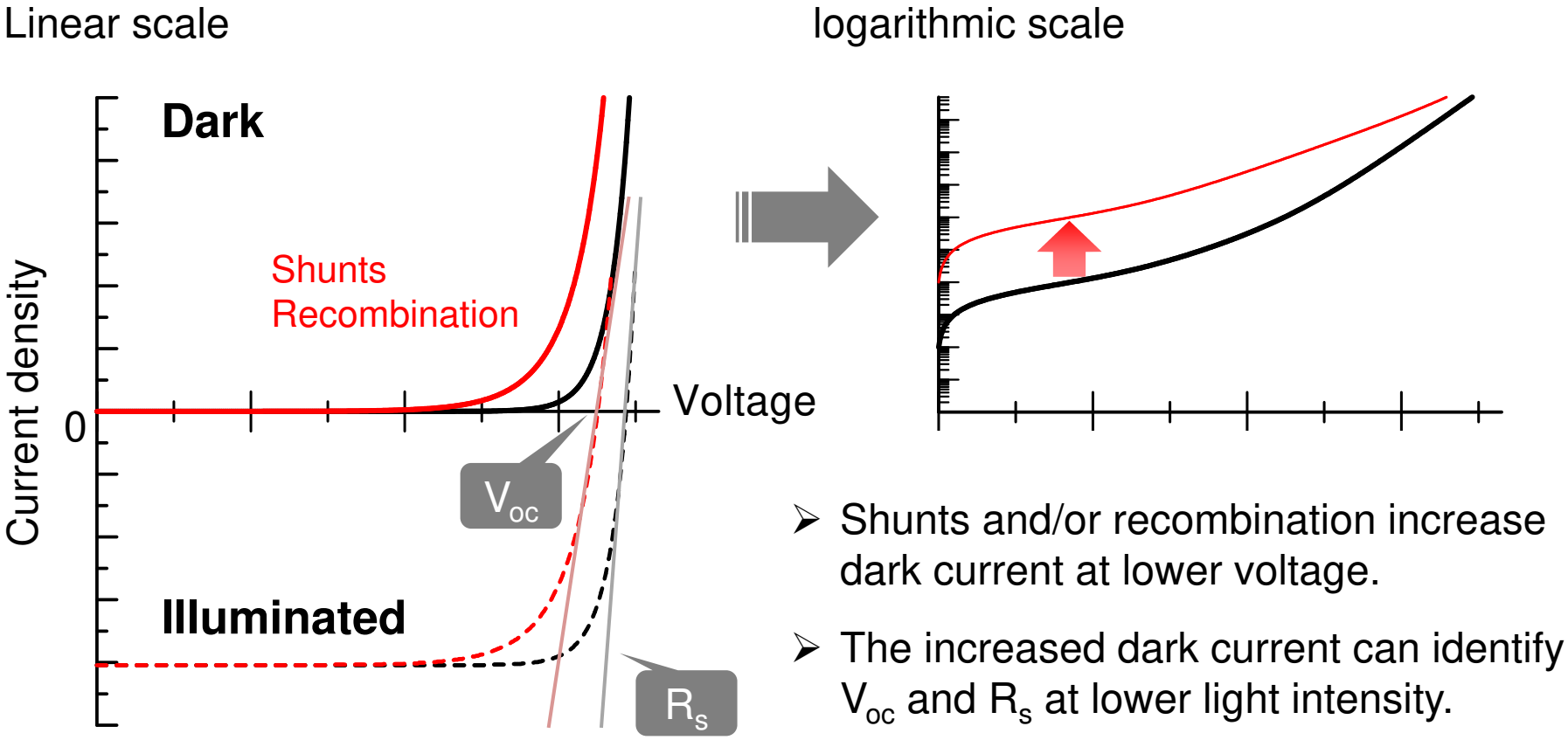
- ✓ F.C. of Ag-only paste have no effects on V_{oc} and FF.
- ✓ F.C. of glass frit paste degrade V_{oc} and R_s, which results in FF decrease, especially at lower light intensities, resulting in Eff decrease.



V_{oc} and R_s degradation at low light intensity relates to dark I-V characteristics.

Dark I-V characteristics

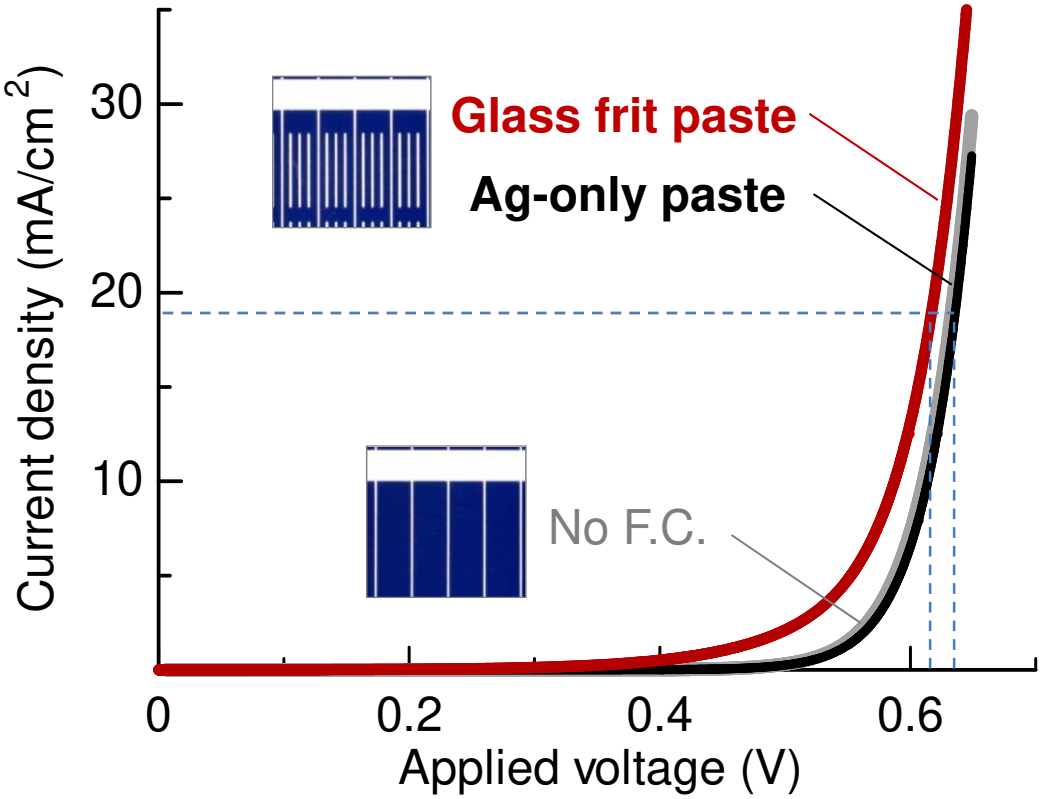
Shunts and recombination identify V_{oc} and R_s at lower intensity.

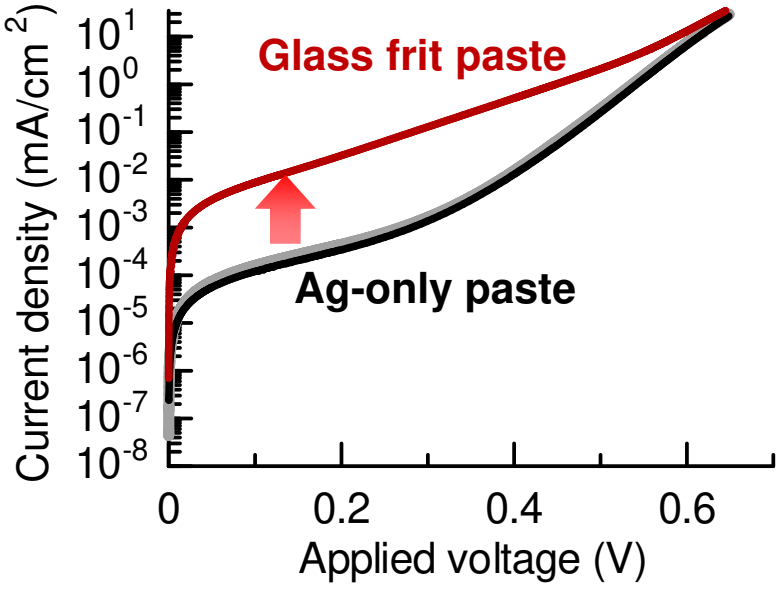


- Shunts and/or recombination increase dark current at lower voltage.
- The increased dark current can identify V_{oc} and R_s at lower light intensity.

Shunts and recombination much important for low light performances.

Dark I-V characteristics due to glass frit





Ag-only paste: No effects on dark I-V characteristics.

Glass frit drastically increases dark current. ➡

- ✓ Low V_{oc}
- ✓ High R_s

Conclusion

Effects of the glass frit itself on the low light performances were investigated with the floating contact method.

- ✓ Glass frit itself degrades V_{oc} and FF at lower light intensities, resulting in Eff decrease.
- ✓ The degradation of the low light performances comes from shunts and recombination.

Effects of paste constituents on shunts and recombination are much important not only for solar cell performances at 1 sun, but also for the performances at low light intensity.

Paste has yet-to-be-elucidated characteristics, and is indispensable for the production cost of solar cells.

Characteristics of paste constituents should be further clarified.

Thank you for your kind attention!

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