REVIEW OF CURRENT SILVER RECYCLING METHODS FROM PV DEVICES AND DISCUSSION OF INNOVATIVE METHODS

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Motivation

State-of-the-art of PV module recycling:

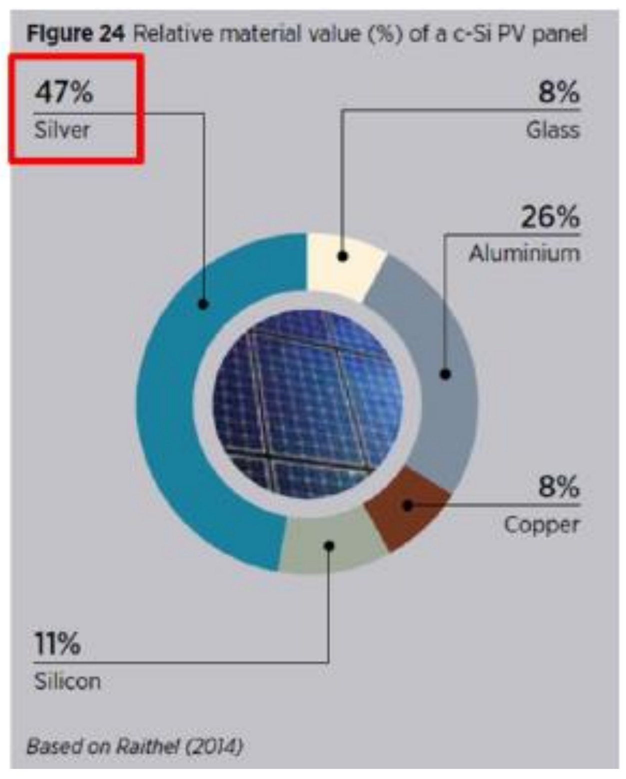
- Technologically **very basic**:
  Shredding, crushing and sorting
- **Only low-value bulk materials recovered**:
  Glass, aluminum and copper.
- **High-value materials not recovered**:
  Silver and silicon.

Innovations needed for advanced PV recycling:

- Recovery of high-value materials
- Low environmental impacts
- Physical methods preferable
  (over chemical methods)

Review of recent literature (2015 – 2018)

Title	Year	First author
Review on feasible recycling pathways and technologies for photovoltaic panels	2015	Tao
A review of recycling processes for photovoltaic modules	2018	Lunardi
Life cycle assessment of current photovoltaic module recycling	2018	Stolz



- Silver recycling doesn't take place in practice (lack of economic and regulatory incentives)
- Exploration of principally applicable silver recycling technologies limited to chemical methods
- Innovations are urgently needed

Conclusions

- There is a lack of innovation for economically viable silver recycling methods from PV devices.
- The small amount of silver in a PV module (≤ 0,05 wt.%) represents a high materials value (of almost 50%) in an end-of-life PV module.
- Physical methods avoid (hazardous) chemical waste and are therefore preferable over chemical methods.
- Initial research shows that electrodynamic fragmentation is suitable for the separation of silver from silicon heterojunction solar cells.
- Initial research shows that plasma-enabled methods are suitable for selective melting of silver on silicon homojunction solar cells.

Silver separation by electrodynamic fragmentation

Electrodynamic fragmentation method

- Ultrashort high voltage pulses in water trigger discharge at solid interfaces leading to separation, see figure 1 (left)
- Working principle is based on inversion of dielectric strengths for ultrashort pulses (< 500 ns), see figure 1 (right)

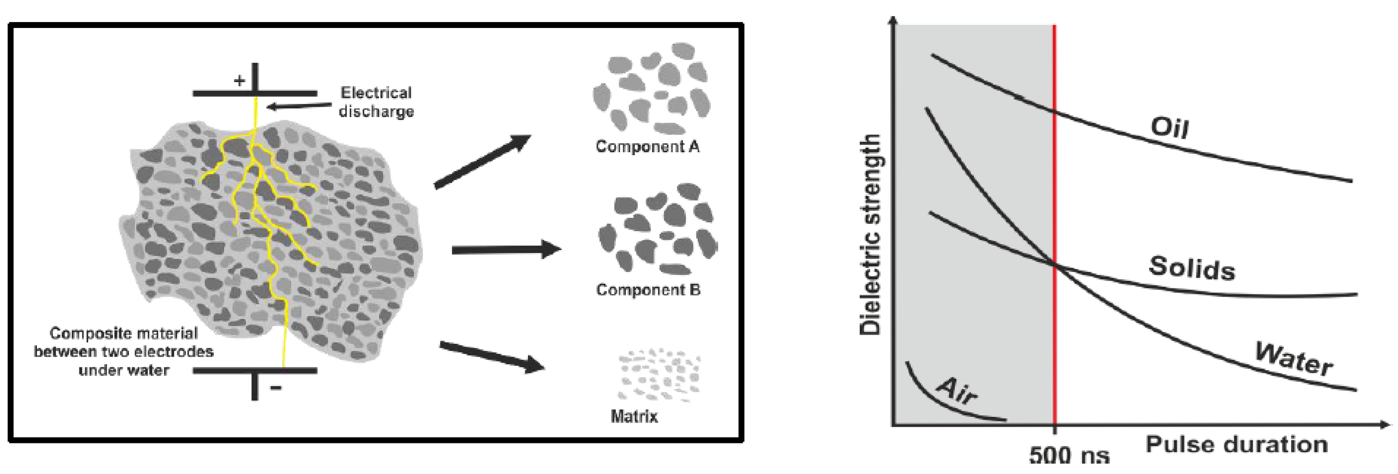


Figure 1: Illustration of discharge and separation during electrodynamic fragmentation (left); Graph showing inversion of dielectric strengths for solids in comparison with water (right).

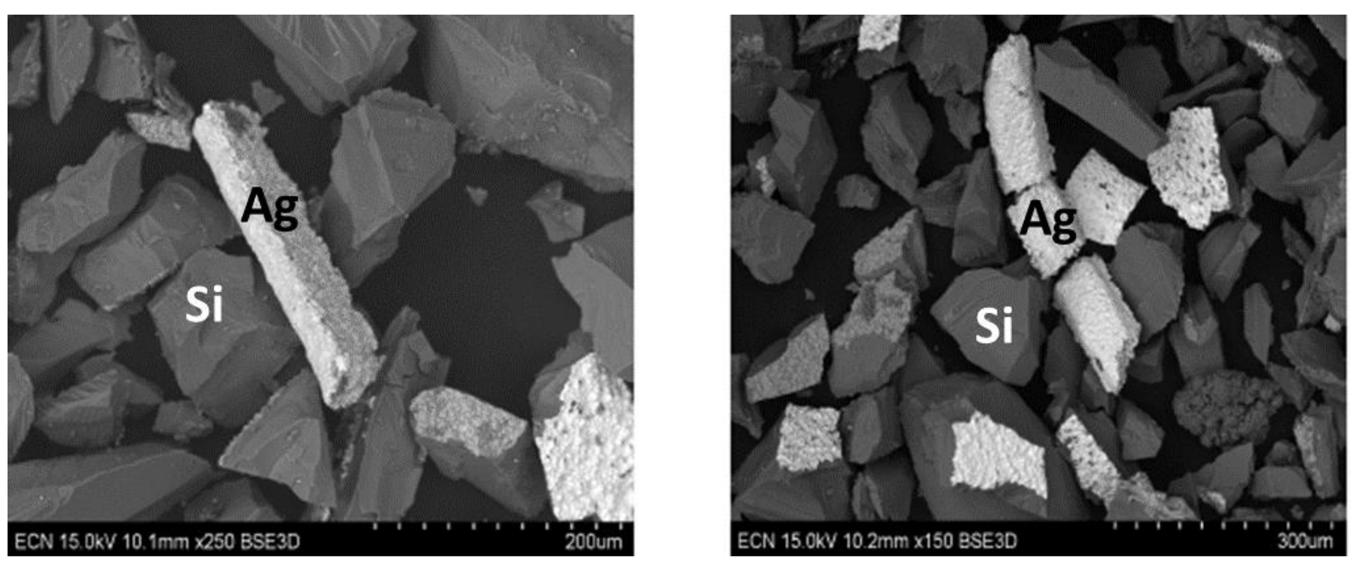


Figure 2: SEM images showing separated silver fingers after electrodynamic fragmentation of a silicon hererojunction solar cell.

Silver melting by plasma-enabled methods

Plasma-enabled method

- Plasma heating leads to selective melting of silver due to melting point differences between silver and silicon
- Melting point of silver: 1235 K
  Melting point of silicon: 1683K

Figure 3: Photograph of a DC plasma.

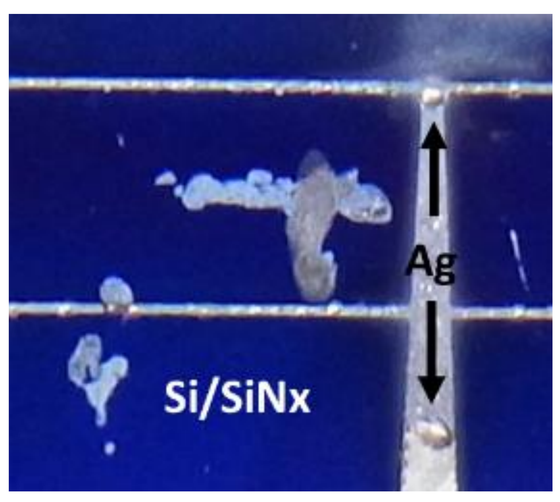


Figure 4: Optical micrograph showing melted silver islands after plasma treatment of a silicon homojunction solar cell.

Acknowledgements
This work is funded by the Dutch Ministry of Economic Affairs.