Cu(In,Ga)Se₂ photovoltaic microcells: high efficiency and low material consumption

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Objectives
Our objective is to take advantage of microscopic polycrystalline thin film solar cells to investigate their behaviour under intense illumination. Our focus is on Cu(In,Ga)Se₂ microcells, with diameter varying from 7 to 500 µm.

Conclusions and perspectives
The microcell structure leads to negligible spreading resistances. The series resistance is modulated with illumination level, leading to $R_s < 5 \times 10^{-8} \text{ ohm.cm}^2$.

High flux operation is thus possible. The microcell structure shown a 21.3% efficiency at 475 mW/cm².

Cu(In, Ga)Se₂ microcells
Fabrication: Cu(In, Ga)Se₂ microcells are created by inserting a patterned insulating layer in a standard Cu(In,Ga)Se₂ cell. Photolithography is used to design microcells with diameter ranging from 7 to 500 µm. Such a design leads to low spreading resistance and heating, even under high light fluxes.

Tests: we use a 532-nm laser to measure $I$-$V$ and PL characteristics of the cells under varying intensity. At this wavelength the external quantum efficiency of the cell is 84%.

Photocurrent linearity
Photocurrent is linear with incident power up to $2 \times 10^7$ W/m². Linearity follows the theoretical relation:

$$I_{ph} = P_{inc} \times QEE(352) \times q \times h \nu.$$ 

Linearity was also found to be valid for the full solar spectrum up to $10^8$ W/m².

Evolution of efficiency with concentration
Efficiency increases with concentration due to an increase of $V_{oc}$.

The efficiency of our record device reach a maximum at a concentration around 475. It reaches 21.3% compared to 16.2% under 1.1 Sun.

$J_{sc} \approx 15.4 \text{ A/cm}^2$, $V_{oc} \approx 852$ mV - FF=77.0%.

The decrease in efficiency at high concentrations is due to low resistive losses that are not size dependent. [2-3]

Temperature analysis
Temperature increase under localized heat source (radius $R$) can be computed from the heat equation.

Results presented here correspond to a heat source of radius 100 µm and 100 W/cm² (1x1000) incident on a CIGS solar cell on glass. Front and back surfaces of the solar cell are prone to natural convection.

Series resistance analysis
Carriers photogenerated in the absorber reduce its resistivity, resulting in total series resistance that is modulated with illumination intensity.

The total series resistance of the microcell $R_s$ is the sum of a constant term (contact resistances) and a modulated term (absorber resistance) as [2]:

$$R_{series} = R_s + R_{abs} = R_s + \left( \frac{L}{T} \right) \times \frac{1}{(1 - \frac{L}{T}) \times \frac{P_{inc}}{E_{inc}} \times R_s \times P_{contact}}$$

$R_s$ decreases by more than 10 in the explored concentration range due to modulation.

From our measurements, we evaluate $L_s$ to be 3 µm. This value is in the high range of reported values.

Maximum efficiencies at concentration ratios $>1000$ would require improved $R_s$. Increased $L_s$ (or reduced $I_s$) would make the absorber contribution to Joule losses negligible at all incident power. [2]

References:

PVTech, Aix, 2012