# Influence of agricultural environment on the degradation of CIGS-based solar cells


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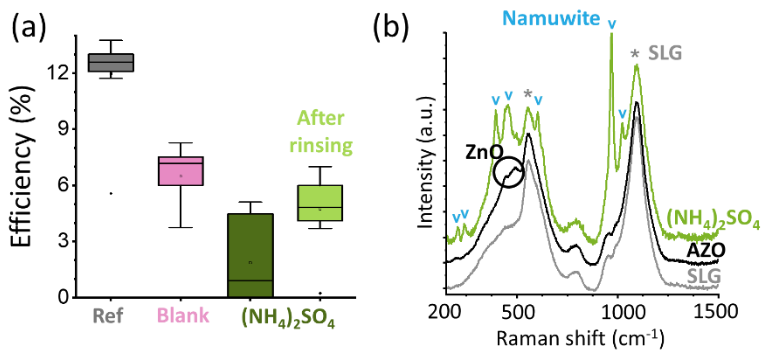
With the development of Agri-PV, it becomes necessary to adapt current photovoltaic (PV) systems to agricultural needs and constraints, in particular by adapting the reliability test to take into account agricultural emissions. For instance, the corrosive properties of $(NH_4)_2SO_4$ [1] (released into the atmosphere from farming activities [2]) are already established but their effect is usually disregarded in the PV reliability tests [3]. Ammonia testing is detailed in standard IEC 62716:2013 and only focuses on the evolution of electrical performance. Understanding of the degradation mechanism in such environment remains relatively unexplored.

The aim of our work is to evaluate the impact of agricultural aerosol on the performance and degradation mechanisms of $Cu(In,Ga)Se_2$ (CIGS)-based solar cell photovoltaics. The study was conducted on both complete cells (composed of SLG/Mo/CIGS/Zn(O,S)/ZnMgO/Al:ZnO/NiAlNi) and representative models of 1-2 layers (500 nm-Mo/SLG, 1.5 µm-CIGS on SLG and Mo/SLG, 480 nm-Al:ZnO (AZO) on 50 nm-i:ZnO and Ni (50 nm)/Al (600 nm)/Ni (50 nm) on AZO). The stability of these systems was studied with and without thin-film encapsulation made of 25 nm ALD-$Al_2O_3$.

The accelerated ageing test was performed in a climatic chamber where day/night variations were modeled by temperature and humidity cycles [4]. A drop of solution containing $(NH_4)_2SO_4$ was deposited daily to simulate an agricultural environment. Cell performances were evaluated by I-V measurements, External Quantum Efficiency, spectrophotometry, and resistivity measurements. The chemical evolution of individual layers and complete cells was studied using Raman spectroscopy, X-ray diffraction, X-Ray photoelectron spectroscopy, scanning electron microscopy and electron dispersive X-Ray spectroscopy, glow discharge-OES.

Complete cells have demonstrated larger efficiency loss after ageing in presence of ammonium sulphate (**Figure 1.a**), highlighting the importance of considering pollutants in reliability testing. Without aerosol, the main loss was due to a decrease in $V_{oc}$, which could be explained by an increase in recombination in the CIGS and its interfaces. The formation of copper selenide and sodium molybdates and sodium migration are likely to reduce the passivation of grain boundaries and have affect the quality of the CIGS layer. In the presence of $(NH_4)_2SO_4$, the efficiency degradation was mainly due to a loss of $J_{sc}$ and FF. The current was certainly affected by the transformation of transparent conductive oxide AZO in namuwite $Zn_4(SO_4)(OH)_6{\cdot}4H_2O$ (illustrated in **Figure 1.b**). The loss of fill factor could be linked to an increase in contact resistance, observed for Mo and AZO (**Figure 1.c**), due to oxidation of Mo and dissolution of AZO. Thin-film encapsulation, though efficient in DHT [5], was dissolved by ammonium sulphate, emphasizing the importance adapting the encapsulation to the in-use environment. In conclusion, fertilizers can significantly affect reliability of thin layer solar cells and their presence must be taken into account for Agri-PV.




(c)

| $R_{sheet}$ (Ω/sq) | SLG/Mo | SLG/i:ZnO/ZnO:Al |
|---|---|---|
| **Ref** | 0.192 ± 0.03 | 50.1 ± 0.7 |
| **Blank** | 5.5 ± 3.03 | 59.7 ± 0.7 |
| **$(NH_4)_2SO_4$** | 0.84 ± 0.70 | 72.9 ± 3.0 |

Figure 1 – (a) Boxplot of cell efficiency evolution before and after ageing, (b) Raman spectra on SLG/i:ZnO/AZO with and without pollutant and (c) Sheet resistivity for Mo back contact and AZO TCO

## REFERENCES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