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# Aiming for a “Flexible PV+” Future: Development of Kesterite Solar Cells on Flexible Stainless Steel Substrate in UNSW

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Flexible thin film photovoltaic solar cells (Flexible PV) on stainless steel are durable, lightweight, aesthetically pleasing and can be bonded directly to various surfaces. With these favourable features, they have attracted vast research and development efforts both from academia and industry aiming to integrate Flexible PV into buildings (Feist, Mills et al. 2012), electric vehicles, and internet of things (Antunez, Bishop et al. 2017). Recent days have seen many a scientist and entrepreneur advocating the “Flexible PV+” future. Kesterite $Cu_2ZnSnS_4$ (CZTS) is a favourable absorber material for thin film solar cells. All earth-abundant and environmentally-friendly constituent and good cell efficiency so far make it a promising candidate for application in Flexible PV. In UNSW, we cooperate with the industry giant Baosteel to develop flexible kesterite solar cells on stainless steel. This paper will provide a review of the work so far and outline key points for future R&D of this technology.

**Introduction**

- The ‘Flexible PV+’ future
    1. The application of flexible PV products in the field of BIPV, EV and IoT.
    2. Industry moves in the direction of Flexible PV+ future.

**Design and fabrication of flexible kesterite solar cells**

- Cell design: considerations of using stainless steel as a substrate
    1. Choosing the right type of stainless steel: stainless steel surface property is critical for the quality of as-deposited thin films as well as the device performance. Figure 1 shows how the tiny defects could cause irregular film growth and shunt the device.
    2. Back contact design: Fe and Cr diffusion from the steel substrate into the film during high temperature processing is a detrimental impurity source. An effective barrier layer is essential between the kesterite film and the steel. Additionally, sodium supply has to be taken into consideration as the steel substrate does not supply sodium as glass substrate does.
- Fabrication method: sputter as an industry proven thin film deposition process
- Key points in developing kesterite solar cells on flexible stainless steel
    1. Development of 6% CZTS solar cells on stainless steel substrate (Table 1)
    2. Path to over 15% efficiency and scaling up considerations
- Module design: module structure, important layers and encapsulation

(a) 50 um stainless steel surface under SEM (left) and CZTS grown on it (right).

(b) 150 um stainless steel surface under SEM (left) and cross-section of the CZTS film stack on steel flap.

(c) 1000 um stainless steel surface under SEM (left) and cross-section of the CZTS film stack on steel flap.

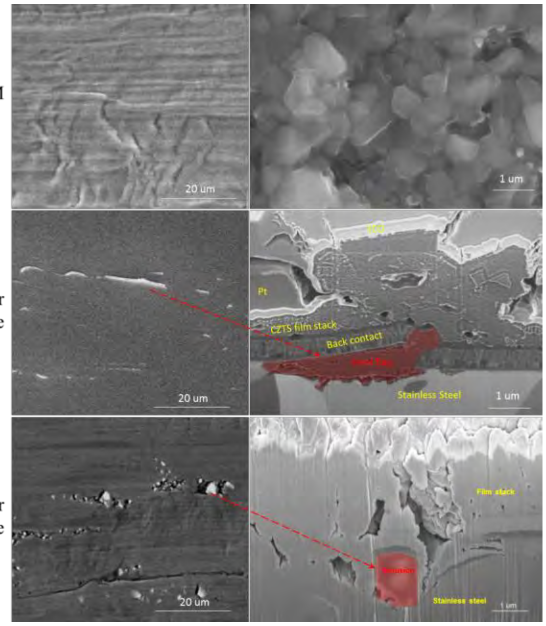


**Figure 1. Surface morphologies of different stainless steels and cross-section of CZTS film stack on different surface defects.**

**Table 1. Performance parameters of CZTS devices on different configurations.**

| Configuration | $V_{OC}$(mV) | $J_{SC}$(mA/cm$^2$) | FF (%) | Efficiency (%) | $R_{S,L}$ (Ω cm$^2$) | $R_{sh,L}$ (Ω cm$^2$) | A | $J_0$(mA/cm$^2$) |
|---|---|---|---|---|---|---|---|---|
| **I** | 581.46 | 14.47 | 53.11 | 4.47 | 4.02 | 170.84 | 2.48 | $1.30*10^{-3}$ |
| **II** | 524.00 | 13.99 | 48.24 | 3.54 | 3.46 | 126.21 | 3.30 | $2.28*10^{-2}$ |
| **III** | 625.45 | 16.52 | 53.60 | 5.54 | 4.62 | 285.74 | 3.15 | $6.79*10^{-3}$ |
| **V** | 628.15 | 17.40 | 57.51 | 6.29 | 2.54 | 391.65 | 3.12 | $5.90*10^{-3}$ |
| **Reference** | 654.90 | 18.39 | 67.56 | 8.14 | 1.58 | 589.45 | 1.68 | $5.00*10^{-6}$ |

**Summary**

In summary, this paper provides a review of the development of kesterite solar cells on flexible stainless steel substrates in UNSW. Key points in cell design and module design are presented. This work aims to contribute to the ‘Flexible PV+’ future.

**References**

Antunez, P. D., et al., 2017. ‘Efficient kesterite solar cells with high open-circuit voltage for applications in powering distributed devices’, Nature Energy 2(11): 884-890.

Feist, R., et al., 2012. ‘Methodology for delivering reliable CIGS based building integrated photovoltaic (BIPV) products’, 2012 IEEE International Reliability Physics Symposium (IRPS).