Title: Binary/ternary phases in Cu$_2$ZnGeSe$_4$ thin-film solar cells and their impact on the cell performance

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Abstract
Kesterite solar cells with a band gap of 1.4-1.5 eV were fabricated with pure Ge substitution and device efficiency above 7% has been achieved. However, the efficiency in these compounds is still below the record efficiency obtained for CZTSe cells. In this work, the device performance and films morphology have been extensively studied and analyzed using advanced characterization techniques, among others FTIR and TEM measurements were used. Several binary/ternary phases were detected in different parts of the absorber which are formed during the films’ growth. But the major loss in the solar cell’s efficiency is engendered by the presence of Cu$_2$GeSe$_3$ ternary phase which creates an internal blocking barrier in the Cu$_2$ZnGeSe$_4$ absorber. In addition, the cell performance is analyzed using numerical modelling and the results show that device efficiency of about 14% can be achieved without the presence of the binary/ternary phases. Thus, further and significant improvement of both absorber materials and device structure need to be evolved to address the new challenges regarding the film growth and the formation of undesirable binary and ternary phases.

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Keywords: kesterite thin-film solar cells; Cu$_2$ZnGeSe$_4$; wide band gap absorbers; binary/ternary phases; efficiency limitations.