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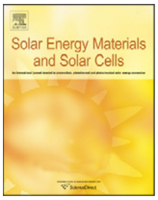

Next generation interconnective laser patterning of CIGS thin film modules

P.-O. Westin [a,b,*], U. Zimmermann [a], M. Ruth [a,1], M. Edoff [a,b]

[a] Uppsala University, Solid State Electronics, P.O. Box 534, SE-75121 Uppsala, Sweden
[b] Solibro Research AB, Vallvägen 5, SE-75651 Uppsala, Sweden

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ABSTRACT

Laser patterning of thin film solar cells has proven technically feasible for all layers but still remains a challenging topic for research and development. We present a method where P2 laser patterning of CIGS thin film solar modules is performed after deposition of the ZnO:Al layer, as opposed to the current state-of-the-art where patterning is performed before the ZnO:Al layer is deposited. This method takes full advantage of the potential of laser processing and works by creating an interconnecting scribe line that "welds" the ZnO:Al and CIGS layers into an electrical contact. In this work we present experimental results of this process on five different sets of CIGS with slightly varying thickness and Cu content. While optimization of the process with respect to the various layers has not been performed, the initial results for CIGS thin film modules show working experimental modules in each set. The best experimental module has a fill factor of 71% and its performance is within the standard deviation of mechanically patterned references. An experimental submodule of $30\times30\,\mathrm{cm}^2$ size with 10% efficiency was manufactured.

1. Introduction

Thin film photovoltaics promises to reduce manufacturing cost of solar cell modules in part due to conservative material usage and monolithic series connection of cells requiring relatively simple automation compared to the lay-up and soldering used in wafer-based technologies. There exist various thin film technologies that differ in the type of materials used, wherein the most notable are those using amorphous Si, $Cu(In,Ga)Se_2$ (CIGS) or CdTe as the solar absorber material (for a comparison see for example [1]). These technologies have much in common in the module configuration and processing sequences. By applying alternating deposition and patterning steps, one achieves the well known cell stripes connected by monolithic interconnect regions. Patterning is necessary to isolate adjacent bottom contacts (P1); provide a connection channel between the top and bottom electrodes of adjacent cells (P2); and to isolate adjacent top electrodes (P3). Depending on the technology, the patterning steps are routinely done using either a combination of laser and mechanical tools or all-laser processing. The advantages of laser processing are many, and although the capital investment costs are still high, it is becoming more and more competitive due to its non-contact, high speed capability and relatively little wear and down-time. Fig. 1(a) shows the industry standard processing of CIGS modules using mechanical tools for the P2 and P3 patterns.

Lasers can be used in processing nearly all layers included in any thin film solar cell using various wavelengths and setups [2]. The use of laser is standard for the P1 patterning of the first (bottom) contact layer; molybdenum in CIGS and a transparent conductive oxide (FTO, ITO, ZnO) in CdTe and a-Si cell technologies. In the case of a-Si and CdTe the transparency of the bottom contact layer permits laser ablation to be used as an alternative for the subsequent patterning steps. Choosing the appropriate wavelength, the laser beam passes through the TCO and energy is deposited at the TCO/absorber interface, which allows selective removal of the absorber or absorber/contact layers [3–6]. The metallic bottom contact makes this approach impossible for CIGS solar cells. One is limited to a top down patterning approach which is very challenging due to the risk of damage to underlying layers. Manufacturers and researchers working with CIGS on flexible substrates have taken the step into laser processing for P2 and P3 patterning, but this has been dictated by mechanical weakness in the substrate rather than inherent advantages of laser processing. P2 patterning of the CIGS layer can be done using the same equipment as for P1 patterning, provided that the deposited energy is controlled not to damage the Mo film. In fact, complete ablation of the CIGS is not necessary since it is possible to locally transform the CIGS layer into a conductive compound [7–9].

In order to successfully perform the third, isolating, patterning step on a CIGS solar cell stack the use of very short laser pulses in the picosecond range has proven to be the key. The challenge is to remove the TCO (ZnO) and the underlying CIGS material without

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[*] Corresponding author at: Uppsala University, Solid State Electronics, P.O. Box 534, SE-75121 Uppsala, Sweden. Tel.: +46 184713149; fax: +46 18555095.
E-mail address: Per-Oskar.Westin@angstrom.uu.se (P.-O. Westin).
[1] Presently with Flisom AG, Zürich, Switzerland.

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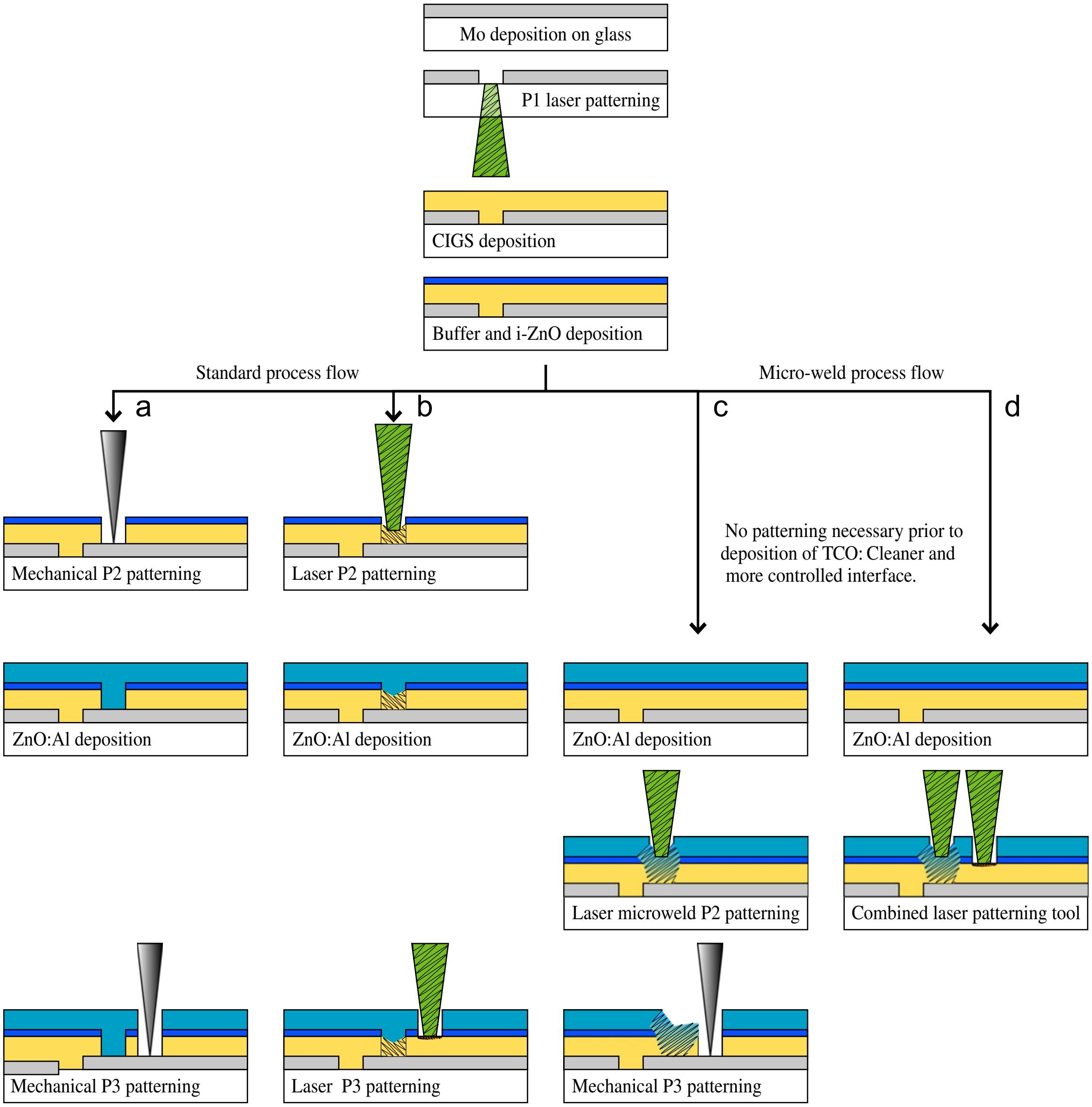

Fig. 1. A systematic comparison of interconnect formation in CIGS module manufacturing showing (a) current industry standard using mechanical tools for P2 and P3 scribing; (b) the possibilities of P2 and P3 laser scribing which have been previously introduced (see [9,16]); (c) laser micro-weld patterning introduced in this work and (d) the envisioned dual laser patterning tool for reduced processing times.

leaving a heat affected edge zone which would short-circuit the cell. Another aspect is the strong absorption in CIGS making it more difficult to limit the ablation at the Mo/CIGS interface. One way to avoid both these issues is to limit the P3 scribe at the TCO/CIGS interface by "direct induced ablation" [10] since removal of only the TCO is enough to electrically isolate adjacent cells. This has been successfully demonstrated using picosecond laser ablation [10–16].

2. Method

2.1. Micro-weld laser patterning

Our previous work has shown how laser scribing can be used to partly metalize the CIGS layer, effectively tracing a conductive line in the absorber layer prior to the deposition of the ZnO:Al window [9], as shown in Fig. 1(b). In this work, the laser scribing step is performed *after* the deposition of buffer and window layers. Interconnect patterning is thus performed on the finished stack using a laser patterning process which "welds" the front contact and CIGS layers along the scribe line. The assumption is that this is possible by simultaneously metalizing the CIGS layer and fusing it with the ZnO:Al layer. The welded line provides electrical connection from the front contact of one cell to the back contact of the next cell, see Fig. 1(c). Isolating P3 patterning can be done using standard mechanical scribing after the micro-welding process, as has been done in this work. However, the P3 pattern could just as well be performed before, or better yet simultaneously with, the P2 laser weld.

2.2. Impact on CIGS module manufacturing

From the introduction we know that laser patterning could already today replace the mechanical tools used in CIGS module manufacturing (compare Fig. 1(a) and (b)). Typical advantages of laser patterning are high speed, accuracy, no chipping, low