All laser processed CdTe monolithic mini-modules deposited by MOCVD

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I. Introduction
The CdTe thin film photovoltaic (PV) technology reached efficiency of 22.1% for cells and 18.6% for modules [1]. The CdTe absorber is commonly vacuum deposited at high temperature (~600°C) using close-space sublimation (CSS, for cell research) and vapor transport deposition (VTD, for manufacturing). Metalorganic chemical vapor deposition (MOCVD) could be a low temperature and non-vacuum alternative, offering in-situ alloying/doping and promising cell performance (~15%) [2].

Scaling-up potential of MOCVD CdTe devices was illustrated using in-line deposition [3] and mini-module devices [4]. However, an all-laser scribed mini-module fabrication by this method has not been demonstrated, which is necessary to improve total area efficiency by reducing dead zones.

In this study, we fabricated both ‘hybrid’ and ‘all-laser’ scribed MOCVD CdTe mini-modules and compared their performance. The hybrid devices used a combination of laser scribe, mechanical scribe, and masked deposition. For all-laser scribed devices, firstly a set of suitable laser parameters was determined, for scribing the transparent front contacts and the semiconductor junction layers using a 532 nm ns-laser.

II. Experimental Details
A horizontal MOCVD reactor was used at atmospheric pressure to deposit the CdZnS/CdTe semiconducting device layers on ITO/borosilicate glass substrates as described in Ref [4]. The CdZnS window layer grown at 360°C had a thickness of 0.15μm. CdTe absorber was deposited at 390°C to ~3.3μm total thickness and doped with ~3×10¹⁸ cm⁻³ As in the bulk. Doping concentration was raised to ~1×10¹⁹ cm⁻³ As in the final 0.3μm of this film to obtain a low-resistivity back contact. The back-contact metal was deposited by thermal evaporation of gold to a thickness of ~100 nm.

Structure of the studied mini-module devices is indicated in Fig. 1. In this process, isolation of the transparent front contact layer, namely P1 scribing, is followed by the growth and activation of the semiconductor (p-n junction) layers and then their isolation, namely P2 scribing. Finally, a suitable back contact material (such as gold) is deposited on the CdTe surface and then isolated, that is P3 scribing. The widths and respective positioning of three scribes P1, P2, and P3 define the “active” and “dead” parts of the modules. Here, the area defined by the start of a P1 scribe to the end of the corresponding P3 scribe is called the “dead-zone” as it does not contribute to device output.

Fig. 1 Schematic (cross-sectional) view of a series-connected monolithic CdTe module.

In this study, P1 scribing is exclusively carried out by laser scribing, whilst several options beside laser scribing were also considered for P2 and P3, namely mechanical scribing (P2, P3) and masked (gold) deposition (P3).

Laser scribes were performed using a Rofin system equipped with a ns-pulsed 532 nm laser. All laser scribes were made through the glass side, to avoid thickness dependent material removal [5]. The laser parameters (beam current, frequency, and speed) were varied to achieve selective removal of semiconductor layers without (P2) and with (P3) the ITO film. Mechanical scribes were done on a
commercial scribe (ATV, Germany) using a sharp diamond tip.

Optical microscopy and scanning electron microscopy were used to evaluate individual scribes as well as alignment of multiple scribe lines within devices. AM1.5 J-V curves were collected using an Abet Technologies Ltd. solar simulator with the light power density calibrated using a GaAs reference cell. Light soaking with fan-provide cooling was performed for 30 min prior to measurements to stabilise device response.

III. Results

Fig. 2 compares mechanically- and laser-processed P2 scribes, before and after the deposition of a gold overlay. The ITO film (~0.15μm thickness) is found to be very sensitive to scribe parameters. In the case of laser processing, usually discontinuities or cracks formed in the middle of the track. For mechanical processing, the diamond tip left an indented track in ITO layer in the middle, with the semiconductor films peeling off substantially on either side of the indentation. Gold deposition bridged over the damages in TCO layer and thereby made these scribes useful in device utilisation. The scribe width ranged from 40 to 80μm for laser processing (depending on the conditions) and up to 250μm for mechanical scribing. It is evident that the latter process can substantially increase the dead-area in a modular device.

Fig. 2 Laser- and mechanically defined P2 scribes before (a, c) and after (b, d) gold back contact deposition. Scribe damages on the ITO film appears to have been masked with the gold film.

Typical ‘hybrid’ and ‘all-laser’ processed mini-modules are shown in Fig. 3. Whilst the dead width of hybrid devices can extend from 500μm (with mechanical P3 scribe) to beyond 1500μm (masked P3 isolation), it can be as small as ~200μm for all-laser processing.

Table 1 compares active-area J-V parameters of mini-modules (each with a 6-cell string), one with mechanical P2 and masked P3 (A), one with laser P2 and masked P3 (B), and the other with laser P2/P3 (C). J-V curves of these devices are shown in Fig. 4. The fill factor (FF) is the prime metric in the assessment of shunt-related and resistive losses in a modular device. For sample C, although the series resistance remains lower than other devices, shunting causes some loss in the FF. The FF also tracks the open-circuit voltage (Voc) which appears to have varied run-to-run due to subcell performance. Preparation of a wider set of devices all within a close duration will be essential to avoid subcell performance variations and hence more effectively compare mini-modules prepared by the various interconnection protocols.

The enhanced shunting effect with sample C could be due to the P2/P3 scribing
which appears to have taken at an energy higher than the threshold of ITO ablation. At such high energy it may be possible to cause some damage to the sidewalls of the semiconductor layers, i.e. within the heat-affected zone (HAZ), promoting formation of metallic (micro-)shunt paths. It will be necessary to assess different scribe parameters to minimize damage to the ITO layer as well as formation of shunt paths within the HAZ.

Tab. 1. J-V data for 6-cell string minimodules: sample A = mechanical P2, masked P3; sample B = laser P2, masked P3; sample C = laser P2, laser P3.

<table>
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<th></th>
<th>η</th>
<th>Jsc</th>
<th>Voc</th>
<th>FF%</th>
<th>Rs</th>
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<td>20.8</td>
<td>0.8</td>
<td>73</td>
<td>17.2</td>
<td>3185</td>
</tr>
<tr>
<td>B</td>
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<td>20.9</td>
<td>0.7</td>
<td>75</td>
<td>9.5</td>
<td>1410</td>
</tr>
<tr>
<td>C</td>
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<td>22.5</td>
<td>0.6</td>
<td>64</td>
<td>7.6</td>
<td>673</td>
</tr>
</tbody>
</table>

Fig. 4 The light J-V curves of 6-cell string minimodules (see Tab. 1 for extracted parameters and sample details).

Finally, it is worth mentioning that the dead area width can be considerably smaller for all-laser-processed devices (e.g. device C) such that ~95% of the total (irradiated) area remains active. Compared to this, only 63% and 75% of the total area was active for hybrid devices A and B. Therefore, in order to prepare CdTe monolithic devices with highest areal utilisation and lowest cost, the best method will be the all-laser processing.

IV. Conclusions

CdTe superstrate minimodule devices prepared on commercial ITO glass substrate using MOCVD and various scribing methods. Laser/mechanical scribe was considered for P2 isolation while masked metal deposition was also assessed for P3 isolation. The damage caused to the ITO layer, observed by the centre of the laser beam and the sharp diamond tip, during P2 scribing was observed to be “repaired” by the back-contact metal deposition. The active-area performance of minimodules having laser P2 and mechanical P2 were similar. Run-to-run variability impeded direct comparison of interconnection approaches. Whilst hybrid devices caused loss of ~30% of the device area, the active/total area ratio for the best all-laser-processed device was ~95%. Optimisation of P2/P3 laser processing and characterisation of associated shunting losses due to these scribes will be studied in near future.

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References


