Technical Communication

Systematic Optimisation of Process Parameters in Laser Drilling of 200 µm Photovoltaic Silicon Wafers Using New Kind of Nanosecond IR Lasers

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In this paper we demonstrate high-speed laser drilling of 50 µm through-vias into 200 µm thick monocrystalline silicon wafers for PV cells. This is required as process step for MWT cell technology. We show systematic optimisation of IR laser parameters with some 100 ns pulse duration for this task. We reach drilling speed of 1.9-2.5 ms per hole with 15-20 laser shots, which matches to the tact rate of 1-2 s (100 holes).

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1. Introduction

For optimising of silicon solar cell efficiency new concepts are discussed to bring the front contacts to the backside of the solar cell. For this a new high-speed technology is required to drill 50-100 µm via holes through the silicon wafer. Typical tact rate for drilling a complete wafer with about 100 vias is only 1-2 seconds.

Laser technologies are favoured for this task. Fundamental mode lasers with laser pulse length in the range of nanoseconds (ns) and with pulse energy in the range of millijoules (mJ) are well suitable for this. Usually pulse duration and pulse repetition rate of the laser source are related to each other, and thus both parameters cannot be tuned independently.

In this paper we present application results processed with a new kind of IR laser source, which is not limited in that manner.

2. Motivation

Today crystalline silicon wafers dominate world production of solar cells. Operating principle is based on carrier separation of photoelectrons in a pn-junction. Production Technology for this is well-known since 1954.

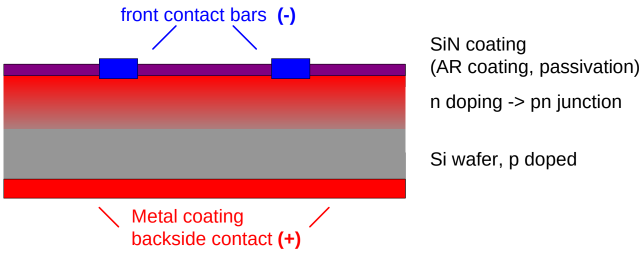

Fig.1 Classical PV cell layer structure with front contacts (bus bars) and large area metallization as backside contact

Today commercially available monocrystalline silicon cells reach 12-17 % efficiency. To reduce recombination losses it is required to arrange contacts within small distance. This is done by a large area back contact (metallic coating) and front side bars, which should be small to reduce consumption of active front-side area by shadowing. For a typical solar cell, front contact pattern takes up to 10% of the complete area.

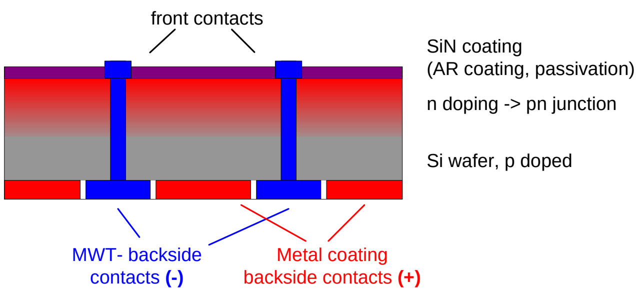

Fig.2 New MWT cell concept "wraps" front contacts to the cell backside. Complete backside wiring is a technological advantage, also wrapped front side contact can take larger area

One modern design concept to reduce shadowing are point contacts, which are "wrapped through" micro-vias to the backside (MWT technology: "metal wrap through") [1]. Thus back-contact can be accessed from the backside as well as front-side contacts. This gives technological advantages for the electrical connection of the cells, and resistance losses of front contact can also be reduced, because dimension of the contact at the backside is not longer limited by shadowing effects.

3. Basic estimations

We have estimated to replace 1.6 mm wide front side bus bars with about 100 point contacts of 200 µm diameter and calculate a reduction of front side area consumption from 5.3% to 2.9%. If this directly contributes to the cell efficiency, we would get an increase of cell efficiency in the range of 0.3-0.4 %. Indeed an enhancement of c-Si solar cell efficiency by 0.5 % to 16.5 % was reported recently using MWT technology[2].

To drill the holes, laser drilling is favoured, because it introduces energy only selectively at the drilling position without any mechanical contact of the drilling tool. Because there is no tool wear-out and laser emission can be controlled precisely, laser drilling process is very reproducible, which is a demand of factory automation. From further investigation to ablate silicon it is known, that ablation rate can be optimized, if laser pulse duration is in the range of some 100 ns.[3]

We have estimated with a simple calorimetric model, that complete evaporation of the volume of a 75 µm hole would consume 35.2 mJ. We will show later, that we really need a total energy of 40-50 mJ.

We also know from further trials[3], that ablation rate will increase for a pulse duration of more than 500 ns because optical absorption is temperature-dependent. For “large” pulse length of some 100 ns there will be a significant temperature rise already in the leading edge of the laser pulse and energy absorption in the trailing edge thus will enhance.

For a wavelength of 1030 nm absorption coefficient in silicon is 4.5 x 10-3 μm^{-1} which gives an optical penetration depth of ~ 200µm.[4] Within this dimension 63.2% of the incoming laser intensity is absorbed (reflection losses at surface neglected). Typical wafer thickness for PV applications now is 180-300 µm, and thus IR lasers will be absorbed efficiently inside the complete wafer thickness, resulting in efficient thermal ablation.

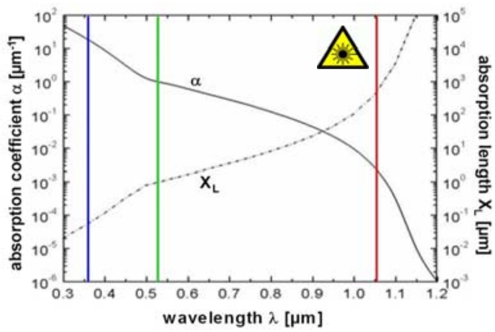

Fig.3 Optical absorption curves for the VIS/NIR region with some relevant laser emission wavelength

4. Application setup

Systematic investigation of ablation process and adaptation of optimum laser parameters require a laser source with independent tuneable main parameters, such as pulse energy, pulse duration, repetition rate. Such a source is JenLas®.IR50 by JENOPTIK.

There is used a new pulse-shaping principle[5]. A typical tuning area is given in fig.4.

It delivers in the tuning range between 8 and 100 kHz, a maximum pulse energy of 5.9 mJ and the pulse duration here is tuneable between 250 and 2000 ns.

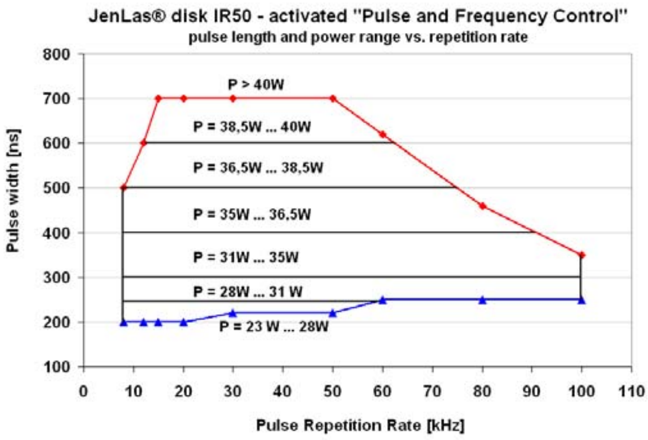

Fig.4 Tuning area of IR50 Laser by JENOPTIK. It can be tuned from 250 up to 700 ns and gives opportunity for systematic optimization of laser pulse length.

Further characterisation[5] shows symmetric beam profile, fundamental-mode beam quality and absence of astigmatism. This laser is equipped with a fast beam shutter, which allows to gate the pulse train down to single pulse. This allows to emit burst-like pulse trains with free timing control.

The intension of the application trials was to optimize laser drilled holes. The setup is depicted in fig.5: we aligned the IR50 laser (1) through a beam expander (3) (JENOPTIK) into a Galvoscanner (4) (SCANLAB, 14 mm aperture). Galvoscanner was equipped with different focussing optics (5) (JENOPTIK) and finally the sample (6) was fixed to a support structure (7). A Galvo controller board (2) (RTC4, SCANLAB) was used to synchronise Galvoscanner and Laser.

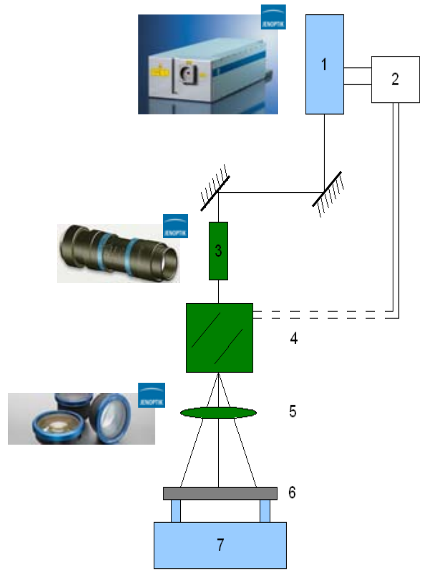

Fig.5 Application setup for high-speed silicon drilling using a Galvoscanner

Application results

In fig.6 the drilling results of 200 µm c-Si wafers are depicted: for 54 mm focal length the entrance diameter of hole increases with pulse energy. If pulse energy exceeds 3 mJ there occurs saturation. For the exit diameter this saturation already occurs at 1 mJ. This means higher pulse energy does not contribute to larger hole diameter. Maximum hole diameter here was 38 µm at exit side with a taper angle of 5.6°.

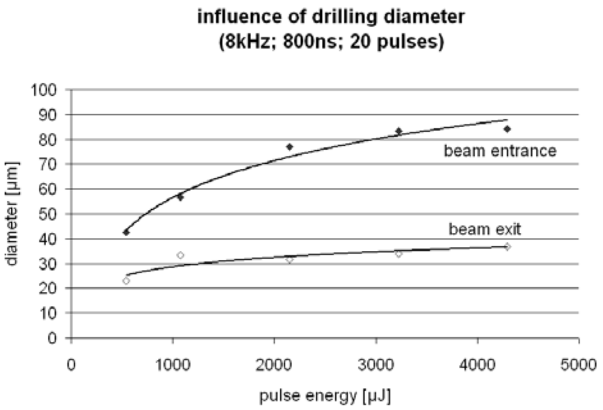

Fig.6 Application result: Exit diameter of laser drilled vias saturates at 38 µm using about 3mJ pulse energy.

By changing the focussing condition it is possible to reach 75 µm at exit side.

Fig.7 shows the influence of pulse duration if all other parameters are constant.

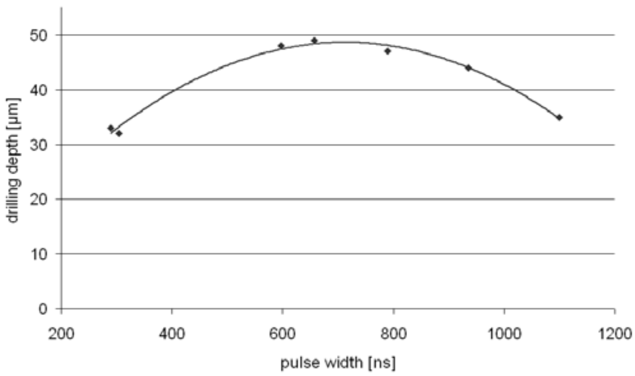

Fig.7 Application result: Best pulse duration is 600-800 ns to achieve maximum drilling depth per pulse (50 µm)

Optimum value is 600 ...800 ns and 15-20 pulses are required for complete drilling process. This means drilling time per hole is 1.9...2.5 ms at 8 kHz repetition rate, total energy per hole is 40-50 mJ. Visual inspection by optical microscope shows best edge quality for 650 ns pulse duration.

It should be mentioned here, that for real laser drilling process in PV industry also post treatment is of huge importance. Usually laser drilling is followed by an etching step. This removes lattice damage caused by the thermal character of laser drilling and extends the hole diameter by further 10-20 µm. Also hole roundness is influenced because of anisotropic edging velocity which is seen in fig.8. Thus hole quality must be evaluated after performing all relevant process steps.

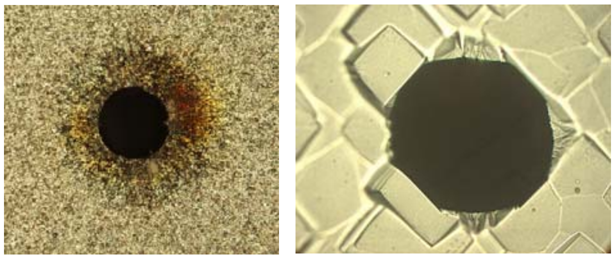

Fig.8 Comparison of pure hole just after laser drilling (left) with hole after next process step (right, after etching): Etching widens hole diameter by 10-20 µm and affects “roundness”. Please note different scaling. (left: hole diameter 63µm, right hole diameter 66µm)

5. Summary

We have demonstrated high-speed drilling of through vias into monocrystalline silicon wafers with thickness which is relevant for new back contact MWT concepts of PV cells. It is possible to drill a complete 50 µm hole within 1.9-2.5 ms with 15-20 laser shots. Further we have optimised laser parameters for this application with a laser source, which allowed to tune pulse energy, repetition rate and pulse duration independently. Best result was observed at 600-800 ns pulse length. Further enhancement of drilling speed is possible by optimised focussing, which was not investigated here.

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