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EVALUATION OF THE LASER MELTING PROCESS OF DIFFERENT MATERIALS FOR THE FRONT-SIDE METALLISATION OF SILICON SOLAR CELLS

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Abstract: This work evaluates the laser-assisted metallization process based on the melting/sintering of metallic powders for the formation of front-side electrical contacts for silicon solar cells, as a part of a two-step metallization concept without masks or photo-lithographical definition. A metallic seed layer is formed by a laser beam and then thickened by light-induced silver plating [1]. The deposition of a homogeneous powder coating was found to be the crucial requirement for a reproducible process.
Keywords: laser processing; coating, metallic powder deposition, front-side metallization, silicon solar cell

1 INTRODUCTION

The increase of the electrical current (produced by bigger and better silicon solar cells) calls for an improvement in the front-side metallization. A two-step metallization concept allows the optimization of both the contact resistance and the conductivity of the fingers separately. The first step is to deposit a thin seed layer on the wafer with a low contact resistance and then thicken it by light induced silver plating [2]. This paper focuses on a technology for the formation of seed layers as shown in Fig. 1 [3].

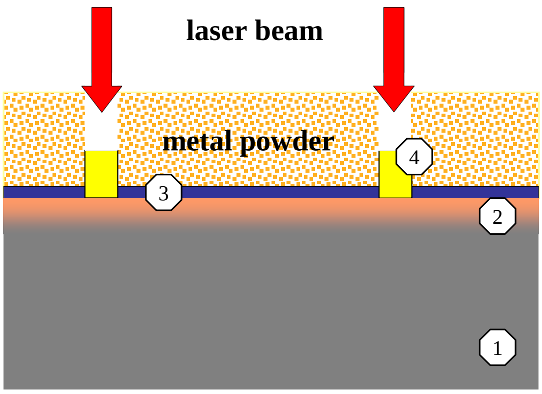

Fig. 1: Deposition of a seed layer by a laser beam
1) p-type base material 2) n-type emitter
3) dielectric layer 4) seed contact

A metallic powder is coated on the wafer. Then a laser beam heats the powder locally to selectively melt metal lines on top of the wafer. It has been observed that the homogeneity of the powder coating has a strong influence in the reproducibility of the process.
Keeping the development of an industrial application as a final aim, the establishment of a robust process is mandatory. Different technologies have been evaluated for the formation of the powder bed to achieve a homogeneity good enough for stability.
Different technologies for the metal powder coating of the wafers, as well as, their advantages and disadvantages, will be presented here.

2 EXPERIMENTAL

Silicon solar cells were formed on p-type silicon, with a phosphorus-diffused emitter with a sheet resistivity of 50 Ω/sq. Some wafers were processed with PECVD ARC SiN_x layer, others without. The rear-side was formed by evaporated aluminum directly in contact to the silicon (no passivation layer).
Different materials (tungsten, zinc oxide and titan nitride) were evaluated using different laser parameters (e.g. wavelength, power, frequency). Then the solar cells were characterized by Suns-Voc and light IV measurements under simulated AM 1.5 global in a solar simulator. The results of these wafers are very inhomogeneous (Fig . 2).

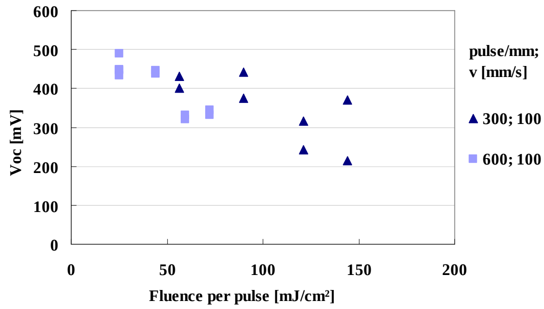

Fig. 2: Suns-Voc measurements of silicon solar cells contacted by laser melting process of titan nitride

3 INFLUENCE OF THE POWDER COATING

The strong variation in the electrical characteristics of the wafers can be explained by the thickness variations of the powder coating. In Fig. 3 a SEM picture of a laser-deposited seed layer is shown, even within the width of one finger, the damage to surface varies strongly.

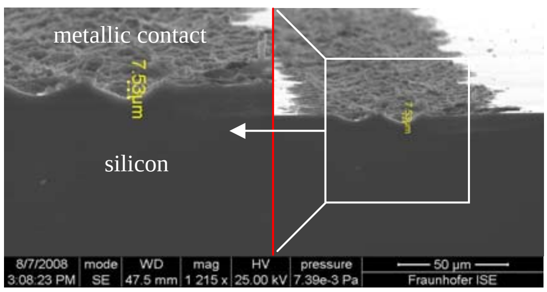

Fig. 3: Influence of the powder roughness for depth damage shown by SEM. Laser parameters (Nd:YAG 1064 nm, 8000 Pulses/mm, pulse energy density: 8.42 mJ/cm²). Powder: TiN

It becomes clear that controlling the roughness of the powder coating is very important. For this reason, the major focus of this research was the production of a homogeneous metal coating on top of the silicon wafers.

4 COATING PROCESSES

Coating with a squeegee

An almost finished solar cell, except for the front-side contacts, is placed in a chamber where a special squeegee spreads the powder along the surface (Fig. 4).

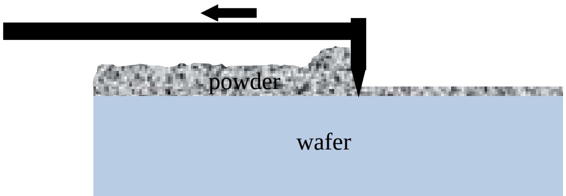

Fig. 4: A squeegee dispenses powder on top of a wafer

Inhomogeneous powder islands were formed due to the van-der-Waals force before laser processing. A modification to the process was applied by assembling a hopper in front of the squeegee. The powder is placed in the hopper achieving a continuous powder supply. Unfortunately, it was not possible to avoid island formation by this technology.

Ultrasonic sieve coating

Sieving is a method generally used to reach a powder distribution with a maximal particle size. To dispense powders without external pressure, the powder is deposited on an ultrasonic sieve. When the wafer is placed under the sieve, the ultrasonic is switched on and the powder falls on top of the wafer. Thanks to this technology the van-der-Waals forces are eliminated, reducing the formation of islands on the surface. Using ultrasonic sieves, instead of normal sieve, allows the use of smaller powders

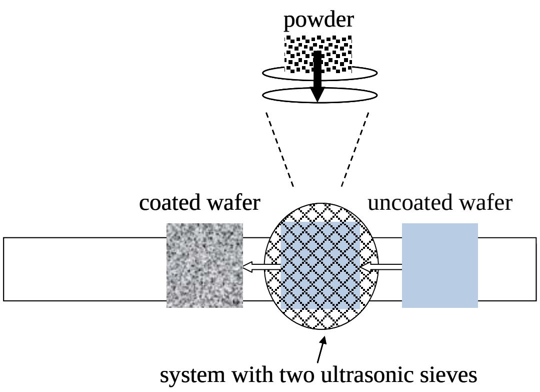

Fig. 5: Configuration of the two ultrasonic sieve techniques

With this technique the homogeneity of the layer depends on the powder thickness and the pressure used to coat the sieve. Different heights and pressure lead to a variation sieving rate over the area.

In an attempt to achieve a more uniform powder distribution on the sieve a second ultrasonic sieve under the powder-loaded sieve was used (Fig. 5). A considerable improvement of the homogeneity of the coating was visible without microscope but still not as good as required. Other modifications like spaying the powder on the upper sieve in order to obtain a homogeneous powder layer could be analyzed.

Coating out of a suspension

A suspension was made by mixing the powder with an alcohol. In this way, a coating out of an alcohol solution, which evaporates in a short time, is created. After the evaporation of the alcohol the laser melting processes was evaluated.
The suspensions are spread on the surface in different ways:

- By a squeegee
- With a Eppendorf pipette
- With a Eppendorf pipette and an ultrasonic bath

The evaporation of the alcohols is so strong, that after depositing the suspension on the surface, the metal particles start to settle down. The spreading of the mix with the squeegee along the whole area results in an inhomogeneous layer. So it is necessary to mix the suspension the whole time and to dispense the fluid as fast as possible. The suspension was spread from on edge of the specimen holder to the other. Depending on the viscosity, the weight of the particles and the time between the deposition of the suspension on the holder and its spreading have a wide influence on the characteristics of the coating (Fig. 6). For a short processing time, a reduced amount of powder settles down before the dispersion is spread over the wafer (Fig. 6 a), as the time increases the coating becomes more inhomogeneous (Fig. 6 b, c).

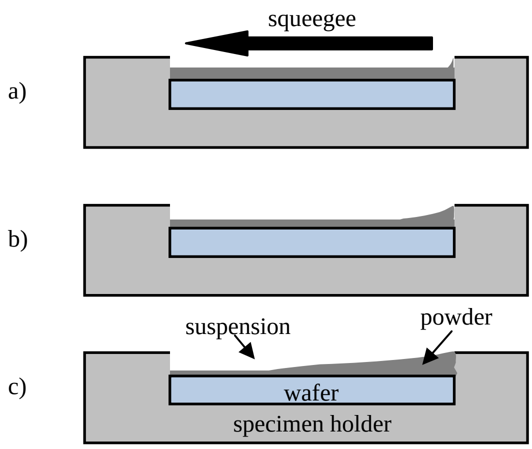

Fig. 6: Different coating distributions depending on the time between depositing a suspension on the edge of the specimen holder and spreading it: a) fast, b) medium, c) slow

A better control of the processing time is provided by a depositing the suspension with an Eppendorf pipette and allowing the fluid to distribute itself along the surface. The suspension is continuously mixed to keep a stable

powder distribution in the fluid. It is important to achieve a low viscosity that would allow the formation of a homogeneous coating.
The suspension can be deposited on top of the wafer by filling up a carrier beyond the edges of the substrate or by using the right amount of solution so that it will only reaches the edge of the wafer.
It is possible to dry the suspension in an ultrasonic bath, allowing an optimal distribution of the powder. A configuration as presented in Fig. 6 was used.

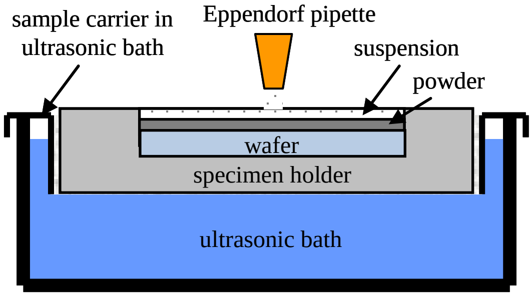

Fig. 7: Configuration for an ultrasonic dryer of a suspension

The roughness (R_a) and the averaged maximum difference of level (R_z) by coating out of a suspension with an Eppendorf pipette have been analyzed by µ-surf measurements.
The particle size and the choice of material have an important influence on the roughness of the coating, as presented in Table 1.

Table 1: µ-surf measurements of coatings made out of different suspension without spreading beyond the wafer

	R_a	R_z
	[µm]	[µm]
	Dried with ultrasonic	
Tungsten <1 µm	1,3	7,4
Tungsten 1-4 µm	0,9	4,8
Tungsten 12 µm	7,7	21,6
Titan nitride 6 µm	1,3	8,3

The use of an ultrasonic bath has also an influence of the roughness of the coating and seems to a beneficial effect for tungsten powder with small particles (see Table 3).

Table 2: µ-surf measurements of coatings made out of suspensions with and without drying in an ultrasonic bath

Powder: Tungsten <1 µm	R_a [µm]	R_z [µm]
Without ultrasonic	0,9	4,8
With ultrasonic	0,6	4,0

Powder: Titan nitride 6 µm	R_a [µm]	R_z [µm]
Without ultrasonic	1,3	8,3
With ultrasonic	1,6	9,4

Another important parameter affecting the roughness is the distribution of the suspension beyond the wafer edges (see Table 2). Experiments performed using tungsten and titan nitride show that the roughness is much smaller when the suspension does not flow beyond the edge of the wafer.

Table 3: µ-surf measurements of coatings made out of suspensions with and without spreading of the suspension beyond the wafer.

Powder: Tungsten <1 µm	R_a [µm]	R_z [µm]
	Dried with ultrasonic	
Without spreading	1,3	7,4
With spreading	4,2	21,2

Powder: Titan nitride 6 µm	R_a [µm]	R_z [µm]
	Dried without ultrasonic	
Without spreading	1,6	9,4
With spreading	3,3	16,9

According to these results, the minimal roughness does not depend on the size of the powder. An optimal combination between powder size, and spreading process should be reached. Further experiments using the coatings with the lowest roughness are under current investigation.

5 CONCLUSION

Implementing a robust laser melting process for the front-side metallization of silicon solar cells requires the deposition of homogeneous powder layers. In this paper different technologies have been presented for the achievement of metal coatings. Many parameters, such as particle size, specific gravity of the material and interactions between the powder and the surface have an influence on the roughness of the coating. It has been shown that a coating out of a suspension with an Eppendorf pipette without spreading beyond the wafer edges is producing the most homogenous layer thickness.

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