Industrial inline PVD metallization for highly efficient crystalline silicon solar cells

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Constance, 15th of April 2010
Status in the year 2003

• Most highly efficient solar cells are metalized on front & back by means of PVD metallization!

But:
Status in the year 2003

• Most highly efficient solar cells are contacted on front & back by means of PVD metallization!

But:
• No industrial machine available for such processes

and even
Status in the year 2003

- Most highly efficient solar cells are contacted on front & back by means of PVD metallization!

But:

- No industrial machine available for such processes

and even

- No idea what method is the best: Sputtering? Thermal evaporation? E-gun evaporation?
Project “INKA”

- Period of time: 2003 – 2006
- Cooperation between Applied Materials and Fraunhofer ISE

Results:

1. All investigated methods as sputtering, thermal evaporation and e-gun evaporation have about the same efficiency potential.
2. Thermal evaporation is the best economic solution
3. Designing and constructing ……
Aton 500

- Pilot line machine
- Throughput of 540 W/h (156 x 156 mm²)
- Evaporation unit for the deposition of Al
- Sputter unit for 2 different metals solderable stack

Entrance Chamber | Vac. 1 Chamber | Vac. 2 Chamber | Evap. Chamber | Transfer Chamber | Sputter Chamber | Vac. 3 Chamber | Vac. 4 Chamber | Exit Chamber
We use Aton 500 for:

- Sputtering front side contacts
- Sputtering solderable layer
- Evaporation of rear side metallization of PERC, back contact back junction and …
- LFC cells
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What needs the metallization layer to look like in the special case of laser fired contacts?
Outline

• Deposition homogeneity < 20 %
• Provide sufficient lateral conductivity
  What layer thickness do we need?
• No harming influence on passivation quality (SiO$_2$)

• → Perfect cell results
Homogeneity

- Adjustable by different wire velocities
- Homogeneity on one 156x156 mm² wafer: ~ 4.5 % (64 m. p.)
- Homogeneity on one tray (9 wafer): ~ 6.3 % (576 m. p.)
- Homogeneity good enough for LFC application
Sheet resistivity $\rho$ – what layer thickness do we need?

- $\rho = R_{sh} \times d$
- Measuring of the thickness $d$ by means of mechanical profilometer and
Sheet resistivity $\rho$ – what layer thickness do we need?

- $\rho = R_{sh} \times d$
- Measuring of the thickness $d$ by means of mechanical profilometer and SEM pictures
- Local measuring of the sheet resistance $R_{sh}$ by four point probe.
- $\rho = 32 \pm 1 \, \text{n}\Omega \cdot \text{m}$
- $\rightarrow$ 20 % higher than bulk Al. (26.5 nΩ·m)
- $\sim$ 10x lower than screen printed Al layer
\( \Delta \eta = \frac{\rho \cdot j_{\text{gen}} \cdot I_x^2}{12 \cdot d_{\text{Al}} \cdot U_{\text{mpp}} \cdot b^2} \cdot \eta \)

(PhD Thesis: Andreas Grohe. ISE 2008)

- \( b = 2 \)
- \( \rho = 32 \text{ n}\Omega \text{m} \)
- \( J_{\text{gen}} = 35 \text{ mA/cm}^2 \)
- \( U_{\text{mpp}} = 560 \text{ mV} \)
- \( \eta = 18 \% \)
η-losses in dependence on the layer thickness

- $b = 2$
- $\rho = 32 \text{n}\Omega\cdot\text{m}$
- $J_{\text{gen}} = 35 \text{mA/cm}^2$
- $U_{\text{mpp}} = 560 \text{mV}$
- $\eta = 18\%$
Investigated deposition processes

Different deposition rates $A_{dep}$:

- Layer thickness: 2 μm
- Rates $A_{dep}$: 0.5 – 6 μm*m/min
- "Lifetime samples"
- Highly efficient solar cells
- Pre experiments showed no influence on homogeneity and sheet resistivity $\rho$

<table>
<thead>
<tr>
<th>process</th>
<th>thickness</th>
<th>$v_{\text{tray}}$</th>
<th>deposition rate $A_{dep}$</th>
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<td>[m/min]</td>
<td>[μm*m/min]</td>
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<td>3</td>
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Influence on SiO₂ passivation

- 40 symmetric samples
- Shiny etched FZ 1 Ω·cm material
- Deposition rates 0.5 – 6 µm*m/min (processes 1-5)
- QSSPC measurement with/without Al-neal
- 100 nm “dry” SiO₂
Influence on SiO₂ passivation

after metallization:
• similar level as before

after Al-neal:
• Very high lifetimes $t > 1\text{ms}$
• Lifetime increases with increasing $A_{\text{dep}}$

![Graph showing lifetime $\tau$ vs. deposition rate $A_{\text{dep}}$]
Solar cell results

High-\(\eta\) cell structure:

- Shiny etched FZ 1 \(\Omega^*\)cm
- 7 sized 2 x 2 cm\(^2\) cells per wafer
- Different deposition rates
- Reference process with e-gun metallization
- Tempering variation
- Laser fired contacts (LFC)
Influence of tempering (hotplate)

- reference e-gun level up to 680 mV (SunsVoc)
- voltage level increases until \( T = 450 \degree C \)
- \( @T > 350 \degree C \) voltage can decrease
- reference level is reached at \( T = 400 - 450 \degree C \) for \( t = 1-5 \) min.
## Solar cell results

<table>
<thead>
<tr>
<th>Process</th>
<th>Deposition rate</th>
<th>$V_{OC}$</th>
<th>$J_{SC}$</th>
<th>FF</th>
<th>η</th>
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<td>[mV]</td>
<td>[mA/cm²]</td>
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</table>

Best cells of batch:

- High efficiency potential over a wide range of different deposition rates
- 21.8 % are best efficiency ever for LFC cell on 1 Ω*cm material
Summary

- Set up of an industrial pilot line system for the evaporation of aluminum layer for LFC cells
- Improved overall cell process
- Shorter temper process
- Cell efficiencies up to 21.8 %
- Best LFC cell ever on 1 Ω*cm material
Thank you for your attention…

… and also special thanks goes to Applied Material for the successful cooperation as well as to the BMU for the financial support of this work!