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Lessons From the 2nd Workshop on Metallization of Crystalline Silicon Solar Cells

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Abstract

About 190 metalization experts gathered in Constance, Germany in April for the 2nd Workshop on Metallization of Crystalline Silicon Solar Cells. Presentations and discussions clearly showed that screen-printing is not running out of steam because of various innovations in processes and pastes. Interest in the seed-and-plate approach has somewhat decreased. Cu plating has gained in importance but is facing several hurdles before it can be industrially implemented.

Introduction

Metalization is one of the key process steps to fabricate solar cells with high performance in a cost-effective way. More than 85 percent of photovoltaic solar cell manufacturing uses thick film screen print metalization to produce solar cells, but a lot of research is also carried out on alternative metalization schemes or variations to screen-printing. The success of metalization technology development is crucial for the evolution of solar cell technology toward lower production costs and higher efficiencies.

Recognizing that existing photovoltaic events did not provide an ideal setting for experts to discuss these topics in detail, we decided to organize a dedicated and focused workshop on the topic of metalization of crystalline Si solar cells. The number of participants in this workshop is limited and much time is reserved for panel discussions, informal exchanges and networking.

The 1st Metallization Workshop, held in Utrecht, The Netherlands, in 2008, turned out to be a great success. The second edition was held in Constance, Germany on April 14 and 15, 2010. Around 190 scientists and engineers from solar energy institutes, universities and companies all over the world gathered in the Konzil, a historical building facing the Lake of Constance, to share and discuss the latest developments in solar cell metalization. This report aims to summarize the major lessons learned from the workshop. More information (including presented slides) is available on the website www.secondmetal.eu.

Screen-printing Still Reigns Supreme

Front-side metalization is commonly achieved by screen-printing a Ag containing paste in a grid pattern on the silicon nitride-coated wafer, and then applying a short thermal anneal, during which the paste etches through the nitride to make contact with the top region in the Si wafer and Ag particles are sintered. The exact mechanism of contact formation was touched upon in several contributions. The process of formation of Ag crystallites and simultaneously of a glass layer on top of those, which was originally described by Gunnar Schubert,[1] seems supported by several contributions, although some in the metalization community questioned the importance of the crystallites in the electrical contact.

It was recognized that much progress has been made at the level of paste development to enable low contact resistance on high sheet resistance emitter, enabling substantial efficiency gain. Further development in that direction and enhanced understanding of the processes will lead

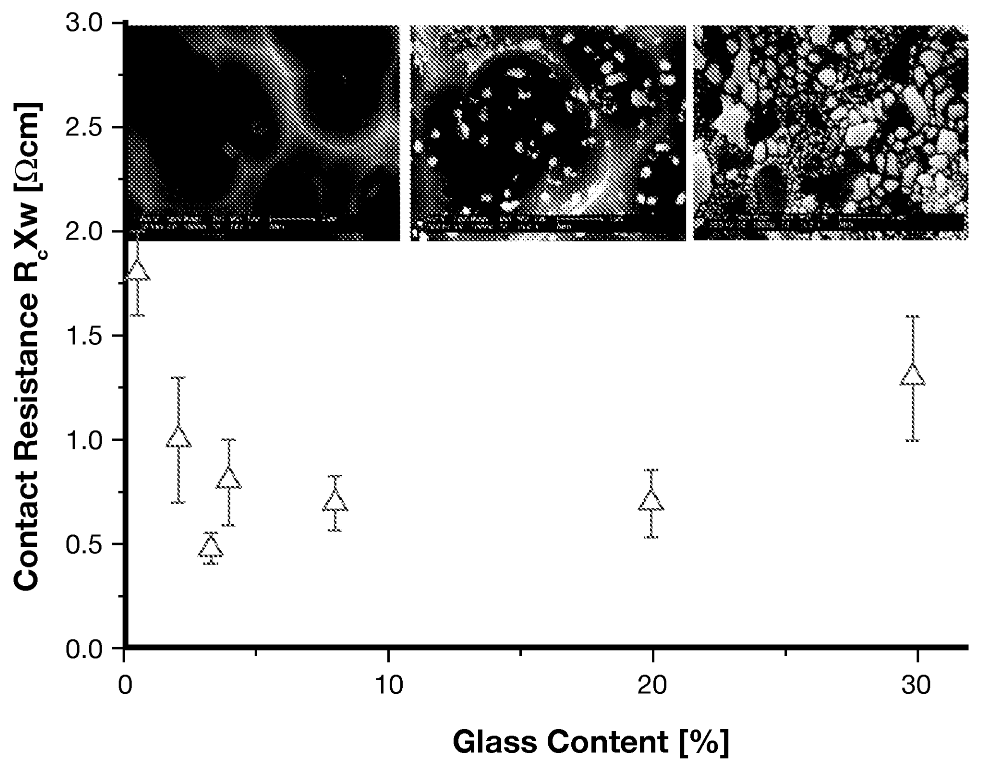

Figure 1 – Contact Resistance Measurements as a Function of Glass Content[2]
Reproduced with permission from the presentation at the workshop of Matthias Hörteis, Fraunhofer ISE

to pastes with even higher performance,[2] but it was stated that at present, no paste can contact emitters with surface concentration below 10^{20} cm^{-3}.

The effect of the peak temperature dwell time on the contact formation, and in particular, the thickness of the glass layer causing high contact resistance, was discussed.[3] The results suggested that improvement in performance might be obtained by innovation in annealing processes. That could be achieved by adapting belt furnaces or by switching to alternative techniques, such as, e.g., induction firing.[4]

The issue of Ag diffusion into sensitive regions of the device was pointed out,[3,5] and clearly represents a danger for shallow emitters. To avoid this problem, a deeper and lowly doped emitter is desired. It is, however, impossible to create by traditional phosphorus diffusion a deep and lowly doped emitter that at the same time displays a high surface concentration necessary for contacting by screen-printing. The advent of new emitter formation methods relying on techniques originally developed for microelectronics, such as epitaxy, was presented as a possible solution.[6]

An often-mentioned drawback of screen-printing is the large line width that leads to high shading losses. Several innovations are being introduced that aim to solve that problem. One solution is to print narrow (but relatively thin) lines twice on top of each other, to achieve narrow (60-100 µm) and sufficiently thick lines. Tests on very large batches demonstrated the feasibility of this approach.[7,8] Another approach with substantially less process complexity could be single printing of narrow lines with large aspect ratio using stencils instead of screens, as indicated by promising results presented by Jaap Hoornstra from ECN.[9] A material-based solution is to use a hot-melt material that solidifies quickly upon printing, also enabling high aspect ratio lines with a single screen-print.[10] Another innovative printing technique that was presented is the off-contact laser transfer printing technique that could become an alternative to screen-printing if sufficiently high aspect ratios are achieved.[11]

In general, thick film printing of a Ag front grid was presented as a versatile technique with a large scope for further improvement both at process and paste level. Its adaptability was also evidenced by successful adaptation for back contact cells with via metalization.[12] Interestingly, the need for lead-free pastes did not seem a primary concern among cell manufacturers, who demand equivalent performance from lead-free alternatives. Bithmuth-based products are, however, in development, and a paste manufacturer felt confident that the performance gap with Pb-containing pastes would be closed in the coming years.[13]

Seed and Plate

The strong progress in Ag screen-printing seems to have decreased interest in the "seed and plate" approach for the front grid. This is a hybrid approach where a very narrow line is first printed by a fine-line printing method (often an off-contact method such as aerosol printing or inkjet printing), fired through silicon nitride, and then thickened by plating, most often Ag light-induced plating (LIP). The introduction of this technique in production, which seemed imminent at the time of the 1st Metallization Workshop, has been slower than anticipated. Nevertheless, outstanding cell results presented at the 2nd workshop reminded the audience of its strong industrial potential, such as an 18.7 percent cell on 239 cm^2 Cz wafers obtained by combining inkjet printing and LIP.[3] This approach also was shown to work well for alternative cell structures, featuring, e.g., alternative front passivation stacks AlO3/SiN stacks and shallow B-emitters on n-type wafers.[14]

The emergent fine-line printing techniques were shown to impose very different requirements on inks in terms of viscosity and particle size compared to screen-printing pastes,[15] but also to enable the printing of alternative metals with conductivity close to bulk if the appropriate solution and nanoparticle-based precursors are used.[16]

Cu Plating Metalization Schemes

Several long-term solutions for front grid metalization are based on Cu plating. Indeed, one can potentially obtain higher performance, through the ability to contact high-efficiency emitters with low surface doping and without glass interlayer, and lower cost through the replacement of Ag by Cu.

A first step toward such long-term Cu-based metalization schemes is to apply the seed-and-plate approach. First a thin-printed Ag line is fired through nitride, but the line is thickened with Ni and Cu plating instead of Ag LIP. In such a structure, diffusion of Cu into the cell and resulting harmful contamination is a concern, but a detailed study of cell degradation showed that plating conditions could be found where Cu diffusion is avoided completely.[17]

Ni is often used as first layer in a Cu metalization scheme. It creates contacts with very low resistance upon annealing through the formation of Ni silicide, even on emitters with low surface concentration. Moreover, it enables self-aligned process schemes, either through selective silicidation or by auto-catalytic plating onto Si. Finally, a sufficiently thick nickel layer is also an effective barrier against diffusion of Cu. Several contributions identified the challenges with Ni, such as the danger of shunting through the emitter[18] and problematic adherence of Ni barrier layers.[19]

A contribution from imec shared the experience learned from a similar switch to Cu that took place in integrated circuit processing in the past. Some learning can be directly transferred, e.g., in the fields of contamination control, diffusion barriers and adherence.[20]

Rear Side

There were fewer presentations on rear-side metalization, although the topic is also of crucial importance for cell performance. For example, the thickness, doping concentration and uniformity of the traditional Al-BSF/Al contact has an important impact on cell efficiency.[21] It was noted that higher temperatures lead to a thicker and more highly doped BSF, leading to better Voc, but that this benefit could only be exploited if the front surface metalization is adapted for higher temperatures.[9]

Detailed studies of local Al BSF formations were presented, which are formed in advanced cell structures with dielectric

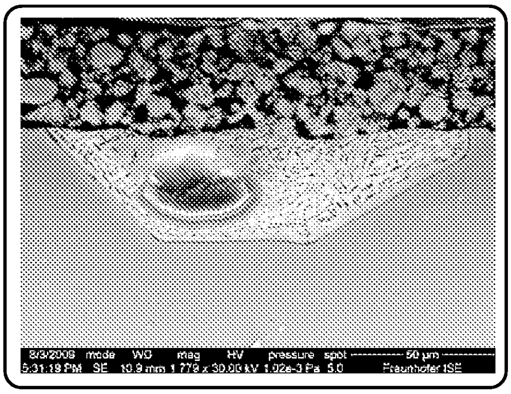

Figure 2 – Cross section SEM picture of a locally alloyed Si-Al contact. Particles with lamellas indicate Al-Si eutectic formation and therefore evidence of Si diffusion. *Reproduced with permission from the presentation at the workshop of F. Grasso and L. Gautero, Fraunhofer ISE.*

passivation and local contacts. These talks confirmed the creation of pits and trenches upon Al alloying in narrow openings described by Guy Beaucarne in the 1st Metallization Workshop.[22] The contributions indicated that Al availability and size of the opening of the dielectric is critical for the depth of the alloyed contact.[23] It was also shown with detailed cross-sectional studies that Si diffuses in Al far away from local contact (up to 20 µm away from the opening), and the link was established between this observation and the relatively thin BSF formation in the locally alloyed region.[24]

Series resistance in the rear structure of dielectric passivated cells is an important issue. It was shown by simulation that resistive losses are likely to be lower in PERC structure (with blanket Al coverage) than in structures with Al fingers at the rear.[21] An optimal structure for cells with rear nitride passivation and metallic grid might involve the use of a firing-through AgAl paste. This was shown to work well on devices with B-BSF,[25] but will be a challenge for cells relying on local Al-BSF.

To obtain the blanket Al deposition for PERC type cells, the traditional technique consisting of screen-printing a thick Al layer can be used. However, for reasons of process control and future cost reduction, high-throughput PVD (physical vapor deposition) is an attractive alternative. An important step toward an industrial solution for Al PVD was demonstrated at the workshop in reports on promising results with prototype in-line vacuum thermal evaporation.[26,27]

Link Between Cell Metalization and Module

New cell metalization can pose challenges for module assembly. Conversely, issues with module assembly might have important implications for the design of the cell metalization. To address this, a special session on the relationship between cell metalization and module fabrication was organized, with only invited speakers.

The first step in module manufacturing is the interconnection of cells by soldering a tin alloy-coated Cu ribbon onto the cell busbars. This process is delicate and can lead to several problems, such as cell breakage, insufficient adhesion and damage to the metalization.[28] Cell designs should minimize the amount of solder joints and display flat busbar surfaces. The stress induced by solder joint cooling combines with stress created by metalization. The resulting stress in the device is also determined by the properties of the interconnection material, the applied thermal treatment and cell geometry, and is directly related to yield.[29]

Electrochemical reactions during interconnection and operation were discussed and shown to have a possible impact on metalization if not well controlled. It was also indicated that present paste-based metals are brittle and that cracks propagate from wafer into the metal.[30]

Finally, a module concept was presented for back-contact MWT cells, where the metalization design of the cells is adapted to the module concept.[31] During this talk, a statement was made that is probably more general than for back-contact modules alone: Cell structures and processes, including metalization, should be developed together with the module concept as one system.

The Participants' View on the Future of Metalization

At the end of the workshop, the participants were asked to give their views on the development of metalization in a questionnaire. The results (Figure 3) showed that screen-printing is expected to remain dominant in the next 10 years, but that emerging concepts will gain significant share within five years.

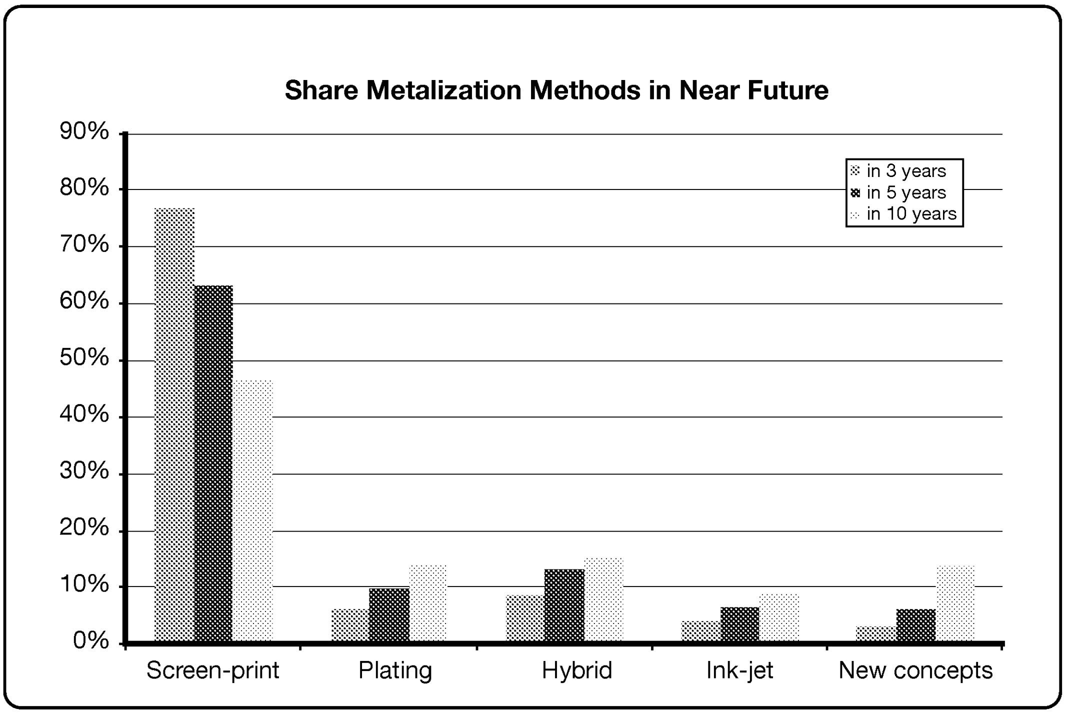

Figure 3 – Anticipated Share of the Different Metalization Techniques in the Coming Years.

Conclusion

The 2nd Workshop on Metallization of Crystalline Silicon Solar Cells provided excellent insights in the status and development of metalization technology. Although screen-printing has been around for a long time, it is efficient, quick and reliable, and its performance is being stretched by some innovations, making it hard for alternative techniques to emerge. The hybrid Ag seed-and-plate approach is the only technique that could be introduced in the short term, but has lost some of its appeal because of improvements in traditional screen-printing. Metalization schemes based on Cu plating appear to be the ultimate solution in terms of line width, cell performance and material costs, but several hurdles need to be overcome before it can be widely adopted.

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About the Authors

Guy Beaucarne *did his Ph.D. on solar cells at imec and obtained his Ph.D. degree from the University of Leuven in 2000. In 2001 and 2002, he was in Australia, first as a post-doc at the University of New South Wales, and then at its thin-film spin-off Pacific Solar. Between 2003 and 2009, Guy was back at imec as solar cell technology group leader. He is presently solar cell science and technology manager at Dow Corning.*

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Gunnar Schubert *obtained his M.Sc. in physics in 2002 at the University of Konstanz. In 2006, he received his Ph.D. in the area of thick film metalization of crystalline silicon solar cells at the photovoltaics department of the University of Konstanz. Since 2006, Gunnar has been working in the R&D department of Sunways AG. He is presently head of R&D Solar Cells at Sunways.*

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