



# Novel Rear Side Metallization Route for Si Solar Cells Using a Transparent Conducting Adhesive

## Preprint

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# Novel Rear Side Metallization Route for Si Solar Cells Using a Transparent Conducting Adhesive

Manuel Schnabel, Talysa Klein, Benjamin Lee, William Nemeth, Vincenzo LaSalvia, Maikel van Hest, Paul Stradins

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**Abstract** — The rear side metallization of Si solar cells comes with a number of inherent losses and trade-offs: a larger metallized area fraction improves fill factor at the expense of open-circuit voltage, depositing directly on textured Si leads to low contact resistivity at the expense of short-circuit current, and some metallization processes create defects in Si. To mitigate many of these losses we have developed a novel approach for rear side metallization of Si solar cells, utilizing a transparent conducting adhesive to metallize Si without exposing the wafer to the metal deposition process. This approach leads to virtually no loss in implied open-circuit voltage upon metallization. Electrical measurements showed that contact resistivities of 3-9  $\Omega\text{cm}^2$  were achieved, and an analysis of the transit resistance per microsphere showed that  $<1 \Omega\text{cm}^2$  should be achievable simply with higher microsphere loading of the transparent conducting adhesive.

## I. INTRODUCTION

A number of losses and trade-offs are inherent in rear side metallization of Si solar cells. A larger metallized area fraction provides better fill factor at the expense of lower open-circuit voltage  $V_{oc}$ , and direct metallization of a wafer rear side leads to good contact resistance at the cost of optical losses as long-wavelength photons generate plasmons in the metal, while adding a spacer may worsen contact resistance and/or lead to new absorption losses. Lastly, some metallization routes, such as sputtering or electron beam evaporation, inherently damage the solar cell by creating defects in the Si wafer.

In this contribution, we present a method whereby a number of these losses could be avoided. Our approach involves bonding the rear side metal to the Si solar cell using a transparent conducting adhesive (TCA). The TCA, which is presented in more detail in a separate contribution to this conference [1], consists of Ag-coated poly(methyl methacrylate) (PMMA) microspheres embedded in an ethylene vinyl acetate (EVA) sheet, and has been found to exhibit a sheet resistance below  $0.5 \Omega\text{cm}^2$  when sandwiched between Ag-coated glass slides, even for an area coverage by the microspheres of only a few percent [1]. This approach has a number of advantages: the metal-semiconductor contact area is reduced, a spacer between Si and metal reduces plasmonic losses, and in Si module production, the metal could be deposited and patterned on the module backsheet, and then glued to the Si solar cells, so the cells would not need to be exposed to the actual metal deposition process.

In the following, we use this approach to metallize symmetric passivated contact lifetime samples on one side, and study the impact on implied  $V_{oc}$  and contact resistance as compared to a TCA-less reference on which metal is deposited directly.

## II. EXPERIMENTAL DETAILS

Symmetric samples using our poly-Si/SiO<sub>x</sub> passivated contact layers were prepared as described in Ref. [2]. Briefly, 3.5  $\Omega\text{cm}$  n-type Cz-Si wafers were KOH- planarized, RCA cleaned [3], thermally oxidized to form a 1.5 nm oxide, and then had n-type amorphous Si deposited on both sides which was thermally crystallized at 850°C to form poly-Si. The planarized surface still has  $\sim 10$  micron surface roughness due to the remaining mesa morphology after planarization. The samples were then hydrogen-passivated by deposition of Al<sub>2</sub>O<sub>3</sub> on both sides followed by a forming gas anneal. The Al<sub>2</sub>O<sub>3</sub> was removed in HF prior to further processing of these passivated contact (PC) samples.

TCA sheet was prepared by depositing a solution of Ag-coated PMMA microspheres and EVA in toluene onto glass, heating to 120°C, and removing the resulting layer with a razor blade. The TCA sheet is then put on the wafer surface. In order to prepare integrated PC/TCA/metal stacks, metal was deposited onto two types of carrier substrates that could later be removed: 1) a transmission line model (TLM) structure as well as large metal pads of 20 nm Ti / 1000 nm Ag / 50 nm Pd stack were deposited onto NaCl crystals using electron beam evaporation shadow masks (Fig. 1(a)), and 2) full-area Ag was deposited on glass as shown in Figure 1(d,e), to be separated from it when immersed in H<sub>2</sub>O/NaCl solution. These materials were then stacked as PC/TCA/NaCl, and PC/TCA/Glass, with the metallized side of the substrate facing towards the TCA and wafer. These stacks were hot-pressed at 120°C and 0.5 bar for 10 min, and subsequently soaked in deionized (DI) water. The DI water dissolves the NaCl crystals, and causes delamination of Ag from the glass, resulting in PC/TCA/Pd/Ag/Ti (Fig. 1(c)), and PC/TCA/Ag stacks (Fig. 1(e)), respectively. Some PCs also had the same metal stack used for the NaCl crystals evaporated on them directly as a reference.

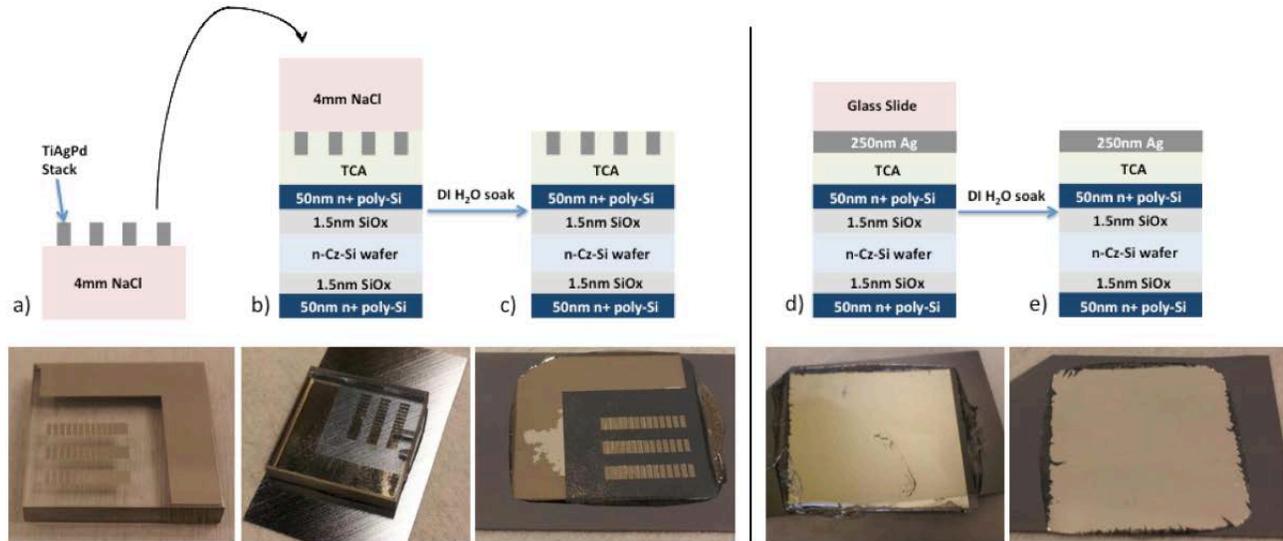


Figure 1: Depiction of metal pattern transfer from a sacrificial NaCl (a,b,c) or glass (d,e) substrate to a passivated contact lifetime sample using TCA. Top: Schematics, bottom: photographs (NaCl and glass are about 1" square). A TLM pattern and a larger metal area are deposited on NaCl using a shadow mask (a). The NaCl is then glued to the PC sample using TCA (b), and removed by dissolving in DI water to leave a metal pattern TCA on a PC sample (c). Similarly, glass with 250 nm Ag deposited on it is glued to a PC sample using TCA (d), and removed by inducing delamination at the Ag/glass interface via a DI water soak (e).

Implied  $V_{oc}$  ( $iV_{oc}$ ) was measured using a WCT-120 Sinton lifetime tester prior to metallization, and changes monitored via photoluminescence (PL) imaging using an in-house 810 nm laser diode source and Si CMOS camera. All samples are placed on a silvered mirror during PL measurement to ensure comparable coupling of emitted PL to the camera, before and after sample metallization. Contact resistance was calculated from current-voltage measurements on TLM structures, and processing monitored via light microscopy.

### III. RESULTS

Figure 1(bottom) indicates that processing was successful and the targeted structures were achieved. Figure 2 shows PL images before and after metallization of the PC samples metallized via metal transfer from NaCl using TCA, via metal transfer from glass using TCA, and via direct metallization of the PC sample. In each case, images are taken from the unmetallized side.

It is immediately apparent that metal transfer from another substrate via the TCA preserves the PL intensity for either metal transfer process used, whereas direct metallization on the PC sample strongly quenches PL. In order to quantify this effect, we analyzed  $iV_{oc}$  changes using the areas marked by boxes in Figure 2, under the assumption that changes in PL are related solely to changes in recombination rate and not to changes in coupling of PL light to the detector. The analysis shows that  $iV_{oc}$  of the two samples metallized by the two different metal transfer processes only drops by 3-4 mV upon metallization, preserving the initial  $iV_{oc}$  of 722 and 728 mV of these two samples very well. On the other hand, the  $iV_{oc}$  of the sample in Fig. 2(c), which was also initially

722 mV, plummeted by 120 mV upon electron beam metallization.

While this is a rather extreme example, difficulties maintaining an initially high  $iV_{oc}$  upon metallization are well-documented for passivated contacts [2, 4, 5]. Transfer of metal to PC samples via the TCA provides an alternative, provided acceptable contact resistance can be attained.

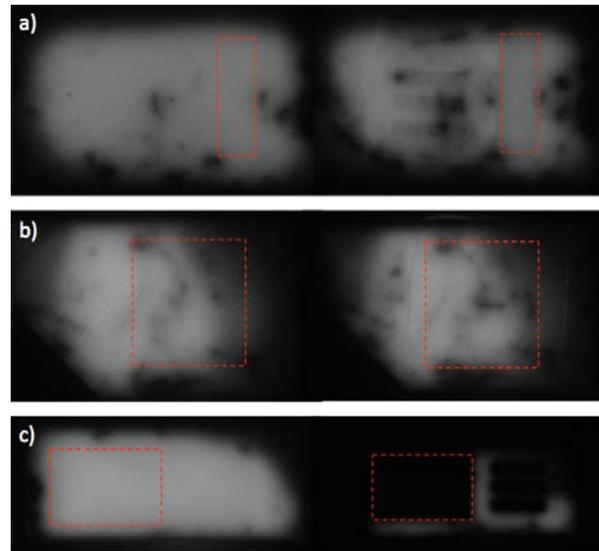


Figure 2: PL images of PC samples before (left) and after (right) metallization. a) PC/TCA/Pd/Ag/Ti prepared using NaCl, b) PC/TCA/AG prepared using glass, c) PC/TCA/Ti/Ag/Pd prepared by direct evaporation on the PC sample. Metal transfer onto PC samples is much less damaging for  $iV_{oc}$  than direct electron beam evaporation onto PC samples. The areas metallized on the right-hand images that are used for  $iV_{oc}$  analysis are marked. Exposure times are 33 ms for (a) and 50 ms for (b,c).

It is important to note that our technique is expected to accommodate the surface roughness texturing of the wafer, because of relatively large  $\sim 40$  micron size of the spheres and their partial deformability under heat and pressure. On one hand, higher temperature facilitates sphere deformation, which helps to comply with rough surfaces. On the other hand, too high T leads to high plasticity and causes flattening of the contact area, with diminished mechanical pressure at the contact points. Detailed study will be presented. Using our current process parameters, an attempt was made to extract the contact resistivity of the metal/TCA/PC stack using the TLM method. As shown in Figure 3, Ohmic current-voltage (IV) curves were obtained, and the inset reveals a general increase in resistance with pad spacing. Typically in such a plot, the slope of a linear fit yields the sheet resistance of the laterally conducting material between the contacts (here, the n+ poly-Si and the n-Si wafer), while the resistance axis intercept yields the contact resistance. However, applying this method to the data in the inset yields a negative contact resistance, and a sheet resistance exceeding  $10^4 \Omega/\text{sq}$ , both of which are unphysical.

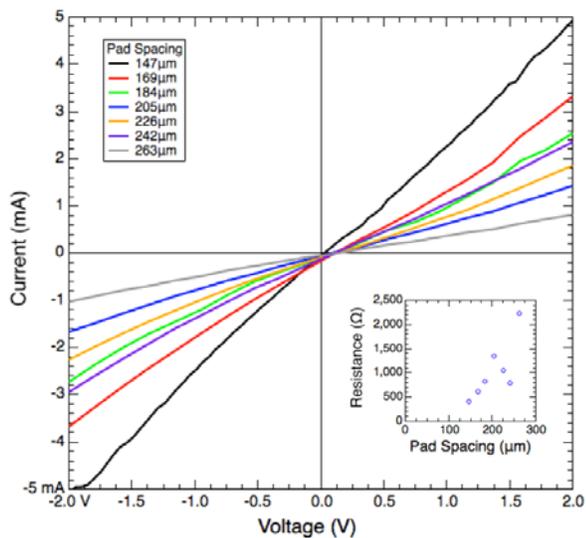


Figure 3: IV curves measured across adjacent TLM pads on a metal/TCA/PC sample prepared using sacrificial NaCl. Inset: plot of Ohmic resistances from main plot as function of pad spacing.

A close inspection of the sample used revealed that the areal density of Ag-coated microspheres in the TCA happened to decrease across the sample as pad spacing increased, providing a more reasonable explanation for the data in the inset. A TLM measurement on the directly metallized PC sample yielded a sheet resistance of  $600 \Omega/\text{sq}$ , and this contribution was subtracted from the measured resistance value for each pad spacing to yield  $2R_c$ , twice the average contact resistance for that pair of contacts. If the widest, anomalously resistive pad spacing is omitted, this method yields  $R_c=180\text{-}640 \Omega$ , and a contact resistivity  $\rho_c=3\text{-}9 \Omega\text{cm}^2$ .

This is too high for use in Si solar cells, but we used quite a low areal density of microspheres in the TCA ( $\sim 1\%$ ), and higher areal densities could be used. To estimate whether sufficiently low  $\rho_c$  could be obtained with more microspheres, the transit resistance of an average microsphere is estimated in the following. By determining the areal density of microspheres left and right of each pad spacing from light microscope images, the number of microspheres under each TLM pad can be estimated to be 8-16. By multiplying  $R_c$  by the number of microspheres per pad at the corresponding pad spacing, transit resistances per microsphere of  $3000\text{-}5000 \Omega$  are obtained. A  $\rho_c < 1 \Omega\text{cm}^2$  thus requires more than  $3000\text{-}5000$  microspheres per  $\text{cm}^2$ . Given the diameter of an average microsphere is about  $40 \mu\text{m}$ , this corresponds to  $5\text{-}8$  area% of microspheres, which is readily achievable [1]. Furthermore, this calculation assumed that the resistance per microsphere is independent of areal density, whereas it will actually decrease with increased density as the spreading resistance associated with current flow into and out of each sphere decreases.

#### IV. CONCLUSION

We have developed a novel approach for rear side metallization of Si solar cells, utilizing a transparent conducting adhesive to metallize Si without exposing the wafer to the metal deposition process. This approach leads to virtually no loss in  $iV_{oc}$  upon metallization. Electrical measurements showed that contact resistivities of  $3\text{-}9 \Omega\text{cm}^2$  were achieved, and that an analysis of the transit resistance per microsphere showed that  $< 1 \Omega\text{cm}^2$  should be achievable with higher microsphere loading of the transparent conducting adhesive.

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