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Influence of emitter properties on contact formation to p$^+$ silicon

Susanne Fritz[a], Stefanie Riegel[a], Sebastian Gloger[a], Dietmar Kohler[a], Markus König[b], Matthias Hörtheis[b], Giso Hahn[a]

[a]*University of Konstanz, Department of Physics, P.O. Box X916, 78457 Konstanz, Germany*
[b]*Heraeus Precious Metals GmbH & Co. KG, Heraeusstr. 12 - 14, 63450 Hanau, Germany*

Abstract

In this study we investigate the influence of the B surface concentration $N_{surface}$ on the contact formation of Ag and Ag/Al thick film pastes to p$^+$-type Si. From literature it is known, that for contacting $POCl_3$ emitters a high P surface concentration is necessary for a reasonable contact resistance [1,2]. This work aims to examine if the same holds for B emitters. For this purpose, three emitters with different B surface concentrations are realized and contacted with pure Ag and Al containing Ag (Ag/Al) thick film pastes: a BBr_3 emitter (I: $N_{surface}$~3E19 cm^{-3}, R_{sh}=50 Ω/□), and two alternative emitters without BBr_3 diffusion (IIa: $N_{surface}$~1E20 cm^{-3}, R_{sh}=55 Ω/□; IIb: $N_{surface}$~1E19 cm^{-3}, R_{sh}=330 Ω/□). The specific contact resistance ϱ_c is determined using the Transfer Length Method (TLM). With Ag/Al paste ϱ_c=9.95 mΩcm^2 on emitter IIa and ϱ_c=37.6 mΩcm^2 on IIb could be determined. For the same emitter type a higher $N_{surface}$ therefore results in a lower ϱ_c. This cannot be observed for different types of emitters as ϱ_c=4.8 mΩcm^2 was measured on emitter I. For a pure Ag paste the same trend can be observed but with ϱ_c being at least a factor of four higher, as expected [3-5]. Electron microscopy analysis reveals that for pure Ag pastes no direct contacts between Ag crystals on the Si surface and the Ag bulk exist. In contrast, for the Ag/Al pastes a direct connection between the Ag/Al particle in contact with the silicon surface and the Ag finger can be found. We propose that the low contact resistance for Ag/Al pastes may be due to direct contacts of Ag/Al spots to the Ag bulk.

Keywords: metallization, srcreen printing, boron emitter.

1. Introduction

During the last years a lot of work has been carried out on understanding the process of contacting n-type emitters (e.g. [1,2]). In contrast, the mechanism of contact formation to p$^+$ Si is not well understood up to now. It has been shown, that adding Al to an Ag thick film paste reduces the specific contact resistance ϱ_c [3-5]. To contact $POCl_3$ emitters, a high P surface concentration ($N_{surface}$~1E20 cm^{-3}), is necessary [1,2], while for B emitters the influence of the surface concentration has not been investigated yet.

In this work, the influence of the B surface concentration of the p-type emitter on the contact formation is examined. Therefore, three emitters differing in B surface concentration $N_{surface}$, depth d and B-glass layer formation are realized. The wafers are contacted with three different pastes: two experimental pastes - a pure Ag paste (paste *Ag*) and an Ag/Al paste with the same glass system (*AgAl*) - as well as a commercially available Ag/Al paste with a different glass system (*AgAlref*).

2. Experimental

For the experiment n-type Czochralski (Cz) wafers with a resistivity of ~4 Ωcm are used. After texturisation in an alkaline bath the different emitters are formed: I) emitter type I ($N_{surface}$~3E19 cm^{-3}, R_{sh}=50 Ω/□, d=0.7 µm), IIa) emitter type II ($N_{surface}$~1E20 cm^{-3}, R_{sh}=55 Ω/□, d=0.47 µm), IIb) emitter type II ($N_{surface}$~1E19 cm^{-3}, R_{sh}=330 Ω/□, d=0.47 µm) - emitter type I is a BBr_3 emitter, for type II the emitter is diffused from a B containing glass. $N_{surface}$ and d are determined by an electrochemical capacitance voltage (ECV) measurement. The corresponding emitter profiles are shown in Fig. 1. The emitters IIa and IIb show up to a depth of ≈0.3 µm almost parallel profiles. The ECV profile of emitter I reveals a deeper emitter and B depletion at the surface.

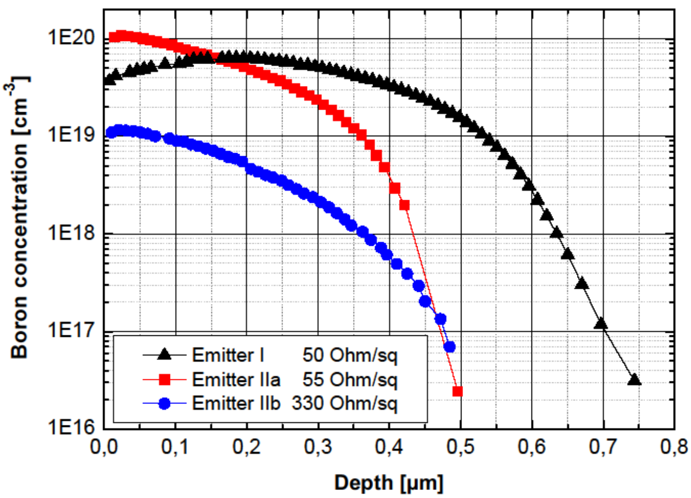

Fig. 1. ECV profiles of emitters I, IIa and IIb. The profiles of the emitters IIa and IIb are almost parallel up to a depth of ≈0.3 µm. Emitter I is deeper and shows B depletion at the surface.

After emitter formation a ~75 nm thick plasma enhanced chemical vapour deposition (PECVD) SiN_x:H layer is deposited. Contact formation of the three different pastes is realized by screen printing a TLM test structure and firing under standard conditions in a belt furnace (peak temperature ~800°C). Contact resistance analysis is done by TLM measurements. For subsequent scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) analysis of the contact area, contacts are etched back in *aqua regia* (HNO_3+HCl, 1:3) to remove only the bulk Ag or in *hydrofluoric acid* (HF (5%)) to remove the glass layer as well.

3. Results

In Fig. 2 the specific contact resistance ϱ_c of the different samples is shown. The error bars indicate the standard deviation of the measurement of different TLM structures on the same wafer. The errors for paste Ag on emitter I are too small to be visible.

In the case of the 50 Ω/□ emitter (I) ϱ_c can be reduced from 22.3 mΩcm^2 (paste *Ag*) to 4.8 mΩcm^2 (*AgAl*) and 6.3 mΩcm^2 (*AgAlref*) by adding Al to the paste. The same trend can be observed for emitters IIa and IIb. Within the limits of accuracy of the measurement, values for ϱ_c of the pastes *AgAl* and *AgAlref* are comparable for all emitters. The reduction of ϱ_c by adding Al to an Ag thick film paste has been observed by other authors as well [3-5].

The influence of $N_{surface}$ can be seen by comparing ϱ_c for the two type II emitters. For paste *AgAl* and emitter IIa ($N_{surface}$~1E20 cm^{-3}) ϱ_c=10.0 mΩcm^2 can be determined, while for emitter IIb ($N_{surface}$~1E19 cm^{-3}) ϱ_c=37.6 mΩcm^2 is measured. The same tendency can be found for the other pastes: for the same emitter type a higher $N_{surface}$ results in a lower contact resistance. This is in accordance with the results for n-type emitters [1,2]. However, the observed relationship between $N_{surface}$ and contact resistance does not hold for different types of emitters. Although emitter I shows a lower surface concentration ($N_{surface}$~3E19 cm^{-3}) than emitter IIa, the measured ϱ_c are reduced by a factor of two for both pastes containing Al and by more than one order of magnitude for paste *Ag*. The detrimental effect of the B depletion at the surface of emitter I therefore seems to be negligible. The emitter depth in contrast may play an important role for the contact resistance, as emitter I is at $N_{surface}$~1E19 cm^{-3} about 200 nm deeper than emitter IIa. Additionally, the different types of emitter formation possibly cause different defects at the emitter surface, and may influence contact formation.

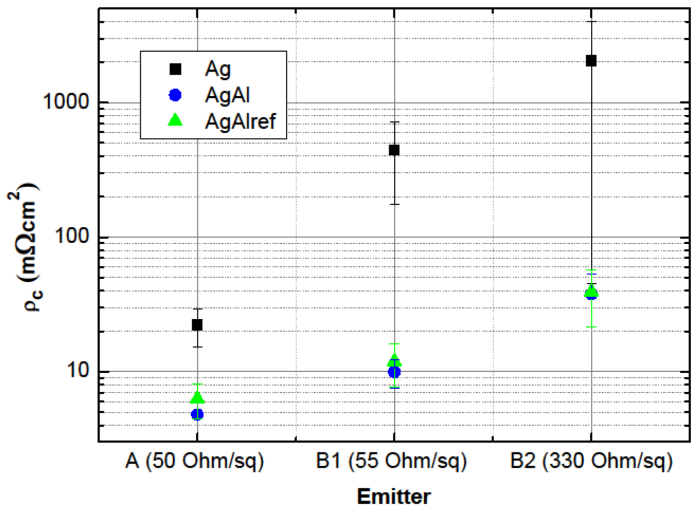

Fig. 2. Specific contact resistance ϱ_c determined by TLM measurements for the three different emitters and the different Ag thick film pastes. The error bars indicate the standard deviation of different TLM measurements on the same sample.

To gain further insight into the process of contact formation for Ag as well as for Ag/Al thick film pastes, the contacts are etched back in either *aqua regia* or HF (5%). Then the contact area is analysed by SEM and EDX.

The analysis of the contact area of paste *Ag* reveals Ag crystals on the silicon surface. On emitters I and IIa large Ag crystals can be found on top of the pyramids and smaller ones in the valleys (Fig. 3, left). The crystals on top of the pyramids stick out of the silicon surface. For emitter IIb regions with large Ag crystals are rare and contain fewer crystals (Fig. 3, right). Additionally some of the contact spots are empty, as the crystals were removed in the HF solution. The low coverage with Ag crystals may explain the high ρ_c of the emitter IIb samples. After etching of the bulk Ag with *aqua regia* no bare Si surface can be found for all emitters. The glass frit is covering the Ag crystals on the Si surface.

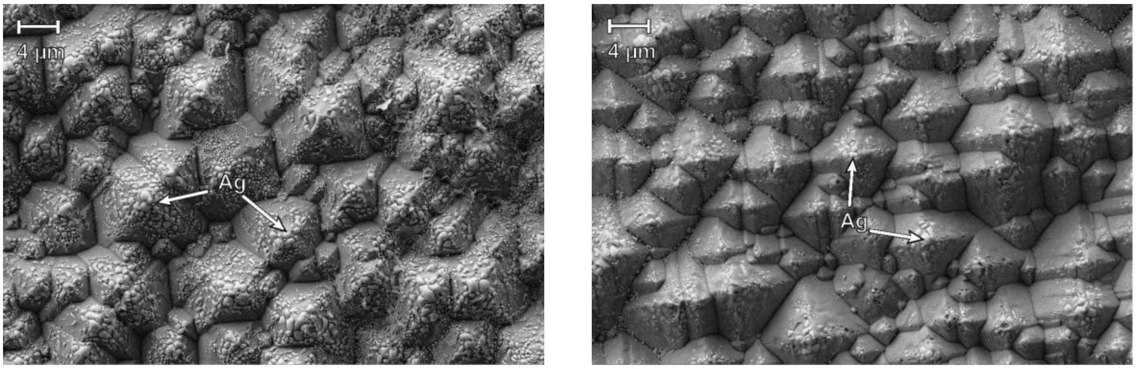

Fig. 3. Top view SEM micrographs of etched back contacts (HF) of paste Ag. Left: emitter I. Large Ag crystals on top of the silicon pyramids, smaller ones in the valleys. Right: emitter IIb. Fewer Ag crystals on top of the pyramids.

For the pastes containing Al (paste *AgAl* and *AgAlref*) the contact area consists of small Ag crystals (<0.5 µm) on the Si surface and larger rectangular spots (>1 µm) containing both Ag and Al (Fig. 4 left), as observed by [6]. These Ag/Al contact spots retain the form of the silicon surface. Additionally, some Pb residuals can be found on the Si surface. After etching of the bulk Ag, EDX analysis shows a glass layer interrupted by spots of pure Si with the shape of the Ag/Al contact spots (Fig. 4, right). They exhibit inverted pyramids on the glass covered surface.

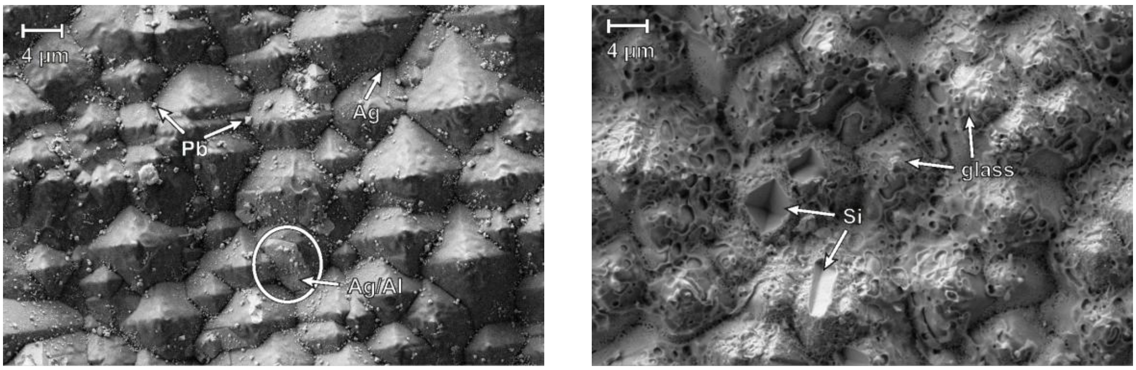

Fig. 4. Top view SEM micrographs of etched back contacts of pastes containing Al. Left: HF (5%). Rectangular spots of Ag/Al and Pb residues. Right: *aqua regia*. Rectangular spots of pure Si and glass layer.

4. Discussion and Outlook

For B emitters of the same emitter type a higher B surface concentration results in a lower ϱ_c. This relationship is no longer obvious for different types of emitters. The ϱ_c to emitter I is slightly lower than to emitter IIa, though $N_{surface}$=3E19 cm^{-3} of emitter I is significantly lower than $N_{surface}$=1E20 cm^{-3} of emitter IIa. Therefore other emitter related factors as for example the emitter profile or the defect concentration at the emitter surface may play a role in contact formation and have to be considered for the development of screen printing pastes. For emitter type II the surface concentration can be varied relatively simple. Thus, it is possible to further analyze the influence of the emitter profile on the contact formation. Additionally, the interaction of the emitter and the paste composition may explain the differences between the emitter types.

SEM and EDX analysis of the etched back contacts of the Al containing pastes revealed Ag/Al contact spots after etching in HF (5%) and spots of pure silicon after a treatment in *aqua regia*. Therefore it is concluded that the Ag/Al spots form a direct connection between the Si surface and the bulk Ag of the contact finger. Such direct connections could not be identified for the pure Ag paste. The reduced contact resistance found for the Ag/Al pastes may be explained by the direct current transport through these contact spots. For the Al containing pastes no obvious difference in contact structure and number of contact spots can be found. Additionally, no difference between the different emitters can be observed for these pastes. In contrast, the high ϱ_c of paste *Ag* to emitter IIb can be explained by the observation, that less Ag contact spots can be detected on emitter IIb than on the other two emitters with higher B surface concentrations.

Acknowledgements

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