ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

Effect of the metal work function on the recombination in passivating contacts using QSSPL

Anh Huy Tuan Le[1], Johannes P. Seif[1], Thomas G. Allen[2], Robert Dumbrell[1],
Christian Samundsett[3], Andres Cuevas[3], Ziv Hameiri[1]

[1]*University of New South Wales, Sydney, NSW 2052, Australia*
[2]*King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia*
[3]*The Australian National University, Canberra, ACT 2601, Australia*
E-mail: huytuananh.le@student.unsw.edu.au

Abstract

Understanding the impact of metal contacts on the recombination within a passivated crystalline silicon (c-Si) wafer is crucial for the optimization of various photovoltaic devices such as passivating-contact-based solar cells. In this type of device, the metal contacts are offset from the c-Si wafer surface by additional layers [1]. The latter (1) minimize recombination losses—either by chemically reducing the density of defects at the wafer surface or by increasing the imbalance between the majority and minority carrier density near the surface—and (2) are selective for one type of carrier [1, 2]. An asymmetric population of electrons and holes near the c-Si surface can be obtained by applying a contact layer with a different work function than that of c-Si [2]. Therefore, we expect that the presence of a metal contact forms an extremely thin accumulation or inversion layer close to the wafer surface. This imbalance in concentration of the two carrier types will change the recombination statistics at the passivated surface.

Usually, the well-established quasi-steady-state (QSS) photoconductance (PC) technique is used to measure the injection-dependent minority-carrier lifetime (τ_{eff}) and to extract the surface recombination current density (J_{0s}). However, the QSSPC technique is not easily applicable to metallized structures due to the dominating conductivity of metals in comparison with the semiconductor conductivity. Several other techniques exist that allow determining the saturation current density at the metallized surface (J_{0m}) [3-5]. Yet, each of them has its own limitations, as discussed in Ref. [6]. Recently, Dumbrell *et al.* presented a robust and contactless method based on QSS photoluminescence (PL) from which τ_{eff} of any metallized structure can be obtained, giving access to J_{0m} [7].

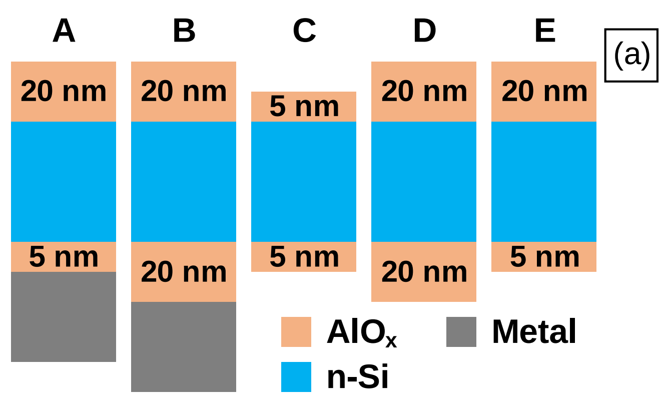
In this study, we use J_{0m} as figure of merit to investigate the impact of the metal work function on the recombination in passivating contacts. N-type Czochralski-grown silicon wafers are passivated by aluminum oxide (AlO_x) films with a thickness of 5 or 20 nm deposited by atomic layer deposition. Five different metals were thermally evaporated at the rear side of Structures A and B, as shown in Fig. 1(a). We measured τ_{eff} of the samples using the QSSPL method, which enabled us to extract their total surface saturation current density ($J_{0s,total}$). J_{0m} is then calculated from $J_{0s,total}$ of the metallized samples and J_{0s} of Structures C and D [Fig. 1(b)].

We find that applying metals with a work function smaller than that of n-type c-Si (<4.2 eV) on the 5-nm-thick AlO_x passivation layer, J_{0m} values are reduced. This indicates an improvement of surface passivation. This can be explained by an increase in electron density and a decrease in hole density near the c-Si surface related to the presence of the metal. As the density of electrons is much larger than the density of holes, the recombination rate at the interface—which is determined by their product—is reduced. We attribute the change in J_{0m} to the change in the hole concentration near the interface. It is also important to note that negative fixed charges are present in the AlO_x layers. These induce a local depletion of the electron concentration at the AlO_x/c-Si interface and may thereby mitigate the positive effect of the metal work function.

When applying the metals with a work function larger than that of n-type c-Si (>4.2 eV) on the 5-nm-thick AlO_x passivation layer, a decrease in the electron density and an increase in the hole density

near the c-Si surface is expected. The presence of negative fixed charges in the AlO_x layers amplifies this asymmetric population of electrons and holes. Consequently, the recombination rate at the AlO_x/c-Si interface is reduced. Therefore, we expected that J_{0m} will be reduced in comparison with J_{0s} of the non-metallized reference sample. The high J_{0m} of the sample with the metal work function of 5.22 eV might be attributed to the abnormally poor surface passivation of this sample. The impact of the metal work function on J_{0m} is strongly reduced in the case of thicker passivation layer (Structure B). We attribute this to the reduced charge transfer probability between the c-Si and the metal through the AlO_x layer once it becomes too thick. Hence, the asymmetric carrier population induced by the difference in work function between them is not achieved.

In summary, we find that J_{0m} increases with the metal work function and that this effect is modulated with the passivation layer thickness. It is more pronounced for thinner passivation layers, which can be attributed to a significant change in the populations of electrons and holes near the silicon surface induced by the metal. Meanwhile thicker layers prevent the charge transfer between the silicon wafer and the metal leading to insignificant changes in J_{0m}. Based on these findings, we suggest that suitable metals should exhibit work function values below that of n-type c-Si—or above for the case of p-type c-Si—to benefit from the asymmetric carrier population induced by the metal in passivating-contact-based solar cells.



Metal	LiF/ Al	Mg	Al	Ag	n-Si	Pd	MoOx/ Ag
Work function (eV)	2.86	3.66	4.20	4.74	4.85	5.22	5.70

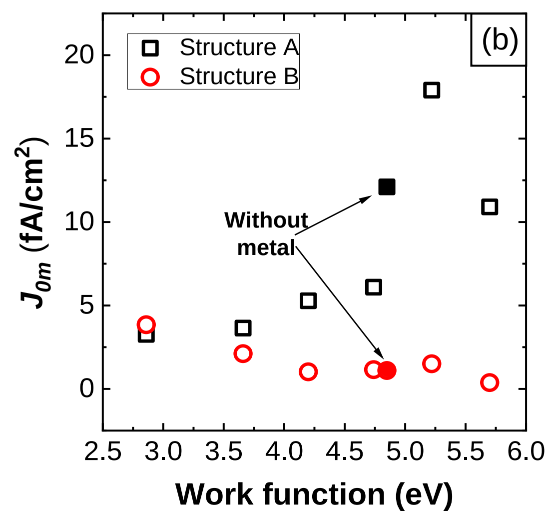


Figure 1: (a) Metal work functions [8, 9] and structures used to extract $J_{0s,total}$, J_{0s}, and J_{0m}; (b) J_{0m} values of Structures A and B determined from $J_{0s,total}$ and J_{0s} values. The rear side J_{0s} values of these structures before metallization are shown as reference (filled symbols).

References

[1] J. Melskens, *et al.*, 2018, *IEEE Journal of Photovoltaics,* vol. 8, no. 2, pp. 373-388.
[2] A. Cuevas, *et al.*, 2018, *Solar Energy Materials and Solar Cells,* vol. 184, pp. 38-47.
[3] T. Fellmeth, *et al.*, 2011, *Energy Procedia,* vol. 8, pp. 115-121.
[4] A. Fell, *et al.*, 2013, *Energy Procedia,* vol. 38, pp. 22-31.
[5] V. Shanmugam, *et al.*, 2015, *Solar Energy,* vol. 118, pp. 20-27.
[6] R. Dumbrell, *et al.*, 2017, in *44th IEEE Photovoltaic Specialist Conference*, pp. 3315-3318.
[7] R. Dumbrell, *et al.*, 2018, *IEEE Journal of Photovoltaics,* no. 99, pp. 1413-1420.
[8] J. Bullock, *et al.*, 2016, *Nature Energy,* vol. 1, no. 3, p. 15031.
[9] D. R. Lide, *CRC Handbook of Chemistry and Physics*, 90th ed. Boca Raton, FL: CRC Press/Taylor and Francis, 2010.