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Understanding metal induced recombination losses in silicon solar cells with screen printed silver contacts

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Abstract

There have been great improvements in silicon solar cell voltage across the last 5 years. A great deal of the gains can be attributed to application of lighter phosphorus emitter diffusions which deliver higher cell voltages, combined with the complementary silver metallization pastes which can contact those emitters. As the voltages continue to increase over time, metal recombination losses become more important to understand. The surface doping, junction depth, and metal contact used are all factors in determining the metal recombination rate which covers a range of approximately 400-1500 fA/cm^2 for standard cases. Silver contact pastes modulate recombination by changing the way they etch the emitter surface, and semiconductor models indicate that the recombination rate can decrease to < 200 fA/cm^2 as metallization paste technology continues to improve.

Keywords: screen print, silver, contact, recombination, silicon, solar cell, metal

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1. Introduction

Industrial solar cell open-circuit voltages (Voc) have increased across the last 5 years, partly enabled by changes in silver paste technology starting in 2011 which could contact lighter, higher efficiency emitters [1]. As Voc continues to climb due to improved wafer lifetimes and improvements to the rear surface, the recombination loss at the screen printed metal contacts becomes increasing important to understand and control. Multiple factors modulate the recombination losses at the contact, and have different importance. The major factors investigate here are sheet resistance, surface doping density, junction depth, metal paste selection, and the firing process.

The metal-induced recombination rate (Jo.m) has been measured for a combination of metal pastes and phosphorus diffusion profiles. This study investigates the factors behind the loss, and then uses emitter recombination models to explain the recombination by emitter etching. This understanding allows us to propose fundamental limits to the expected recombination rates.

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2. Measurement of metal induced recombination $J_{o.m}$

The test structure for measuring Jo.m is shown in Fig. 1. The technique is reviewed only briefly here, with full detail available in Ref [2]. Multiple metal grids are printed on the surface of a single wafer – this ensures bulk doping and lifetime are the consistent across a measurement set, preventing external factors influencing cell voltage. No edge isolation is used near a grid as this can introduce extra recombination and non-idealities which must be avoided in order to cleanly assess the recombination from the silver contacts. Voc is measured using the Suns-Voc technique [3] and the two-diode model fit is used to determine the diode saturation current (Jo) values. It should be noted that there was no non-ideal recombination or shunt observed due to silver metallization in this work. The J_{sc} must be known to estimate Jo accurately, and due to the lack of edge isolation it is not directly measured on these test structure. In this study, active area J_{sc} was assessed on standard solar cells, and the J_{sc} for each test grid was calculated from the measured shading. Other measurements such as spectral response could determine the J_{sc}.

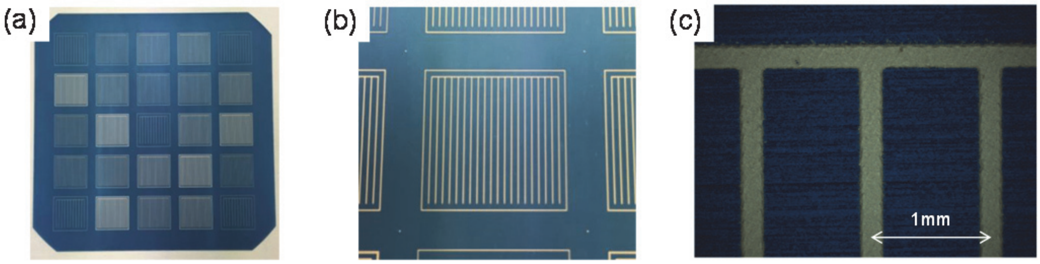

Fig. 1. (a) photograph of 25 test grids on a standard wafer with contact area 5 to 30%; (b) close up photograph of a test grid showing design features; (c) optical microscope image of a grid with approximately 10% contact area.

Fig. 2 shows a typical data set obtained using this method. Voltage is measured and Jo determined. The slope of the line is proportional to the metal induced recombination: in Fig. 2b the slope is approximately 460 fA/cm^2. The Jo.m value is the sum of the slope and emitter recombination Jo.e [2], which was determined from photoconductance lifetime tests [4] as 70 fA/cm^2. This data set then delivers a Jo.m value of 530 fA/cm^2. Due to the scatter in the data in Fig. 2b, the linear fit has a low R^2 of 0.8. This ultimately gives an uncertainty in Jo.m of +/- 50 fA/cm^2, as taken from the standard error of the fitted slope. The R^2 value from 0.8-0.9 is common and difficult to improve upon due to the inhomogeneities in recombination across a test wafer.

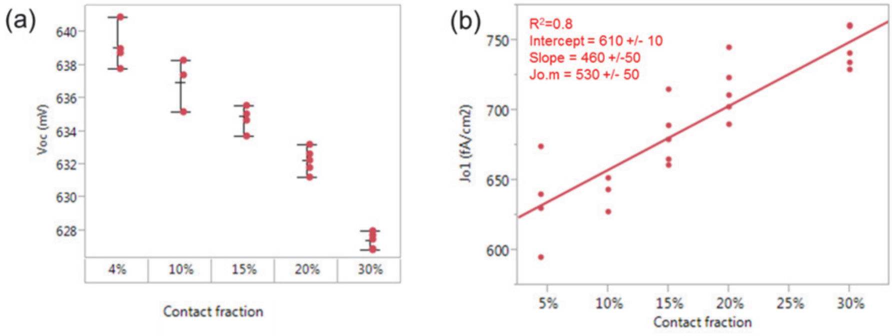

Fig. 2. (a) Voc data for grids with different contact area; (b) Jo fit, showing metal recombination Jo.m = 530 fA/cm^2.