Front contact design and optimization engineering essay

Engineering

ASSIGN BUSTER

Instructors: Bakhtiar Ali KhanD. Thejani Fernando.

Written by: G/wold, Habtamu Tsegaye

Sahle , Binyam Wondifraw

Rweyemamu, Imelda Kokuhumbya

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FRONT CONTACT DESIGN OPTIMIZATION LAB

Introduction

This experiment was conducted with the aim of exploring the effects of contact resistance on the efficiency of solar cells. Over the years, optimization of the solar cell design has become an important topic since the design has a lot to do with the cell's efficiency and increasing efficiency means getting more useful current out of the cell. Resistances in the solar cell lead to power losses. Losses caused by the cell design can be categorized into two main types, optical and electrical losses. Optical losses are those due to reflection from the top silicon layer of the cell and this can minimized by using anti-reflection coating of which operation will be explained in the pre-lab section later. These losses can also be from the surface contact grid design which has fingers and busbars. Depending on the size, shape and spacing of the fingers and busbars on the cell, shadowing can occur which leads to power loss and a decrease in the efficiency of the cell. A basic overview of optical losses from the surface of the solar cell is illustrated in the following diagram. reflection lossesOptical losses due to reflection on the solar cellElectrical losses come three-fold, they can be caused by the bulk resistance, the emitter resistance or the contact resistance. For the purpose of this experiment, we will focus on the contact resistance. Contact resistance can generally be accrued from the design of the solar cell and the main contributors of this resistance are the fingers and busbars which are found in the contact grid. The finger resistance will be our main focus throughout this experiment. Below, we see a common front side design of a solar cell and the formula for calculating the finger resistance. A close-up of this design can be seen in the diagram below. Power losses in the fingers can be calculated with formulae below using the conditions named on the following figure. Power loss from the fingers can be due to resistivity in the fingers: It can also be due to contact resistance of the fingers: Where ρc is the specific contact resistanceThe total power loss which also considers power loss due to lateral current flow can be calculated as seen below: Where ρs is the sheet resistivity of the layerResistivity (ρ) of the semiconductor is another important contributor in the power loss profile of the solar cell. This resistivity depends mainly on the carrier concentration as well as the mobility of the carriers in the semiconductor. A general formula for calculating resistivity in a semiconductor material is seen below. But when dealing with an n-type material, the general equation can be simplified to: Where n is the carrier concentration and µn is the mobility of the carrier. (q is a constant= charge of an electron)

PRE- LAB

Problem 1

(A)An antireflective or anti-reflection (AR) coating is a layer of dielectric material applied to the surface of lenses and other optical devices to reduce reflection. Anti-reflection coating works under the principle of destructive interference. The idea behind is that the creation of a double interface by means of a thin film gives you two reflected waves. If these waves are out of phase, they partially or totally cancel. The thickness of the coating is of great importance. Usually, the thickness is chosen so that the wavelength of light in the dielectric material is a quarter of the wavelength of the incoming light wave. Anti-reflection coatings can be used to reduce optical losses because it reduces the surface reflection and eventually improves the cell efficiency. The principle of destructive interference is illustrated below:

(B)

SinceIsc is linearly proportional to the incident power Pin hence a 50 % decrease in Pin causes 50% decrease in Isc. So ultimately, there will be no change on Efficiency.

(C)

GivenNormally, Ideal solar cell equation is given as -Isc. Since the above expression is given in the Pre-lab problem, our derivation considers it. The open-circuit voltage, VOC, is the maximum voltage available from a solar cell, and this occurs at zero current. So, setting the current I= 0 we will get the expression for Voc,-IscNow inserting the given values we will get the Open circuit voltage to be, Voc = 0. 637voltsProblem 2: Shadowing of fingersMatlab codefunction shadow()s= 2;% spacing between fingers in mmwf= 50e-3: 5e-3: 150e-3;%d=[]for i= 1: length(wf)psf(i)= (wf(i)/s)*100; endplot(wf, psf,'r'); grid; xlabel('width of finger/mm'); ylabel('shadowing loss/%'); endplot of power loss versus width of fingerfig. 1We see that the optical losses due to shadowing by the fingers is linearly related to the finger width

Problem 3: Resistivity

Matlab Codefunction resistivity()m= 40;%mobility in cm2/Vsq= 1. 602e-19n= 1e12: 1e12: 1e14for i= 1: length(n)r(i)= 1/(q*n(i)*m)endplot(log(n), log(r),'r'); grid; xlabel('concentrations/cm^3 -Log scale'); ylabel('Resistivity -Log scale'); endPlot of Resistivity as a function of concentration (a double log plot)fig. 2Here, the resistivity decreases as the concentration of electrons increases, it is easy to observe that they have an inverse relationship.

THE EXPERIMENT

Theoretically we know that the finger spacing have relation with different optical and electrical loss in the front contact design of solar cell. When the spacing is small, shadowing will happen which leads to a higher optical loss. Power losses due to the contact resistance of the fingers increase with increasing finger spacing(S) to finger width(Wf) ratio. Based on the sheet resistivity, the power loss due to the emitter resistance can be calculated as a function of finger spacing in the top contact. Power loss due to lateral current flow depends on the square of the finger spacing and power losses due to the resistivity in the fingers is also another electrical loss due to the finger. In the Lab, we wrote some matlab code to see the different power loss relationships with the finger spacing. The following constants were used throughout the experiment;

PROBLEM 1: OPTICAL LOSS

The total optical losses due to the finger spacing, excluding reflection loss, can be calculated using the following equation, Where, Wf is the average width of the fingers and S is the spacing between fingers. Here is the Matlab code for calculating this power loss: function OptLoss()wf= 100e-6; Psf= []; s= 0: 1e-4: 5e-3for i= 1: length(s)Psf(i)=(wf/s(i))*100; endplot(s, Psf); xlim([0, 5e-3]); ylim([0, 20]); grid; xlabel('Fingerspacing/mm'); ylabel('Optical loss/%'); endThe plot is as seen below, C: UsersinaDesktopoptical loss. pngfig. 3The optical power lose can be minimized with higher finger spacing since we can see that the optical loss, neglecting loss due to reflection, decreases with finger spacing.

PROBLEM 2: ELECTRICAL LOSS

The different electrical losses can be expressed as a function of finger spacing as illustrated below, Power losses due to the resistivity in the fingers is given by (normalized)Where: m = 3, 4 (3 for uniform width and 4 for non-uniform width), S is the distance between the fingers, Wf is the average width of the fingers. df is the depth of the fingers. is the sheet resistvity of the contact metal layer for the fingers and Jmp , Vmp are the maximum current and voltage densities. Power losses due to the contact resistance of the fingers is given by, Where: is the specific contact resistanceHere, The contact resistance loss due to the busbar is insignificant. The remaining electrical power loss which is due to lateral current flow, expressing as fractional power loss with the maximum generated power loss is as follows, Here is the matlab code we wrote for plotting the above three electrical losses and their total as a function of finger spacing. The previous plot of

Optical loss is included as well. function ElecLoss()wf= 100e-6; d= 30e-6; L= 25e-3; s= 0: 1e-4: 5e-3m= 3; pc= 2e-6; pf= 5e-8; ps= 40; Prf=[]; Pcf=[]; Ptl=[]; Jmp= 300; Vmp= 0. 45; for i= 1: length(s)Prf(i)= (2*L^2*(pf*Jmp*s(i))/(m*Vmp*wf*d))*100; Pcf(i)= (pc*(Jmp*s(i))/(Vmp*wf))*100; Ptl(i)= (ps*(Jmp*s(i)^2)/(12*Vmp))*100; psf(i)=(wf/s(i))*100; endptot= Prf+Pcf+Ptl; plot(s, Prf,'r', s, Pcf,'b', s, Ptl,'m', s, ptot,'k', s, psf,'g'); xlim([0, 5e-3]); ylim([0, 20]); grid; xlabel('Fingerspacing/mm'); ylabel('power loss/%'); endThe plot is as seen below: Fig 4

PROBLEM 3: TOTAL POWER LOSS

The total power loss which is the sum of optical and electrical power losses is calculated and plotted using the matlab code, adding " ptot= Psf+Prf+Pcf+Ptl;" line in the above codefunction TotalLoss()wf= 100e-6; d= 30e-6; L= 25e-3; s= 0: 1e-4: 5e-3m= 3; pc= 2e-6; pf= 5e-8; ps= 40; Psf=[]; Prf=[]; Pcf=[]; Ptl=[]; Jmp= 300; Vmp= 0. 45; for i= 1: length(s)Psf(i)=(wf/s(i))*100; Prf(i)= (2*L^2*(pf*Jmp*s(i))/(m*Vmp*wf*d))*100; Pcf(i)= (pc*(Jmp*s(i))/(Vmp*wf))*100; Ptl(i)= (ps*(Jmp*s(i)^2)/(12*Vmp))*100; endptot= Psf+Prf+Pcf+Ptl; plot(s, Psf,'g', s, Prf,'r', s, Pcf,'b', s, Ptl,'m', s, ptot,'k'); xlim([0, 5e-3]); ylim([0, 20]); grid; xlabel('Fingerspacing/mm'); ylabel('Power loss/%'); endThe resulting plot from the summation of the previously calculated losses is illustrated below: fig 5From the above plot we can see that though the electrical losses increase with finger spacing the total loss is minimum at specific finger spacing values around S= 2 micro-meter. So our front contact design with the data given in the lab should have finger spacing of about S= 2 micro-meter in order to have less power loss due to the front contact (fingers and busbar).

Conclusion

The design of the top contact should involve not only the minimization of the finger and busbar resistance, but the overall reduction of losses associated with the top contact. These include resistive losses in the emitter, resistive losses in the metal top contact (contact and finger resistance) and shading losses. The critical features of the top contact design which is the finger spacing determine the magnitude of these losses and during design, we should optimize the electrical losses over optical losses to have the optimum Power loss.

Sources

Bakhtiar Ali Khan, D. Thejani Fernando, " Front contact optimization handout spring 2013", Photonics & Photovoltaics Lab 2013, Jacobs University BremenHonsberg, Christiana. " Solar Electric Systems, University of Delaware, ECE Spring 2008." Lecture. University of Delaware. Web. 11 Feb. 2013. .