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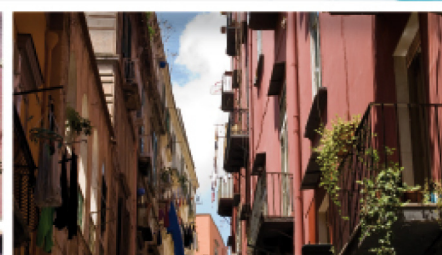
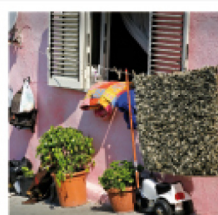
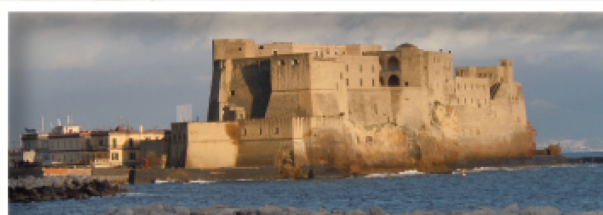
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Nanostructured Photonic Biosensor for Heavy Metal Detection

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Evaluation of the Absorption Spectrum in Quantum Dots for Efficient Solar Cells

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Light Trapping Systems for Biosensor Application***Forest of Silica Nanowires Decorated with Plasmonic Nanoparticles***

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Backscattering Noise Control in the Readout Circuit of Innovative Optoelectronic Resonant Gyroscopes

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Analysis of the Impact of Rear Side Geometry on Performance of Back-Contact Back-Junction Solar Cells

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Abstract— In this work, we performed a study of rear side geometry of a back-contact back-junction solar cell parameters: the emitter, the back surface field (BSF) and their gap distance by exploiting two-dimensional TCAD numerical simulations. All figures of merit have been considered in order to understand the impact of the dominant ones. Higher efficiency are lead by higher emitter width/pitch ratios, lower pitches, and minimum BSF and gap widths. The impact of emitter is explained in terms of lower recombination in bulk due to a larger p-n junction, the impact of BSF and gap dimensions are explained in terms of surface recombination losses at back interface and the impact of pitch in terms of higher series resistance.

Keywords—solar cell; photovoltaics; back-contact solar cell; numerical simulation; dark analysis

I. INTRODUCTION

High efficiency Silicon-based back-contact back-junction (BC-BJ) solar cells have been demonstrated particularly promising in order to improve the light conversion efficiency (currently more than 24% [1]). The absence of front contact allows simultaneously the simplification of cell interconnection at module level and the elimination of optical shadowing losses. However, the location of both contacts in the rear side leads to a reduction of the emitter size that means a smaller p-n junction. In this way, photogenerated minority carriers are more difficult to collect because of the presence of an horizontal component in the arrival path to the junction, and consequently increased recombination.

Some works have been developed to study the impact of BC-BJ rear geometry over the figures of merit compared for different bulk lifetime and surface recombination velocities by Kim [2], and an extensive study of short circuit current density has been developed by Ritchel *et al.* [3] by analysing collection probability produced by electrical shadow effects.

The aim of this work is to improve the physical understanding of the impact of different rear geometries on the performance of BC-BJ solar cells by a systematic simulation analysis under light conditions to understand the losses [4] that influence the overall figures of merit: short circuit current density (J_{sc}), open circuit voltage (V_{oc}) and fill factor (FF).

II. SIMULATION METHODOLOGY

Fig. 1 shows the sketch of the symmetry element of the simulated solar cells. In this work we considered a FZ-Si n-type doped 200 μ m-thick wafer featuring resistivity 2 Ω -cm. The doping profiles in back surface field (BSF), front surface field (FSF) and emitter are gaussian functions of the spatial coordinate featuring the peak located at the edge of the interface and junction depth of 2 μ m for BSF and emitter and of 0.5 μ m for FSF region. Peak concentration doping is 4.16x10¹⁹cm⁻³ for emitter, 4.16x10¹⁹cm⁻³ for BSF and 1x10¹⁸cm⁻³ for FSF[5].

The front surface is coated by a double-layer anti reflective coating (ARC), without texturing. In order to achieve realistic predictions, physical models and parameters has been calibrated by means of state-of-the-art parameterizations [6]. Fermi–Dirac statistics is enabled to correctly deal with large doping concentrations. Bandgap narrowing model (BGN) by Schenk is used to account for realistic values of intrinsic carrier density ($n_i=9.65 \times 10^{-9}$ cm⁻³ at T=300 K) [7]. The model proposed by Klaassen in [8] has been adopted in order to model the doping dependent carrier mobility. Recombination losses due to trap-assisted recombination is modeled by assuming the single-level trap model by Shockley–Read–Hall (SRH); the doping-dependent carrier lifetimes in phosphorus-doped FZ-Si are calculated according to [3]. Auger recombination model has been parameterized according to Altermatt *et al.* [9]. Surface recombination velocity (SRV) at passivated interfaces has been modeled according to semiempirical models proposed in Cuevas [10]. The surface velocity at electrodes is set to 1x10⁶ cm/s.

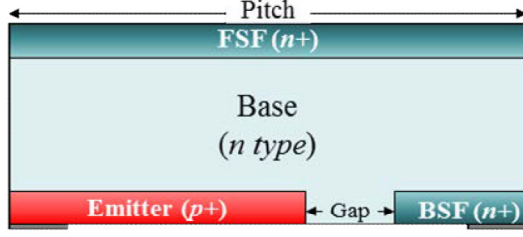


Fig. 1. Sketch of the symmetry element of simulated back-contact back-junction solar cell.

The optical generation rate profiles have been calculated by means of a mono-dimensional TMM simulation [3] of plane waves propagating in silicon, assuming direct illumination with a standard AM1.5G spectrum (1000 W/m^2) [11].

The solar cell has been simulated changing two parameters at same time: a) emitter width (W_e) and BSF width (W_{BSF}) to understand the impact of emitter size, b) gap width and W_{BSF} to understand gap's effects and complement the study of W_{BSF} . Finally, it has been developed an analysis for different pitches keeping constant the emitter/pitch ratio and the gap to calculate the impact of geometry variations on the performance.

III. RESULTS AND DISCUSSION

In order to understand the impact of geometric parameters on the main figures of merit, we have performed an extensive set of numerical simulations by using the state-of-the-art finite element simulator Sentaurus TCAD [6]. We assumed as simulation parameters W_e , W_{BSF} , the gap between these regions and the pitch. We discuss separately each analysis.

A. Emitter and BSF width analysis

For this analysis we performed simulations changing W_e and W_{BSF} at the same time, keeping constant pitch and gap. The change of W_e expressed as ratio normalized with pitch has a significant impact on J_{sc} as it is shown in Fig. 2. We observed an increasing trend of J_{sc} with increasing emitter/pitch ratio due to a larger p-n junction that enhance the effectiveness of the electrical field over bulk region preventing minority carrier recombination in this region and enhancing their collection.

It is worth noting that FF and V_{oc} have the opposite behavior of J_{sc} . Degradation of V_{oc} can be explained by recombination currents. The contribution of the surface recombination becomes significant for higher values of emitter/pitch ratio since surface recombination contribution of emitter is stronger than BSF because different doping species lead to different SRV. In the same way, FF trend is explained by a trade-off between emitter and BSF sheet resistivity.

In our simulations, the impact of the V_{oc} and FF due to recombination and resistive losses becomes significant at higher emitter/pitch ratio and there is a slight optimum point

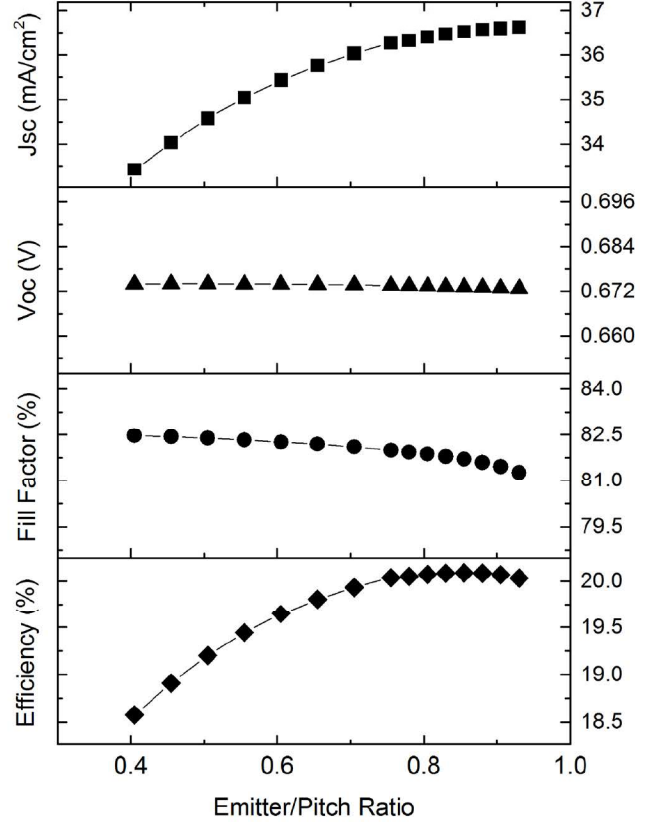


Fig. 2. Solar cell figures of merit for different emitter/pitch ratio. The efficiency is higher for higher ratio following J_{sc} trend. However, V_{oc} and FF decreases due to recombination and resistive losses. The trade-off leads to an optimum value around 0.84

around 0.84. It means that there is an optimum ratio due to a trade-off among a larger p-n junction, quality of passivation in rear Si/SiO₂ interface and BSF and emitter sheet resistance. In conclusion, W_e has to be as higher as possible, depending on the quality of passivation in the rear of the cell, and at the same time W_{BSF} as smaller as the BSF contact allows.

B. Gap and BSF width analysis

For this analysis we performed simulations changing W_{BSF} and gap at the same time, keeping constant pitch and W_e .

The change of the gap length has an impact on all figures of merit as shown in Fig. 3. We observe a degradation of J_{sc} with increasing gap due to the poor effectiveness of the electrical field which allows minority carrier recombination at the rear interface in gap region. In the same way, this leads to a slight decrease in V_{oc} that can be explained in terms of saturation current increase. The contribution of surface recombination becomes more important for higher gap due to the weaker electrical field. In addition, FF drops due to an increase of series resistance explained by the higher resistivity in gap region (lower doping) compared with BSF region

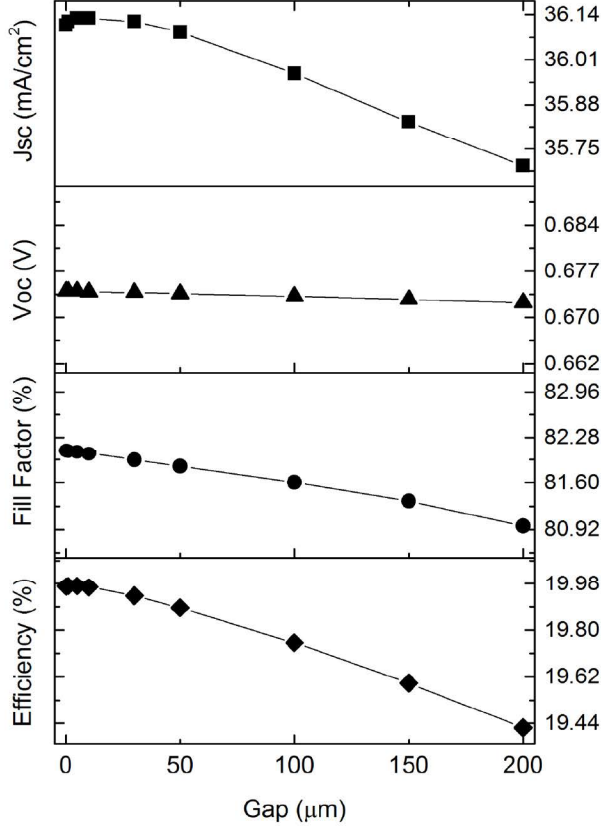


Fig. 3. Solar cell figures of merit for different gap. A general decrease is observed in all the cases for higher values of gap, especially for J_{sc}

(higher doping). In conclusion, gap variation influence over efficiency is mainly due to recombination losses at gap interface and the higher efficiency is obtained with the smallest gap possible, even if the trend is not linear. In fact for gap smaller than 10 μm the efficiency trend tends to become constant.

C. Pitch analysis

For this analysis we performed the simulations changing pitch, W_e and W_{BSF} at the same time, keeping constant emitter/pitch ratio and gap.

The change on pitch has a significant impact on FF as shown in Fig. 4. We observed a degradation of FF with increasing pitch longitude due to the increase of series resistance, because the mean path for minority carriers to be collected increase in all regions: FSF, BSF, emitter and bulk. Increment on V_{oc} can be explained in terms of recombination current, in fact there is a reduction of the contact recombination component due to a smaller portion of the pitch covered by contact region (it occurs because while pitch is changing contact width is kept constant). The changes over J_{sc} are small and can be explained by the trade-off between

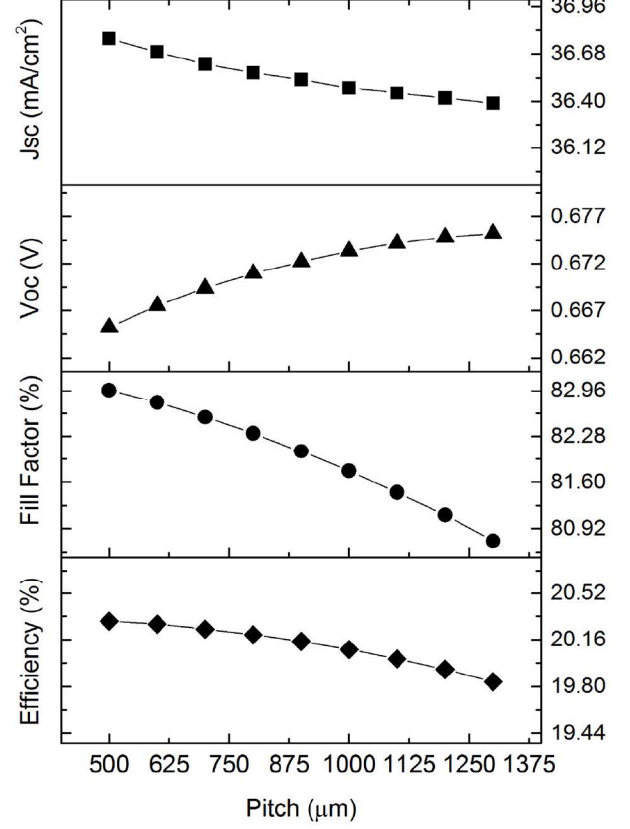


Fig. 4. Solar cell figures of merit for different pitch ratio. Although V_{oc} increases the efficiency trends is dominated by FF that decreases for higher pitches values.

photocurrent generation and recombination losses in bulk region. In conclusion, even if the V_{oc} increase with increasing pitch, this effect is not strong enough to compensate the FF reduction, so the greater efficiency is obtained for smaller pitch.

IV. CONCLUSIONS

In this work we performed an analysis of the rear geometry impact on the performance of a back-contact back-junction solar cells. The main parameter to be considered is the longitude of the emitter, because it defines the extension of the p-n junction, thus the width of minority carriers collection zone. Then the pitch longitude which defines the FF due to series resistance losses. Finally, gap and BSF widths have an impact on surface recombination losses. From these considerations, higher values of efficiency are reached for: a) larger emitters/pitch ratio, b) smaller pitches, c) smaller BSF and gap.

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