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Influence of dislocations on photovoltaic properties of multicrystalline silicon solar cells

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Résumé. — Les propriétés photovoltaïques des cellules solaires au silicium multicristallin à gros grains, sont principalement affectées par la présence de dislocations. Nous nous intéressons plus particulièrement à la recombinaison des porteurs de charges aux dislocations qui affecte en premier lieu le photocourant et au transport des charges le long du cœur des dislocations traversant la jonction et qui est responsable de l'augmentation du courant d'obscurité. Nous avons modélisé l'influence de la densité de dislocations N_{dis} et de leur activité recombinante S_d sur les principaux paramètres photovoltaïques (le courant de court-circuit J_{sc} , la tension de circuit ouvert V_{oc} , le facteur de forme FF , et le rendement η). Le modèle est ensuite confronté aux résultats expérimentaux.

Abstract. — The photovoltaic properties of large grained polycrystalline silicon solar cells are mainly affected by the presence of dislocations. Both the recombination of carriers at dislocation (which degrades the photocurrent) and the transport of carriers along the dislocation cores crossing the junction (which increases the dark current) are taken into account. The influence of the density N_{dis} and recombination activity S_d of dislocations on the short circuit current density J_{sc} , open circuit voltage V_{oc} , fill factor FF , and efficiency η are computed. The computed values are compared to experimental results.

1. Introduction.

In large grained cast multicrystalline silicon, the mean grain size is actually greater than 1 mm, and the influence of grain boundaries (GB's) is negligible compared to that of intragrain defects, especially dislocations. We have to distinguish between two different mechanisms which occur at dislocations. The first one is the recombination of minority carriers which takes place at the edge of the space charge cylinder surrounding a dislocation line. This recombination mechanism reduces the minority carrier diffusion length and consequently the

photocurrent [1, 3]. It also increases the dark current but to a less extent. The second mechanism would be the transport of the captured carriers along the dislocation core [4, 5]. This mechanism is very harmful especially when dislocations cross the junction space charge region (SCR). In this case they could constitute shunting paths through the junction. The part of the dislocations which lies within the junction SCR could introduce an additional conduction. We have demonstrated in the preceding paper in this journal [6] that the value of this conduction is not constant but depends upon the applied voltage. Thanks to reasonable assumptions the global forward dark current of a dislocated junction could be expressed by

$$J_o = J_{o1} \left(\exp \left(\frac{qV}{kT} \right) - 1 \right) + J_{o2} \left(\exp \left(\frac{qV}{2kT} \right) - 1 \right)$$

where J_{o2} is proportional to the dislocation density N_{dis} and J_{o1} depends on the dislocation density and recombination strength S_d (S_d was defined as the recombination velocity at the edge of the space charge cylinder surrounding the dislocations [3]). Consequently, the dark current increases sharply due to this shunt resistance, especially at high dislocation densities and low applied voltage.

In this paper we give a theoretical computation of the influence of dislocations on the photovoltaic properties of the solar cells : short circuit photocurrent density (J_{sc}), open circuit photovoltage (V_{oc}), fill factor (FF), and conversion efficiency (η) taking into account both recombination and conduction mechanisms at the dislocations. Then we compare the results with experimental measurements.

2. Experimental.

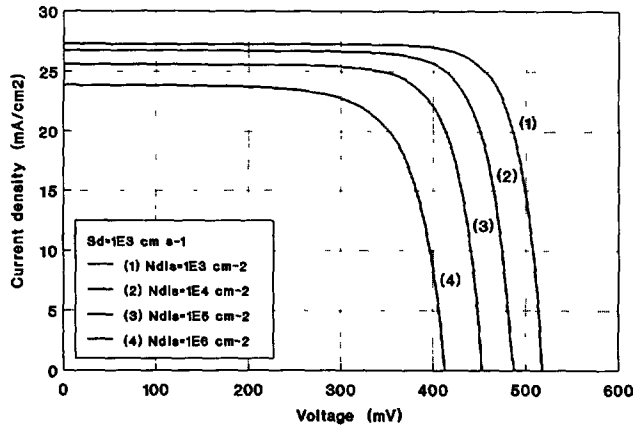
N^+ P junction solar cells were made with P-type Polyx multicrystalline silicon wafers prepared by Photowatt S. A. by phosphorus diffusion from a $POCl_3$ source at 850 °C for 15 mn.

Arrays of small mesa diodes were realized as described in a previous paper [3]. They allowed the measurements of I-V curves, when the diodes were illuminated under AM1.5 condition. The temperature of the illuminated samples was maintained constant at 25 °C, by means of a circulation of cooled water in a copper support. Thanks to a computer assisted set up the I-V curves the values of short circuit photocurrent density J_{sc} , open circuit photovoltage V_{oc} , fill factor FF , and conversion efficiency η were automatically deduced respectively.

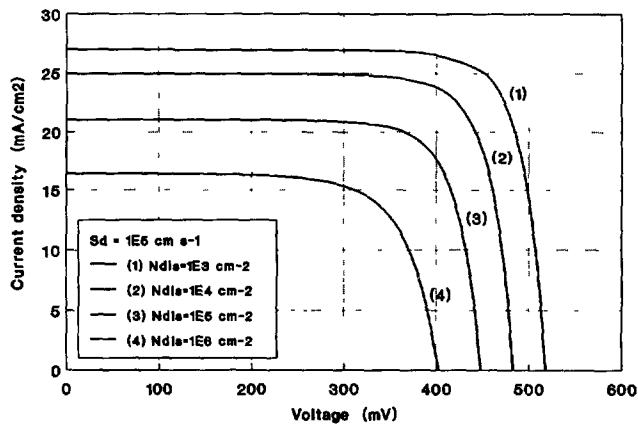
Endly the mesa diodes were chemically etched in order to reveal the presence of extended crystallographic defects.

3. Results and discussion.

In the following calculations we have used the values of the parameters given in [6], and we have neglected the emitter contribution. The I-V characteristics under AM1.5 illumination condition is shown in figure 1 for different N_{dis} . The first family of curves (Fig. 1a) is plotted for $S_d = 10^3 \text{ cm s}^{-1}$ while the second (Fig. 1b) is plotted for $S_d = 10^5 \text{ cm s}^{-1}$. We observe that at low values of S_d , J_{sc} is slightly affected by the increase in N_{dis} while at high values of S_d both J_{sc} and V_{oc} decrease with N_{dis} . The illuminated I-V curves under AM1.5 conditions for two mesa diodes having different densities of crystallographic defects 10^3 cm^{-2} and 10^6 cm^{-2} are shown by figure 2. A degradation in J_{sc} , V_{oc} and FF is observed as the density of dislocations increases. In the calculations of V_{oc} we have considered the worst case for the diffusion component of dark current, i.e. when $S_d \rightarrow \infty$, in order to avoid over estimation of the computed values of V_{oc} which are, practically, always weak in highly dislocated samples. Under this condition, and if we allow only the change of photocurrent with S_d , we observe that



a)



b)

Fig. 1. — I-V characteristics under AM1.5 illumination conditions. (a) $S_d = 10^3 \text{ cm s}^{-1}$ (b) $S_d = 10^5 \text{ cm s}^{-1}$

the variations of V_{oc} with N_{dis} given by figure 3 show a weak dependence on S_d . This means that V_{oc} is mainly controlled by the dark current which is enhanced by the conduction mechanism of dislocations. On the other hand, the variations of J_{sc} with N_{dis} given in figure 4 present a strong dependence on S_d especially at high values of N_{dis} , indicating that the recombination mechanism has a marked effect on J_{sc} . The variations of fill factor with N_{dis} at different values of S_d is given in figure 5. These variations are similar to that of V_{oc} , as expected, since FF is generally controlled by V_{oc} . The theoretical calculations of the conversion efficiency η at AM1.5 is shown in figure 6. We observe that η decreases when N_{dis} increases. This decrease is more pronounced for high values of S_d .

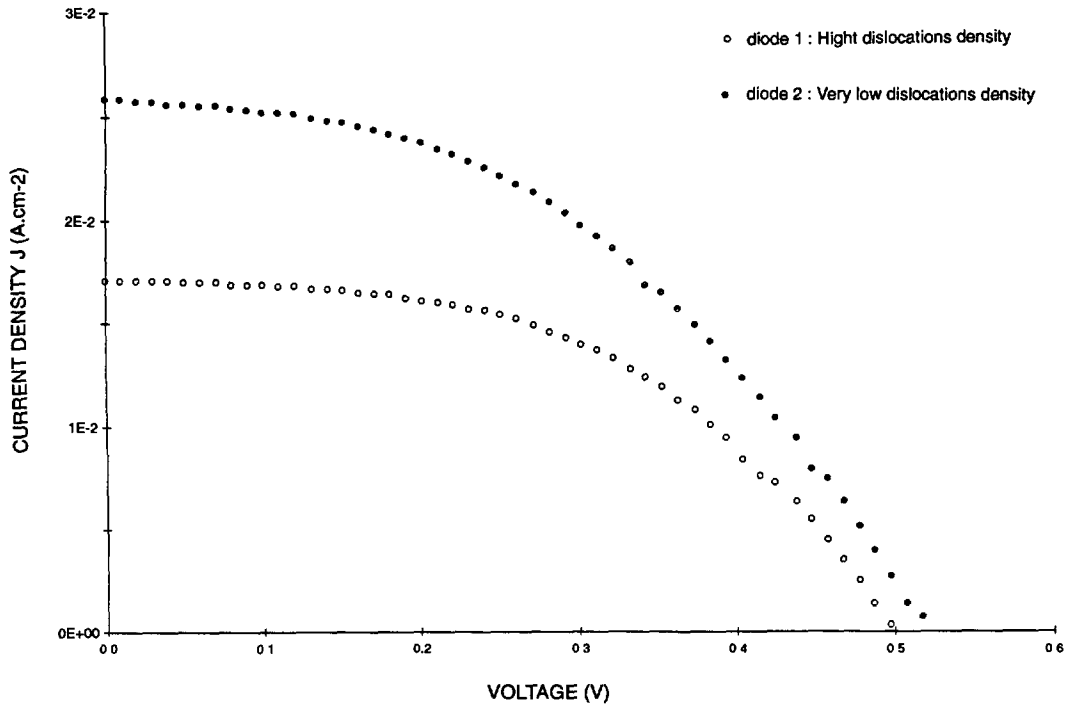


Fig. 2. — Experimental I-V measurements for two mesa diodes under AM1.5 illumination condition.

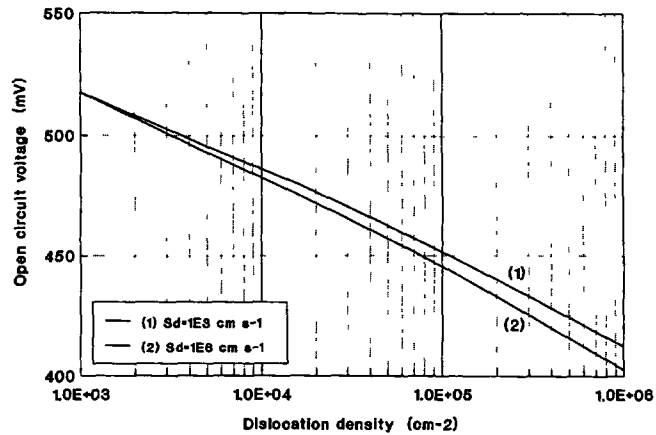


Fig. 3. — Variations of V_{oc} with N_{dis} for different values of S_d .

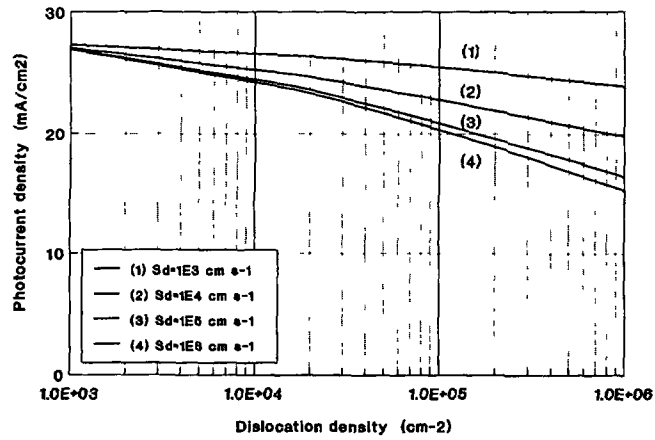


Fig. 4. — Variations of J_{sc} with N_{dis} for different values of S_d .

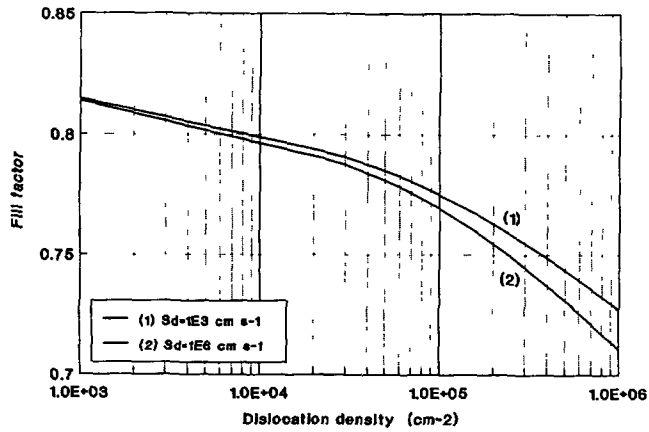


Fig. 5. — Variations of Fill Factor FF with N_{dis} for different values of S_d .

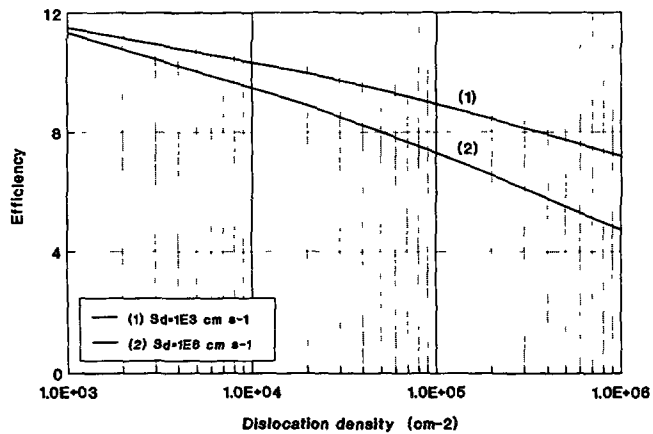


Fig. 6. — Variations of efficiency η at AM1.5 with N_{dis} for different values of S_d .

4. Conclusion.

The influence of the density N_{dis} and of the recombination activity S_d of dislocations on the photovoltaic properties of large grained polycrystalline solar cells is investigated. Two different mechanisms occur at dislocations. The first is the conventional recombination mechanism which mainly reduces the photocurrent. The second is a conduction mechanism which results of the transport of carriers along the dislocation core crossing the junction. This last mechanism is responsible of the increase of dark current and consequently of the degradation of photovoltage and fill factor. The efficiency of the cells is severely affected by these two mechanisms.

A passivation process (like hydrogenation) [7]) could reduce the recombination activity of dislocations and improve J_{sc} but if the conductivity of dislocations is not decreased the photovoltage values will be limited. Therefore it is needful to apply new treatments, may be external gettering, which could be able to reduce this conductivity and to increase the conversion efficiency.

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