DESIGN CONSIDERATIONS FOR THE TANDEM JUNCTION SOLAR CELL*

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SUMMARY

Structure and operation of the Tandem Junction Cell (TJC) are described. The impact of using only back contacts is discussed. A model is presented which explains operation of the TJC in terms of transistor action. The model is applied to predict TJC performance as a function of physical parameters.

INTRODUCTION

The Tandem Junction Solar Cell (TJC) is a back contact cell which has exhibited high efficiency in terrestrial applications (ref. 1,2). A model has been presented which explains operation of the TJC and provides general design criteria (ref. 3). The model is applied here to predict TJC performance in terms of physical parameters.

SYMBOLS

The International System of Units is used throughout.

D	Diffusion coefficient
$G(X)$	Generation rate for carriers as a function of depth
I_{CS}	Saturation current for collector-base junction
I_{SC}	Short-circuit current
I_λ	Total photon generated current
$I_{\lambda C}$	Photon generated current at collector-base junction
$I_{\lambda E}$	Photon generated current at emitter-base junction
J_{SC}	Short-circuit current density
kT	Thermal energy
L	Diffusion Length
$N(X)$	Minority carrier concentration as a function of distance
$N'(X)$	Gradient of minority carrier concentration as a function of distance
q	Magnitude of electronic charge
X	Distance normal to surface
X_E	Emitter junction depth
W	Base width
V_{OC}	Open circuit voltage
τ	Minority carrier lifetime
α_N	Normal (forward) current transfer ratio
α_I	Inverse current transfer ratio
γ_E	Injection efficiency of emitter-base junction

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TJC STRUCTURE

As illustrated in the cross section of Figure 1, the TJC consists of a P-type base with a thin N+ region at the front surface and interdigitated P+ and N+ regions at the back. The front N+ region is uncontacted. Current is collected at the N+ and P+ contacts at the back of the cell. The front surface is texturized. Refraction of incident light and reflection at the back surface give a long optical path so that a high percent of the light is absorbed, even in very thin cells.

Benefits of using contacts on only the back surface include:

- o Elimination of metal shadowing
- o Potential of low series resistance
- o Convenience of interconnect

Additionally, high short circuit current and open circuit voltage have been achieved in very thin cells. An inherent limitation of back contact cells is that good performance is dependent upon high lifetime.

TRANSISTOR MODEL FOR THE TJC

Operation of the TJC is explained by the basic transistor model shown in Figure 2. In the cross section of Figure 2(a), the front N+ region corresponds to the emitter, the P-region to the base, and the back N+ region to the collector. The current sources $I_{\lambda E}$ and $I_{\lambda C}$ in Figure 2(b) result from carrier generation in the vicinity of emitter-base and collector-base junctions, respectively.

Generation and flow of carriers is illustrated in Figure 3. When carriers are generated in the emitter, holes diffuse to the base region. For short-circuit conditions, the holes move by fields through the base to the P+ contact. To maintain charge neutrality, a potential is built up across the junction such that electrons are injected from emitter to base in approximately equal quantities. Carrier generation in the base also contributes to the emitter-base junction potential; a boundary condition for base-generated carriers is that net flow of electrons across the emitter-base junction is zero (assuming emitter injection efficiency is unity, as discussed in a later section).

From the equivalent circuit of Figure 2(b), the short circuit current is

$$I_{SC} = \alpha_N \; I_{\lambda E} + I_{\lambda C} \tag{1}$$

where α_N is the forward (normal) current transfer ratio. Most of the current is generated very close to the surface. As a first order approximation, the total photon-generated current I_λ is at the emitter junction so that

$$I_{SC} \cong \alpha_N I_\lambda. \quad (2)$$

Open circuit voltage determined from the Ebers-Moll relationship (ref. 4), is

$$V_{OC} = \frac{kT}{q} \ln \frac{I_{SC}}{I_{CS} (1-\alpha_N \alpha_I)} \quad (3)$$

where I_{CS} is the saturation current of the collector-base junction. In principle, V_{OC} can be made quite high if forward and inverse current transfer ratios, α_N and α_I, approach unity.

High measured values of short circuit current, open circuit voltage, and good response at short wavelength are consistent with the transistor model.

DESIGN CONSIDERATIONS

The transistor model provides a familiar frame of reference for optimizing the TJC structure and estimating performance. Short circuit current, in Equation 2, is related to physical parameters of the cell by expressing current transfer ratio as

$$\alpha_N = \gamma_E \frac{1}{\cosh \frac{W}{L}} \quad (4)$$

where W is base width, L is diffusion length for minority carriers in the base, and γ_E is injection efficiency for the emitter-base junction. Values of γ_E near unity can be obtained using heavily-doped emitters.

From equations 2 and 4, short circuit current is approximated as

$$I_{SC} = I_\lambda \frac{1}{\cosh \frac{W}{L}} \quad (5)$$

A more accurate calculation has been carried out using the carrier continuity equation

$$qD \frac{d^2N}{dX^2} - \frac{q}{\tau} N + G(X) = 0 \quad (6)$$

The carrier generation function, G(X), has been adapted to the TJC by including the effects of refraction and reflection. The continuity equation is solved by a computer routine to obtain short-circuit current due to carriers generated in the base. Boundary conditions are

$$N'(X_E) = 0 \qquad \text{(assuming } \gamma_E = 1.0\text{)}$$

$$N(X_E + W) = 0$$

where X_E is emitter junction depth and W is base width. Emitter generation current is obtained from the transistor model.

Short-circuit current density is plotted in Figure 4 as a function of base width for several constant values of diffusion length. The solid lines are results from the computer solution; the transistor approximation from Equation 5 is shown by the dotted lines. For small values of W/L the two are essentially coincident. The transistor model deviates for large values of W/L but still gives a useful engineering estimate. Measured values for several cells are shown in Figure 4. These follow predicted trends and are within limits of lifetime measurement.

Dependence of open circuit voltage on cell parameters can be calculated from Equation 3, using values of short-circuit current density obtained from Figure 4.

SUMMARY

A conceptual model has been described which explains operation of the Tandem Junction Cell. Structural optimization follows transistor design principles.

Short-circuit current density has been calculated in terms of the physical parameters of the cell. Estimates from the basic transistor model are quite close to values determined from a computer solution. Measured results follow predicted trends and are within reasonable accuracy of physical constants.

The transistor model can also be used to caluclate open circuit voltage.

Measured values of TJC parameters after exposure to a simulated space environment will be presented in the next session by Bruce Anspaugh.

REFERENCES

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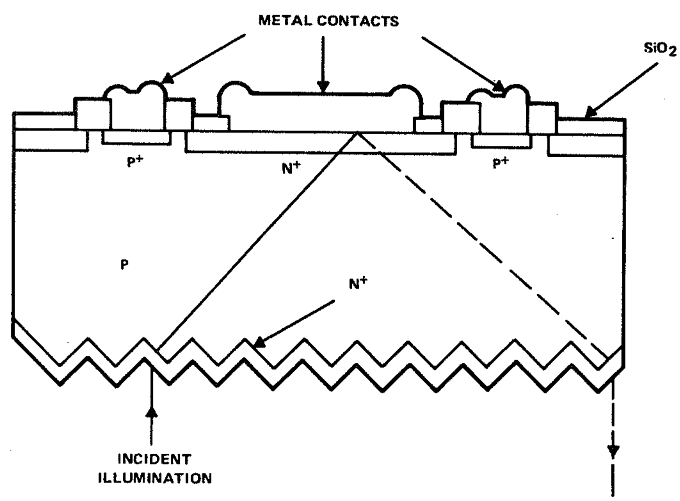

FIGURE 1 SKETCH OF TANDEM JUNCTION SOLAR CELL

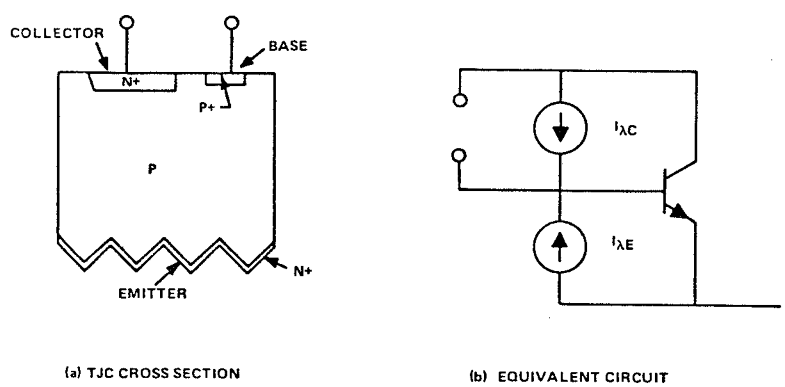

FIGURE 2 REPRESENTATION OF TJC AS TRANSISTOR STRUCTURE

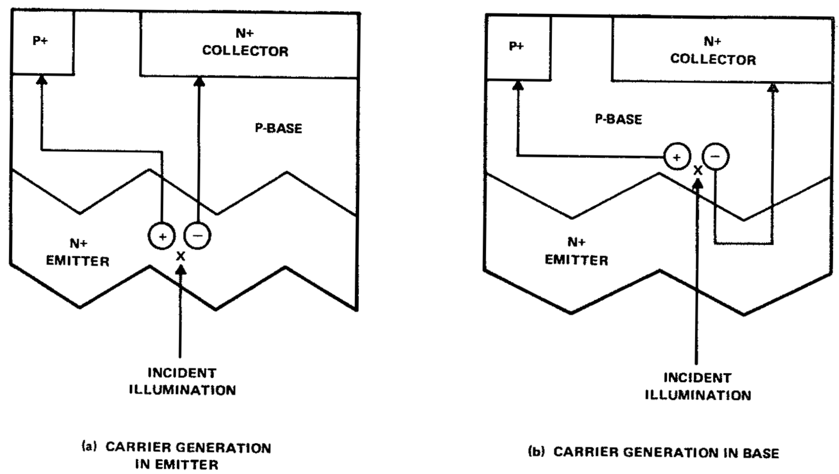

FIGURE 3 SCHEMATIC REPRESENTATION OF CARRIER FLOW IN TANDEM JUNCTION CELL

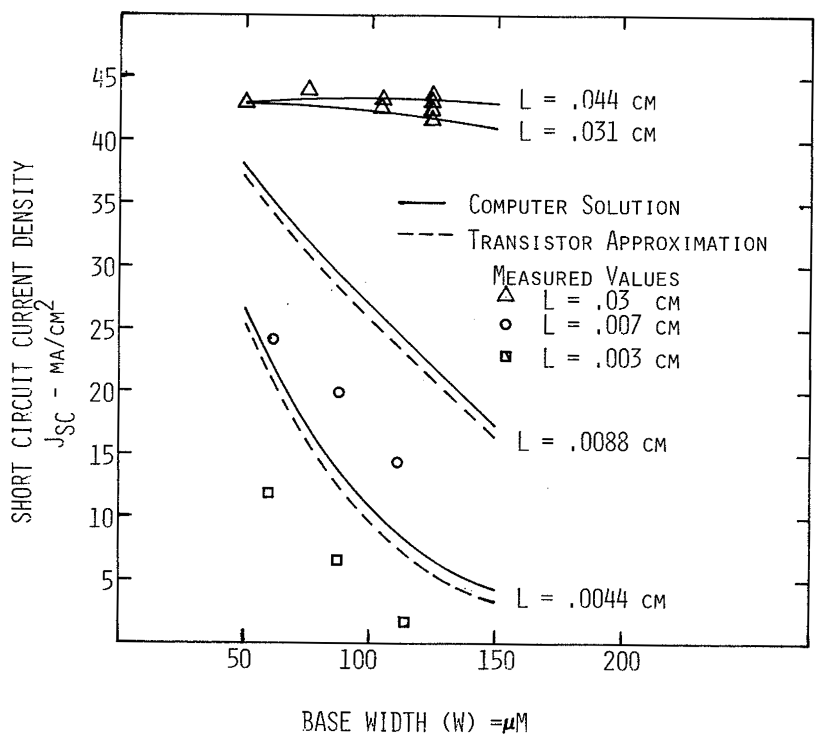

FIGURE 4

SHORT CIRCUIT CURRENT DENSITY (AMO) FOR THE TANDEM JUNCTION CELL AS A FUNCTION OF BASE WIDTH FOR CONSTANT VALUES OF MINORITY CARRIER DIFFUSION LENGTH, L.