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DESIGN AND OPTIMIZATION OF A CONTACT GRID PATTERN FOR CIRCULAR Cu_2S-CdS SOLAR CELL — A CASE STUDY

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ABSTRACT

A circular two component grid pattern for sintered Cu_2S-CdS solar cells has been evolved theoretically. The finger width, its repeated spacing, bus bar width and thickness of metallization have been optimized for minimum power loss. An optimized and low cost design of a grid pattern is proposed using vacuum evaporation technique through metal mask fabricated by photoresist process. A theoretical interpretation of the grid metallization and the effect of its resistance on the I-V characteristics of the cell has been attempted.

Key Words: Solar cell, Cu_2S–CdS cells, Grid design.

INTRODUCTION

In the front wall Cu_2S-CdS cell, mostly gold ohmic contacts are used as the grid material on the Cu_2S layer for improved efficiency (figure 1). But maximum efficiency can be attained by minimizing the power drop at the cell-contact grid region through optimum grid design.

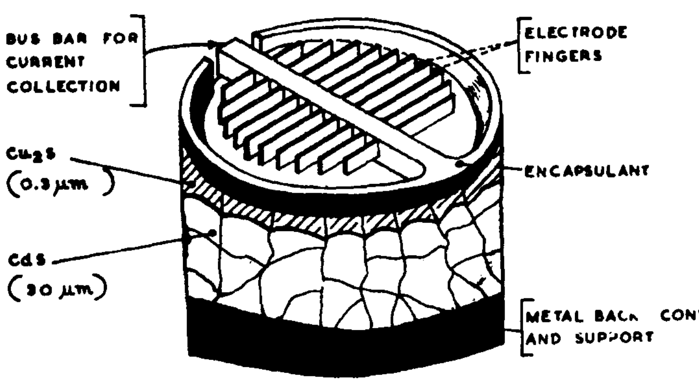

Fig. 1: Blown-up cross-sectional view of polycrystalline Cu_2S-CdS circular solar cell

Much attention has been devoted in selecting suitable metals for the grid design [1,2] and theories have been postulated [3,4] to optimize the grid structure for minimum power loss. For the design of the grid pattern, assuming a moderate efficiency of about 5% for sintered Cu_2S-CdS cells, a simple circular approximation formula has been used [3].

This paper describes the following:

(i) The optimization of the design parameters such as finger width, its spacing, the bus bar width and the grid thickness

(ii) Optimization of the maximum base area inside the vacuum chamber to grid many cells simultaneously and

(iii) Study of the effect of the series resistance due to the grid metallization on the current-voltage characteristics of the solar cell

OPTIMIZATION OF THE GRID DESIGN

The optimization is carried out in the following manner: First, the optimum repeat spacing for an array of parallel grid lines (fingers) is determined taking the appropriate cell parameters. Then the bus pattern is optimized. The total loss of the net-work is the sum of the losses for the grid and bus pattern.

The following assumptions have been made for optimizing the grid pattern. For a circular cell, the finger width and length are constant assuming the length of the finger equal to the radius of the cell. A constant width single bus bar with its length equal to the diameter of the cell is considered here.

The power loss (PL) due to the fingers is given as

$$PL_{Finger} = \frac{MJ\,(S-T)^3}{12\,VS} + \frac{M^*JL^2\,(S-T)^2}{3TVS} + \frac{T}{S} \quad \ldots (1)$$

and the loss due to bus bar is given as

$$PL_{Bus} = 2.336\,\frac{M^*Jr^3}{WV} + 0.75\,\frac{W}{r}$$

Table I: Input values taken for the calculation

M	=	Sheet resistance of Cu_2S surface = 10^3 ohms/sq
M*	=	Sheet resistance of metallization of thickness $3\mu m = 7.33 - 10^{-3}$ ohm/sq. for Au
J	=	Current density generated in the cell at AM 1 = 15.8 mA/cm^2
L	=	Length of the finger = Cell radius when single bus bar is assumed
T	=	Width of the finger = 0.5 to 0.001 cm
S	=	Repeat spacing of fingers = To be optimized
V	=	Maximum output voltage = 0.54 volt
W	=	Optimum width of bus bar = $1.625\, r_2 \left(\frac{M^*J}{V}\right)^{1/2}$
r	=	Radius of the circular cell

The first two factors on the right hand side (RHS) of the equation (1) and the first factor on the RHS of the equation (2) represent the power losses I^2R due to series resistance of the cell. T/S and W/r terms represent losses due to the shadowing effect [3]. The various parameters involved in the optimization process have been chosen for a sintered Cu_2S-CdS cell [5]. The significance of various terms in the equation (1) and (2) and the input values used for the calculation are given in Table I.

Figure 2 shows the variation of the power loss with repeated spacing (S) for different widths when gold is considered as the grid forming material. The power loss decreases with an increase in spacing up to a

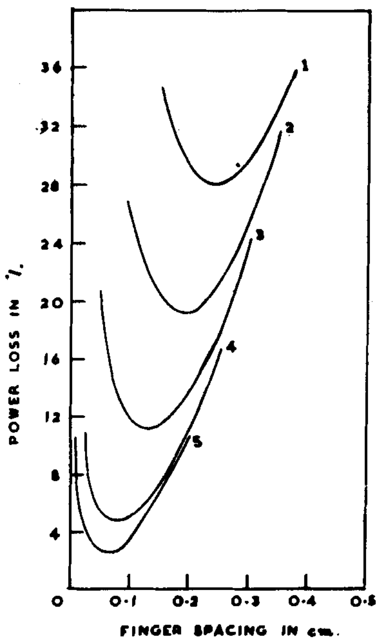

Fig. 2: Power loss vs grid repeat spacing (S) for different width (T) of the fingers (1) T = 0.05 cm (2) 0.025 cm (3) 0.01 cm (4) 0.0025 cm (5) 0.001 cm

minimum value and thereafter starts increasing. Figure 3 shows a linear relation between the optimum power loss (OPL) and 'S' which can be represented by an empirical equation

$$OPL = 136.29\,S - 6.22 \quad (3)$$

and the same was verified to hold good for Au, Ag, Cu, Al and Ni. The shaded portion shows the permissible power loss due to the fingers for a reasonable design of a metal grid. In other words, the finger spacing can be chosen in such a way that the number of fingers in the grid can be from 8 to 14 corresponding to an OPL from 10% to 3.2% for 1 cm^2 area of the cell.

The influence of the finger width (T) over OPL is brought out in figure 4. For smaller increments of T, the variation in OPL is exponential. Beyond 1.5×10^{-2} cm, the variation is linear and rapid. Considering the experimental limits in obtaining thinner fingers, the lowest possible width is 2.5×10^{-3} cm. Above this, the OPL will be higher besides the increase in the metallization cost. The shaded region of figure 4 gives the economic region for finding the width of fingers which can have a compromise between OPL and cost of metallization.

Equation (2) describes the variation of the PL with the width of the bus bar and is represented in figure 5. For thicknesses of 6 μm, 12 μm and 15 μm, the reduction in PL is less significant compared to that for 3 μm. It is therefore evident from the curves that a bus bar thickness of 6 to 9 μm is good enough for the minimum PL. Increasing the thickness further will enhance the material cost which cannot be overlooked for an insignificant PL reduction. Any width in the range from 7.5×10^{-3} cm to 1.5×10^{-2} cm can be used for the design of bus bar, keeping the PL within the permissible range. As per the proposed design, the total power loss due to the fingers and bus bar can be kept within 15% [6].

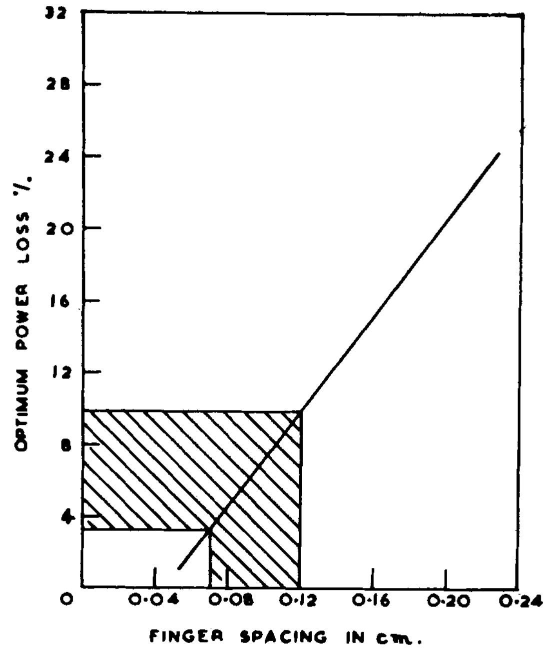

Fig. 3: Optimum power loss vs finger repeat spacing (S).

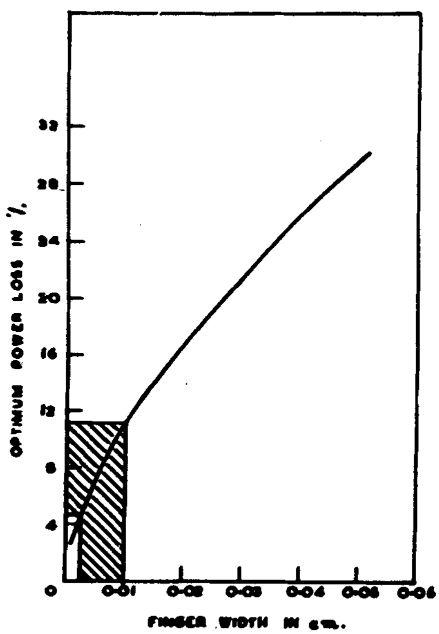

Fig. 4: Optimum power loss vs finger width (T).

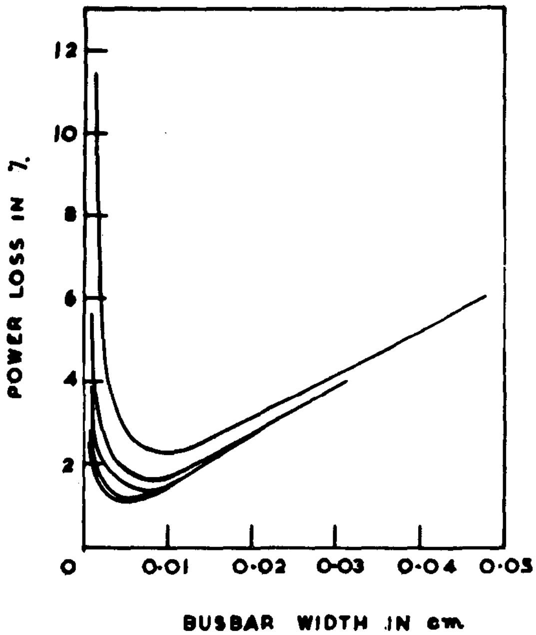

Fig. 5: Power loss vs bus bar width for different thickness. Thickness values (for curves from top to bottom) 3μm, 6 μm, 9μm, 12 μm and 15 μm

FABRICATION OF THE GRID

Vacuum evaporation technique is widely used for the fabrication of grids for Cu_2S-CdS solar cells. It permits very fine and sharp finger patterns providing lower linear resistance [7] and better adherence to the surface. Edwards vacuum coating unit has been used for the design.

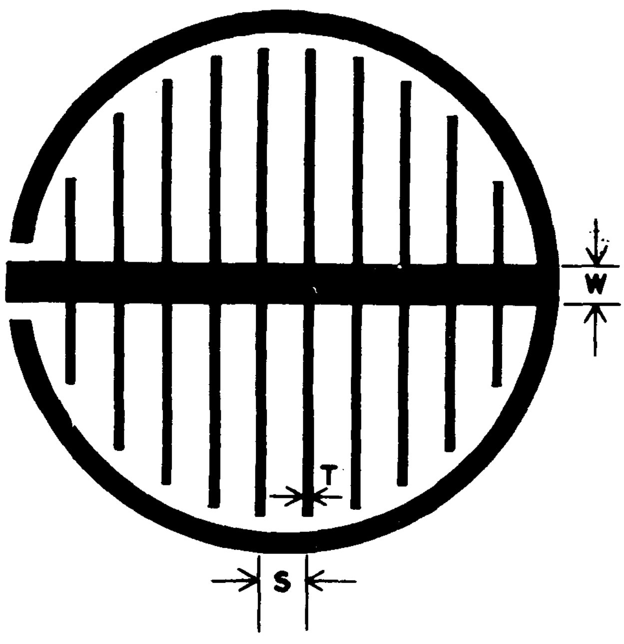

Fig. 6: The proposed optimum grid structure of 1 cm^2 area. Finger width T = 0.0025 cm, finger repeat spacing S = 0.077 cm and bus bar width W = 0.01 cm. The power loss is about 6%.

With the tungsten filament at 10 cm from the bottom of the chamber, the evaporated films over a circular area of 7 cm diameter have uniform thickness and 8 cells of 1 cm^2 area can be simultaneously given grid pattern. Aperture masks using copper sheets of thickness 8×10^{-3} cm have been fabricated employing positive acting photoresist process [8]. Figure 6 shows the proposed design of the grid structure with the optimised parameters. The likely maximum power loss for this structure is about 6% for a cell area 1 cm^2. The area available for current generation is 96% (ie. the ungridded portion of Cu_2S layer) and the resistance introduced is calculated to be about 5×10^{-3} ohms which is very less compared to the internal series resistance of 0.4 ohm of the cell [5].

EFFECT OF THE GRID RESISTANCE ON THE I-V CHARACTERISTICS

The analysis of the I-V characteristics of the solar cell in terms of an equivalent circuit gives useful information about the optimization of each step and helps one to study the impact on solar cell fabrication. The equivalent circuit is shown in figure 7.

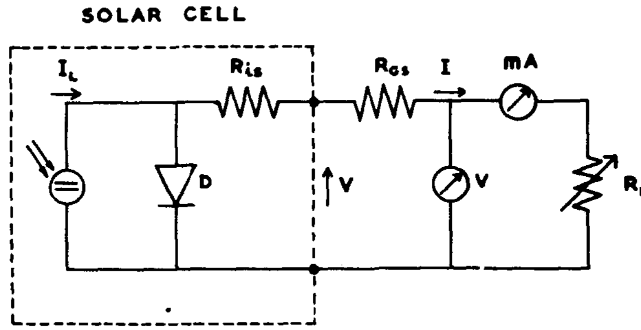

Fig. 7: Equivalent circuit of illuminated solar cell. The cell is represented by the diode 'D' and the internal series resistance R_{is}. The resistance introduced by the grid structure is R_{GS} while R_L is the variable load resistor.

The I-V characteristics of the cell without the grid structure and neglecting the shunt resistance can be represented by

$$I = I_o[\exp(\tfrac{q}{AKT} V) - 1] - I_L \qquad \text{..... (4)}$$

where, $V \geq 0$ is the terminal voltage with R_{is} (output); $I \leq 0$ the terminal current (output) (both are measured by varying the load resistor R_L); I_o the Reverse saturation current; A, the diode factor and I_L, the light generated current.

After the grid formation, the grid metallization resistance R_{GS} is introduced in series with R_{is} and the I-V characteristic equation is modified as

$$I = I_o[\exp \tfrac{q}{AKT} (V - IR_{GS}) - 1] - I_L [1-A_G] \qquad \text{..... (5)}$$

where A_G is the area covered by the grid which obstructs light from falling over the cell thereby reducing the light generated current density.

Equations (4) and (5) were fitted to the I-V values by the least-square technique [7] to find the cell parameters. When equation (4) is fitted to the experimental values, curve (1) of figure 8 is obtained and the corresponding cell parameters calculated are given in Table II. Introducing $R_{GS} = 5 \times 10^{-3}$ ohm and $A_G = 0.04$ (for the proposed grid structure) in the equation (5), the resulting I-V values are represented as curve (2) in figure 8. The decrease in A and I_o values shows a slight improvement in efficiency by better collection of the output current after the grid formation. Though the power maximum P_{max} is slightly decreased the Fill factor increases slightly. When R_{GS} values are increased to 0.05 ohm and 0.5 ohm by decreasing the thickness of the grid, an increasing trend in A and I_o is observed while P_{max} remains almost constant (Table II) (also