PHOTOVOLTAIC EFFECT OF n-TYPE WEDGE-SHAPED FILM WITH p-TYPE SURFACE LAYER

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Abstract

It has been shown that opposite gradients of electron and hole concentration could be generated when n-type wedge-shaped film with p-type surface layer is illuminated. The resulting photovoltage generated along the film is higher than corresponding Dember voltage, which could explain the experimental results obtained for CdS wedge-shaped films whose upper surface has been subject to a treatment.

It has been found experimentaly that wedge-shaped thin film possess photovoltaic property[1,2]. The wedge geometry of the film, with good photoconducting property, is able to generate photovoltage on the bases of two mechanisms: Dember-effect and surface recombination[3,4,5]. The maximal photovoltage developed between the film ends does not exceed the value of Dember voltage generated at the same illumination in a bulk semiconductor.

In order to explain higher than Dember voltage, which has been found experimentaly, another model is considered, in which p-type surface layer is placed on the top surface of n-type wedge-shaped film. The illumination is taken to be through the p-layer and the measuring electrodes are placed at the both ends at the film base/ Fig. 1/.

The basic source of nonuniform distribution of photogenerated carriers, i.e. the existance of a concentration gradients along the film length, is the contact field that exists in the depletion layer of p-n contact and the inclined position of this field with respect to the film base. This field is taken to be so strong that all photogenerated carriers are swept out from the depletion layer/W/.

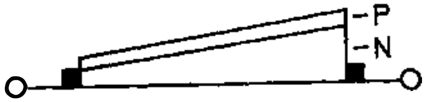


Fig.1

For the sake of simplicity we shall consider planparallel n-type film with p-type thin layer on the top/Fig.2/. First of all we shall find the distribution of photogenerated carriers in n-region in the dependence on the film thickness/d, z_i/, and after that we shall consider a film with variable thickness/ wedge-shaped film/. For planparallel geometry the problem is one dimensional with z-coordinate normal to the film surface. For n- region, which has $0 < z < z_i$ the contact field is zero, and the equation for the excess hole concentration /$\delta_p = p_n - p_{no}$ / is

$$D_p \frac{d^2\delta_p}{dz^2} + G\exp[-\alpha(d-z)] - \frac{\delta_p}{\tau_p} = 0\,, \qquad /1/$$

where D_p is diffusion coeficient, τ_p average life time of the holes in n-region, and G is generation of electron- hole pairs by incident light at the surface $z=d$, and α is light absorption coeficient. The equation of the excess electron concentration /$\delta_n = n - n_o$/ is simply obtained by substitution of p by n in eq./1/. The boundary condition for δ_p and δ_n on the lower surface/ $z=0$; film base/is defined by the surface recombination velocities S_p and S_n, and coresponding surface recombination current densities:

$$D_p \frac{d\delta_p}{dz} = S_p\delta_p$$

$$D_n \frac{d\delta_n}{dz} = S_n\delta_n\,. \qquad /2/$$

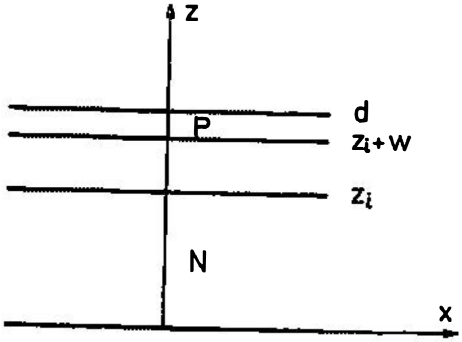


Fig.2

The sweeping action of the contact field, at the top surface of n-region/$z=z_i$/ is such that all the holes are swept out from the depletion layer, and all the electrons generated within the depletion layer/W/ are injected into n-region, i.e.

$$\delta_p = 0$$

$$D_n\frac{d\delta_n}{dz} = \int_{z_i}^{z_i+W} G\exp[-\alpha(d-z)]\,dz \qquad \text{for } z=z_i \qquad /3/$$

Since our measuring electrodes are placed at the film base/$z=0$//, we shall take the solution of eq./1/ with conditions /2/ and

/3/ for z=0, which for the excess hole concentration is

$$\delta p(0)=\frac{G\tau_p\,\eta_p \exp(-\alpha d)\ \mathrm{sh}\frac{z_i}{L_p}}{(1+\alpha L_p)\left(\mathrm{sh}\frac{z_i}{L_p}+\eta_p\,\mathrm{ch}\frac{z_i}{L_p}\right)}\ , \qquad /4/$$

and for the excess electron concentration is

$$\delta n(0)=\frac{G\tau_n \exp(-\alpha d)}{(1-\alpha^2 L_n^2)}\ \cdot$$

$$\cdot\ \frac{\left(\mathrm{sh}\frac{z_i}{L_n}-\alpha L_n \mathrm{ch}\frac{z_i}{L_n}-\frac{1}{\alpha L_n}\left[\exp\alpha z_i-(\alpha^2 L_n^2-1)\exp\alpha(z_i+W)\right]\right)}{\left(\frac{1}{\eta_n}\ \mathrm{oh}\frac{z_i}{L_n}+\ \mathrm{sh}\frac{z_i}{L_n}\right)} \qquad /5/$$

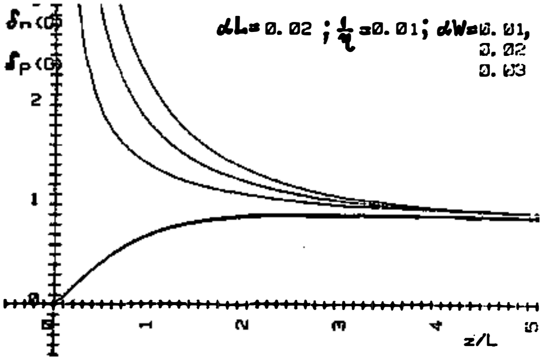
where L_p and L_n are corresponding diffusion lengths, and η_n and η_p are constants defined by

$$\eta_n=\frac{D_n}{S_n L_n}\ ,\ \eta_p=\frac{D_p}{S_p L_p}\ .$$

The expression /4/ and /5/ has been analysed by Hewlet-Packard computer and graphic plotter. The presentation has been done on the same coordinate system, where $\delta n(0)/G\tau_n$ and $\delta p(0)/G\tau_p$ have been presented v.s. z_i/L_n and z_i/L_p. The analysis has been performed for different , S_p and S_n, and different W. For $\alpha L=0.02$; $1/\eta=0.01$ and three different values of $k=\alpha W$, the plot is given on Fig.3.

As one can see, the hole concentration increases and the electron concentration decreases with the film thickness.

Fig.3



Clear physical interpretation of the results can be done by an analysis of /4/ and /5/ for particular case /$\alpha = 0$, S_p, $S_n \to 0$/. For this case

$$\delta p(0) = G\tau_p \frac{\operatorname{sh} \frac{z_i}{L_p}}{\operatorname{ch} \frac{z_i}{L_p}}, \qquad /6/$$

which gives a monothonic increase of the hole concentration, tending to the saturation value $G\tau_p$. The physical meaning of this is that, as far as z_i increases the possibility of hole extraction fron n-region is decreased, and the concetration becomes equal to that in bulk.

The exceess electron concentration is given by

$$\delta n(0) = G\tau_n \left(1 + \frac{W}{L_n} \frac{1}{\operatorname{sh} \frac{z_i}{L_n}}\right) \qquad /7/$$

which gives decrease of the concentration with z_i, but it allways remain higher than the concentration in bulk /$G\tau_n$/. This comes out because of the injection action of the surface field.

This analysis can be applied for the film with variable z_i and d as far as variation is neglegible with respect to the other film dimensions. For wedge-shaped film z_i and d are linear functions of the film length /x/. For such a film geometry $\delta n(0)$ and $\delta p(0)$ give concentration gradients along x with opposite signs and their partial contributions to the photovoltage will be added. As a result of this, a higher than Dember voltage will apear along the film length/x/.

The surface recombination can substantially change the results, which can be shown by the analysis of /4/ and /5/ for the extreme cases. Two cases has been analysed, $z_i \ll L_{p(n)}$ and $z_i \gg L_{p(n)}$, for which the excess concentrations are

$$\begin{aligned} \delta p(0) &= G\tau_p \frac{z_i}{L_p} && \text{for } z_i \ll L_p \\ \delta p(0) &= G\tau_p && \text{for } z_i \gg L_p \end{aligned} \qquad /8/$$

and

$$\begin{aligned} \delta n(0) &= G\tau_n\left(1 - \frac{L_n/\eta_n}{z_i + L_n/\eta_n} + \frac{W}{z_i + L_n/\eta_n}\right) && \text{for } z_i \ll L_n \\ \delta n(0) &= G\tau_n && \text{for } z_i \gg L_n \end{aligned} \qquad /9/$$

The expression /9/ for the case $z_i \ll L_n$ gives a decrease or in -

crease of the concentration, which depends on the magnitude of the second and third term. The second term gives a decrease because of the surface recombination, and the third term gives an increase because of the electron injetion from the depletion layer. In this case the concentration gradients can have equal or opposite signs, which will depend on $1/\eta_n$ and W.

For the case of very strong surface recombination, expressions /4/ and /5/ become

$$\delta p(0) = G\tau_p \frac{z_i}{L_p} \qquad \text{for } z_i \ll L_p$$

$$\delta p(0) = G\tau_p \eta_p \qquad \text{for } z_i \gg L_p$$

and

$$\delta n(0) = G\tau_n (W + z_i) \frac{\eta_n}{L_n} \qquad \text{for } z_i \ll L_n$$

$$\delta n(0) = G\tau_n \eta_n \qquad \text{for } z_i \gg L_n \ .$$

As one can see , the concentration gradients have the same signs, and the photovoltage will be proportional to their difference. For the case of very strong surface recombination the developed photovoltage will be equal or less than Dember voltage.

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