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DISTRIBUTION OF INJECTED CHARGE CARRIERS CONCENTRATION IN BASE REGION UNDER THE IMPACT OF MAGNETIC FIELD IN BIPOLAR MAGNETOSENSITIVE STRUCTURES

The paper studies the impact of magnetic field on the distribution of charge carriers concentration in base region of bipolar magnetosensitive structures. Theoretical dependences of bipolar transistors parametrs are obtained while taking into account this impact.

Key words: *magnetic field, sensors, bipolar transistor.*

Introduction

Sensors of magnetic field, based on bipolar transistors are widely used in automation and control of technological processes, monitoring of the environment, control of parameters of nuclear fusion, space engineering, scientific research, medicine, transport, etc. Experimentally the parameters of these sensors are investigated, although theoretically, not all dependences of bipolar magnetosensitive structures parameters are calculated and studied [1, 2]. The dependence of distribution of injected charge carriers concentration in base region of bipolar magnetosensitive transistor on magnetic field is of great interest for the researchers. On the basis of this dependence main parameters of magnetic field sensor are calculated.

The given paper investigated the impact of magnetic field on distribution of injected charge carriers concentration in bipolar magnetosensitive structures, emitter and collector currents have been determined.

Mathematical model

Horizontal magnetotransistors, where the collectors are located at a certain distance from the emitter on the same surface of the plate, got wide practical application (Fig. 1) [2]. In such transistors magnetosensitive properties are stipulated by two effects: change of effective length of the base and deviation of injected carriers from the collector or to it. If magnetic field is absent, the injected charge carriers move from emitter to collector under the impact of electric field. During time interval $t = l / \mu E$ they enter the region of space charge of the collector, at the same time they are diffusing simultaneously in the space of the base at the distance

$$h = \sqrt{\frac{kT}{qE} l},$$

where l – is the distance between the emitter and collector, k – is Boltzmann's constant, T – temperature, E – is electric field strength in the transistor base, q – is electron charge. Route length of charge carriers, leaving point $x = 0$, will equal $W_0 = \sqrt{l^2 + h^2}$.

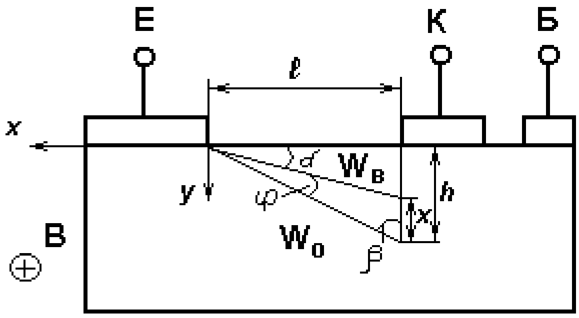

Fig. 1. Structure of single collector magnetosensitive transistor [2]

In magnetic field $\oplus B$ polarity charge carriers deviate to upper side and their route is reduced to the value W_B. Let us calculate the value W_B, proceeding from Fig. 1. We assume, that charge carriers are calculated according to direct paths. Proceeding from Fig. 1 we can write

$$\sin(\alpha+\varphi)=\frac{h}{W_0}, \tag{1}$$

$$\sin\alpha=\frac{h-x}{W_B}, \tag{2}$$

$$\cos\alpha=\frac{l}{W_B}. \tag{3}$$

On the other hand, $\sin(\alpha+\varphi)$ equals [3]

$$\sin(\alpha+\varphi)=\sin\alpha\cos\varphi+\cos\alpha\sin\varphi. \tag{4}$$

Substituting (2) and (3) in the expression (4), we obtain

$$\frac{h}{W_0}=\frac{h-x}{W_B}\cos\varphi+\frac{l}{W_B}\sin\varphi, \tag{5}$$

thus

$$h-x=\frac{hW_B}{W_0\cos\varphi}-l\tan\varphi. \tag{6}$$

From theorem of sines [3] we define

$$\frac{x}{\sin\varphi}=\frac{W_B}{\sin\beta}, \tag{7}$$

where $\sin\beta=l/W_0$. Hence, from (7) we can define

$$x=\frac{W_BW_0\sin\varphi}{l}. \tag{8}$$

Substituting (8) into (6) we will define the dependence of effective thickness of the base W_B by means of W_0 under the impact of magnetic field. Hall angle equals $\varphi=\mu B$, in case of weak magnetic filed $\mu B<1$, that is why, $\sin\varphi\approx 0$. Hence,

$$W_B=W_0\left(1+\frac{l}{h}\tan\varphi\right)\cos\varphi. \tag{9}$$

Taking into account weak magnetic field formula (9) will take the final form

$$W_B = W_0 \cos\varphi . \tag{10}$$

While expansion into a series $\cos\varphi$ and saving two first members of decomposition we obtain

$$\cos\varphi = 1 - \frac{1}{2}\varphi^2 = 1 - \frac{1}{2}(\mu B)^2 \tag{11}$$

While substitution of (11) into the formula (10), we will define the dependence of efficient length of base W_B change on the impact of magnetic field

$$W_B = W_0\left[1 - \frac{1}{2}(\mu B)^2\right]. \tag{12}$$

Now we will define the dependence of the currents of bipolar magnetosensitive transistor on the impact of magnetic field. We will consider single-dimensional case and stationary operation mode. It is necessary to find distribution of injected charge carriers concentration under the impact of magnetic field from the solution of transfer equation [4]

$$\frac{d^2 p}{dx^2} - \frac{p - p_n}{L_p^2} = 0 , \tag{13}$$

where D_p – is the coefficient injected holes diffusion into the base , L_p – is diffusion length of charge carriers, p – is concentration of injected holes into the base , p_n – is equilibrium concentration of holes in base. We think, that charge carriers move in the base in a diffusive manner, then boundary conditions take the form

$$p(0) = p_n\left(e^{\frac{qU_E}{kT}} - 1\right), \tag{14}$$

$$p(W_B) = p_n\left(e^{\frac{qU_K}{kT}} - 1\right). \tag{15}$$

Solution of the equation (13) is the following

$$p(x) = A_1 e^{K_1 x} + A_2 e^{K_2 x} , \tag{16}$$

where K_1 and K_2 are roots of square equation

$$K^2 - \frac{1}{L_p^2} = 0 , \tag{17}$$

then

$$K_1 = \frac{1}{L_p} ,\ K_2 = -\frac{1}{L_p} . \tag{18}$$

Coefficients A_1 and A_2 are found from boundary conditions (14) and (15), substituting values 0 and W_B instead of x. Thus, we can write

$$A_1 = \frac{p(W_B) - p(0)e^{-\frac{W_B}{L_p}}}{2sh\left(\frac{W_B}{L_p}\right)} , \qquad A_2 = -\frac{p(W_B) - p(0)e^{\frac{W_B}{L_p}}}{2sh\left(\frac{W_B}{L_p}\right)} . \tag{19}$$

Taking into account (19) the solution of transfer equation (13) will take the form

$$p(x,B)-p_n=\frac{p(W_B)-p(0)e^{-\frac{W_B}{L_p}}}{2sh\left(\frac{W_B}{L_p}\right)}e^{\frac{x}{L_p}}-\frac{p(W_B)-p(0)e^{\frac{W_B}{L_p}}}{2sh\left(\frac{W_B}{L_p}\right)}e^{-\frac{x}{L_p}}. \qquad (20)$$

We substitute instead of W_B its value (12) in the formula (20), then

$$p(x,B)-p_n=\frac{p(W_B)-p(0)e^{-\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}}}{2sh\left(\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}\right)}e^{\frac{x}{L_p}}-\frac{p(W_B)-p(0)e^{\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}}}{2sh\left(\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}\right)}e^{-\frac{x}{L_p}}, \qquad (21)$$

where μ_p – is hole mobility, B – is magnetic induction.

From the formula (21) we will find emitter and collector currents, applying the expressions

$$I_E=-S_EqD_P\left.\frac{dp}{dx}\right|_{x=0}, \qquad (22)$$

$$I_K=-S_KqD_P\left.\frac{dp}{dx}\right|_{x=W_B}, \qquad (23)$$

where S_E, S_K – is cross-section area of emitter and collector regions. Electronic components of emitter and collector currents are not taken into account, since they have the value only for establishment of electric neutrality in transistor, but the main role is played by hole current in *p-n-p* transistor. Having performed differentiation and substituted the results obtained in (22) and (23), we obtain the value of emitter and collector currents as a result of the impact of magnetic field

$$I_E=\frac{S_EqD_pp_n}{L_p}cth\left(\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}\right)\left[\left(e^{\frac{qU_E}{kT}}-1\right)-\frac{1}{ch\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}}\left(e^{\frac{qU_K}{kT}}-1\right)\right], \qquad (24)$$

$$I_K=\frac{S_KqD_pp_n}{L_p}\frac{1}{sh\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}}\left[\left(e^{\frac{qU_E}{kT}}-1\right)-cth\frac{W_0\left(1-\frac{(\mu_pB)^2}{2}\right)}{L_p}\left(e^{\frac{qU_K}{kT}}-1\right)\right]. \qquad (25)$$

If charge carriers drift occurs in base region of magnetotransistor, then emitter and collector currents are described by the expressions

$$I_E = S_E q\mu_p \, p(x)\big|_{x=0} E\,, \tag{26}$$

$$I_K = S_K q\mu_p \, p(x)\big|_{x=W_B} E\,, \tag{27}$$

where E – is electric field strength is base region while substituting the expression (21) in formulas (26) and (27), we define emitter and collector currents

$$I_E = S_E q\mu_p p_n \left[\frac{\left(e^{\frac{qU_K}{kT}} - 1\right) - \left(e^{\frac{qU_E}{kT}} - 1\right) e^{-\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}}}{2sh\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} - \frac{\left(e^{\frac{qU_K}{kT}} - 1\right) - \left(e^{\frac{qU_E}{kT}} - 1\right) e^{\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}}}{2sh\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} \right] E\,, \tag{28}$$

$$\begin{aligned} I_K = S_K q\mu_p p_n \Bigg[& \frac{\left(e^{\frac{qU_K}{kT}} - 1\right) - \left(e^{\frac{qU_E}{kT}} - 1\right) e^{-\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}}}{2sh\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} e^{\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} - \\ & - \frac{\left(e^{\frac{qU_K}{kT}} - 1\right) - \left(e^{\frac{qU_E}{kT}} - 1\right) e^{\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}}}{2sh\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} e^{-\frac{W_0\left(1-\frac{(\mu_p B)^2}{2}\right)}{L_p}} \Bigg] E. \end{aligned} \tag{29}$$

Analysis of formulas (24), (25) and (28), (29) shows that while drift mechanism of charge carriers motion in the base o magnetosensitive bipolar transistor dependence of emitter an d collector currents on the action of magnetic field is much more stronger , as compared with diffusive mechanism of motion.

Conclusions

The dependence of injected charge carriers concentration on the impact of magnetic field induction is obtained on the basis of the solution of transfer equation for magnetosensitive single-collector bipolar transistors. Proceeding from the distribution of injected charge carriers concentration in base region of magnetosensitive transistor, analytical dependences of emitter and collector currents on magnetic field induction for cases of diffusive and drift mechanism of charge carriers motion have been obtained.

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