The volume concentration-recombination mechanism responsible for negative current sensitivity

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ABSTRACT

The operation of dual collector magnetotransistors has been studied to increase collector sensitivity. To analyze the electrical characteristics and sensor performances of these machines, the complete device structure has been modeled using technological and physical parameters extracted from actual experimental measurements. Through this, joining the contacts of the base and well has been shown to create an operating threshold, negative magnetosensitivity, and an increased sensitivity to weak magnetic fields. Furthermore, magnetic fields are shown to cause a volumetric concentration-recombination that causes a negative sensitivity in the electron-hole plasma. However, lateral bipolar magnetotransistors with bases and wells have shown the most significant increases (up to 2000 V/T) in magnetosensitivity.

Keywords: bipolar magnetotransistor, device-technological simulating, negative sensitivity, electron-hole plasma, relative sensitivity on the current.

1. INTRODUCTION

One of the microsystem elements of this device is the magnetic field sensor, i.e., the bipolar magnetotransistor (BMT) [1], which possesses a high sensitivity to and selectivity of the direction of a magnetic field. A BMT with an integrated circuit (IC), which is used to build the matrix conversions of a magnetic field [2], has increased magnetosensitivity of up to 1.2 V/T. BMTs using this technology are compatible with complementary-symmetry metal-oxide-semiconductor (CMOS) circuits. This work focuses on improving the sensitivity of BMTs by examining their sensitivity mechanisms and creating designs that consider the peculiarities of BMTs and their associated concentration-recombination sensitivities.

2. INCREASING THE SENSITIVITY OF A BIPOLAR LATERAL MAGNITOTRANSISTOR

For the optimization the of electrical state of a working instrument, BMT samples are explored, having alike topology, but distinguished on the structure, as shown in Fig. 1.

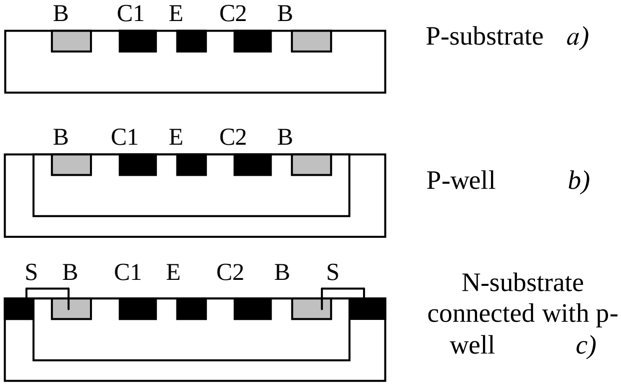

Fig. 1. The structural elements of a BMT are labeled as follows: E: emitter; B: base contacts; C1 and C2: collectors; and S: substrate contacts.

Sample a) uses p-type conduction in its substrate, and samples b) and c) use n-type substrates with p-type diffusional wells. However, the substrate-to-substrate contact in sample b) is also connected to the base contact. To increase the sensitivity, a collector circuit impedance of 30 kΩ is used. The absolute sensitivity is presented in Fig. 2, with an observed dependence on the current base of the BMT. The emitter currents are shown in Fig. 3, with respect to the current base. A total current collector, Ic1 + Ic2, with respect to the current base is presented in Fig. 4.

As shown in Fig. 3, joining the substrate with the base doubles the maximum values of the emitter current and the output of the working collectors at saturation. The increase in current is connected to saturation because a large part of the current-carrier output leaves through the well-substrate junction. The maximum sensitivity of this system is twice that of the previous maximum (4 V/T) (Fig. 2). Therefore, the maximum sensitivity is proportional to the value of the emitter current.

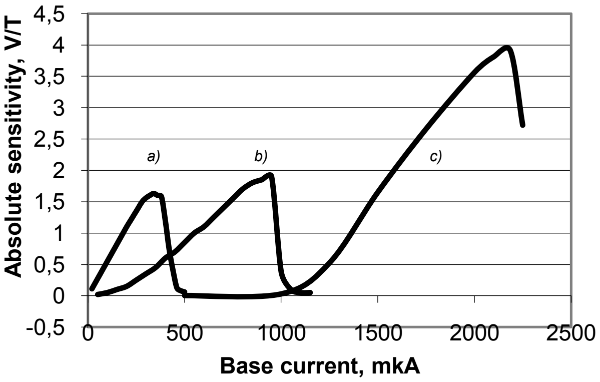

Fig.2. Absolute sensitivity of the BMT structures *a), b),* and *c)*.

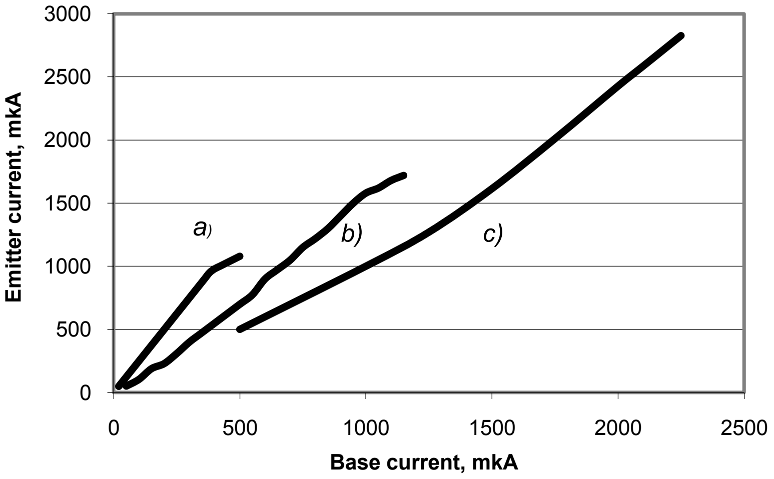

Fig.3. Emitter current of BMTs with structures *a), b),* and *c)*.

The relative sensitivity of a BMT with a substrate base to the emitter current is 1600 V/T/A, but that of a BMT with a well with a sail substrate is 1300 V/T/A. Additionally, when the substrate is joined to the base, the BMT sensitivity is 1400 V/T/A. The collector currents have similar saturation point values (Fig. 4), and their relative sensitivities to the emitter currents differ only slightly. An increase in the absolute sensitivity occurs in structure c) when the base is joined to the substrate, even without increasing the collector currents.

Sample c) has a threshold current collector and threshold sensitivity (Fig. 2, Fig. 4).

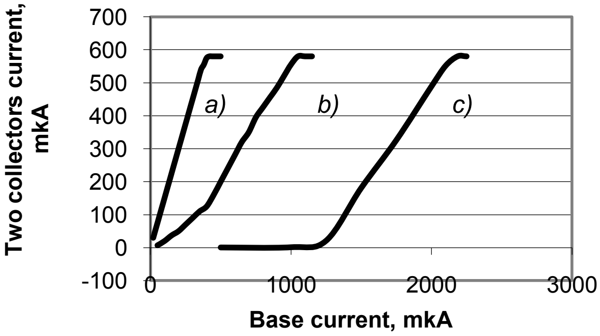

Fig.4. Two current collectors of BMTs with structure *a), b),* and *c).*

In particular, a BMT with a well joining the base and substrate has a negative voltage imbalance across the collectors when in a magnetic field. This negative sensitivity has not been previously reported. As shown in [3], the voltage of the transition well (base) in the substrate changes the state of the BMT. The junction and well (base) BMT has a substrate that absorbs most of the current injected by the emitter, which changes the mechanisms of the BMT. The well has a substrate junction that is a triplet collector.

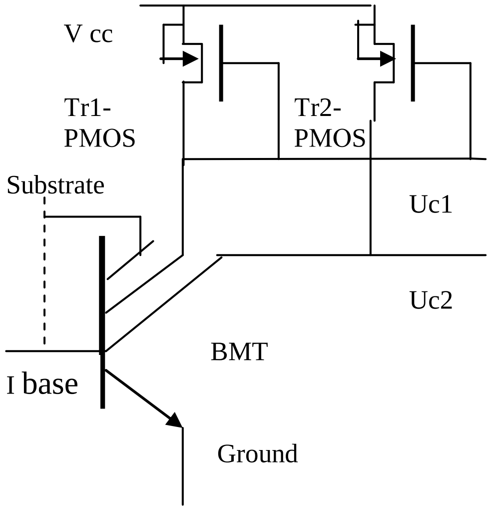

Fig. 5. BMT with p-type metal-oxide-semiconductor logic (PMOS) transistor loads.

At its connection to the substrate, the potential of the base absorbs the injections of charges and serves as a structural element with an endless recombination velocity. Structure a) strongly depends on the recombination of carriers on its surface. In a BMT with a surface and a well, the substrate junction is on the opposite side of the device, away from the currents of the working collectors. Therefore, the deflection of currents in the presence of a magnetic field creates action force, i.e. Lorenz force, which results in an opposite change in the currents of the working collectors in the recombination process.

To increase the BMT sensitivity, transistor loads were used with PMOS transistors to create an enclosed current mirror scheme, as shown in Fig. 5. Fig. 6 shows the dependence of the BMT sensitivity on the load of the current mirrored by the PMOS transistors, which is altered by the base current but not the substrate current, for two magnetic field directions (up to 0.18 T). Accordingly, this figure shows two dependencies: Sa- and Sa+. The maximum value of the absolute sensitivity of the circuit due to the load of the PMOS transistors increases by up to 7 V/T and can be further increased using these transistors because this scenario has high-value dynamic resistances in the valance band of the voltage-current structure.

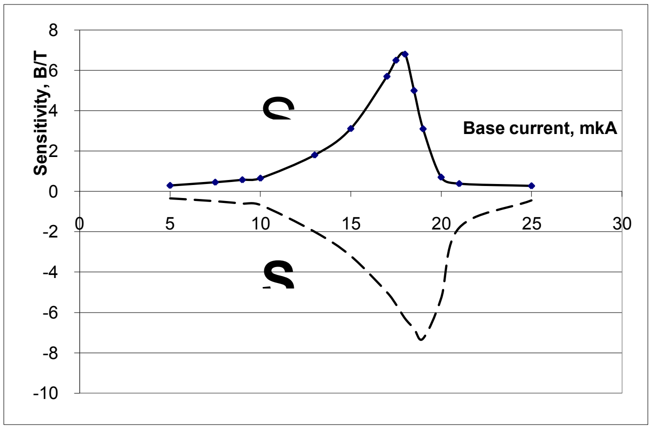

Fig. 6. Sensitivity of a BMT with PMOS transistor loads.

The increased sensitivity [4] of the BMT when the well and substrate contacts are connected should also be considered.

3. MECHANISMS OF RELATIVE MAGNETOSENSITIVITIES

Increasing sensitivity [4-8] comes at the expense of changing the structure of the BMT because the specific arrangement of the structural elements influences the mechanisms of transformation. The following physical effects were considered: the Hall effect, the redistribution of the current emitters between the collectors, the recombination on the surfaces of the crystal, and the angle of the injection from the emitter due to the local magnetoconcentration effects.

The dual-collectors of the lateral n-p-n BMT are formed in the p-well of the n-substrate [9, 10] and are triplet collector transistors. When the contacts of the well and substrate are joined, the maximum sensitivity of this structure increases.

ISE TCAD software was used to study the influence of the total flow of charge carriers in a BMT with a triplet collector on the transformation and sensitivity mechanisms. Using a two-dimensional mathematical simulation of this type of BMT, the influences of these mechanisms were studied, as shown in Fig. 7.

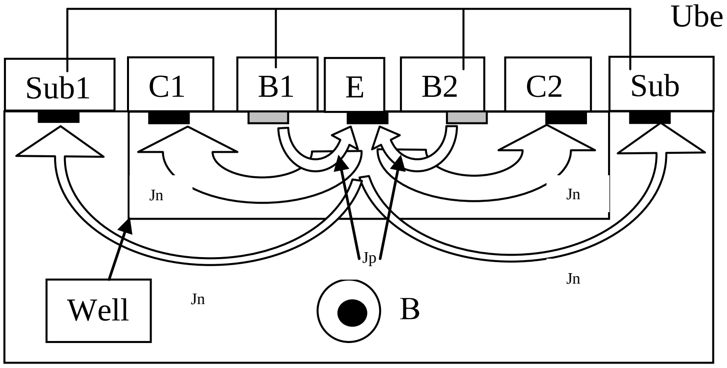

Fig. 7. Structure of a BMT via two-dimensional mathematical simulation.

The analysis of the total current-carrier flows shows that an injection from an emitter spreads the current in the substrate evenly and that the carrier concentration decreases when the emitter is removed. This concentration also decreases due to the carrier recombinations in the base and the surfaces and collector of the substrate. Carrier extraction from the working collectors also reduces the carrier concentration. These processes are difficult to describe mathematically without crucial simplifications. However, to determine the optimal design for a BMT, an analog experimental structure, which uses calculated methods from device-technological modeling, is used to study the mechanisms of transformation and conduction in various structures.

As shown in Fig. 8, for the illustrated arrangement, the emitter can be run at voltages of Ube=0.6, 0.7, 0.79, 0.9, or 1.0 V via emitter transitions, i.e., by using different injection levels.

Figs. 8 and 9 show the total densities of the flows of electrons and holes in the structure.

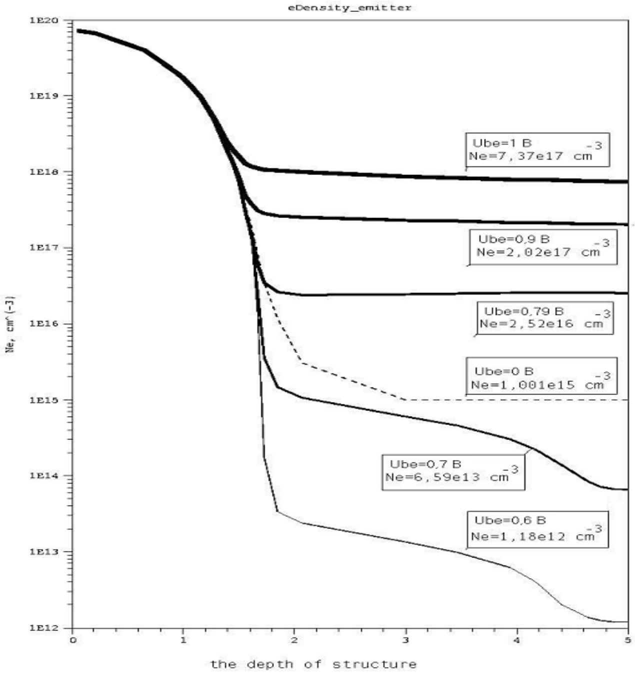

Fig. 8. Distribution of the electron concentrations near the emitter of the BMT.

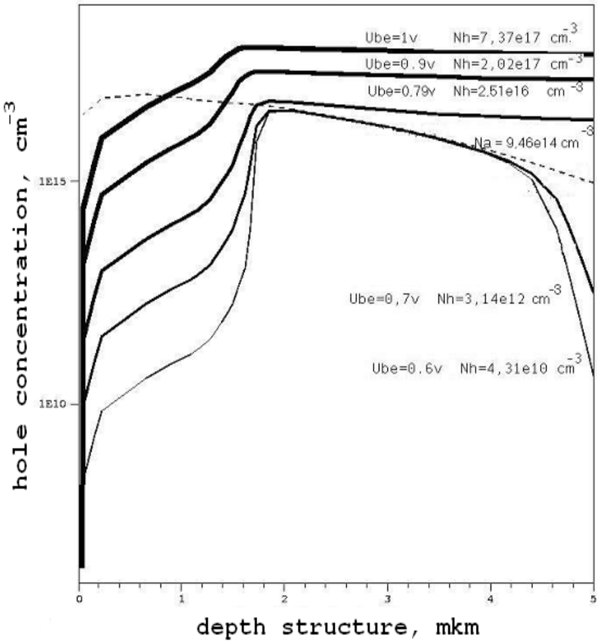

Fig. 9. Distribution of the hole concentrations near the emitter of the BMT.

With increased injections, electrons show concentrations of more holes at the base, such that the pn junction between the n-substrate and p-base disappears. The electrons are injected into not only the base but also the substrate. The electrons in the substrate penetrate the holes there, which balances the charges of the electrons. Therefore, a cloud of plasma forms in the substrate that consists of electrons and holes.

At reduced injection levels, the carrier distributions are hardly distinguishable from those at equilibrium. Electrons reach the collectors on the paths situated in the well. The electron concentrations decrease in volume and surface recombination (Fig. 10), which is given as a current with a voltage of Ube=0.756 V. The highest density of electron currents is observed between the emitter and contacts toward the substrate, but the working collector branch also has a small current.

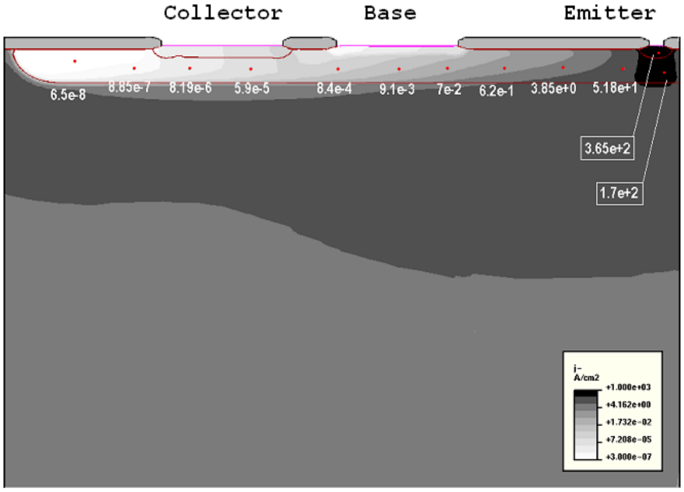

Fig. 10. Distribution electron currents in the BMT at low injection level (Ube=0.756 V).

A BMT with a well and a high injection level in a magnetic field works similar to a BMT with a transistor without a well (Fig. 11).

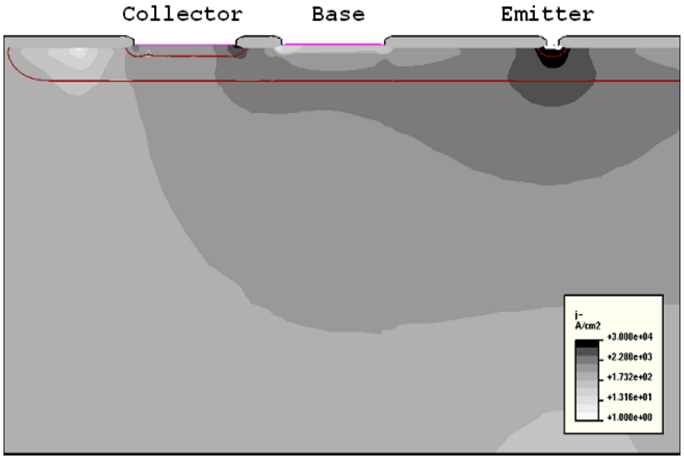

Fig. 11. Distribution electron current in the BMT at high injection level (Ube=1.0 V).

TABLE 1. Accounting parameters BMT

Parameters BMT	U_{be}= 0,75 V	U_{be}= 1 V
Emiter current, Ie	5,15 μA	82 mA
Substrate current, Is	4,65 μA	15 mA
Base current, Ib	48 nA	24 mA
1 collector current, Ic1	123 nA	25 мA
2 collector current, Ic2	323 nA	18 mA
Ic1-Ic2, B= 1 T	- 200 nA	7 mA
S_r, (Ic1-Ic2/Ic1+Ic2/B)	- 0,43 T^{-1}	0,16 T^{-1}

The values of the electrode currents and the relative magnetosensitivity defined for a BMT structure with an emitter length of 80 μ are summarized in Table 1. The dependencies of the currents of the collectors and their relative sensitivities to the differences in voltages on the base-emitter Ube have the following particularities. For Ube=0.7-0.8 V, the first collector current is less than that of the second collector, and their relative sensitivities are negative, with a maximum value of 0.43 T^{-1}. For Ube=0.8-1.0 V, the first collector current is greater than the second collector current, and the sensitivity is 0.16 T^{-1}. Changing the currents of the collectors in a magnetic field B=1 T at a low level of injection shows a sign opposite than that at a high level of injections.

A triplet collector magnetotransistor has a substrate current equal to its emitter current. The base has a substrate interconnection that forms its threshold sensitivity, doubling the maximum emitter current and sensitivity. This result demonstrates a new form of the law of sensitivity.

A BMT with a well has negative and positive sensitivities. The device-technological simulations show that the sign of sensitivity is defined by the level of injected charge carriers. Electron-hole plasma plays a key role in the structure of a BMT with triplet collectors. A BMT with triplet collectors and a potential in the substrate and well also generates this plasma.

BMT with triplet collectors has absolute sensitivity 7 V/T at the load in the manner of PMOS transistors.

4. TWO-DIMENSIONAL SIMULATION OF THE NEGATIVE SENSITIVITY OF THE BMT WITH TRIPLET COLLECTORS

In previous works on BMTs [4-8, 11, 12], a negative sensitivity was not considered. In addition, charge carrier recombination, which has a considerable impact on BMTs with long bases [7], was not considered in previous studies.

Experimental studies on the total charge carriers and recombination during the use of BMTs are not possible. Therefore, device-technological simulations of BMT structures are used instead and match the experimental test conditions well.

4.1. BMT structures

Studies of the concentrations of electrons and holes and the velocities of their recombinations are provided [13, 14] using software from ISE AG.

The n^+ diffusion emitter is located in the center of the well; furthermore, two p^+-type diffusion areas ensure contact with the well, which acts as the base transistor. There are also two n+ diffusion areas outside the well that provide contacts to the substrate.

All diffusion areas are 80 μ long. The working collector has a voltage of 1.5 V when the emitter is zero. The magnetic field is chosen from the magnetic inductions of B=1 T along the emitter.

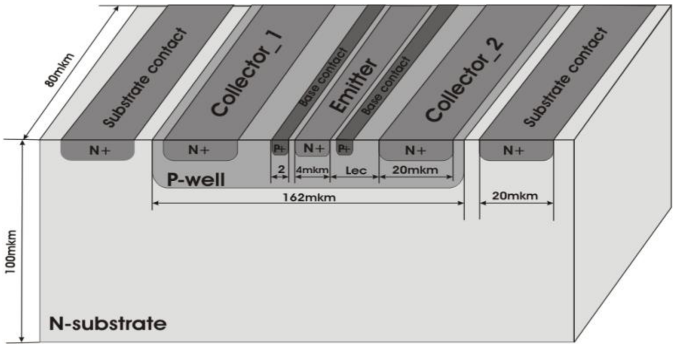

Fig. 12. The structure BMt with well is calculated.

4.2. Currents and their relative sensitivities in a BMT

The dependence of the currents in a BMT on the voltage between the contacts of the base and emitter Ube is shown in Fig. 13.

When changing the value of the displacement on the base via different injection levels, the correlation of the currents of the working collectors Ic1 and Ic2 are also changed when in a magnetic field.

When a small voltage is added, the left collector has a lower current than the right collector, but the addition of a greater voltage causes the current of the left collector to be greater than that of the right collector. Given the correlation of the currents of the collectors and the magnetosensitivity of the device, the formula $Sr=Ic1-Ic2/(Ic1+Ic2)B$ is defined such that it has negative values for low base currents but positive values for high base currents.

When small voltages displace the base current, the emitter (before Ube=0.75 V) dependencies of the currents Ie and Ib on the current displacements are exponential. The attitude of the emitter current to the base current, i.e., the direction of the injection emitter, is 800.

With a small base current, the resistance of the emitter junction is greater than that of the base resistance.

The current emitter has a substrate current of Is, but the collector currents are small. Therefore, nearly all electrons injected from the emitter move through the substrate, with only a small fraction making it to the working collector.

This split in the currents reflects the structure of the device. Electrons from the emitter pass through the substrate and through the diffusion well, over a total distance of 4 μ. The concentration of the admixture in the well decreases when it is removed from the substrate, so the concentration of holes decreases from a maximum at the surface until it is zero at the pn junction. Accordingly, the recombination velocity of the charge carriers due to the Shockley-Read-Hall mechanism has a maximum value near the emitter and falls near the pn junction of the well substrate.

The gradient of concentrations in the admixtures of the well and the difference potentials of the contacts at the junction create magnetic fields, pulling electrons and thereby forming electron drift currents in the well.

The electrons from the emitter have difficulty passing through the base contacts to the collectors along the surface diffusion well, where there is a high concentration of holes and a related high recombination speed. Therefore, the most likely path for electrons is through the working collectors into the well, near the pn junction of the well substrate.

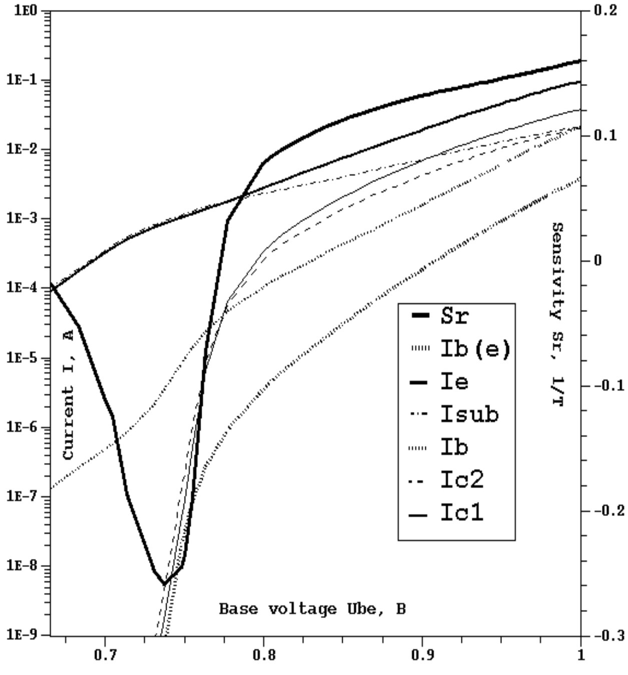

Fig. 13. Currents and sensitivity of a BMT with a well for different base voltages.

At a base-emitter voltage of more Ube=0.72 V, the current in a BMT begins to steepen, showing the exponential growth of the general base current and a high-level mode of injection. The growth of the current emitter is slow, but this signifies that the resistances of the passive and junction emitter bases are justified and that the resistance of the passive base limits the growth of the emitter current. The concentration of the electrons injected near the base contact increases until a lateral mode p-i-n diode appears. There is a double injection of electrons at the emitter in the base contact and holes at the base contact in the base. An ohmic base contact, implemented at the expense of the electron cloud, becomes an injection. Near the base contact, there are enlarged concentrations of both types of current carriers, and an intensive recombination of charge carriers occurs. To find the total base current, the known emitter injection is added to the base current of the holes that is required to maintain the electrical neutrality in the base and ensure an influx of holes to replace those holes that disappear due to recombination.

When the injections of the working collector currents increase in speed, more electrons move to the collectors, but the growth of the substrate current is slow. Given Ube=0.8 V, the collector currents are comparable to the base current and can change signs relatively easily. The attitude of the emitter current to the base current ceases to be constant, and the values of the base current tend toward those of the emitter current, with attitudes dropping to less 10.

Given a displacing voltage of 0.9 V, the currents of the working collectors increase enough to exceed the substrate current. Given a high level of injection, the concentration of the injected electrons is greater than the concentration of the holes available in the base, which accounts for doping and ensures the electroneutrality of the base, i.e., maintaining a constant injection of holes equal to the electron concentrations. At a high level of injection, the electrons are easily able to pass through the working collectors, the relative sensitivity is not limited by recombination, and sensitivity has a positive sign.

4.3. Mechanism of the negative sensitivity of a bipolar magnetotransistor

To determine the physical mechanism responsible for the observed negative sensitivity, the joint concentrations of charge carriers and recombination velocity at Ube=0.74 V on the contacts of the base and substrate, which is near the maximum negative relative sensitivity of the current, are studied.

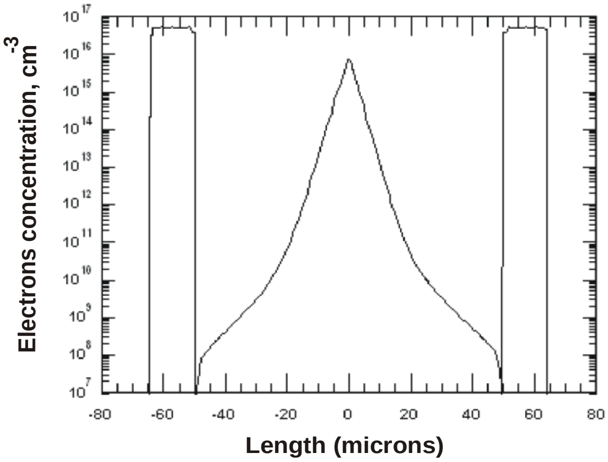

Fig. 14. Electron concentrations of a BMT at a depth 1.8 μ.

The charge carriers spread to all sides of the well after being injected by the emitter. The carrier concentration decreases as the measurements move away from the emitter due to the recombination of charge carriers in the base and on the surfaces of the substrate. Some of the carriers reach the working collectors, resulting in their extraction, but this reduces the concentration of carriers in the base. Some of the charge carriers leave the well in the substrate through the substrate and base contacts; some of the electron flow also leaves through the substrate contact, creating the substrate current.

Fig. 14 shows a diagram of the shared electron concentrations in the well at a depth of 1.8 μ. The electron concentrations on the axis of symmetry of the device form at more than 10^{19} cm^{-3} in both the well and the substrate near the well.

This result signifies how much the substrate is enriched by the injection of electrons in contrast to the concentration of the donor admixture (10^{15} cm^{-3}).

In the well, near the working collector, the electron concentration drops to concentrations of 10^7 cm^{-3}.

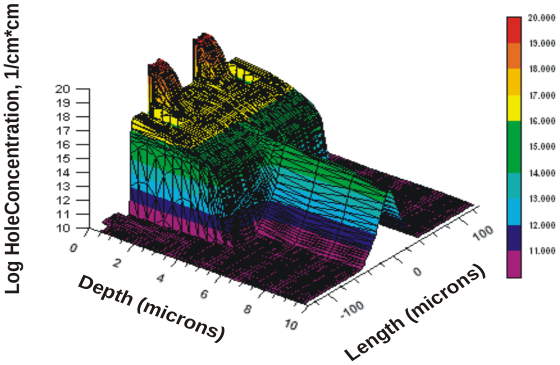

Fig. 15. Hole concentration of a BMT.

Fig. 15 is a volumetric diagram of the hole distribution in a BMT. The hole concentration is shown graphically and appears to account for the doping of the well with the acceptor admixture and for the holes that come out of the well with the electrons in the substrate, which ensure the neutrality of both the diffusion well and substrate. Therefore, an electron-hole plasma is developed and goes through the electron-hole recombination process.

The velocity of recombination of the charge carriers U (sm^{-3} s^{-1}) is defined through Shockley-Read-Hall statistics, using non-equilibrium concentrations of both electrons n and holes p, as well as the formula $U \sim (pn - n_i^2)$, where n_i is the concentration of the charge carriers in its own conductivity semiconductor.

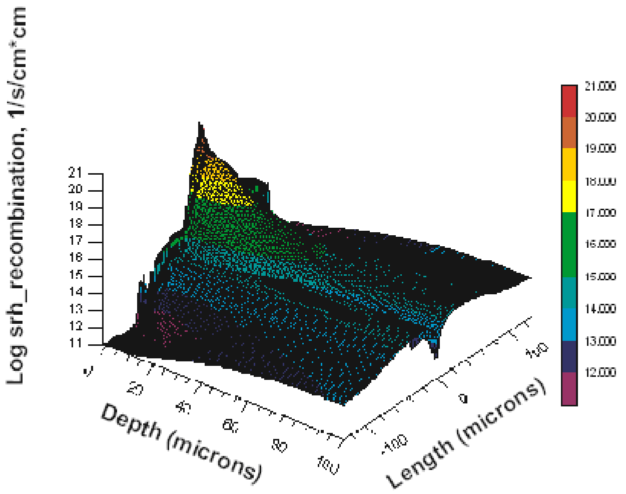

Fig.16. Shockley-Read-Hall recombination velocity for a BMT.

In Fig. 16, the total recombination velocity distribution derived from the Shockley-Read-Hall statistics for a BMT without a magnetic field is presented. A maximum recombination velocity of more than 10^{20} cm^{-3} s^{-1} occurs near the emitter, where higher concentrations of injected electrons and holes are present, in accordance with the high-level doping of the diffusion well with the admixture.

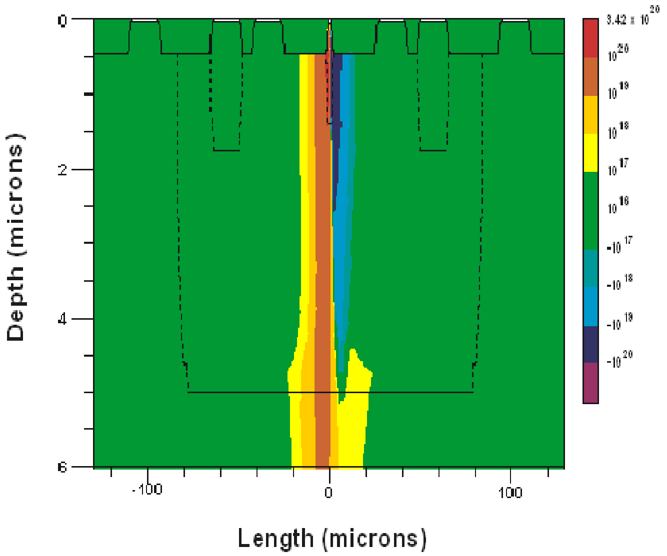

Fig. 17. The cross section residual Shockley-Read-Hall recombination velocity of a BMT in a magnetic field.

When moving away from the emitter in the well, the reduced electron and hole concentrations also showed reduction of their recombination velocities. The speeds of the recombinations of electrons and holes show two maxima. These maxima are caused by the electrons flowing along two paths from the emitter to the two contacts to the substrate and the holes flowing through the substrate between the two contacts to the base.

The speed of the recombination velocity in the substrate is on the order of 10^{16}-10^{17} sm^{-3} s^{-1}; near the working collector, this speed is less than 10^{12} sm^{-3} s^{-1}.

The spatial locations of the emitter and its contacts to the well are defined to ensure that recombination occurs and that the holes create a flow from the contacts to the well other than that seen along the structural center, which is also where the main stream of the electrons is. The flow of holes from the two contacts to the well creates two flows of holes from the two sides, in addition to a flow of electrons. All three flows run from the surface of the device, down through the well and into the substrate. Equally direct flows of electrons and holes forced by Lorenz power deviate along the sides. The flow of electrons under the chosen direction of the magnetic field deviates from the axis of symmetry to the left, but the flow of holes moves to the right. The leftward deflection of the electrons must cause an increase in the current of the left working collector and reduction in the current of the right working collector, which defines the positive sensitivity of a BMT.

However, in addition to the deflection of the flow of electrons, there is also a deflection of the flow of the holes. The flow of the holes moves away from the left contact of the well and is deflected to the right, moving toward the deflected flow of electrons, which increases the recombination velocity in the left part of the device. The flow of the holes moves away from the right contact to the well, and this rightward deflection disperses with the electrons flow; by definition, this creates a reduction of the recombination velocity in the right of the device. The absolute changes are small even in strong magnetic fields. The differences in the recombination velocities are shown in Fig. 17.

As seen from the drawing, to the left of the axis of symmetry, the recombination velocity increases considerably, but to the right, the velocity falls to near that of the well-substrate junction. The flow of electrons splits creates two flows through the different contacts to the substrate, which decreases the concentration of electrons of both flows and decreases their recombination velocity.

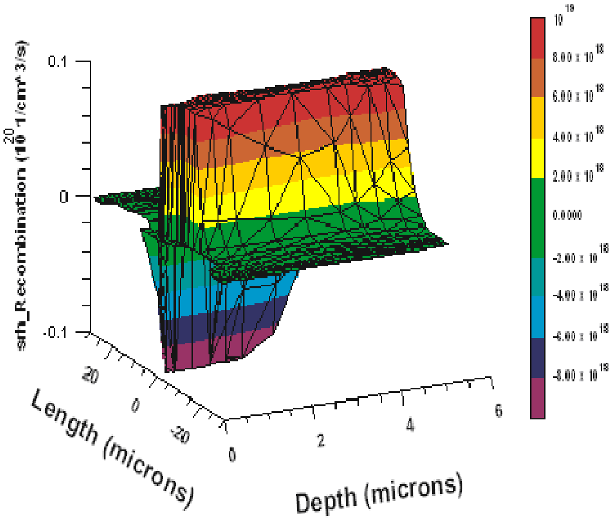

Fig. 18. The residual Shockley-Read-Hall recombination velocity for a BMT in a magnetic field.

The combined difference of the velocities and recombinations range from -10^{19} to 10^{19} sm^{-3} s^{-1} near the emitter, as shown in the volumetric diagram in Fig. 18. As shown in this figure, to the left of the axis of symmetry, the recombination velocity strongly increases, but to the right, it decreases.

The effect of the changing recombination velocity on the number of electrons entering the working collectors is seen in the different concentrations of electrons within a magnetic field versus in its absence.

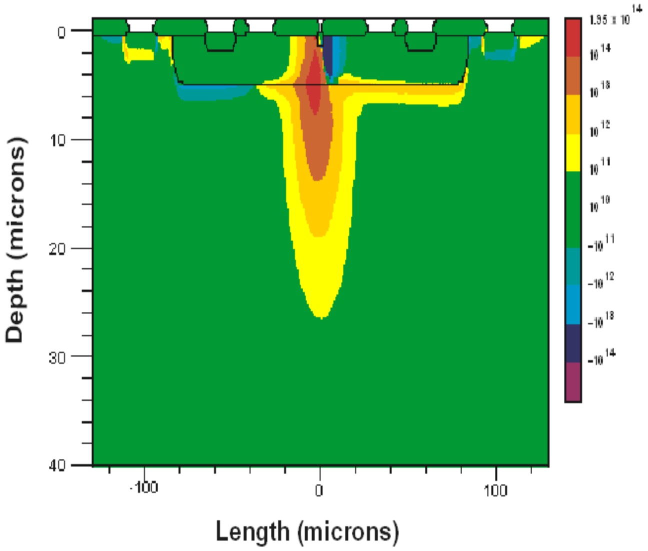

Fig. 19. Residual electrons concentrations for a BMT in a magnetic field.

The differences in the concentrations of electrons across the whole instrument (Fig. 19) are within the range of -10^{14} to 10^{14} sm^{-3} and show a profound change in the concentrations of electrons near the surfaces along the narrow section along the axis of symmetry. Left of the axis of symmetry, the concentration of electrons increases, but to the right, it decreases, showing the effect of the Lorenz power on the flows of electrons and holes. Away from the axis of symmetry, the concentration of electrons decreases due to the recombination in the high-injection areas of the well, decreasing more quickly to the left and slower to the right. Particularly large changes in the concentrations of electrons are found bordering the well-substrate junction. Their distribution shows that near the left collector, the concentration of electrons decreases, but near the right collector, the concentration of electrons increases. This defines the negative sensitivity phenomenon.

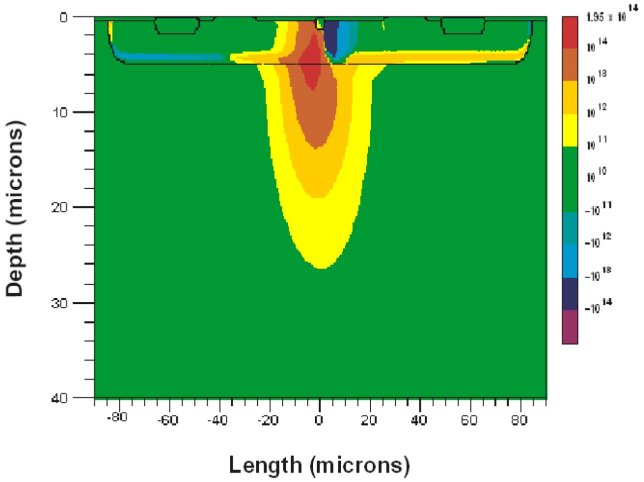

Fig. 20. Residual holes concentration BMT in magnetic field.

Fig. 20 shows that the differences in the concentrations of holes for the area near the emitter are within the range of -10^{13} to 10^{13} sm^{-3}. In the well near the emitter, the greatest reduction in the concentration of holes occurs along the narrow band right of the axis of symmetry. The concentration of holes increases to the left.

Observable changes in the concentrations of holes occur near the borders of the well-substrate junction. Left of the axis of symmetry and opposite the left collector in the substrate, a reduction in the concentration of holes is observed, but the opposite is true for the right collector in the weakly doped part of the well, where an increase in the concentration of holes is observed.

The origin of the negative sensitivity formed in the well of a dual collector lateral BMT may be due to its substrate when the recombination of the electrons and holes crosses the flows of the electron current from the emitter and the hole current from the base contacts. This effect is called the volumetric concentration-recombination mechanism, which occurs with a negative relative magnetosensitivity.

Recombination of charge carriers occurs within the semiconductor rather than on its surfaces.

This fact is important for reducing the dependency of the parameters of the BMT on the conditions at the surfaces of the device.

Using numerical device-technology modeling shows that the combined currents and relative sensitivity to the current of a dual collector lateral BMT form a diffusion well when the contacts to the substrate and the well are joined. This also depends on the level of charge carriers injected by the emitter.

The Shockley-Read-Hall recombination mechanism explains the negative sensitivity of a BMT.

5. SENSOR OF THE BMT WITH A BASE IN THE WELL

A substrate junction is incorporated into a BMT to insulate it from other elements of its integral circuit and well, but it does not protect the BMT. Instead, the substrate junction can change its mode to work as a third collector.

A study of the parameters of a transistor with a lateral bipolar structure dual collector n-p-n BMT is conducted, assuming a p diffusion base and an internal n diffusion well (BMTBW) on a p silicon substrate.

A cross section of the BMTBW structure is shown in Fig. 21. Variations of transistor topologies were used, and their local oxidation patterns were clearly different. These variations are defined by the following parameters: a clearance emitter-base Lbe, a collector Dc, a base contact width Db, and an emitter length He. The structure of a BMTBW is improved the length of the base is increased.

The process of the volumetric recombination of electrons and holes plays an important role in the function of the BMTBW. Lorenz power is seen in the influence of the magnetic field on the flows of electrons and holes, which causes their redistribution and the original sensitivity concentration-recombination mechanism.

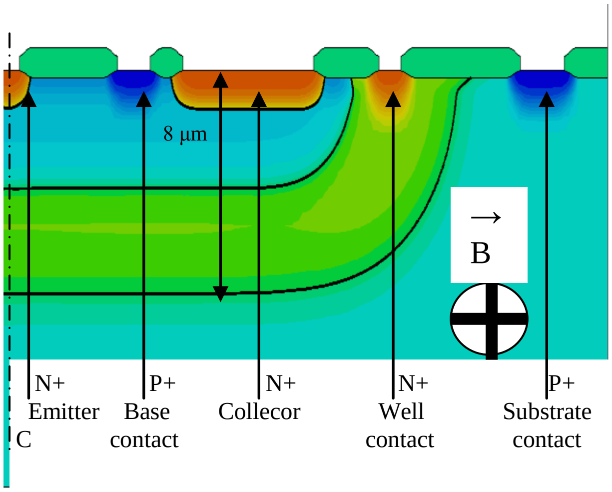

Fig. 21. Structure of a BMTBW.

When high-level injection occurs, a double injection also occurs, one of electrons from the emitter and the other of holes from the base contact. The hole current compensates for the charge of the injected electrons. This forms the electron-hole plasma in which recombination occurs. The plasma penetrates the base-well and well-substrate junctions. As such, the well and substrate generate an electron-hole plasma. The measurements of the BMTBW from the base and well contacts show equal potentials. The voltage on the emitter is a zero, but that measured on the collectors is 1.5 V. A 180 mT magnetic induction was used for the sensitivity measurement

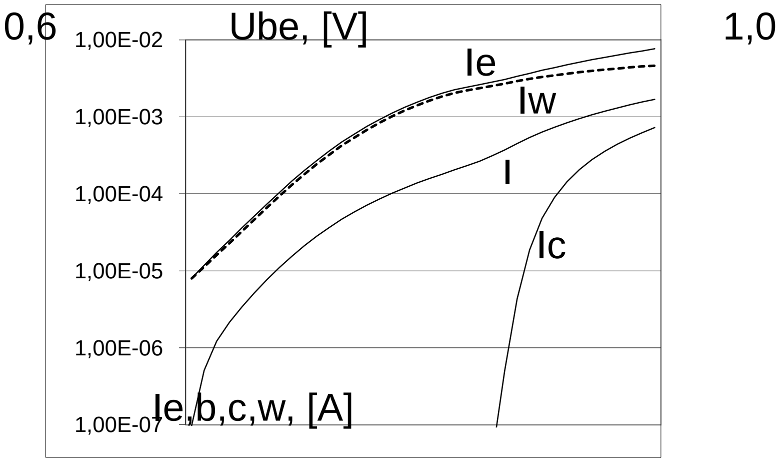

Fig. 22. Emitter, well, base and collector currents of the BMTBW as functions of the voltage of the displacing Ube (here, 0.6 to 1.0 V).

A study of the characteristics of the transistors has shown that when changing Ube from 0.5 to 1.0 V, the well and emitter currents are close to 0.9 V (Fig. 22). The electron current flows through the base of the well. A current of less than 0.1 μA flows through the measuring collector for voltages up to 0.775 V, which is the operating threshold.

A rapid growth of the collector current occurs above the operating threshold.

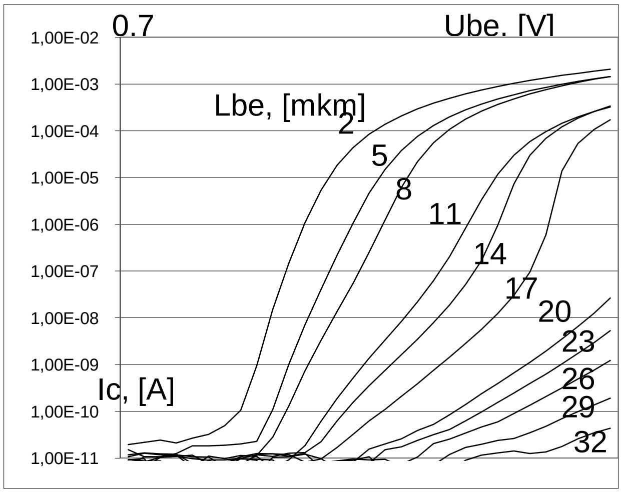

Fig. 23. Dependencies of the characteristics of a BMTBW on the distance between the emitter and base contacts.

The base doping level defines a characteristic of the BMTBW.

The dependency of a BMTBW on the distance between the emitter and base contact is shown in Fig. 23.

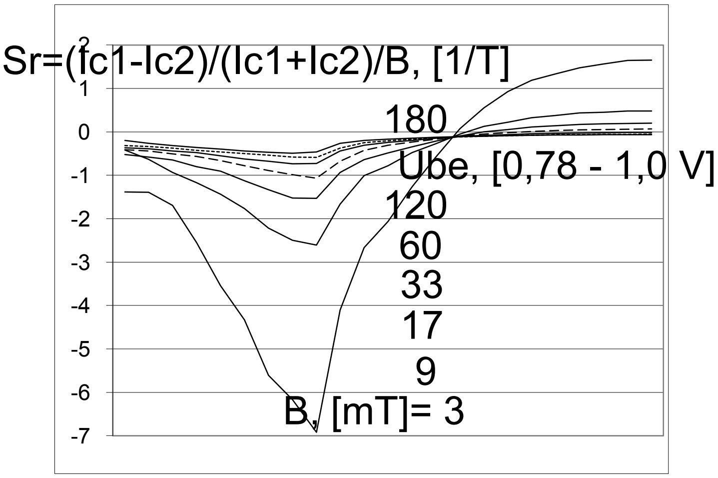

Fig. 24. Dependency of relative sensitivity of a BMTBW on the Ube current for several values of magnetic induction.

Fig. 24 shows the dependency of the relative sensitivity of a BMTBW on the current from the emitter for several values of magnetic induction. The sensitivity of the BMTBW increases when the value of the induced magnetic field is reduced.

This sensitivity changes sign when Ube=0.91 V.

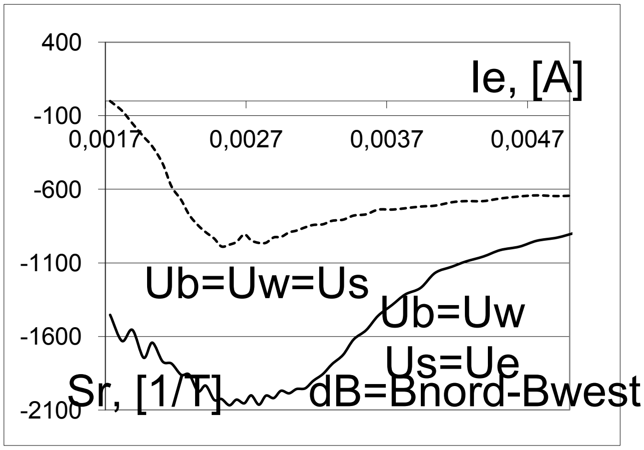

Fig. 25. Sensitivity of the current to the magnetic field of the earth.

In Fig. 25, the values of the relative sensitivity to the magnetic field of the earth are shown. These sensitivity was calculated using the changes in the currents at collectors Ic1n and Ic2n when the long sides of the emitter are oriented north and west for Ic1w and Ic2w, respectively, if the value of the magnetic induction from the magnetic field of the earth is 30 µT and Sr=(Ic1n-Ic2n)/(Ic1w+Ic2w) 0.00003 [1/T]. Measurements were conduct in two modes: 1) with the potential of the substrate set to the potential of the base and well and 2) with the potential of the substrate set to the zero-potential emitter.

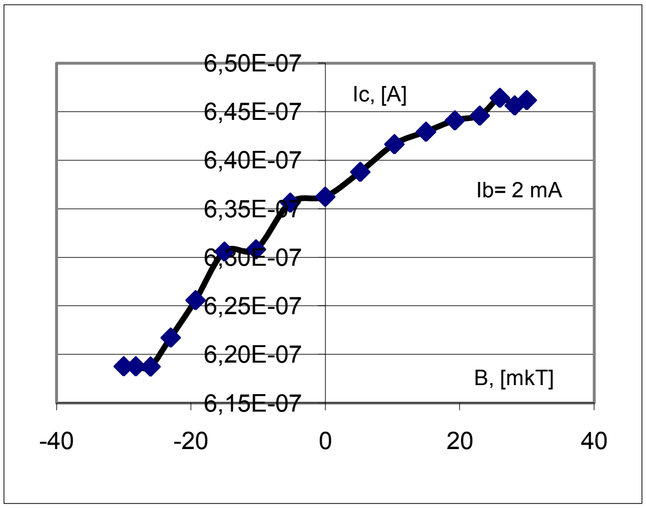

Fig. 26. Collector current of a BMTBW as function of the longitudinal component of the magnetic field of earth.

The maximum value of the relative sensitivity of the current, on the order of 2070 1/T, is observed when the substrate is connected with the emitter. The high sensitivity of the BMTBW is explained by this, providing a new method of increasing sensitivity.

The Lorenz force acting upon a sufficiently strong current emitter forms a current in the measuring collectors comparable to the initial value.

The maximum sensitivity is observed when the collector current is 2 nA and the corresponding emitter current is 2.5 mA. The emitter current was therefore 1,250,000 times the collector current.

Fig. 26 presents the dependency of the collector current of a BMTBW as a function of the longitudinal component of the magnetic field of the earth, given the rotation of the device.

The mathematical model showing the influence of the magnetic field on the combined currents is complex (Fig. 27, 28).

The electron current flow (Fig. 27) from the emitter splits into two, forming one current that runs through the measuring collectors and another, through the well contacts.

The hole current in Fig. 28 runs from the base contacts beside the emitter and then with the flow of the electrons injected in the well into the substrate. Magnetic field acts on all currents of holes and of electrons. This magnetic influence changes the positions of the current lines, their efficient lengths, the charge carrier distributions and the velocity of recombination in different areas of the device.

These results far exceed the data from previous publications and monographs on magnetotransistors [15]. This characterization of the BMTBW suggests that additional sensors on the base may be of broad use for micromagnetoelectronic devices [16-22].

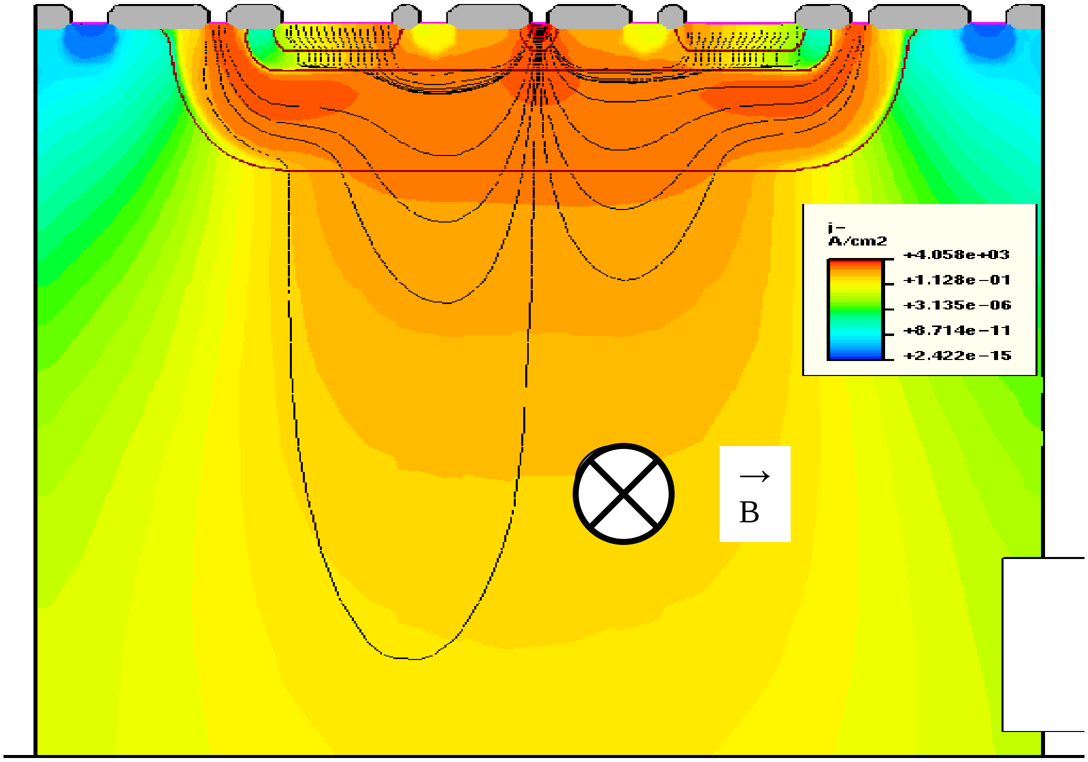

Fig. 27. Electron current flows and collector current lines of a BMTBW.

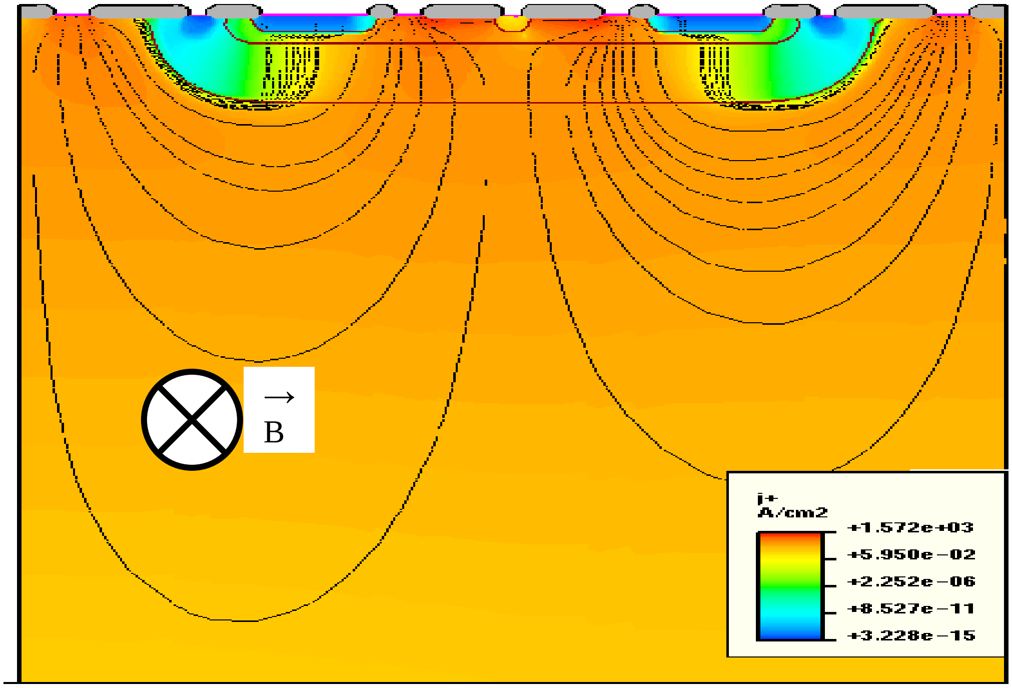

Fig. 28. Hole current flows and current lines of the base and substrate contacts of a BMTBW.

CONCLUSIONS

A lateral magnetotransistor has an emitter, two collectors, and a contact to the base, which is located on the surface of the substrate. Increasing the distance between the emitter and collectors, increasing the alloy substrate (when the base acts as a diffusive well) and connecting an additional contact from the substrate to the base reduce the transfer efficiency of the injected charge carriers to the collectors. This causes an increase in the currents of the base and emitter, producing specific values at the current collectors. The emitter current is significantly increased, , which increases the magnetosensitivity. By definition, the sensitivity of a magnetotransistor is determined by the influence of the magnetic field on the emitter current. Measuring this sensitivity is related to the changes in the currents of the collectors in a magnetic field, such that the influence of the magnetic field is recorded on the current collectors. An accurate evaluation of the mechanisms of the magnetotransistor sensitivity is possible only when the emitter and collector currents are considered separately.

A magnetotransistor with a diffusive well has a threshold when it is connected to a database and has contacts to the substrate. With a small base current, the injected charge carriers follow the shortest route from the emitter to the substrate rather than through the collectors. However, with a larger current, the well and collector currents appear.

A very important factor related to this process is the increased sensitivity of the BMT when the well and substrate contacts are connected.

Recombination within a dual collector lateral BMT is the reason for the detected negative sensitivity, which is formed in the well.

Specifically, this finding describes the recombination of electrons and holes in the cross flows of the charge carriers, i.e., the flow of electrons from the emitter and the flow of holes from the base contacts. This effect can be called the volumetric concentration-recombination mechanism, which leads to a negative relative magnetosensitivity.

The above findings confirm the distributions of electrons and holes that were obtained through a device-technological simulation.

When the substrate is connected to the emitter, the maximum observed value of the relative sensitivity of a current is 2070 1/T.

The high sensitivity of the BMTBW is explained using a new principle of increasing sensitivity. Furthermore, the Lorenz force is shown to act upon sufficiently strong current emitters and to create a current across the collectors comparable to that of a weak initial collector current.

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