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High Quality InSb Microcrystal Hall Sensor Doped with Te or Bi

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Abstract: InSb microcrystal doped with Cr, Al or Sn, which were radiation-resistant and were applied as magnetic microsensors in Satellites. The magnetic field sensitivity, γ , as a function of temperature was determined for both Bi and Te doped InSb microcrystals. Tellurium doping of InSb microcrystals at 3 x10 ^{17} cm^{-3} leads to increase of the magnetic field sensitivity, γ , to ≈ 1.1 V/AT, but it decreases to ≈ 0.45 V/AT at 450K. On the other hand doping with Bi at 1 x 10^{17} cm^{-3} gives γ ≈ 1 V/AT. The charge carriers mobility of the investigated microcrystals varies from about 2.11m^2/V.s to 3.4 m^2/V.s, for Te doped samples and from 3.2 m^2/V.s to 4.3 m^2/V.s for Bi doped samples at room temperature. The electrical resistivity variation with temperature was also studied.

Keywords: InSb, Hall magnetic sensor, Te, Bi, Sensitivity, Magnetoresistance, Chemical Transport Reaction (CTR).

1. INTRODUCTION

This study is a continuation of a previous work on InSb microcrystals [1, 2]. High-temperature sensors made from InSb layer on GaAs substrates have been studied [3]. The maximum working temperature was 573K.

InSb is a binary III-V narrow band gap compound semiconductor widely used in infrared (IR) radiation detectors [4]. It is also known that it possesses high magnetoresistance effect [5] and high electron mobility [6]. InSb can also be grown by evaporation, epitaxy, and by electrochemical methods [7]. The large dielectric constant (ε=16.8) and acceptable mechanical properties of the electrodeposited InSb makes it an attractive material for photonic crystal applications

Indium antimonite microcrystals have been already applied in magnetic field sensors in Satellites for television. These microcrystals were radiation-resistant [8]. A good knowledge of incorporation of dopants is an important problem in semiconductor physics, since most of the device applications of semiconductors requires doping of the starting material with donor or acceptor impurities [9].

Incorporation of deep impurity levels favors stabilization of the electrophysical semiconducting properties [8]. It must be taken in consideration that magnetic field devices, may be fabricated for devices, which are subjected to high temperature such as magnetic field sensors in Satellites. Therefore high-temperature sensors made from InSb layer on GaAs substrates have been studied [3]. The maximum working temperature was 573K.

In the present work high quality magnetic sensors made from InSb microcrystals, doped with either Te or Bi with different doping levels was investigated.

2. EXPERIMENTAL

2.1. Fabrication of InSb Microcrystals

InSb microcrystals investigated in the present paper were grown from the vapor phase by the method of chemical transport reactions (CTR) in a closed ampoule-like reactor in an iodine system, as described in [1]. This method permits us to get microcrystals shaped as whiskers and separate microplates. Mathematical modelling was used to determine the main kinetic crystallization parameters of these microcrystals. We have determined the dependence between technological modes, growth rate and geometry, which allows crystals of specified dimensions to be obtained [10]. Doping microcrystals with Te or Bi donor impurities allows the carrier concentration in crystals to vary from 1x10^{17} up to 3x10^{17} cm^{-3} for Te doped samples and from 1x10^{17} up to 5x10^{17}cm^{-3} for Bi doped samples, which enables one to fabricate micro sensors with specified characteristics that can be varied in a wide range. Figure (**1**) shows the scheme of the holder with tentative sample without mounting leads, Table (**1**) represents system of numbering and identification of sample contacts, and typical dimensions and parameters of the investigated samples are summarized in Table (**2**).

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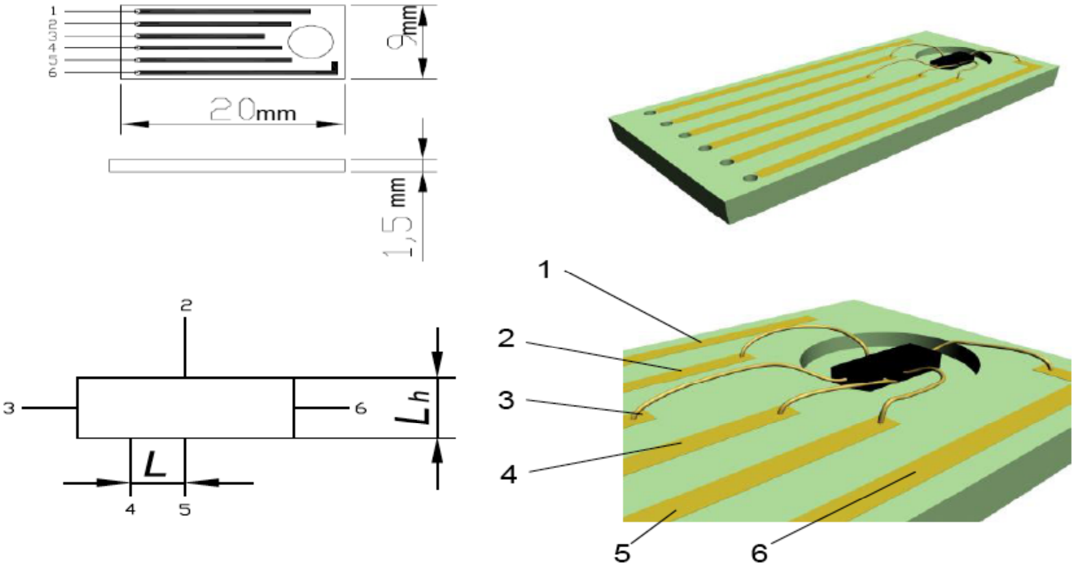

Figure 1: Scheme of the holder with tentative sample without mounting leads.

Table 1: System of Numbering and Identification of Sample Contacts

Contact Number	Contact Identification	Description
1	-	-
2	UH+	Hall-contact "+"
3	I-	Current contact "-"
4	Uσ	Potentiometer contact
5	UH-	Hall-contact "-"
6	I+	Current contact "+"

2.2. Characterization Techniques

The Hall voltage and magneto resistance measuring experiment contains an electro-magnet (NEWPORT instruments-Type A) with a current source power supply (Ealing Beck Ltd. Germany). The power supply is controlled by a digital current controller (Lake Shore, 321 Auto tuning). The sample was placed in a copper holder of a metallic cryostat (Cryo. Industries, USA), which was suitable for the magnetic measurements.

The Hall voltage was measured from potential difference (V_H) between two points that were normal to the sample current direction. The sensitivity, γ, is calculated as follows [3]:

$$\gamma = V_h / IB \qquad (1)$$

Where I is the applied current, and B is the applied magnetic field.

The resistance (R) was measured between two points that were parallel to the sample current direction. The relative magneto resistance was calculated as follows:

$$\frac{\Delta\rho}{\rho_o} = \frac{\rho_B - \rho_o}{\rho_o} = \frac{R_B - R_o}{R_o} \qquad (2)$$

Where ρ is the resistivity, R is the sample resistance. The subscripts B and 0 denote the measurements under magnetic field effect and at zero magnetic field respectively.

The current across the sample was measured by a milliammeter, while the voltage was measured by a Kiethley 617 electrometer. All measurements were done under constant applied current (100mA), magnetic field 0.573T and different temperatures.

3. RESULTS AND DISCUSSIONS

If InSb is doped with Bi, which is an isovalent element of group "V", it either replaces Sb or takes an interstitial position. On the other hand, if InSb is doped with Te of group "VI", it leaves one electron and either substitutes Sb or takes an interstitial position. The atomic radius of Sb, Te and Bi are 138, 135 and 146 pm respectively. Therefore when Te, of less diameter, replaces Sb, lattice shrinkage occurs leading to some defects, while Bi, of larger diameter, if it enters the lattice it makes dilation leading to defect also.

Table 2: Typical Dimensions and Parameters of Investigated Samples

Sample number	Material	Dopant	Carrier Concentration, cm-3	Dimensions	
				Width, µm	Surface Area, µm2
1	InSb	Te	2.1017	92	6176
2	InSb	Te	3.1017	70	2928
3	InSb	Te	1.1017	80	4224
4	InSb	Bi	3.1017	64	3816
5	InSb	Bi	5.1017	144	2112
6	InSb	Bi	1.1017	88	6560

Figure **2** shows the magnetic field sensitivity dependence upon temperature for InSb microcrystals doped with either tellurium or bismuth with three different doping concentrations for each of them. Concerning doping with Te, it is observed that the magnetic field sensitivity, γ, is stable against heating up to about 300, 325 and 225K, for the doping level 1x10^{17} cm^{-3} , 2x10^{17} cm^{-3} and 3x10^{17} cm^{-3} respectively. The value of γ increases from about 0.62 to 1.1 V/AT with increase of doping level. As heating continues up to 450K the value of γ decreases to 0.25 - 0.51 V/AT as doping level increases.

Concerning doping with bismuth, an opposite behavior is observed, since the value of γ decreases from about 1.0 to 0.39 V/AT as the Bi doping level increases from 1x10^{17} cm^{-3} to 3x10^{17} cm^{-3}. It is interesting that InSb microcrystals doped with Bi at 3x10^{17} cm^{-3} doping level shows constant sensitivity with heating up to 450K. The other two Bi-doped InSb microcrystals show a stable sensitivity up to about 250-300K.

Comparing the sensitivity of InSb doped with Te or Bi, it is observed that the doping with Te gives the comparatively highest sensitivity, γ, at temperatures illustrated before then it decreases to ≈0.51 V/AT at 450K.

From the results of magnetic field sensitivity of doped InSb microcrystals, it is advisable to use Bi-doped InSb samples with concentration of 3x10^{17}cm^{-3} to obtain a stable sensitivity, γ, in the whole studied temperature range.

The highest magnetic field sensitivity of Te-doped InSb microcrystals with concentration of 3x10^{17}cm^{-3} corresponds to the highest magnetic field sensitivity

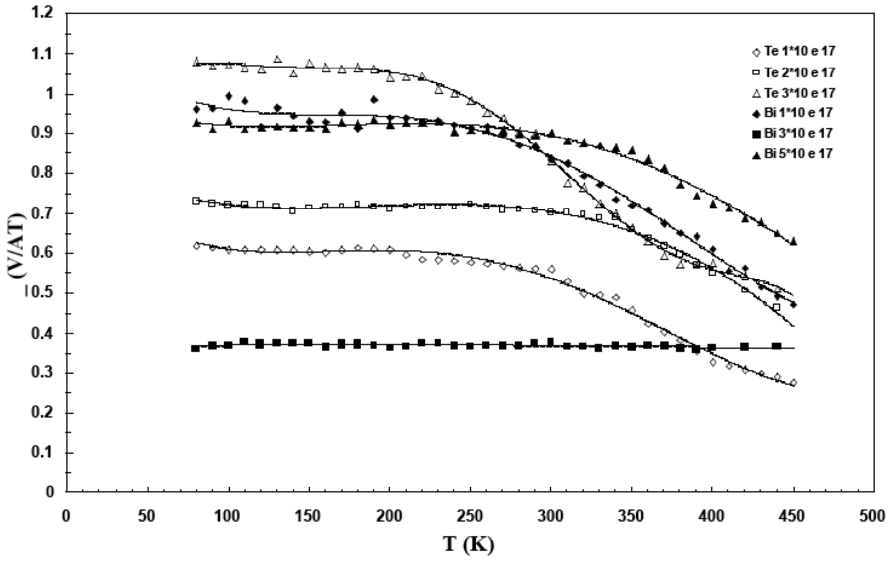

Figure 2: Magnetic field sensitivity dependence upon temperature for InSb microcrystals doped with either tellurium or bismuth with three different doping concentrations for each of them.

(1.1V/AT), but it decrease with heating above about 225K.

The relationship between the electrical resistivity, ρ, and the temperature is represented in Figure **3**. The InSb microcrystals with definite orientation during the preparation process generally show low resistivity ranging from $4x10^{-4}$-$1.4x10^{-3}$ Ωm at room temperature. The electrical resistivity starts to decrease by heating, showing a normal semiconducting behavior. Concerning InSb microcrystals doped with Te, it appears that the electrical resistivity remains unchanged by heating from 80-200K, 80-260K and 80-325K for the doping level $1x10^{17}$ cm^{-3}, $2x10^{17}$ cm^{-3} and $3x10^{17}$ cm^{-3} respectively, and then tends to decrease by further heating to 450K. Besides as the doping level increases from $1x10^{17}$ - $3x10^{17}$ cm^{-3} the electrical resistivity decreases from about $1.5x10^{-4}$ to $9x10^{-4}$ Ωm in the stable range resistivity.

If the results of magnetic field sensitivity, γ, are correlated with the electrical resistivity for Te-doped InSb microcrystals, it is shown that the increase of Te doping level leads to an increase of γ and decrease of ρ due to the creation of some defect in lattice. Besides the Te doping concentration $3x10^{17}$ cm^{-3} is the most suitable one to give the comparatively highest γ value, which is needed for the magnetic sensor application.

For Bi-doped InSb microcrystals the same behavior of resistivity is observed. The Bi-doped InSb microcrystals with doping concentration $1x10^{17}$ cm^{-3}

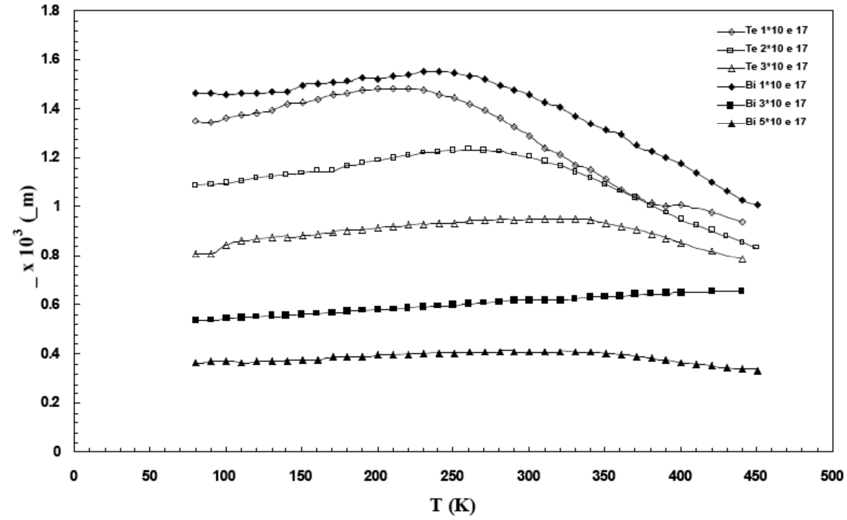

Figure 3: Relationship between the electrical resistivity and the temperature of InSb microcrystals doped with either tellurium or bismuth with three different doping concentrations for each of them.

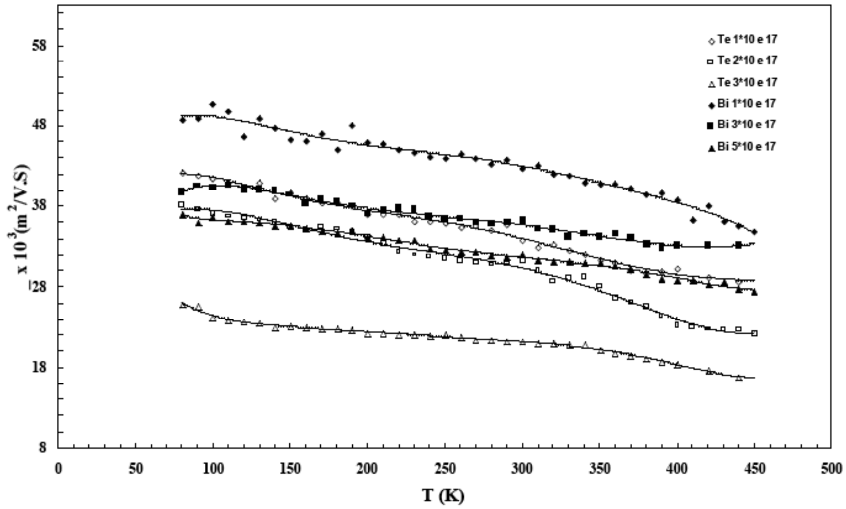

Figure 4: Dependence of charge carriers mobility upon temperature in the range 100 - 450 K for both Te doped and Bi doped InSb microcrystals.

gives the highest, γ, value for this group of samples, which is desired for application of sensing. This also confirms the presence of defects in InSb lattice by introducing Bi in it.

From the Figure (**2**), it appears that the γ value is comparable with those given in [3] for InSb layers deposited on GaAs wafers. It is of worth mentioning that the preparation of InSb microcrystals is more economic since GaAs wafers as a substrate is not needed. The doping level and the crystalline orientation of InSb microcrystals are controllable during preparation by chemical reactive method.

The charge carriers mobility of doped InSb microcrystals ranges from 21160 m^2/V.s to 33934 m^2/V.s, for Te doped samples and from 32042 m^2/V.s to 42712 m^2/V.s for Bi doped samples at room temperature. These values of mobility are suitable for application as Hall effect magnetic field sensors. *e.g.* for Satellites.

Figure **4** shows the dependence of charge carriers mobility upon temperature in the range 100 - 450 K for both Te doped and Bi doped InSb microcrystals. Concerning Te-doped InSb microcrystals the mobility decreases as the doping level increases from $1x10^{17}$ - $3x10^{17}$ cm^{-3}. This means again that Te-doping level $1x10^{17}$ cm^{-3} is sufficient to yield high mobility samples. Such behavior is also observed for Bi-doped microcrystals.

For both Te and Bi-doped InSb microcrystals, the mobility slightly decreases with heating. This is interpreted to be due to phonon scattering, which is a characteristic behavior of single crystalline samples. The highest mobility corresponds to Bi-doped samples with doping concentration $1x10^{17}cm^{-3}$ followed by Te-doped samples with doping level $1x10^{17}$ cm^{-3}. This indicates that slight doping is needed to minimize the defects in InSb microcrystal.

The magnetoresistance, MR, of both Te-doped and Bi-doped microcrystals were studied as a function of temperature as illustrated in Figure **5**. In general, MR% for all the samples is stable against heating for the whole temperature.

The comparatively highest MR% corresponds to InSb microcrystal slightly doped with Bi ($1x10^{17}cm^{-3}$) which posses the comparatively highest charge carriers mobility also. Despite Te doped InSb sample with concentration $3x10^{17}cm^{-3}$ shows comparatively lowest mobility (≈$1.2x10^4$ m^2/Vs) it shows the highest MR%, concerning doping with Te.

If the present results are compared with those reported in [3], the present results show stable and regular values of MR% if compared with those for InSb deposited on GaAs substrates, which shows scattered values of MR%. This confirms the applicability of doped InSb microcrystals as magnetic field sensors by using either Te or Bi as a dopant. The highest value of MR corresponds to Bi-doped InSb microcrystals with doping level $1x10^{17}$ cm^{-3}, followed by Te doped InSb microcrystals with doping level $3x10^{17}$ cm^{-3}.

4. CONCLUSION

Doping microcrystals with Te or Bi donor impurities allows the carrier concentration in crystals to vary from $1x10^{17}$ up to $5x10^{17}cm^{-3}$. The effect of InSb microcrystal doping with different levels of Te or Bi on magnetic field sensitivity, resistivity, mobility and magneto resistance

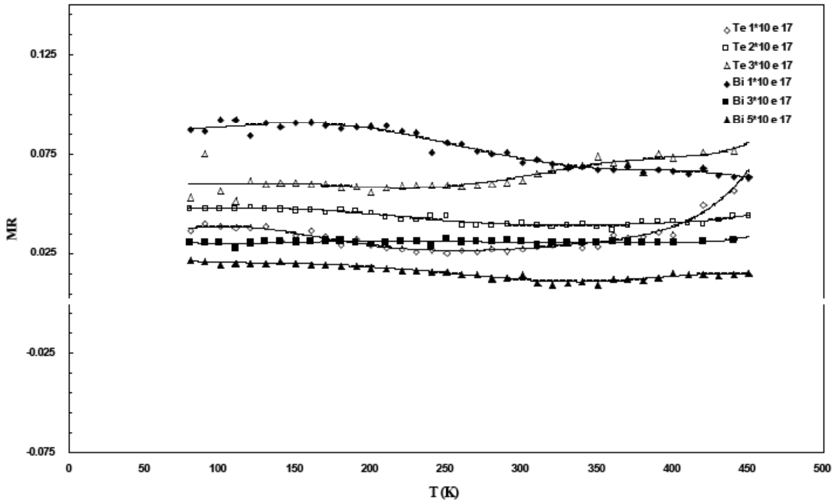

Figure 5: Magnetoresistance, MR, of both Te and Bi-doped microcrystals as a function of temperature.

was studied at 0.573T magnetic field, 100mA current and different temperatures. The most suitable for obtaining InSb microcrystal magnetic sensor with comparatively stable MR and stable sensitivity with temperature is to use Bi with dopant concentration $3x10^{17}cm^{-3}$. We expect that its stability with temperature will be stable with higher temperature which may be to about 600-700K or higher. For this reason sample with such level of doping can be used as a high temperature Hall sensor. For Te doped InSb microcrystal, stable sensitivity with temperature (80-350K) is obtained with using dopant concentration $2x10^{17}cm^{-3}$. So, this concentration is the most suitable for obtaining InSb microcrystal magnetic sensor with comparatively stable sensitivity with temperature in range from 80 to 350K.

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