# HIGH MAGNETORESISTANCE IN INHOMOGENEOUS BISMUTH MICROWIRES

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## Introduction

The present paper describes investigation of the dependence of magnetoresistance (MR) of microwires made of semimetal or semiconductor materials with high electric mobility doped with impurities introduced in the form of deposits at solidification.

Till present it has been assumed that microscopic inhomogeneity in semimetals or semiconductors leads to a decrease of mobilities due to additional dispersion of charge carriers on impurities. Wolfe et al. [1] have shown that impurities in the material with high mobility lead to an increase of mobilities due to geometric effect. In our case it is shown that presence of magnetic impurities in bismuth semimetal characterized by high mobility leads to an increase of magnetoresistance. This increase is very important for the technology of magnetic field converters and especially for application of high velocities of record of a magnetic head with a high capability of magnetic record.

## Magnetoresistance of Bi microwires with metal inclusions

The simplest effect of MR is the normal effect shown in all materials and alloys due to deviation of the current carrier trajectory in the magnetic field. Normal MR depends on squared magnetic field and, therefore, it is very low in simple metals, e.g., Cu and Au.

However, at favorable combinations of electron properties, e.g., in Bi, the MR effect may be very strong [2]. The most important MR value is $\omega_c\tau$, where $\omega_c = eH/m^*c$ is the cyclotron frequency, $\tau$ is the current carrier relaxation time, and $m^*$ is the effective mass of the carriers. The carrier relaxation time $\tau$ relates to the mean free path of the carriers $\lambda = v_F\tau$ and conductivity $\sigma = ne^2\tau/m$, where $v_F$ is the Fermi velocity of carriers and n is their concentration. It should be noted that $\omega_c\tau = H\sigma/nec$, where $\omega_c\tau$ means the deviation angle in radians in the range of the relaxation time $\tau$ for the time of the carrier spiral movement. For the classical MR, $\omega_c\tau$ must be lower than 1.

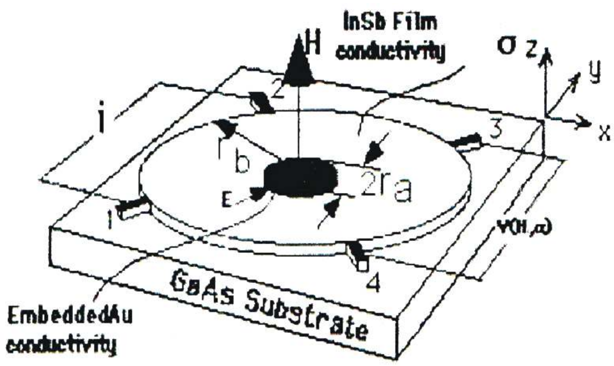



Fig. 1. Sensor in the form of a Carbino disk.

Extraordinary magnetoresistances have been found in Carbino disks. In this geometrical form, if instead of an empty Carbino disk a metal of high conductivity is introduced, e.g., Au, the magnetoresistance grows up to $10^6$% (Fig. 1) in the magnetic field of 5T [3].

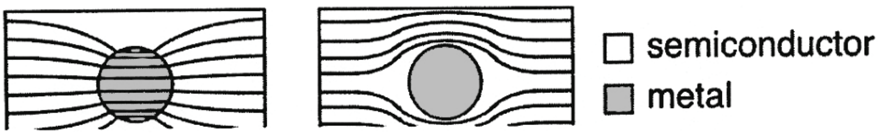
Figure 1 shows a Carbino disk with a radius of $2r_b$ in the form of a film with four contacts: two for the electric current and two for registration of the signal V. In the middle of the Carbino disk a film of Au with the radius $r_a$ is introduced. In this construction the magnetoresistance increases up to 200% in a magnetic field of 1T at room temperature.

In our case the problem is solved by obtaining of microwires in glass isolation in the process of drawing from materials with high mobility (Bi) with magnetic impurities (Fe).

In order to introduce impurities in the form of clusters (inhomogeneities) we select base materials and impurities so that at solidification an impurity will deposit on a chemically neutral base material. The most suitable base material of microwire is bismuth semimetal being a material with high mobility and, therefore, with high magnetoresistance [4].

As a material for impurities, according to structures of the state diagrams of binary alloys [5], the following neutral materials were tested at the temperature of solidification with respect to Bi base material: Cd, Co, Cr, Cu, Fe, Ga, and Al.

Physical principles of metal impurities in bismuth semimetal consist in the following. In the magnetic field absence in the base material (Bi) electrons of conductivity move linearly under the electric field action. When an inhomogeneity is introduced the electric current lines deviate from the linear movement as it is shown in Fig. 2, and the electric resistance in the zero magnetic field may decrease if the electric resistance of the impurities is less than that of the base material.




a) b)

Fig. 2. Illustration of the electric current path in the samples: in the magnetic field absence (a) and in the magnetic field presence (b).

If we introduce a converter in the magnetic field, the angle of deviation of the electron diverges in the opposite side and, in dependence on the field value, may approach 90°; in this case the electric current density **J** may be even perpendicular to the electric field **E**, this leading to a sharp increase of the magnetoresistance.

In dependence on number of the impurities it is possible to control the magnetoresistance value in the selected converter.

The basic parameter, which determines properties of the magnetoresistive material used in converters of magnetic field into electric signal, is the relative ratio of the magnetoresistance $\Delta\rho/\rho_0$ determined by the electric and magnetic characteristics of the material by the expression

$$\Delta\rho/\rho_0 = ( \rho (H) - \rho_0 )/\rho_0, \qquad (1)$$

where $\rho_0$ is the microwire resistivity in zero magnetic field; $\rho$ (H) is the material resistance in the magnetic field H; $\Delta \rho/\rho_0$ is the relative magnetoresistance; H is the magnetic field intensity.

One can see from expression (1) that maximal values for $\rho(H)$ and minimal values for $\rho_0$ are necessary for obtaining of high values of the magnetoresistance. On the other hand, in the classical magnetic fields the resistance in the magnetic field is equal to [6]

$$\rho (H) = \rho_0 ( 1 + A \mu^2 H^2). \qquad (2)$$

From expressions (1) and (2) we obtain

$$\Delta\rho/\rho_0 = A \mu^2 H^2, \qquad (3)$$

where A is the constant which does not depend on value of the magnetic field intensity H, $\mu$ is the mobility of current carriers.

It is known that in the quasi-classical approximation it is possible that the electron of conductivity between two acts of dispersion, correspondingly, on phonons or on defects moves linearly. In the magnetic field under the Lorenz force action the electron trajectory deviates. The radius of this trajectory curve is determined by the cyclotron radius (Larmor). The deviation of the trajectory of the conductivity electron leads to variation of the electric resistance. In weak magnetic fields (classical) the resistance in the magnetic field is equal to (2). One can see from formulae (2) and (3) that as value of the magnetic field intensity H increases the magnetoresistance grows proportional to it.

Numerous experiments have shown that the most suitable material for impurities in the base element of bismuth is iron (Fe). Figure 3 presents a metallographic sample of the transverse cross-section of Bi microwire with inclusions of Fe.

Figure 4 presents the results of the magnetoresistance measurements carried out for samples of pure Bi (curve B) and bismuth doped with iron (1–3 at %) (curve C) in dependence on magnetic field intensity H up to 0.8T at the temperature of liquid nitrogen (77.4 K).

Fig. 3. Metallographic sample of the transverse cross-section of Bi microwire with Fe inclusions.

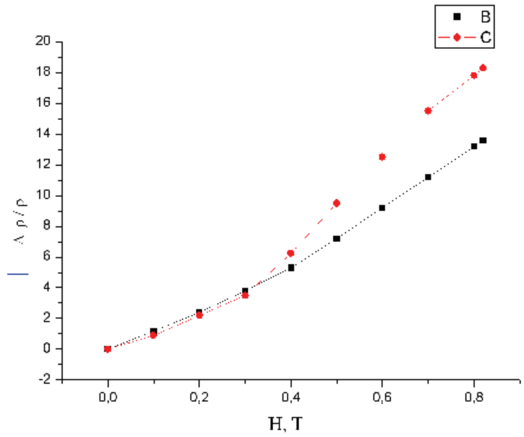



Fig. 4. Magnetoresistance dependence $\Delta \rho/\rho_0$ on magnetic field intensity value at the liquid nitrogen temperature: (B) – Bi; (C) – Bi + Fe.

As one can see from Fig. 4, the magnetoresistance in microwires of bismuth with iron impurities increases from 1358% up to 1814%.

## Conclusions

It is possible to increase the magnetoresistance value in bismuth microwires by virtue of neutral impurities which are deposited in the form of clusters (inhomogeneities) at room temperature.

## References

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