Investigations into the Magnetoresistive Effect of Semiconducting Diamond Films

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ABSTRACT: The magnetoresistive effect in both homoepitaxial and heteroepitaxial semiconducting diamond thin films was investigated at different temperatures and magnetic field strengths. The films were grown by microwave plasma chemical vapor deposition (MPCVD) and in situ boron doping was performed by cold ion implantation and rapid thermal annealing. Diamond based magnetoresistive devices were patterned by etching the boron-doped diamond film layers on the undoped diamond using an oxygen-plasma in a reactive ion etching chamber at 200 W and 38 mtorr. There are two kinds of device structures, i.e., strip and Corbino disk. The experimental results showed that the changes in the film resistance strongly depended on the boron dopant concentration, temperature, magnetic field strength and geometry of the samples. The magnetoresistive effect was degraded with an increase of boron concentration and temperature. Experimental evidence revealed that the effect in disk structures was greater than in the strip type samples. Variation in the resistance of homoepitaxial diamond films was also greater than that of heteroepitaxial diamond films. The resistance of homoepitaxial diamond films with the disk structure was increased by a factor of 2.1 at room temperature under a magnetic field of 5 T, but only by 0.85 for heteroepitaxial diamond films. The mechanism of magnetoresistive effect in the diamond films was also studied in detail based on F-S theory, taking into account lattice vibration scattering and impurities. A relationship between magnetoresistance and film thickness and magnetic field has been developed. The theoretical analysis was in good agreement with the experimental results.

KEY WORDS: magnetoresistive, diamond films, form effect, conductivity.

INTRODUCTION

THE OUTSTANDING PHYSICAL, chemical, electronic and optical properties of diamond films hold great promise for the realization of a wide range of applica-

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tions particularly for electronic devices [1–5]. However, compared to fundamental research and developments in processing technology, progress in the application of diamond films in the electronic industry has still been slow so far. This is mainly because polycrystalline diamond films contain a large number of grain boundaries and defects, which lead to a lower carrier mobility. Heteroepitaxial diamond films have been successfully grown on mirror polished silicon substrates, which could speed up the application of diamond films in the electronic industry, because heteroepitaxial diamond films have lower defect densities and higher carrier mobilities in comparison to polycrystalline diamond films. The magnetoresistive effect is an important effect in diamond films which could possibly stimulate their application in microelectronic devices. There are, however, only a few open literature studies on the magnetoresistive effect of the heteroepitaxial and homoepitaxial diamond films to date. Recently, it was found that heteroepitaxial and homoepitaxial diamond films have a high magnetoresistive effect [6,7], which can make their application as diamond magnetoresistive sensors practical.

In this paper, we report on studies of the magnetoresistive effect in both heteroepitaxial and homoepitaxial p-type semiconducting diamond films produced by microwave plasma CVD. Experiment and theoretical calculations show that the magnetoresistive effect strongly depends not only on magnetic field intensity and temperature but also on the geometry of the devices. Based on F-S films theory, theoretical calculations of magnetoresistance were made by assuming hole conduction from three uncoupled valence bands: spherical energy surface, mixed scattering by lattice vibrations, and ionized impurities. A relationship between magnetoresistive effect and film thickness and magnetic field has been developed. The calculated magnetoresistance was compared with experimental data. The theoretical analysis results are in good agreement with the experimental data.

EXPERIMENT AND RESULTS

Diamond films were deposited by microwave plasma CVD onto mirror-polished p-type (001) silicon (10×10 mm) and (001) diamond (2×2 mm) substrates. The reactive gases were mixtures of CH_4 and H_2. The deposition parameters were as follows: microwave power and frequency 800 W and 2.45 GHz, total pressure 18–20 mbar, a gas flow rate of 300 sccm, and a substrate temperature of 850°C. The nucleation step lasted 20 min. by applying a dc bias of –200 V to the substrate. After the nucleation, the diamond film growth lasted for 20 h at 0.5 vol % CH_4 and a substrate temperature of 720°C. The diamond film thickness was 4 μm.

Boron-doped diamond films were made by the cold implantation-rapid annealing technique. At –76°C, the diamond films were boron-implanted with a dose of 1.5×10^{13} ions/cm^2 and then rapidly heated at 1050°C for 10 min. Subsequent, heat annealing was done at 1350°C for 10 min. Finally, diamond films were cleaned in acid to remove surface graphite.

In order to study the magnetoresistive effect of p-type epitaxial diamond films, diamond-based magnetoresistive devices were patterned by etching the boron-doped diamond films layers on the undoped diamond with an oxygen plasma in a reactive ion etching chamber at 200 W and 38 mTorr. There are two kinds of device structures, i.e., a strip (500 μm × 100 μm) and Corbino disk (radius: 250 μm). Au/Ti double layer electrodes were made by electron beam evaporation. The magnetoresistance measurements have been carried out in a magnetic field ranging from 0 to 5 T, using the four probe method.

Figure 1 shows that magnetoresistance ($\Delta\rho/\rho_0$) of diamond films as a function of magnetic field intensity for different device structures. The ρ and ρ_0 symbols represent the resistivity of a device with and without magnetic field. The changes of magnetoresistance strongly depended on the magnetic field strength and the geometry of the sample. Figure 1 illustrates one kind of form effect. It can be seen that the magnetoresistance effect in a Corbino disk structure sample is greater than that of strip sample, 0.4 for strip sample and 0.85 for a Corbino disk at a magnetic field strength of 5 T. The magnetoresistance effect in homoepitaxial diamond films was much stronger than that of heteroepitaxial diamond films, 2.1 for homoepitaxial diamond disk structures at room temperature under a magnetic field intensity of 5 T, but only 0.85 for heteroepitaxial diamond films. Figure 2 shows the other type of form effect. The magnetoresistance effect of homoepitaxial diamond films strongly depends on the width-to-length ratio of the strip structure. The greater the ratio, the greater the magnetoresistance effect.

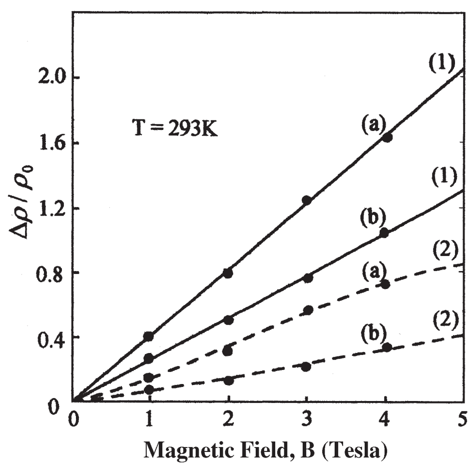

Figure 1. *Relationship between the magnetoresistance and magnetic field intensity,* B*: (a) disk, (b) strip; (1) homoepitaxial diamond films; (2) heteroepitaxial diamond films.*

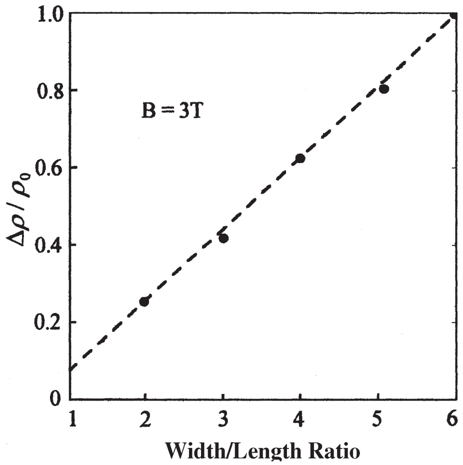

Figure 2. *Variation of the magnetoresistance as a function of the width-to-length ratio at a magnetic field intensity of 3 T for homoepitaxial diamond films with the strip structure.*

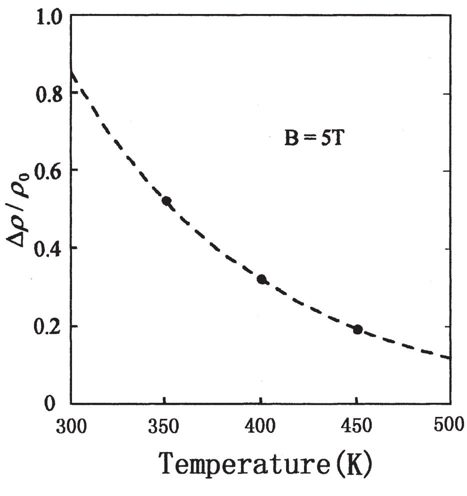

Figure 3. *Relationship between the magnetoresistance and temperature at a magnetic field intensity of 5 T for heteroepitaxial diamond films with the disk structure.*

The magnetoresistance effect increases linearly with the width-to-length ratio. Figure 3 shows the magnetoresistance effect as a function of temperature for heteroepitaxial diamond films with the disk structure. As temperature increases from 300 K to 500 K, the magnetoresistance is seen to decrease from 0.85 to 0.15.

THEORETICAL CALCULATIONS

Consider p-type epitaxial diamond films of thickness d. Based on the F-S thin theory [8], and considering first order terms to the electric field $\vec{E}$ along the x direction only and second order terms to the magnetic field $\vec{H}$ along the z direction, the current density can be written as [9],

$$\vec{j}_i(\vec{k},\vec{r}) = \sum_{i=1}^{3} \sigma_{ij} E_j \tag{1}$$

Here $\sigma_{i,j}$ is the conductivity,

$$\sigma_{i,j} = \frac{2e^2}{(2\pi)^3} \int \left[\frac{\tau A}{1+\omega^2\tau^2 A^2} v_i v_j + \frac{\omega \tau^2 A^2 v_i (\vec{v} \times \vec{H})_j}{H(1+\omega^2\tau^2 A^2)} \right] \cdot \vec{E} \frac{\partial f_0}{\partial \varepsilon} d^3k \tag{2}$$

where $f_0(\vec{v})$ is the equilibrium distribution function of a hole, $\omega = eH/m^*$ (m^*: the effective mass of a hole), $\vec{v}$ is the velocity of a hole, and τ is the relaxation time, while A represents a function:

$$A = 1 + F(\vec{v}) \cdot \exp\left(-\frac{z}{\tau v_z} \right) \tag{3}$$

in which,

$$z = 0 \qquad F(\vec{v}) = -1 \qquad (v_z > 0) \tag{4}$$

$$z = d \qquad F(\vec{v}) = -\exp\left(\frac{d}{\tau v_z} \right) \qquad (v_z < 0) \tag{5}$$

MAGNETORESISTANCE OF A STRIP SAMPLE

For a single valence band, Maxwell-Boltzmann statistics and spherical energy band surfaces were assumed. On the condition of weak field, the conductivity components of strip samples σ_{xx} and σ_{xy} may be written as [9],

$$\sigma_{xx}^* = \frac{4e^2 p}{3m^* \sqrt{\pi}} \int_0^\infty \frac{\tau\varphi(k)}{1+\omega^2\tau^2} \alpha^{3/2} e^{-\alpha} d\alpha = \sigma_{xx}^0 \varphi(k) \tag{6}$$

$$\sigma_{xy}^* = -\frac{4e^2 p}{3m^* \sqrt{\pi}} \int_0^\infty \frac{\tau^2\omega\eta(k)}{1+\omega^2\tau^2} \alpha^{3/2} e^{-\alpha} d\alpha = \sigma_{xy}^0 \eta(k) \tag{7}$$

in which p is the hole density, and σ_{xx}^0 and σ_{xy}^0 are the conductivities of p-type semiconducting diamond [10]. The functions $\varphi(k)$ and $\eta(k)$ as determined by k, are

$$\varphi(k) = 1 - \frac{3}{8k} + \left[\frac{3}{8k} - \frac{5}{8} - \frac{k}{16}(1-k)\right] e^{-k} + \frac{3k}{4}\left(1 - \frac{k^2}{12}\right) B(k) \tag{8}$$

$$\eta(k) = 1 - \frac{9}{16k} + \left[\frac{3}{4k} - \frac{5}{4} - \frac{k}{8}(1-k)\right] e^{-k} + \frac{3k}{2}\left(1 - \frac{k^2}{12}\right) B(k) \tag{9}$$

$$k = \frac{d}{\tau v_0}, \qquad \frac{k}{\cos\theta} = T, \qquad B(k) = \int_k^\infty \frac{1}{T} e^{-T} dT \tag{10}$$

For the case of mixed scattering by lattice vibrations and ionized impurities, the relaxation time can be written as [11],

$$\tau = \frac{3\sqrt{\pi} m^* \mu_L}{4e} \cdot \frac{\alpha^{3/2}}{\beta + \alpha^2}, \qquad \alpha = (E_V - \varepsilon)/KT \tag{11}$$

where μ_L is the hole mobility for a spherical band and β is a slowly varying function of energy indicating the degree of impurity scattering (pure lattice scattering $\beta = 0$). Then, σ_{xx}^* and σ_{xy}^* may be rewritten as,

$$\sigma_{xx}^* = pe\mu_L \varphi(k) K(\beta, r) \tag{12}$$

$$\sigma_{xy}^* = -\frac{1}{2}\sqrt{\pi}\, pe\mu_L r^{1/2} \eta(k) L(\beta, r) \tag{13}$$

in which,

$$K(\beta, r) = \int_0^\infty \frac{\alpha^3 e^{-\alpha}(\alpha^2 + \beta)}{(\alpha^2+\beta)^2 + r\alpha^3} d\alpha \tag{14}$$

$$L(\beta, r) = \frac{2}{\sqrt{\pi}} \int_0^\infty \frac{\alpha^{9/2} e^{-\alpha}}{(\alpha^2 + \beta^2) + r\alpha^3} d\alpha \tag{15}$$

$$r = \frac{9\pi}{16}(\mu_L H)^2 \tag{16}$$

The valence bands of diamond are composed of a light-hole band, a heavy-hole band and a split-off band. Considering a parallel connection model for the hole band of diamond films, the traverse magnetoresistance may be had from [12]:

$$\frac{\Delta\rho_s}{\rho_{0s}} = \frac{S_{xx}(H)S_{xx}(0)}{S_{xx}^2(H) + S_{xy}^2(H)} - 1 \tag{17}$$

$$S_{xx}(H) = \sigma_{xx}^*(1) + \sigma_{xx}^*(2) + \sigma_{xx}^*(3) \tag{18}$$

$$S_{xy}(H) = \sigma_{xy}^*(1) + \sigma_{xy}^*(2) + \sigma_{xy}^*(3) \tag{19}$$

The expressions $\sigma_{xx}^*(i)$ and $\sigma_{xy}^*(i)$ are given by Equation (12) and Equation (13) while $i = 1,2,3$ designates a particular hole band.

Finally, the transverse magnetoresistance becomes,

$$\frac{\Delta p_s}{\rho_{0s}} = \frac{A(\beta,r)A(\beta,0)}{[A(\beta,r)]^2 + \frac{\pi}{4}\cdot r_2 \cdot B(\beta,r)} - 1 \tag{20}$$

in which,

$$A(\beta,r) = \frac{p_1 u_{L1}}{p_2 u_{L2}}\varphi(k_1)K(\beta_1,r_1) + \varphi(k_2)K(\beta_2,r_2) + \frac{p_3\mu_{L3}}{p_2\mu_{L2}}\varphi(k_3)K(\beta_3,r_3) \tag{21}$$

$$B(\beta,r) = \left[\frac{p_1}{p_2}\left(\frac{u_{L1}}{u_{L2}}\right)^2 \eta(k_1)L(\beta_1,r_1) + \eta(k_2)L(\beta_2,r_2)\right.$$

$$\left. + \frac{p_3}{p_2}\left(\frac{\mu_{L3}}{\mu_{L2}}\right)^2 \eta(k_3)L(\beta_3,r_3)\right]^2 \tag{22}$$

MAGNETORESISTANCE OF A CORBINO DISK

In a manner similar to the calculations above, we can obtain from Equation (2), for a single valence band, the conductivity components of a Corbino disk σ_{rr}^* and $\sigma_{\varphi r}^*$ as [9],

Table 1. The hole density ratio [10].

Source	p_1/p_2	p_1/p_2
Theoretical value	0.19	0.28

$$\sigma^*_{rr} = 2pe\mu_L \varphi(k) K(\beta, r) \tag{23}$$

$$\sigma^*_{\varphi r} = -\sqrt{\pi} pe\mu_L r^{1/2} \eta(k) L(\beta, r) \tag{24}$$

where $\varphi(k)$ and $\eta(k)$ are obtained from Equation (8) and Equation (9), and $K(\beta,r)$ and $L(\beta,r)$ are expressed by Equation (14) and Equation (15). Considering a parallel connection model for the light-hole band (σ_1), the heavy-hole band (σ_2) and the split-off band (σ_3), the current density can be written as,

$$\vec{j}_r = \vec{j}_{r1} + \vec{j}_{r2} + \vec{j}_{r3} = (\sigma^*_{rr1} + \sigma^*_{rr2} + \sigma^*_{rr3}) \cdot E \cdot \vec{e}_r = \sigma_r \cdot E \cdot \vec{e}_r \tag{25}$$

$$\vec{j}_\varphi = \vec{j}_{\varphi 1} + \vec{j}_{\varphi 2} + \vec{j}_{\varphi 3} = (\sigma^*_{\varphi r1} + \sigma^*_{\varphi r2} + \sigma^*_{\varphi r3}) \cdot E \cdot \vec{e}_\varphi = \sigma_\varphi \cdot E \cdot \vec{e}_\varphi \tag{26}$$

$$j = \sqrt{j_r^2 + j_\varphi^2} = \sqrt{(\sigma_r)^2 + (\sigma_\varphi)^2} \cdot E = \sigma_c \cdot E \tag{27}$$

where

$$\sigma_c = \sqrt{(\sigma_r)^2 + (\sigma_\varphi)^2} \tag{28}$$

The transverse magnetoresistance may now be written as,

$$\frac{\Delta\rho}{\rho_0} = \frac{\sigma_c(0)}{\sigma_c(H)} - 1 = \sqrt{\frac{4A^2(\beta,0) + \pi \cdot r_2 B(\beta,0)}{4A^2(\beta,r) + \pi \cdot r_2 B(\beta,r)}} - 1 \tag{29}$$

in which the values of $A(\beta,r)$ and $B(\beta,r)$ are obtained from Equations (21) and (22).

Table 2. Values of the parameters μ_L, β, k, and m_h^* [10].

Parameter	Band 1	Band 2	Band 3
μ_L (cm^2/v·s)	3900	195	1365
β	0.001	0.0001	0.0003
k	9.2	60.7	17.3
m_h^*	$0.7m_0$	$2.12m_0$	$1.06m_0$

Equations (20)–(22) for strips and Equations (28) and (29) for Corbino disks, express the principal theoretical results for the magnetoresistance of p-type semiconducting diamond films. In the following section, we shall discuss the results of numerical calculation of the magnetoresistance of heteroepitaxial diamond films of the strip and Corbino disk type. The values of the calculated parameters are shown in Tables 1 and 2.

NUMERICAL CALCULATION RESULTS AND DISCUSSION

Figure 4 shows the numerical calculation results for heteroepitaxial diamond films with the strip and Corbino disk structure. The magnetoresistance of the Corbino disk is much higher than that of the strip. When $H = 5$ T, the calculated magnetoresistances are 0.38 for the strip and 0.74 for a Corbino disk. Compared to the experimental results of 0.4 for the strip and 0.85 for the Corbino disk, the deviations between experimental data and theoretical calculations are 5% for strip types and 13% for Corbino disks. As can be seen from Figure 4 the theoretical values are in reasonable agreement with experimental results for strips, but unsatisfactory for Corbino disks. This indicates that the parallel connection model is reasonable for strips, but not for Corbino disks.

Considering the difference in effective mass between the light hole and heavy hole, we propose two revisions for the parallel connection model of a Corbino disk in a weak magnetic field. (1) The heavy hole has no contribution for $\vec{j}_\varphi$ ($\vec{j}_{\varphi 2} = 0$).

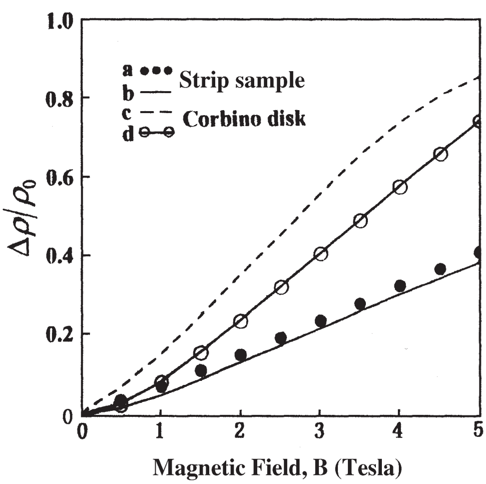

Figure 4. *Comparison between experimental results and theoretical calculation for strip and Corbino disk: (a) The experimental results for a strip sample; (b) the theoretical calculations for a strip sample; (c) the experimental results for a Corbino disk; and (d) the theoretical calculations for a Corbino disk.*

(2) There is a weight distribution of the light hole for $\vec{j}_{r1}$ and $\vec{j}_{\varphi 1}$, and the split band holes for $\vec{j}_{r3}$ and $\vec{j}_{\varphi 3}$, in which the weight distribution is related to the magnetic field H. The $\vec{j}_r$ and $\vec{j}_\varphi$ can be rewritten as follows,

$$\vec{j}_r = \xi(H) \cdot \vec{j}_{r1} + \vec{j}_{r2} + \xi(H) \cdot \vec{j}_{r3}$$

$$= [\xi(H) \cdot \sigma^*_{rr1} + \sigma^*_{rr2} + \xi(H) \cdot \sigma^*_{rr3}]E\vec{e}_r = \sigma_r E\vec{e}_r \tag{30}$$

$$\vec{j}_\varphi = (1 - \xi(H)) \cdot \vec{j}_{\varphi 1} + (1 - \xi(H)) \cdot \vec{j}_{\varphi 3}$$

$$= [(1 - \xi(H)) \cdot \sigma^*_{\varphi r1} + (1 - \xi(H)) \cdot \sigma^*_{\varphi r3}]E\vec{e}_\varphi = \sigma_\varphi E\vec{e}_\varphi \tag{31}$$

Assuming $\xi(H) = C_1 \cdot \exp(-C_2 \cdot H)$, when $C_1 = 0.55$ and $C_2 = 0.1$, the model gives a more satisfying result, as shown in Figure 5.

For pure lattice scattering, β is zero. The numerical calculation showed that the variation of magnetoresistance was very small, only about 1.8% for strip and 1.0% for the Corbino disk at $H = 5$ T. So, we may neglect the effect of impurities. Furthermore, in order to compare the influence of different values of k, we assumed $k_1 = k_2 = k_3 = 9.2$. The change of magnetoresistance was only about 2.37% for strip and 2.0% for a Corbino disk at $H = 5$ T. It indicates that we could ignore the effect of valence band's structure on k for thick films, and calculate the magnetoresistance with the k of light-hole band.

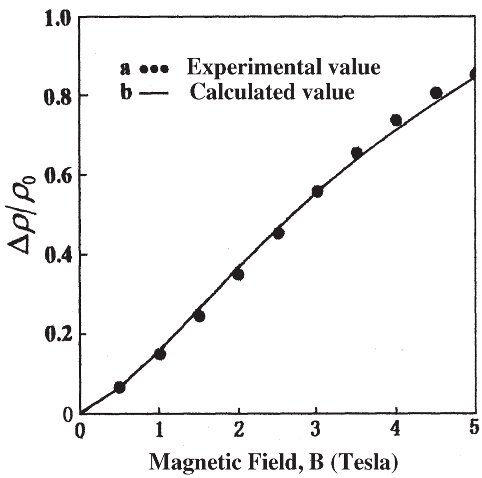

Figure 5. *Comparison between experimental results and a new theoretical model (calculation) for a Corbino disk: (a) The experimental results for a Corbino disk and (b) the theoretical results for a new model Corbino disk.*

Figure 6 shows the magnetoresistance values for various film thicknesses. It is found that magnetoresistance increases with a decrease in film thickness. The smaller *d*, the bigger the magnetoresistance, although the differences are very small for thicknesses varying from 1 μm to 100 μm, the change in magnetoresistance was 0.07 for a strip and 0.03 for a Corbino disk. The impact of thickness is bigger for a strip than for Corbino disks.

It is of interest to compare the contributions of each hole band to the magnetoresistance. Numerical calculations showed that the magnetoresistance levels of heavy-hole band is the lowest and the magnetoresistance for a light-hole band the highest. When the magnetic field equals 5 T, the ratio of the magnetoresistance for the heavy-hole band to that of the light-hole band is about 0.023 for a strip sample and 0.03 for a Corbino disk. If we did not consider the heavy-hole band, the change of magnetoresistance is about 0.03 for both strip sample and Corbino disk.

In the following, we present a discussion for the geometric form effect of the magnetoresistance of p-type semiconducting diamond films. For the strip sample, if the Hall effect equaled zero, the current density could be written as:

$$\vec{j}_x = \vec{j}_{x1} + \vec{j}_{x2} + \vec{j}_{x3} = (\sigma^*_{xx1} + \sigma^*_{xx2} + \sigma^*_{xx3})E\vec{e}_x = \sigma_x E\vec{e}_x \tag{32}$$

$$\vec{j}_y = \vec{j}_{y1} + \vec{j}_{y2} + \vec{j}_{y3} = (\sigma^*_{xy1} + \sigma^*_{xy2} + \sigma^*_{xy3})E\vec{e}_y = \sigma_y E\vec{e}_y \tag{33}$$

$$j = \sqrt{(\sigma_x)^2 + (\sigma_y)^2} \cdot E = \sigma_s \cdot E \tag{34}$$

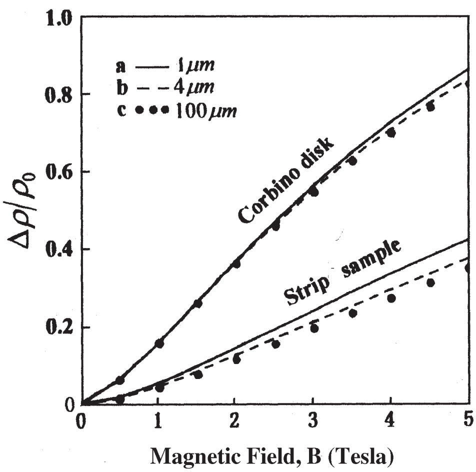

Figure 6. *The magnetoresistance of p-type semiconducting diamond films of different thicknesses: (a)* d = *1* μm*, (b)* d = *4* μm *and (c)* d = *100* μm*.*

From Equations (19) and (20), we obtain the magnetoresistance of a strip as,

$$\frac{\Delta\rho_s}{\rho_{0s}} = \frac{\sigma_s(0)}{\sigma_s(H)} - 1 = \sqrt{\frac{4A^2(\beta,0) + \pi \cdot r_2 B(\beta,0)}{4A^2(\beta,r) + \pi \cdot r_2 B(\beta,r)}} - 1 \tag{35}$$

The $A(\beta,r)$ and $B(\beta,r)$ values can be obtained from Equation (21) and Equation (22). The magnetoresistance of a Corbino disk shows that the Hall effect contribution is intrinsic to the geometric form effect. One could, therefore, change the magnetoresistance of a strip by changing the form of the device or by exerting an electronic field on the strip sample along a direction opposite to that of the Hall electronic field.

However, the Hall effect could not be zero for a strip. As a result, we assume that the Hall effect can't decrease j_y to zero for thin diamond films. A similar model with Corbino disk can be used. From Equations (30) and (31), the $\vec{j}_x$ and $\vec{j}_y$ can be rewritten as,

$$\vec{j}_x = \varsigma(H,s)\cdot\vec{j}_{x1} + \vec{j}_{x2} + \varsigma(H,s)\cdot\vec{j}_{x3}$$

$$= [\varsigma(H,s)\cdot\sigma^*_{xx1} + \sigma^*_{xx2} + \varsigma(H,s)\cdot\sigma^*_{xx3}]\cdot E\vec{e}_x = \sigma_x E\vec{e}_x \tag{36}$$

$$\vec{j}_y = (1-\varsigma(H,s))\vec{j}_{y1} + (1-\varsigma(H,s))\vec{j}_{y3}$$

$$= [(1-\varsigma(H,s))\cdot\sigma^*_{yy1} + (1-\varsigma(H,s))\cdot\sigma^*_{yy3}]\cdot E\vec{e}_y = \sigma_y E\vec{e}_y \tag{37}$$

where $\varsigma(H,s)$ is determined by the magnetic field intensity H and the width-to-length ratio. With this model, one could further investigate the form effect for strip samples with different width-to-length ratios.

SUMMARY

We have investigated the magnetoresistive effect of p-type semiconductor diamond films using both an experimental and theoretical approach. The experimental evidence revealed that the effect of disk structures was greater than for strip samples, and that the variation in the resistance was greater for homoepitaxial diamond films than for heteroepitaxial diamond films. The magnetoresistive effect strongly depends on the magnetic field intensity, temperature and sample geometry. Based on the F-S theory, we have presented analytical expressions for the magnetoresistance of p-type semiconducting diamond films with the device structure of the strip and Corbino disk types. Giving out a revision model for the magnetoresistance of Corbino disk, in which the contribution of heavy holes for $\vec{j}_\varphi$ was zero and the current of light holes and split holes has a weight distribution for $\vec{j}_r$ and $\vec{j}_\varphi$. Overall the results show that the experimental data are in good agreement with the theoretical estimates. Lattice scattering is seen to predominate over ionized impurity scattering. Surface scattering can be neglected for thick films. The magnetoresistances of the light-hole band and the split-off band are much larger than that of heavy-hole band. The geometric form effect is closed related to the Hall effect.

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REFERENCES

1. N. M. Miskovsky, P. H. Cutler and Z. H. Huang, "Calculation of Electronic Properties of Defects in Diamond: Application to Electron Emission," J. Vac. Sci. Technol. B, 14 (1996) 2037.
2. X.-P. Wang, N. Yao, Y.-J. Li et al., "High Average Emission Sites Density of Electron Field Emission from Broad Area Diamond-Amorphous Carbon Thin Films," Chin. Phys. Lett. 15 (1998) 611.
3. M. Aslam, I. Taher, A. Masood et al., "Piezoresistivity in Vapor-Deposited Diamond Films," Appl. Phys. Lett. 60 (1992) 2923.
4. W. L. Wang, K. J. Liao, B. Feng et al., "Piezoresistivity of p-Type Heteroepitaxial Diamond Films on Si (100)," Diam. Relat. Mater. 7 (1998) 528.
5. J.-L. Li, G. Meng, K.-H. Wu et al., "Highly Oriented Diamond Film Growth by Atomic Force Microscopy," Chin. Phys. Lett. 15 (1998) 822.
6. W.-L. Wang, K.-J. Liao and B.-B. Wang, "Enhanced Transverse Magnetoresistive Effect in Semiconducting Diamond Films," Chin. Phys. Let.. 17 (2000) 370.
7. K. J. Liao, W. L. Wang and B. B. Wang, "Magnetoresistive Effect of Semiconductor Diamond Films," Microfabrication Technology 1 (2000) 75.
8. E. H. Sondheimer, Adv. Phys. 1 (1952) 1.
9. C. Y. Kong, W.-L. Wang, K.-J. Liao et al., "Study on the Magnetoresistive Effect of p-Type Semiconducting Diamond Films," J. Appl. Phys. (to be submitted).
10. J. K. Russell and W. J. Leivo, "High-Field Magnetoresistance of Semiconducting Diamond," Phys. Rev. B6 (1972) 4588.
11. A. C. Beer and R. K. Willardson, "Hall and Transverse Magnetoresistance Effects for Warped Bands and Mixed Scattering," Phys. Rev. 110 (1958) 1286.
12. A. C. Beer, in Solid State Physics, edited by F. Seitz and D. Turnbull (Academic, New York, 1963), Suppl. 4.