The Study Influence of Parameter of P-Type Diamond Hall Sensor Synthesized by HFCVD

Wasin Panyalert, Wisut Titiroongraung and Surasak Niemcharoen, *Member, IAENG*

Abstract— **This paper is the study of the influence of parameter of p-type diamond Hall sensors, which were synthesized by HFCVD. In this study concentrate on influence of thickness and impurity concentration of response sensitivity to magnetic field. Boron was added in ethyl alcohol as the reactant to obtain p-type diamond film at B/C ratio of 10,000 ppm. The synthesis durations of 6, 12 and 36 hours at the substrate temperature of 750°C were selected to achieve the required diamond film thicknesses of 50, 100 and 150 µm, respectively. The synthetic diamond films were confirmed to be diamond using Raman spectroscopy and the cross sections were analyzed using SEM (Scanning Electron Microscopy). Then, simple p-type diamond Hall sensors were fabricated using four silver electrodes adhered on the diamond film. The ohmic of the electrodes were confirmed by the measurement of electrical properties of electrodes and magnetic field response at three different diamond thicknesses. The response sensitivity to magnetic field were 12, 9 and 6 µV/Gauss, respectively. When the thickness of the p-type diamond Hall sensor increased, the response sensitivity to magnetic field decreased. The thickness 50 µm were selected, Boron was added in ethyl alcohol as the reactant to obtain p-type diamond film at B/C ratio of 15,000, 20,000 and 25,000 ppm. The response sensitivity to magnetic field were 9, 7 and 5 µV/Gauss, respectively.**

Index Terms— **HFCVD, p-type Diamond, Hall Sensor**

I. INTRODUCTION

Nowadays, the diamond had classified as semiconductor because it can be applied in electronics. In addition, diamond has greater properties than other semiconductors such as has a wide band gap of 5.5 eV, which is 5 times more than the silicon. Moreover, semiconductor that is made from diamond can be used in high temperature conditions, which silicon semiconductor cannot be applied.

Nevertheless, the cost to use the diamond semiconductor is more expensive compared to silicon semiconductor.

Moreover, it is hard to use because of impurities in the crystal structure of the natural diamond itself, which cannot be controlled, and difficulty to cut to usable shape.

The purpose of this research is to study the step of diamond film synthesis by HFCVD method [1] to be applied as a Hall sensor
Various test data is used to analyze the behavior of Hall Effect and related phenomena, and calculate to find parameters that can explain the type of carrier in semiconductor such as carrier density and carrier mobility.

II. METHODOLOGY

The diamond synthesis [2] by HFCVD method is a non-complexity method because it simply applies the principle of the disintegration of carbon atoms by using the thermal energy from a tungsten solenoid (hot filament). Hydrogen gas is used to carry carbon atoms in the test tube. When that carbon atoms reached on the heated substrate, the diamond is formed. Factors influence the carbon atom reaction is the hot filament temperature as it activates the carbon atom disintegration, and the substrate temperature that affect the crystal orientation of diamond on the substrate. The setting of substrate preparation is shown in Fig. 1.

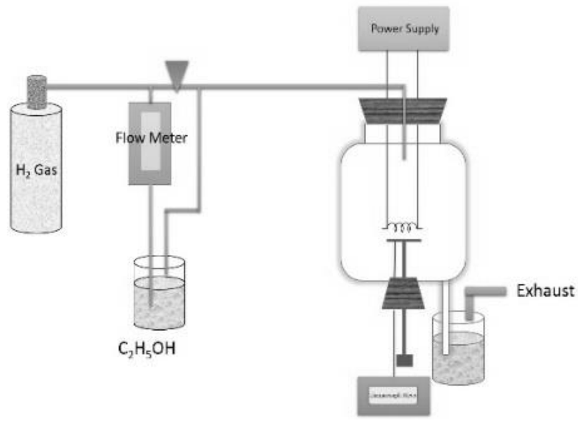

Fig. 1. HFCVD synthesis method.

The Hall's phenomena test [3] can be evaluated by measuring the parameter of semiconductor such as type of majority carrier, density of carrier and mobility of carrier. The density of carrier can be calculated from Eq. (1) and mobility of carrier can be estimated from Eq. (3). Phenomena of Lorentz force [4] and Hall testing in semiconductor is shown in Fig. 2.

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W. Panyalert is with the Electronics Department, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok Thailand. (e-mail:wasinerc@gmail.com).

S. Neamchalern is with the Electronics Department, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok Thailand. (e-mail: surasak.ni@kmitl.ac.th).

W. Thitirungraung is with the Electronics Department, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok Thailand. (e-mail: ktwisut@kmitl.ac.th).

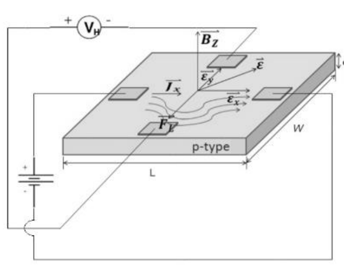


Fig. 2. Hall Effect and other phenomenon in p-type diamond

Electrical density

$$p = \frac{1}{qR_H} = \frac{I_X B_Z}{qd.V_H} \quad (1)$$

Electrical resistivity

$$\rho = \frac{V}{I_X} = \frac{w.d}{L} \quad (2)$$

Electrical mobility

$$\mu_p = \frac{1}{\rho \cdot p \cdot q} = \frac{1}{\rho} \cdot R_H \quad (3)$$

Before using a substrate for diamond film synthesis, the preparation of the substrate is critical for carbon atoms to form in the structure of diamond. This research chose the silicon (Si) to make the substrate. Silicon surface was polished using 0.5 µm diamond paste to remove any oxide on the substrate surface as it affects the carbon formation on the substrate. After that, the substrate was cut in 5x5 mm^2.

After the substrate preparation, the p-type diamond [5] to make a Hall sensor was built by HFCVD in the synthesis

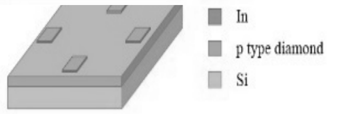
TABLE I. ANALYSIS OF CARBON TYPE USING RAMA SPECTROSCOPY

Peak position(cm^{-1})	Type of carbon	Description
~1140	Small size(<0.1 µm) cubic diamond	Occasionally observed in diamond films with very small grain size (<0.1 µm).
1315-1326	Hexagonaldiamond	Broad band, observed in shock wave produced diamond.
1332	Cubicdiamond	First order peak with FWHM of $19cm^{-1}$for natural diamond.
1345	Amorphous carbon	Broad band, it becomes a shoulder of the 1550 cm^{-1}band when the material is hydrogenated.
1355	Microcrystalline graphite	Observed in material with small grain size.
1550	Amorphous or diamond-like carbon	Broad band.
1580	Graphite	First order peak.
2458	Cubic diamond	Second order peak.
2710	Microcrystalline graphite	Second order peak.
3240	Graphite	Second order peak.

~~system as shown in Fig. 1. Boron was doped in the synthetic~~ diamond by mixing boron-trioxide (B_2O_3) and ethyl alcohol together at B/C ratio of 10,000 ppm. The synthesis durations of 6, 12 and 36 hours at the substrate temperature of 750°C. The thickness 50 µm were selected, Boron was added in ethyl alcohol [6] as the reactant to obtain p-type diamond film at B/C ratio of 15,000, 20,000 and 25,000 ppm.

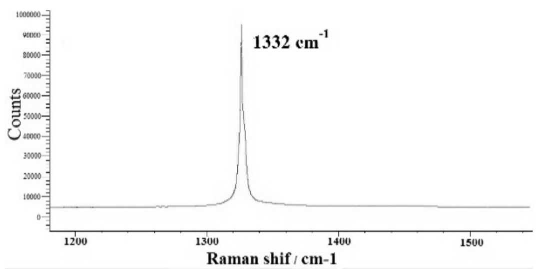
The Raman spectroscopy technique was applied to confirm the diamond characteristic from peak position obtained from Raman graph and interpret using information in Table 1.

TABLE II. FABRICATION PROCESS OF P-TYPE DIAMOND HALL SENSOR [7]

Figure	Description
	Prepare a 5 mm. x 5 mm. silicon substrate, scrub the surface using diamond paste, and clean the substrate after preparation.
	Synthesis of diamond film by HFCVD method.
	Annealing of the synthesis diamond film under hydrogen atmosphere at the substrate temperature of 750 °C for 9 minutes.
	Building four silver pastes on the surface of p-type diamond film.
	p-type diamond for Hall sensor

III. RESULTS AND DISSCUSSION

The p-type synthetic diamond films by HFCVD were conducted for 6, 12 and 36 h at the substrate temperature of 750°C. To investigate the carbon type of the synthetic films, Raman spectroscopy was applied. The results are as shown in Figure 3(a), 3(b) and 3(c), respectively. All three figures, the peak of the graphs is at 1332 cm^{-1} only. According to Table 1, it was found that the peak corresponds to diamond. Therefore, the synthetic diamond films are complete diamond films.



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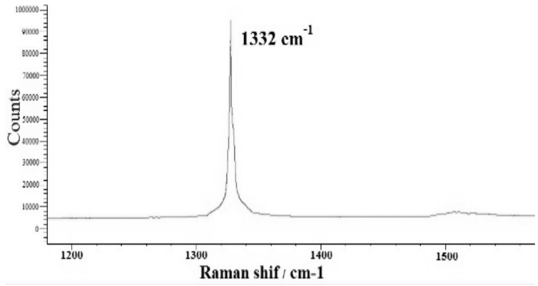

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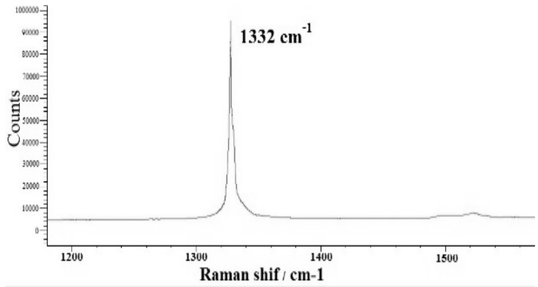
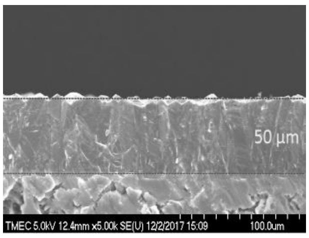


(C)

Fig.3 Raman spectrum of p-type diamond films.
(a) P-type diamond film synthesized by HFCVD for 6 hrs. at the substrate temperature of 750 °C.
(b) P-type diamond film synthesized by HFCVD for 12 hrs. at the substrate temperature of 750 °C.
(C) P-type diamond film synthesized by HFCVD for 36 hrs. at the substrate temperature of 750 °C.

The cross section of all three diamond films were analyzed using SEM. To investigate the synthesis duration on the film thickness, it was found that at the synthesis duration of 6, 12 and 36 h at the substrate temperature of 750 °C, the diamond film thicknesses of 50, 100 and 150 μm were achieved, respectively, as shown in Figure 4(a), 4(b) and 4(C).



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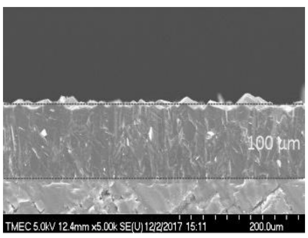

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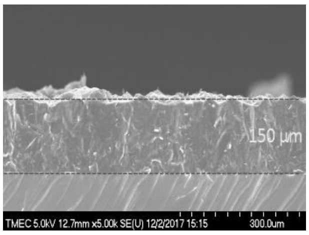
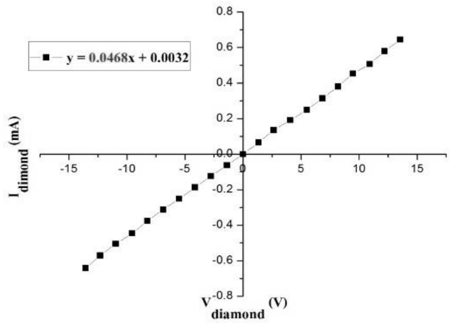


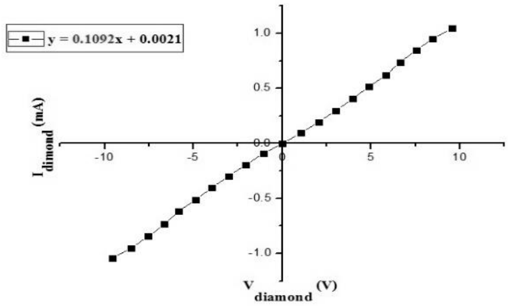
(C)

Fig. 4 Cross section analysis of diamond film using SEM.
(a) Diamond film thickness of 50 μm.
(b) Diamond film thickness of 100 μm.
(C) Diamond film thickness of 150 μm.

The electrical properties of the diamond films at the thickness of 50, 100 and 150 μm were examined. According to the relationship between current and voltage as shown in Figure 5, all three relationships are linear. This indicates the ohmic property of the electrodes. From the linear relationship, resistance is equal to the inverse of the slope, which are 21.36, 9.15 and 6.11 k□, respectively.



(a)



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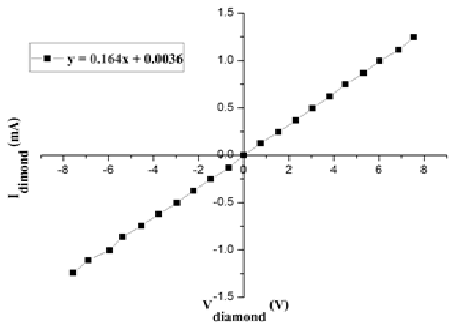

(C)

Fig. 5 Analysis results of the electrical properties of p-type diamond film.
(a) Diamond film thickness of 50 μm.
(b) Diamond film thickness of 100 μm.
(C) Diamond film thickness of 150 μm.

Onward, the response sensitivity to the magnetic field was analyzed at the diamond film thicknesses of 50, 100 and 150 μ m as shown in Figure 7. The magnetic field response sensitivity measured were 12, 9 and 6 μV/Gauss. From the analysis, the hole density can be estimated, which were 2.49×10^{15}, 1.48×10^{15} and $1.13 \times 10^{15} cm^{-3}$, respectively, and the electrical mobility were 23.65, 45.96 and 60.35 cm^2/V-sec, respectively.

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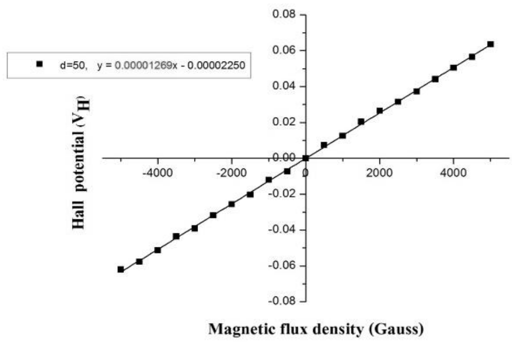
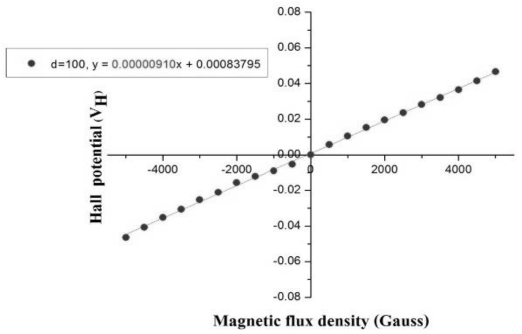


(a)



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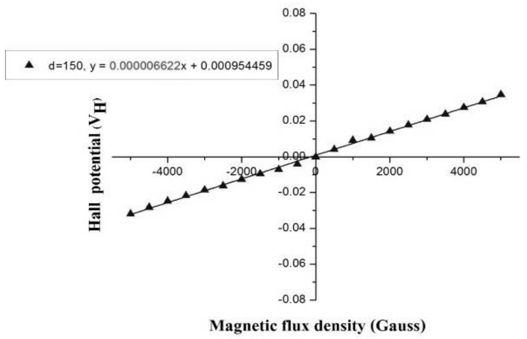
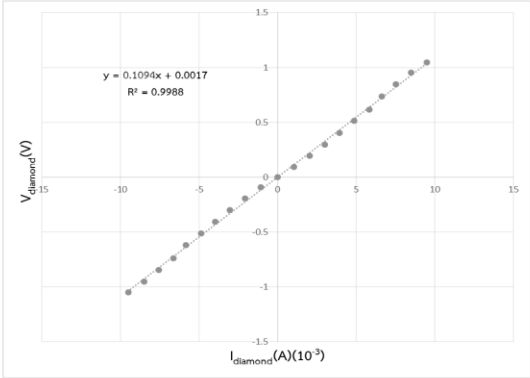


(C)

Fig. 6 Analysis results of magnetic field response sensitivity of p-type diamond Hall sensor.
(a) Diamond film thickness of 50 µm.
(b) Diamond film thickness of 100 µm.
(C) Diamond film thickness of 150 µm.



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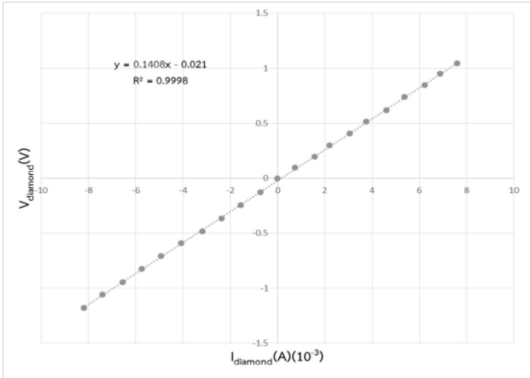

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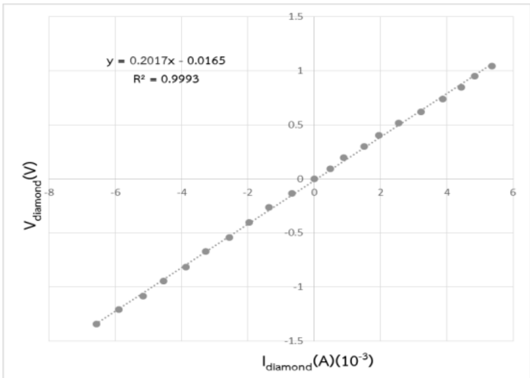

(C)

Fig. 7 Analysis results of the electrical properties of p-type diamond film.
(a) B/C 15,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C
(b) B/C 20,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C
(C) B/C 25,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C

The thickness 50 µm were selected, Boron was added in ethyl alcohol as the reactant to obtain p-type diamond film at B/C ratio of 15,000, 20,000 and 25,000 ppm respectively. The synthesis durations of 6 hours the substrate temperature of 750 °C. According to the relationship between current and voltage as shown in Figure 7, all three relationships are linear. This indicates the ohmic property of the electrodes. From the linear relationship, resistance is equal to the inverse of the slope, which are 9.15, 7.11 and 4.94 k□, respectively.

Further, the response sensitivity to the magnetic field was analyzed at B/C ratio of 15,000, 20,000 and 25,000 ppm respectively. The synthesis durations of 6 hours the substrate temperature of 750 °C. The magnetic field response sensitivity measured were 9, 7 and 5 µV/Gauss as shown in Figure 8. From the analysis, the hole density can be estimated, which were 1.47×10^{15}, 1.84×10^{15} and 3.46×10^{15} respectively, and the electrical mobility were 46.30, 48.29 and 36.60 cm^2/V-sec

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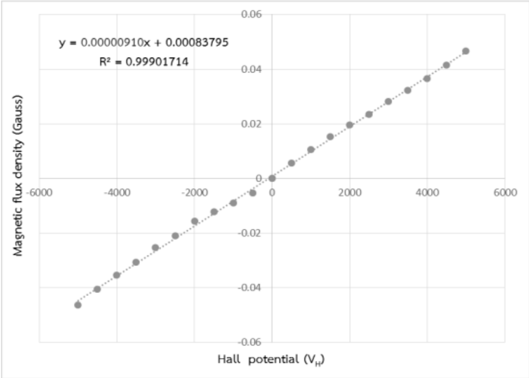
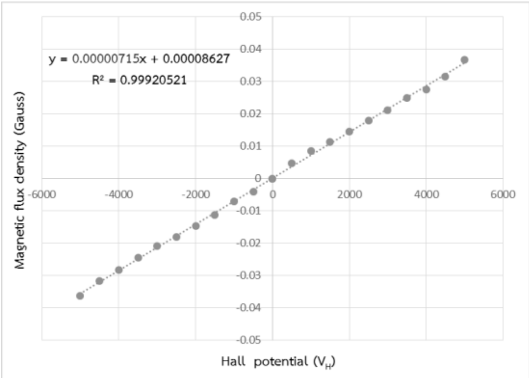


(a)



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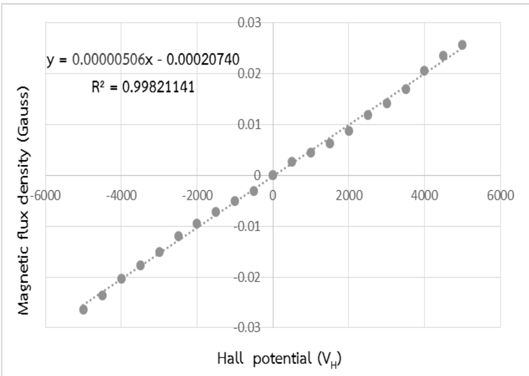

(c)

Fig. 8 Analysis results of magnetic field response sensitivity of p-type diamond Hall sensor.
(a) B/C 15,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C
(b) B/C 20,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C
(c) B/C 25,000 ppm by HFCVD at 6 hrs. Substrate Temperature 750 °C

IV. CONCLUSION

The influence of parameter of p-type diamond Hall sensors, which were synthesized by HFCVD is studied. The diamond film thickness and impurity concentration affected the magnetic field response sensitivity of Hall sensor. The results can be conclude that the thickness of the p-type diamond Hall sensor and impurity concentration increased, the response sensitivity to magnetic field decreased.

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