The Study of Fabricated N-Type Diamond for Hall Sensor by Hot Filament Chemical Vapor Deposition (HFCVD) Method

Prasert Chanthep, Wasin Panyalert, Vilailuck Siriwongrungson, Narin Atiwongsangthong and Wisut Titiroongraung, *Member, IAENG*

Abstract— **In this research, the study of fabricated n-type diamond for Hall sensor by hot filament chemical vapor deposition (HFCVD) method is presented. The fabricated n-type diamond film doped with phosphorus in ethanol (C_2H_5OH) at P/C ratio of 10,000 ppm was synthesis on silicon substrate at 750 °C for 12 hours. Its morphology, crystallinity and types of carbon were analyzed using optical microscope and Raman spectroscope. The structure of n-type diamond for Hall Sensor comprises of four silver paste electrodes on the surface of the fabricated n-type diamond film. An electrical property of electrode, Ohmic, was tested on the fabricated silver paste electrodes. The impact of temperature on the fabricated n-type diamond for Hall sensor was evaluated. The operating temperature as high as 240 °C was observed. Magnetic response characteristic of the fabricated n-type diamond was measured. The absolute sensitivity of 9 µV/Gauss was observed. Properties of the fabricated n-type diamond for Hall sensor under operation were measured. The electrical density is 1.82 x 10^{15} cm^{-3}, electrical resistance is 5.443 Ω·cm and electrical mobility is 630 cm^2/v-sec.**

Index Terms—**HFCVD, n-type diamond, Hall sensor**

I. INTRODUCTION

Nowadays, the structure of diamond carbon is another popular semiconductor due to its remarkable properties. It has band gap of 5.5 eV, which is five times higher than silicon. This can be implied that if we built a semiconductor device using this diamond structure of carbon, it can be used in higher temperature than silicon. In this research, we studied the fabrication process of n-type diamond for Hall sensor by HFCVD method and investigated the effect of temperature on the fabricated n-type diamond Hall sensor. Various parameters such as density of electrical resistance and electrical mobility; can be calculated.

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

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

V. Siriwongrungson is with the College of Advanced Manufacturing Innovation, King Mongkut's Institute of Technology Ladkrabang, Bangkok Thailand. (e-mail: vilailuck.si@kmitl.ac.th).

N. Atiwongsangthong is with the Electronics Department, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok Thailand. (e-mail: narin.at@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).

II. THEORY

The diamond film synthesis by HFCVD (hot filament chemical vapor deposition is a low cost method. The synthesis by HFCVD method is shown in figure 1.

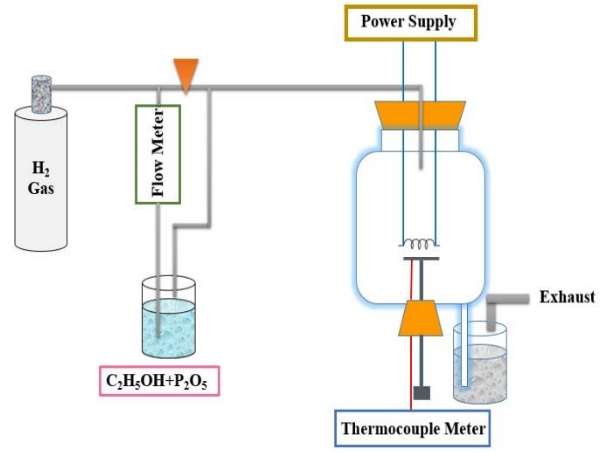

Fig. 1. HFCVD synthesis method.

Firstly, hydrogen gas (H_2) flows through ethanol (C_2H_5OH), which is mixed with phosphorus penta-oxide (P_2O_5). Atoms of carbon and phosphorus are transported by hydrogen gas (H_2) into a chamber that provides activated heat at 2,000 °C from a hot filament in the chamber. This reaction causes the atoms of carbon and phosphorus to break and then fall on a silicon substrate at 750 °C. Finally, the broken carbon and phosphorus atoms Compose to n-type diamond film.

According to Hall effect study [1], it can be confirmed that there are two different carriers in semiconductor. These are electron and hole. The Hall effect can also identify the type of semiconductor and use to calculate electrical density, electrical resistance and electrical mobility as shown in (1), (2) and (3), respectively. Electrical density, electrical resistance and electrical mobility can be calculate from equations as follows. Figure 2 shows the Hall effect and phenomenon occurred in n-type semiconductor.

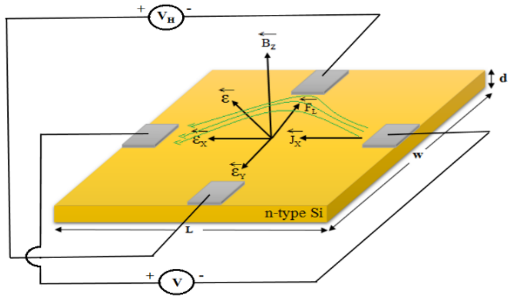

Fig. 2. Hall effect and another phenomenon in n-type semiconductor.

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electrical density

$$n = \frac{1}{qR_H} = \frac{I_X B_Z}{qd.V_H} \qquad (1)$$

electrical resistivity

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

electrical mobility

$$\mu_{p,n} = \frac{1}{p\cdot(p,n)\cdot q} = \frac{1}{\rho}\cdot R_H \qquad (3)$$

where, V is voltage, w is width, I_x is current, ρ is resistivity, B_z is magnetic field, q is electron charge, V_H is Hall voltaged d is thickness, R_H is Hall coefficient and L is length.

Optical microscope at 1,500x is normally applied to characterize the structure and surface of synthesis diamond.

The Raman spectroscopy technique is used for analysis of carbon type through the Raman spectrum, which indicates types of bonds between carbon atoms.

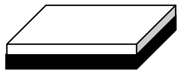
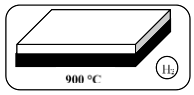
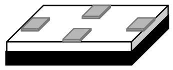
III. The Fabrication Process N-Type Diamond for Hall Sensor.

The process of n-type Hall sensor building by HFCVD is as follow. Firstly, prepare a 5 mm. x 5 mm. silicon substrate and scrub the surface by diamond paste. Secondly, clean the substrate after preparation using acetone. Then the carbon is synthesized by HFCVD method with addition of phosphorus substance at P/C ratio of 10,000 ppm at 750 °C for 12 hours. After that, the synthesis diamond film was annealed to improve the quality of the diamond film under hydrogen atmosphere at the substrate temperature of 900 °C for 9 minute. Lastly, the synthesis diamond film surface was characterized using optical microscope and the type of carbon was analyzed using Raman spectroscope. The carbon type will be compared with carbon type as shown in Table I

TABLE I
Analysis of Carbon Type Using Rama Spectroscopy [2]

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	Hexagonal diamond	Broad band, observed in shock wave produced diamond.
1332	Cubic diamond	First order peak with FWHM of 19 cm^{-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.

TABLE II
Fabrication Process of N-Type Diamond for Hall Sensor

Figure	Description
	Prepare a 5mm.x 5 mm. silicon substrate, scrub the surface by diamond paste, and clean the substrate after preparation.
	The synthesis of diamond film by HFCVD method.
	Annealing of the synthesis diamond film under hydrogen atmosphere at the base temperature of 900 °C for 9 minute.
	Building four silver pastes on the surface of n-type diamond film.

The overall fabrication process of n-type Hall sensor is summarized in Table II.

After the fabrication, all four silver pastes was electrical tested to study type of contracts as show in Figure 3.and measured the temperature of n-type Hall sensor.

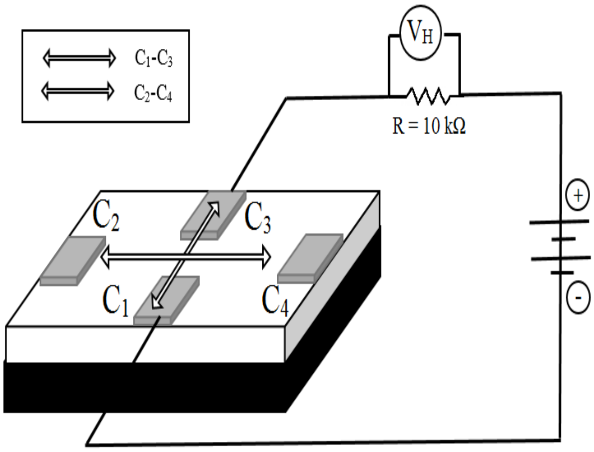


Fig. 3. Electrical test for study type of contracts.

The responsibility test of n-type diamond Hall sensor to magnetic fields is shown in Figure 4. The data obtained is used to calculate the electrical density, electrical resistance and electrical mobility, respectively.

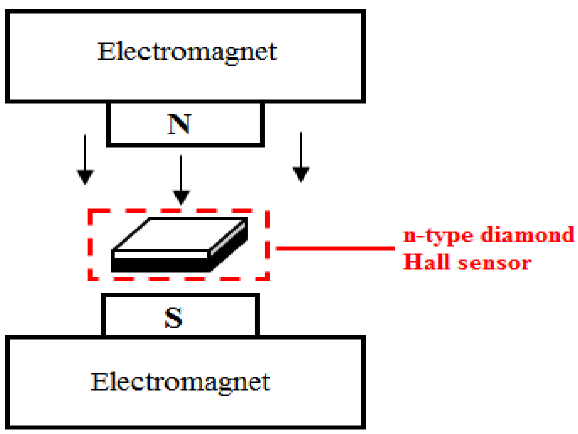


Fig. 4. The responsibility test of n-type diamond Hall sensor to magnetic fields.

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IV. Result and Discussion

Diamond film synthesized by HFCVD method at silicon substrate 750 °C for 12 hours was characterized using optical microscope at 1,500x. The image obtained is shown in Fig. 5.

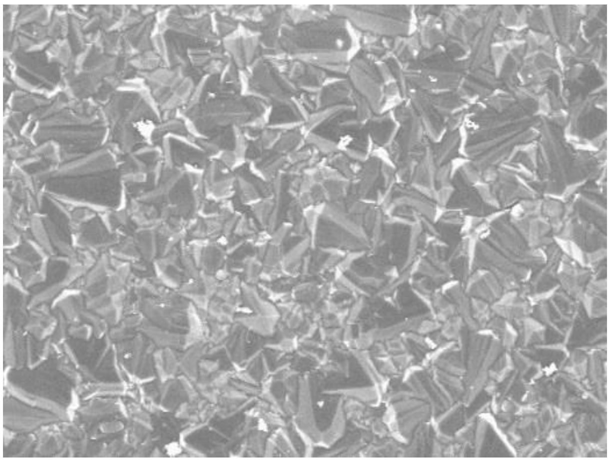

Fig. 5. The surface of diamond film synthesized by HFCVD method at substrate temperature of 750 °C for 12 hours. Diamond film thickness is 100 µm.

Figure 5 shows the surface of diamond film with triangle and plane (111). After that, type of carbon of the diamond film was analyzed using Raman spectroscope.

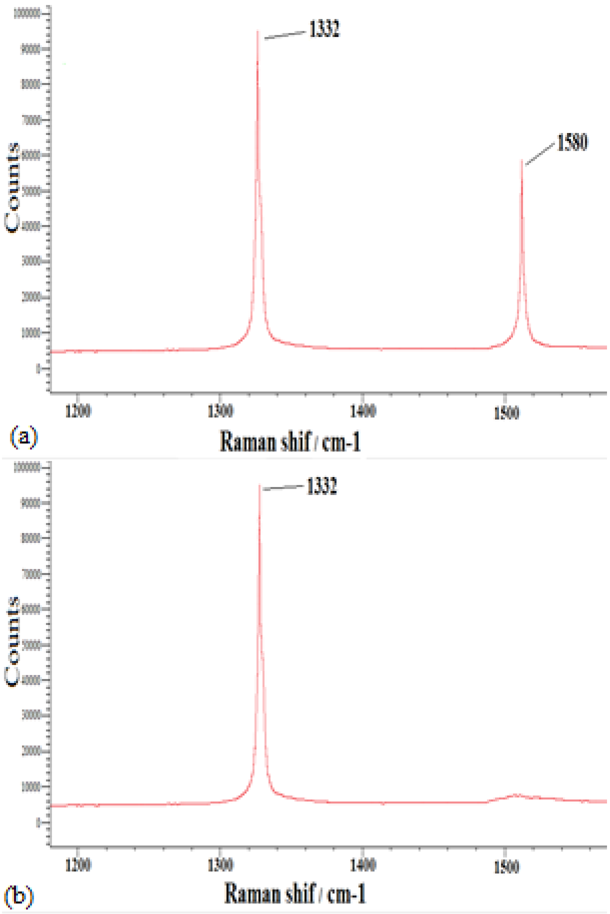

Fig. 6. Raman spectrum of the diamond film synthesized by HFCVD at substrate temperature of 750 °C for 12 hours (a) Raman spectrum of n-type diamond film before annealing (b) Raman spectrum of n-type diamond film after annealing.

From Figure 6 (a) there are 2 peaks at 1332 cm^{-1} and 1580 cm^{-1} .When compare these peaks with Table I, these peaks correspond to diamond and graphite, respectively. As a result, the graphite, which is a contaminant, was removed by annealing method at substrate temperature of 900 °C for 9 minute under hydrogen atmosphere [3]. After that, the annealed film was reanalyzed using Raman spectroscope. The graphite's peak decreased drastically as shown in Fig. 6 (b). The annealed film was taken to build the n-type diamond Hall sensor according to Table II and test its electrical properties.

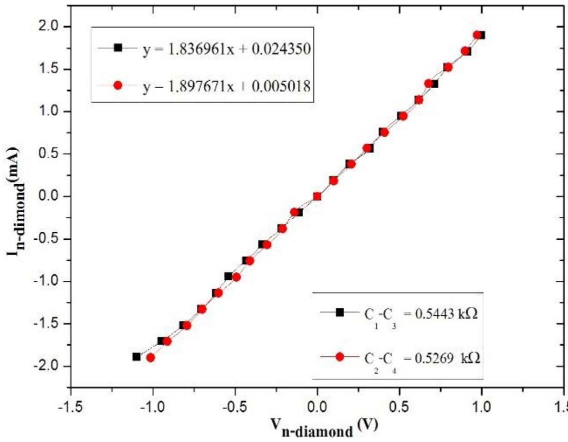

Fig. 7. Result of electrical test.

From Fig. 7, the relationship between current and voltage, from the measurement of C_1- C_3 and C_2- C_4, is linear that follows the Ohm's theory. The linear equation, which is y = 1.836961x + 0.024350, can be used to calculate the resistance of the C_1- C_3. The resistance is the inverse of the slope, which is equal to 0.5443 kΩ. This relationship shows Ohmic properties of the fabricated contacts. Then, the effect of temperature on n-type diamond film was tested. The result is shown in Fig. 8.

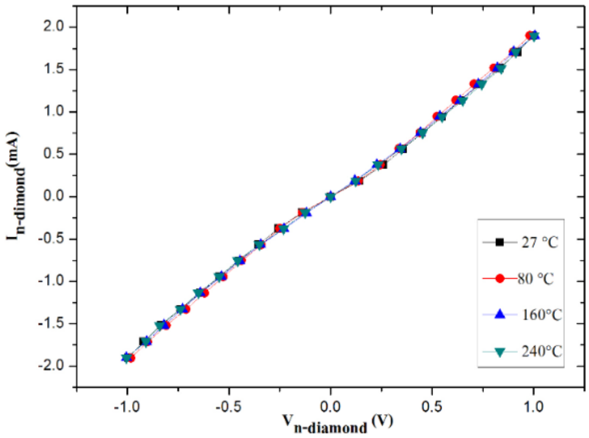

Fig. 8. The relationship between current and voltage of n-type diamond film at different temperatures.

From Fig. 8, when test the electrical properties of n-type diamond film at different temperatures at 27, 80, 160, 240 °C, respectively, it was found that the electrical properties of n-type diamond film did not change with temperatures. This can be observed from the linear relationship between current-voltage and temperature. The slope of each graph is relatively similar. Therefore, it can be implied that this n-type diamond film can be used in high temperatures up to 240 °C without electrical property changes.

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The responsibility to magnetic fields of n-type diamond Hall sensor was tested and the obtained values was used to calculate critical parameters as shown in Figure 9.

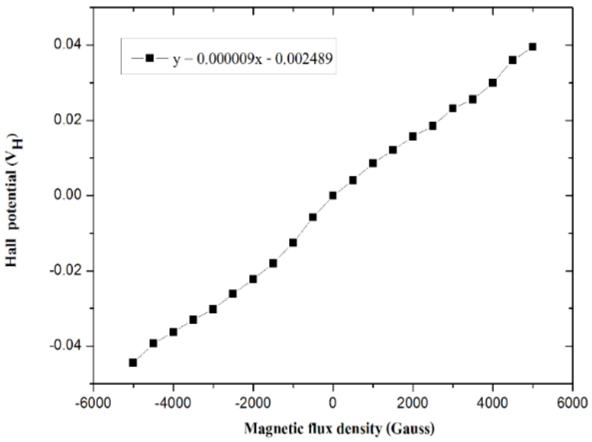

Fig. 9. The responsibility to magnetic fields of n-type diamond Hall sensor.

Figure 9 shows the responsibility of n-type diamond Hall sensor to magnetic fields. The relationship is linear with linear equation y = 0.000009x + 0.002989, which indicates the ability of response. From the slope, the absolute sensitivity is equal to 9 µV/ Gauss. Regarding the obtained data, electrical density and electrical mobility can be calculated from (1) and (2), respectively. The calculated electrical density and electrical mobility is equal to 1.82 x 10^{15} cm^{-3} and 630 cm^2/V-sec, respectively.

V. Conclusion

From the study of the fabrication process of n-type diamond for Hall sensor by HFCVD method, it is shown that the synthesized n-type diamond film can be used to build Hall sensor. The result of electrical properties testing at different temperatures shows that the electrical properties of n-type diamond film remain unchanged. Therefore, it can be used at high temperatures up to 240 °C. The responsibility testing with magnetic field shows the absolute sensitivity is equal to 9 µV/Gauss. The electrical properties of n-type diamond Hall sensor are electrical density, electrical resistance and electrical mobility, which are equal to 1.82 x 10^{15} cm^{-3}, 5.443 Ω·cm and 630 cm^2/V-sec, respectively.

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