Effect of Nitrogen Doping in Amorphous Carbon Thin Films Grown By Thermal Chemical Vapor Deposition (CVD) Method

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Abstract-Thin films of amorphous carbon with different nitrogen were deposited on quartz substrate by Thermal flow rates Chemical Vapor Deposition (CVD) technique. Camphor oil was used as the precursor while argon and nitrogen were used as carrier gas. The electrical, optical and structural properties were characterized by using Bukoh Keiki (CEP2000) Solar Simulator system at room temperature, Perkin Elmer (LAMBDA 750) UV/Vis spectroscope, Raman spectroscope and Atomic ForceAtomic XE-100 PARK SYSTEM Microscope (AFM) respectively. There are significant changes in conductivity (dark and illumination), optical bandgap and structural properties when Nitrogen doping was introduced and the flow rate was varied .Nitrogen flow rate of 30 bubbles per minute sample gives the highest value of conductivity, absorption coefficient and intensity and have a narrow band gap.

Keywords - Amorphous carbon thin films; Camphor oil; Thermal Chemical Vapor Deposition (CVD); Electrical **Properties; Optical Properties; Structure Properties**

I. INTRODUCTION

Carbon is often considered to replace silicon in the future because of the unique properties resulting from the variety of possible structural forms such as graphite, diamond, nanotubes and fullerenes [1]. Carbon also occurs in amorphous form like soot, carbon fibers and evaporated carbon, and it is also believed that many more forms of carbon are yet to be discovered [2].

Amorphous carbon (a-C) is an interesting material with mechanical and electronic properties close to those of diamond. a-C thin film are also cheap and environmentally benign material with outstanding properties such as chemical inertness, high hardness, high electrical resistivity and tunable band gap by adjusting sp² and sp³ carbon bonding ratio for semiconductor technology [3]. In recent research, amorphous carbon (a-C) has been shown to behave as a semiconducting material, which is able to accept dopants, shows photoconductivity and suitable for optoelectronic devices due to its chemical inertness, high electrical resistivity, high thermal conductivity, high dielectric strength, infrared transparency and band gap varying over a wide range from 5.5 eV for insulating diamond to 0.0 eV for metallic graphite [4].

Doping of impurities such as nitrogen (N) and phosphorus (P) can modify optoelectronic properties of the films by increasing either the electron or hole concentration in the semiconductor device. The incorporation of N can strongly decreased defect density, which gives prospects on its use as a semiconductor material. However, there are some problems such as low conversion efficiency due to the sp²/sp³ bonding structure and the difficulties in controlling the conduction type, carrier concentration and optical band gap [5].

Camphor (C₁₀H₁₆O) is very cheap, and also user-friendly for pyrolysis due to its volatile and non-toxic nature. It is a white crystalline solid that sublimes even at room temperature and melts at 180°C [2]. Camphor (C₁₀H₁₆O) was used as carbon source in thermal CVD system to form a-C thin films. Since of camphor (C₁₀H₁₆O) has both sp² and sp³hybridized bonds, it was used as starting material to prepare a-C films with various sp^2/sp^3 ratios [6].

Thermal CVD, electron gun evaporation, sputter deposition, cathodic arc deposition, and pulsed laser deposition were the different techniques to deposit the a-C thin films but the thermal CVD process is the most economical method in the production a-C [7].

In this report, the a-C thin film was prepared by using Thermal Chemical Vapor Deposition (CVD) process. The effect of carrier gas flow rate was studied. The experimental results were analyzed in terms of their electrical properties, optical properties and structural properties.

Π METHODOLOGY

Α. Material Preparation

The process starts by cleaning the glass substrate with Acetone C₃H₆O) using an ultrasonic cleaner (Power Sonic 405) for 10 minutes. Next, the glass substrate was cleaned again with methanol (CH₃OH) using an ultrasonic cleaner for 10 minutes followed by rinsing with deionised (DI) water. Lastly, the glass was dried with nitrogen gas (N_2) .

B. Thermal CVD Preparation

Experimental procedure for the a-C deposition was divided into the preparation of the undoped thin film followed by the nitrogen doping. The a-C thin films were deposited onto the quartz substrates using the Thermal CVD method with camphor oil as the precursor and Argon gas as the carrier gas. From Figure 2, it shows that the Thermal CVD method consists of two furnaces, a quartz tube and water bubbler system. The first furnace (F1) used to vaporize camphor oil (3ml) was set at 200 °C and the second furnace (F2) was used to deposit a-C thin film with fixed temperature of 550 °C. Before the deposition of a-C thin film start, the whole deposition unit was filled with carrier gas for approximately 10 minutes in order to flush out the air inside the quartz tube. When the substrate reached the desired temperature, camphor oil kept in combustion boat was vaporized at 200°C and the vaporized gas was allowed to pass inside the quartz tube. Argon gas was flushed until the furnaces were cooled down to room temperature. For nitrogen doping, the nitrogen were introduced as dopant by changing the carrier gas, argon with nitrogen gas. The carrier gas flow rate was varied at 15 bubbles per minutes, 30bubbles per minutes, 45bubbles per minutes and 60bubbles per minutes. The deposition time of the thin film was 30minutes. The optical characterization of deposited a-C thin films was investigated using UV-Vis spectroscopy measurements and I-V characteristics of dark and under illumination were measured by Bukoh Keiki (CEP2000) Solar Simulator system at room temperature. Atomic Force Microscopy XE-100 PARK SYSTEM and Raman spectroscope were used for structural properties characterization.



Figure 1: Flowchart of methodology



Figure 2: Schematic diagram of thermal CVD system (A) Double furnace setup (B) Substrate (C) Combustion boat with camphor oil (D) Water bubbling system (E) Carrier gas cylinder (F) Temperature controller (G) Quartz tube

III RESULT AND DISCUSSION

A. Electrical Properties

The electrical properties are one of the important ways to address many issues related to the electronics structure and properties of a-C thin films [4]. Figure 3 and Figure 4 shows the IV measurement of nitrogen –doped a-C thin films using BUKOH KEIKI (CEP 2000) Solar Simulator /spectral sensitivity measurement was done by two probe method using gold as the metal contact(Thickness = 60nm). The function of the gold metal contact is to act as the conductor material to get the ohmic contacts with the a-C: N thin films. The thickness of the thin films was measured using Surface Profiler VEE CD/D 150+. Table 2 and Table 4 shows the summary of thickness obtained from undoped and doped a-C thin films sample at different nitrogen flow rates respectively. From the I-V curve, the value of resistivity (ρ) and conductivity (σ) was calculated using the following equation (1) and (2):

$$\rho = \left(\frac{\varphi}{t}\right) \left(\frac{\omega t}{t}\right) \qquad \text{In unit } \Omega.\text{cm} \qquad (1)$$

$$\sigma = \frac{1}{t} \qquad \text{In unit S.cm}^{-1} \qquad (2)$$

where w is the width of the electrode, t is the thickness of the a-C thin film and L is the distance between the electrodes.



Figure 3: Current-voltage (I-V) measurement of doped a-C thin films at different nitrogen flow rates in dark.



Figure 4: Current-voltage (I-V) measurement of doped a-C thin films at different nitrogen flow rates under illumination.

Figure 5 shows the electrical conductivity of the undoped and nitrogen doped a-C thin films at the same gas flow rate of 30 bubbles per minute and the details of conductivity in dark and under illumination was summarized in Table 1.From the result it was observed that the conductivity increase from 3.19822x10⁻⁶Scm⁻¹ to 7.61416 x10⁻⁶Scm⁻¹ (in dark) and 8.2170 x10⁻⁶ Scm⁻¹ to 8.7018 x10⁻⁶ Scm⁻¹ (under illumination) when nitrogen doping is introduced. This is due to the nitrogen doping in the films, where large amount of C and N atoms can form the C-Nx bonds, and as an impurity center it has activated the films conductivity performance, which leads to the increase of the electrical conductivity [14]. Other than that, the conductivity change arises essentially from an increase in mobility, with the free electron concentration remaining practically unchanged. [15].It is also due to the increase in density of defects and activation energy with nitrogen incorporation. [16].

The Figure 6 shows electrical conductivity as a function of flow rate in dark and illumination while the Table 3 indicated their details value. The conductivity increase from 1.3078×10^{-6} Scm⁻¹ to 7.6141×10^{-6} Scm⁻¹ when the flow rate increase from 15 bubbles per minute to 30 bubbles per minutes. It is assume that at 15 bubbles per minute the Nitrogen atom does has not enough energy to form bonding with the a-C atom due to the slow flow of Nitrogen gas in the quartz tube and results in low level of Nitrogen doping with a-C. However, when the carrier gas flow rate increase to 45 bubbles per minute and 60 bubbles per minute the value of conductivity decrease to 3.3701×10^{-6} Scm⁻¹ and $1.9262 \times$

10⁻⁶Scm^{-1.} It is believe that the faster carrier gas flow in the quartz tube reduce the chances of Nitrogen bonding to form with a-C results only small percentage of doping occurred. This is due to the Nitrogen as n-type dopant in a-C consist more electrons that can generated more current inside the thin films and plays an important role in the increase of the electrical conductivity [8].Increasing the conductivity also can be related to the effective doping [17].Therefore, the small percentage of Nitrogen doping in a-C results the low conductivity. Besides that, all the illumination samples show an improvement in conductivity value compared to the samples without illumination condition as shown in Table 1 and Table 3 because of the generation of excess carriers. The excess carriers are possible due to the existence of sp² rich in

interfacial layer [12]. This indicates the photoresponse characteristic for the thin films. Nevertheless, Figure 4 shows the photoresponse of undoped sample higher than Nitrogen doped sample at the same condition (30 bubbles per minute). This is because, when Nitrogen introduced in a-C thin films, the a-C thin film become thicker. So, it is difficult for electron to move due to the surface states increase with increasing film thickness [25] and decrease the excess carriers generation.



Figure 5: Electrical conductivity (0) of undoped and Nitrogen doped a-C thin films in dark and under illumination.

TABLE 1: CONDUCTIVITY (DARK AND ILLUMINATION) OF DOPED AND UNDOPED A-C THIN FILMS

Flow rate	Conductivity (x 10 ⁻⁶ S.cm ⁻¹)		
(Bubbles per minute)	undoped	Doped	
Dark	3.1982	7.6142	
Illumination	8.2170	8.7018	

TABLE 2: THICKNESS FOR DOPED AND UNDOPED

Sample	Thickness(nm)
Undoped	34.488
Doped	41.814



Figure 6: In dark and illumination electrical conductivity (o) as a function of flow rate

TABLE 3: CONDUCTIVTY IN DARK AND ILLUMINATION OF DOPED A-C THIN FILMS AT DIFFERENCE NITROGEN FLOW RATES

Flow rate(bubbles per	Conductivity (x 10 ⁻⁶ S.cm ⁻¹)		
minute)	dark	illumination	
15	1.3078	1.6007	
30	7.6141	8.7017	
45	3.3701	3.4537	
60	1.9262	2.0955	

TABLE 4: THIN FILMS THICKNESS AT DIFFERENCE NITROGEN FLOW RATES

Flow rate(bubbles per minute)	Thickness(nm)
15	35.540
30	41.814
45	37.648
60	32.334

B. Optical Properties

The optical properties of a-C thin films were characterized using UV-Vis-NIR spectrophotometer was carried out in the range 200-2000nm. The transmittance, absorption coefficient and the optical bandgap are the three main aspects related to the optical properties. The absorption coefficient (α) and energy bandgap (E_g) was calculated by transmittance and thickness. The absorption coefficient was obtained from the equation (3).

$$\alpha = \frac{1}{t} \left(\ln \frac{1}{\tau} \right) \tag{3}$$

where t is the thickness of the thin films and T is the transmittance.

Figure 7 shows the transmittance spectra of the undoped and nitrogen doped a-C thin films at different nitrogen flow rates. The transmittance decrease from 87% to 86% when nitrogen doping was introduced at the visible region from 390nm to 790nm (~ 1.56eV to 3.18eV), which contain the largest amount of energy based on the solar spectrum. This attributed to the light scattering induced by large density of defects and impurities [24]. The 60 bubbles per minute flow rate sample has the highest transparency (98%) followed by the 15 bubbles per minute (93%) and 45 bubbles per minute (92%) while the 30 bubbles per minute flow rate sample has the lowest transmission (86%). The high value of transmittance indicate the imperfection of Nitrogen doped a-C thin films growth for particular flow rates [6].

Absorption coefficient, α was used to express the measurement of how far the light can be penetrated inside the thin film before it is absorbed by that thin film. Equation 3 clearly indicated that the calculation of absorption coefficient, $\boldsymbol{\alpha}$ depends on the transmittance value and also the thickness of the thin film, t. Therefore, the higher transmittance can give the lowest absorption coefficient.Refer to the Figure 8, the absorption coefficient of undoped sample is high than nitrogen doped a-C thin films at same condition (30 bubbles per minute). This is because absorption coefficient depends on material and also on the wavelength of light which is being absorbed. the light which energy below the band gap does not have sufficient energy to raise an electron across band gap and therefore this light is not absorbed[4] and results the low absorption coefficient . Besides that, undoped sample were deposited in pure Argon ambient possesses low transmittance owing to higher absorption as a result of the higher content of sp^3 -bonded carbon atoms[8]. The result obtained is in the range $\sim 10^5$ cm⁻¹ same as reported by other researcher [20].

For the nitrogen doped a-C thin films, the 30 bubbles per minutes flow rate sample results in the higher absorption coefficient followed by 15 bubbles per minute, 45 bubbles

per minute and 60 bubbles per minute flow rate sample has the lowest absorption coefficient. The high absorption in the power-law (Tauc) region is ascribed to the presence of more graphitic component (sp^2 bonds) in the carbon film [9]. The slight absorption for 45 bubbles per minute and 60 bubbles per minute flow rate sample in the visible light region was attributed to that few substitutionally nitrogen existing in them.

The gap between the extended state in the valence band and the conduction band is called optical bandgap. The optical band gap has been calculated using the Tauc plot equation:

$$(ahv)^{1/2} = B(E_g - hv)$$
 (4)

where α is the absorption coefficient, B is the Tauc parameter, h is Planck constant while \mathbf{v} is frequency and hv is the photon energy.

Figure 9 shows the plot of $(\alpha hv)^{\frac{1}{2}}$ as a function of photon energy (hv) and Table 5 shows the summary of optical bandgap obtained from undoped and doped a-C thin films at 30 bubbles per minute gas flow rate. From the results obtained the optical bandgap energy of a-C thin film decrease from 0.65 to 0.60eV with nitrogen incorporation. The optical properties of amorphous C films are known to be dominated by $\pi - \pi^*$ and $\sigma - \sigma^*$ electronic transitions, along with $\pi - \sigma^*$ and $\sigma - \pi^*$ transitions. The $\pi - \pi^*$ contribution originates exclusively from sp² carbon [26]. The change of optical gap can be related to structural change in a-C thin film. This is because of the presence of nitrogen inclusions that act as bridging atoms between clusters. This in turn increases the size of sp² clusters, broadening the associating π and π^* states and decreases the E_{ρ} [10]. On the other hand, low Tauc optical bandgap induces high absorption coefficient of the thin film. [11].

Refer to Table 6, the optical bandgap of 15 bubbles per minute is 1.18eV. But, when the flow rate increases from 15 bubbles per minute to 30 bubbles per minute the optical bandgap was decreased to 0.60eV. It is assume that the decrease of optical bandgap due to improvement of nitrogen content in the a-C thin film. This may be due to an increased sp² form of carbon bonding or N-induced graphitization of the films. Since π states are more weakly bonded, they lie closer to the Fermi level than the \acute{o} states. Therefore filled π states from valence bands and empty π states from conduction bands determine the characteristics of gap states[12]. However, when the Nitrogen gas flow rate varied to 45 bubbles per minute and 60 bubbles per minute the value of the optical bandgap also increases from 0.90 to 1.49eV. The Eg value also correlates with the fraction of sp³ bonded atoms, with higher values of E_g corresponding to higher values of sp³ fraction [23]. The small of Nitrogen doping with a-C give the high value of sp³ bonded atoms in the thin films and cause the increase of optical bandgap. With such a small gap, the presence of a small percentage of a doping material also causes the increase of conductivity [4].



Figure 7: UV-VIS-NIR transmission spectra of the undoped and Nitrogen doped a-C thin films at different nitrogen flow rates



Figure 8: Optical absorption coefficient edge for (a) to(d) a-C:N thin film at different nitrogen flow rates and (e)undoped.



Figure 9: The Tauc plot of $(\alpha hv)^{1/2}$ as a function of photon energy (eV) for undoped and Nitrogen doped a-C thin films at different nitrogen flow rates.

TABLE 5: THE OPTICAL BANDGAP OF UNDOPED AND DOPED A-C THIN FILMS

Sample	Optical band gap(eV)
Undoped	0.65
Doped	0.60

TABLE 6: THE OPTICAL BANDGAP OF DOPED A-C THIN FILMS AT DIFFERENT NITROGEN FLOW RATES.

Flow rate(Bubbles per minute)	Optical band gap(eV)
15	1.18
30	0.60
45	0.90
60	1.49

C. Structural properties

Raman scattering is used as a powerful technique to understand the micro-structural changes of a-C films. Raman spectra typically show two peaks, namely G and D peaks [12] The G peak centers at approximately 1580cm^{-1} , which corresponds to the only Raman-active mode in monocrystalline graphite (stretching vibration mode of the C=C double bond in the plane of the hexagonal layers). The D peak also known as the "disorder peak" centers at approximately 1350cm^{-1} , which appears in micro-crystalline or defective graphite [12].

Raman spectra of undoped and nitrogen doped a-C thin films at different nitrogen flow rates are shown in Figure 10. Figure 11 shows G-peak position, D-peak position while the I_D/I_G intensity ratio at different nitrogen flow rates was shown in Figure 12.Table 7 shows when nitrogen doping was introduced at the same condition (30 bubbles per minute) the G-peak position decreases from 1604cm⁻¹ (undoped) to 1603cm⁻¹ (doped) ,the D peak position also decreases from 1356cm⁻¹ to 1351cm⁻¹, the I_D/I_G intensity ratio increases from 0.8384 to 0.8982 ,the full width at half maximum(FWHM) of G-peak decreases from 71.61cm⁻¹ to 71.04cm⁻¹ and FWHM of D-peak width also decrease from 215.98cm⁻¹ to 213.38cm⁻¹. This reflects the structural disorder for films with nitrogen doping introduced [13]. Ferrari et. al [18] have reported that FWHM decays with an increase in nitrogen concentration. Incorporation of nitrogen into the a-C volume relaxes the lattice, which can contribute to a decrease in the position of the G band. This process can be said to predominate at the beginning, making the G position moves to a lower value of frequencies bonded carbon atoms increases. [16].



Figure 10: Raman spectra of undoped and nitrogen doped a-C thin films at different nitrogen flow rates

From the Table 8, it can be seen the value of I_D/I_G intensity ratio increase from 0.7585 to 0.8982 as the Nitrogen flow rate increase from 15 bubbles per minutes to 30 bubbles per minute. However, the value of I_D/I_G intensity ratio

decrease to 0.7855 and 0.6211 when the Nitrogen flow rate increase to 45 bubbles per minute and 60 bubbles per minute. The main feature of this result is the increase of the I_D/I_G intensity ratio with percentage of a doping occurs in the thin film. This is due to the structural disorder of thin film with higher content of Nitrogen [10] .The Nitrogen addition has replaced the C=C olefinic groups with aromatic groups [19]. The integrated intensity of the G and D peaks ratio (I_D/I_G) increases with higher N content, leading to an enhancement and clustering of sp² phase. The suitable flow rate of Nitrogen induces the dissociation/ recombination of species and the formation of a large amount of disorder and defects in the deposited films [19]. FWHM(The Full Width at Half Maximum) of G-peak increase from 64.1531 to 71.0374 and FWHM of D-peak also increase from 186.7445 to 213.3840 when the Nitrogen flow rate increase from 15 bubbles per minutes to 30 bubbles per minute but decrease to 61.1632 and 52.5900 when the flow rate increase to 45 and 60 bubbles per minute. The FWHM depend on composition and disorder of the thin film as well as on incorporation of impurities [18].The FWHM is said due to the site-to-site variation in the number of next nearest neighbour that is, when sp² carbon atoms have sp³ neighbours [21].So, as I_D/I_G ratio high and the G-peak line width broad, the size of the sp² clusters in the films becomes larger. Therefore, the fraction of sp²-bonded carbon atoms increases [11].The increase of sp²-bonded leads to more graphitization of a-C thin films.

TABLE 7: RAMAN SHIFT, INTENSITY, RATIO OF INTENSITY (ID/IG) AND FWHM FOR UNDOPED AND NITROGEN DOPED A-C THIN FILMS.

Sample	Raman sl	nift(cm ⁻¹)	Intensity		FWHM(G)	FWHM(D)	
	G peak	D peak	ID	IG	I_D/I_G		
	position	position					
Undoped	1604	1356	104.9570	125.1873	0.8375	71.6092	215.98
Doped	1603	1351	131.1714	146.0379	0.8982	71.0374	213.38

TABLE 8: RAMAN SHIFT, INTENSITY, RATIO OF INTENSITY (I_D/I_G) and FWHM FOR DOPED A-C THIN FILMS AT DIFFERENT NITROGEN FLOW RATES.

Flow rate	Raman sl	hift(cm ⁻¹)	Intensity		I _D /I _G	FWHM(G)	FWHM(D)
(Bubbles Per	G peak	D peak	ID	IG			
minute)	position	position					
15	1604	1353	32.7371	43.1610	0.7585	64.1531	186.7445
30	1603	1351	131.1714	146.0379	0.8982	71.0374	213.3840
45	1605	1352	28.8586	36.7389	0.7855	61.1632	179.8562
60	1607	1355	8.4462	13.5997	0.6211	52.5900	120.9444



--- Intensity ---- Intensity --- Intensity ---- Intensity ----

Figure 12: Intensity ratio I_D/I_G of doped a-C thin films at different nitrogen flow rates

Figure 11: G-peak position and D-peak position of doped a-C thin films at different nitrogen flow rates

D. Surface Morphology

The Atomic Force Microscopy (AFM) was used to characterize the surface morphologies of the thin films. The surface roughness, defined as the measurement of the variation in height of the surface [22] was studied.

AFM analysis (Figure 13) done on undoped and Nitrogen doped a-C thin films show the presence of grains that are agglomerated and lack definite grain boundaries. Table 9 shows the details of surface roughness for undoped and Nitrogen doped a-C thin films. The surface roughness was increase from 0.118nm to 0.164nm when Nitrogen introduced to the a-C thin films. The increase in surface roughness with the increase in film thickness is due to grain growth during the deposition [19]. The increase of roughness in Nitrogen doped a-C thin films would be due to the presence of Nitrogen atom in a-C thin films and increase of grain boundary.



Figure 13: AFM image of (a) undoped and (b) doped

 TABLE 9: SURFACE ROUGHNESS FOR UNDOPED AND NITROGEN

 DOPED A-C THIN FILMS

Sample	Roughness(nm)
Undoped	0.118
Doped	0.164

Figure 14 shows AFM image of Nitrogen doped a-C thin films with different flow rate and the details of surface roughness indicated in the Table 10. It can be seen that the roughness of thin films decrease from 0.216nm to 0.164nm when the nitrogen gas flow rate increase from 15 bubbles per minute to 30 bubbles per minute. Then, the value of surface roughness of thin film increase from 0.205nm and 1.118nm as flow rate increase from 45bubbles per minute to 60 bubbles per minute .The roughness can be related to the Nitrogen content in the a-C thin film. This is because the suitable flow rate leads to an augment of transference rate of films surface atoms. The result of transference of surface atoms is the fluctuant vales and peaks of the surface are levelled off, thus the surface energy and roughness decrease. The above conclusions all demonstrate that effective nitrogen doping can make the films surface become more homogeneous and thus improve the films surface morphology [23]. It also due to the increase of sp² in the a-C that leads to decrease of dangling bond.Dangling bonds is defines as error in structure creations or can be say as the unsatisfied valence in immobilized atom. Due to decrease in dangling bond, there is a decrease of small particulate with lower grain boundaries [8]. The reduction in

grain boundary can be said that the particles in the a-C thin film are close to each other, and thin films become smoother.



Figure 14: AFM image of Nitrogen doped a-C thin films at different Nitrogen flow rate (a) 15b/m (b) 30b/m (c) 45b/m and (d) 60b/m.

TABLE 10: SURFACE ROUGHNESS FOR NITROGEN DOPED A-C THIN FILMS AT DIFFERENCE FLOW RATE

Flow rate (Bubbles per	Roughness(nm)
minute)	
15	0.216
30	0.164
45	0.205
60	1.118

IV CONCLUSION

The electrical, optical and structural properties of nitrogen doped amorphous carbon thin films prepared by Thermal Chemical Vapor Deposition (CVD) method have been investigated as a function of N₂ flow rate. It was found that the presence of n-type doping which is the N₂ effect the value of conductivity and optical band gap of the thin film. When nitrogen doping was introduced, the value of conductivity increases, optical bandgap decrease and Raman intensity increase. It can be conclude that the doping can change the properties of a-C thin films. The 30 bubbles per minute samples give the optimum value of conductivity, absorption coefficient, and intensity ratio and have the narrow band gap. The change of the optical and electrical properties of a-C: N film with different nitrogen flow rate probably due to the modification of C–N bonding (decreasing sp³ bonds) configuration leading to more graphitization. In a conclusion, the appropriate flow rate results the effective Nitrogen doping on a-C thin films and Nitrogen doping with 30-bubbles per minute are most preferable. In the future, it is recommended to the surface morphology measurement of Nitrogen doped amorphous Carbon using field emission scanning electron microscope (FESEM).Beside that, it is also possible to use other natural precursor that has high carbon content such as coconut oil.

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