Breakdown Voltage of Carbon Ionised by Impurity of Butane and Air at Slightly Atmospheric Pressure

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Abstract: This paper investigates the breakdown voltage of Carbon ionised affected by butane and air gas impurities at slightly atmospheric pressure. The ionization process is conducted by electrical discharge using graphite electrode with the gap in millimeter scale to generate plasma by the direct current voltage less than 3.5kV. The experimental results show the breakdown voltage and current of plasma. Carbon plasma density and temperature are calculated from the current and voltage. These results show the ionization of air at slightly low pressure having a maximum voltage of 570V. The breakdown voltage and current are respectively 530-570V and 0.27 to 0.45mA. At high pressure it has a maximum voltage of 1160 V, the voltage and the current breakdown are respectively 900-1100V and 0.46 to 0.6 mA. When gas impurities are injected at slightly low pressure, it has maximum voltage of 772V, the breakdown voltage is 536-775V and the current is 0.03 to 0.45mA, whereas at high pressure it has a maximum voltage of 1044V, the breakdown voltage is 675-105 V and the current is 0.03 to 0.69mA. The results are interesting phenomena and can also be applied to develop a level of purity of Carbon Nano Tube formation at the cathode end of the effects of the density and temperature of the plasma generated.

Keywords: Arc Discharge, DC Voltage Ionization, Plasma Carbon,

1. Introduction

The development of atmospheric plasma and technology research is nowadays increasingly important in industries such as steel cutting, welding, as a source of energy and the development of materials, especially to grow Carbon Nano Tubes (CNTs) in the cathode surface as well [1]. Particularly in the growth of CNTs, the effort to ionize the gas, produce and grow CNT remains a research choice today. Many research results are found, such as a mixture of Helium-Argon gases has been carried out to generate plasma by arc-discharge technique at atmospheric pressure using a mixture of Nickel and Yttrium catalysts. This ionization process produces Single-walled-nanotubes (SWNTs) purified by oxidation and centrifugation techniques [2]. CNTs have attracted great attention due to the demands of nanotechnology, conservation and storage energies, and large nanosensors. CNTs have been produced effectively by arc-discharge methods at atmospheric pressure using a gas mixture and are essential for producing high density Carbon species [3]. The degree of purity of ionization is very important to be observed in forming CNTs, especially ionization products with high purity Carbon species in generating CNT density in their structural and geometric diversity. The gases used are Methane, Argon, Helium and Argon + Helium mixtures [4]. Another example is the method of arc discharge method, laser ablation, HIPCo, Molten Salt Technique and chemical vapor deposition (CVD) [5]. The arc discharge method is
the first method used in finding CNTs and this method is the easiest and most efficient method of generating carbon ion ionization [6].

Given the impurity of ionized gases causing source and media factors greatly affect CNT formation. The source of the voltage breakdown on ionization will experience some contribution and resistance to the formation of Carbon ions. At a small electrode distance and diffusion length will also deliver ionizing effects that require varying energy. The DC voltage source is expected to deliver a positive Carbon ion to the negative cathode so that its mobilization can be formed in large quantities and regular structures and geometries. Under the same conditions high voltage power and the impurity of air in the Alkane group gas will increase the higher the breakdown voltage. In the case of a high-density gas, the collisions of gases mostly produce elastic collisions or electron excitations in atoms amongst particles, and polarization of dielectric gases by an electric field. This direct current voltage source (DC) will inhibit ionization while the movement of the gas particles will also be hampered not only because of the gas crossover, but also the atomic and molecular polarization effect reduces the kinetic velocity of the particles so that the kinetic energy and potential energy for ionization will decrease.

Therefore, although experimentally the phenomenon of breakdown voltage has been successfully understood because it works at the state of before and after the ionization occurs, but the understanding of the processes and effects of the particle gases diversity, high pressure and DC voltage remain the research concern for an increase in the number of CNTs formed. In this experiment, a small plasma reactor tube contains a pressurized atmospheric carbon gas with two electrodes is connected to a voltage source. The carbon gas used will be ionized and produce plasma discharge so that the density and temperature can be calculated. This density and temperature analysis can be utilized to predict the growth of CNTs, their purity, geometry, structure and chain formation produced.

2. Ionization of Carbon Plasma on Butane and Air Mixture

Ionization of gas by electron impact collision is very significant to produce plasma at high pressure [7]. Kinetically, plasma can occur when the temperature or energy of the gas is increased by the electrons out of the orbit. The magnitude of the ionization energy of an atom or molecule can be written in Equation 1:

\[(1) \text{Where the particle mass, } m \text{ is the velocity of the particles, } v \text{ is effort because the electric field, } W_E \text{ is the electrical potential energy, } m_e \text{ is the mass of the electron, } v_e \text{ is the velocity of the electron, } e \text{ is the charge of the electron, and } v_i \text{ is the ionization potential.}\]

The process of plasma is influenced by several factors including the kinetic energy of atomic, molecular and photon collisions; Thermal and acoustic mechanical energy from external sources that accelerate atomic/molecular motion to excite electrons to ionization. Another factor is the potential energy source of the electric field and the external magnetic field thus accelerating the ionization process. The ionization process is also accelerated by involving both kinetic energy and potential energy. The ionization process, arc discharge can occur with two electrodes and high electric potential difference through the medium gas ((N\(_2\)+O\(_2\)+CO\(_2\)+trace)\(_{\text{air}}\) + C\(_4\)H\(_{10}\) ionisasi (Air + Butane)). The high voltage causes the polarization current and the kinetic collision leads the excited electrons to ionize to form ions [8]. Although the ambipolar diffusion process of polarization inhibits kinetic motion, high electrode voltage difference, electrode distance and short diffusion length will help the ionization process to occur fast along the degree of ionization of Butane which is of low ionization energy. Butane has a large density, large latitude appearance, relatively small velocity and ionization energy of 10.6eV which facilitates ionization. The ionization energy required for each molecule in the butane gas for ionization is a vector quantity that can be defined as follows, (2) The energy distribution function of each atom or molecule will collide for each particle and contribute diverse ionization energy. Therefore, by knowing the distribution of this energy, the ionization potential will easily form the plasma until the breakdown voltage occurs.
3. Experiment
The ionization process is carried out by increasing the voltage gradually so as to form plasma with voltage and electric current shown in Figure 1.

![Figure 1. Design and operation of directional carbon plasma](image)

Figure 1 is an electric discharge schematic of the gas ionization tube. A direct voltage source is provided by connecting a carbon electrode (commercial pencil) about 1mm away. Voltage is given until the electric spark is reached and maintained until it is in arc discharge condition. The air in the gas cylinder is reduced in the order of 0.1Atm which then occurs the breakdown voltage of any reduction in air pressure. The electric current is maintained only at the order of 10mA in order to maintain arc discharge conditions. The butane gas are also alternately streamed until 1Atm is subtracted to obtain a voltage drop phenomenon until the air density becomes smaller as a form of impurity of ionized gas, dominated by Alkane gas. Butane are used interchangeably and not mixed in the same process. The butane gas which is flowed with the air gas is in a random velocity. This speed can be known statistically by using the Maxwell Boltzmann Equation:

\[(3)\text{The velocity distribution of gas particles in the tube can be shown in Figure 2.}\]

Figure 2. Gas particle velocity distribution at atmospheric pressure

\[(4)\text{Physically, the kinetic and thermodynamic contributions strongly dominate the event of the breakdown voltage with the electric field effect that atomic and molecular polarization speeds up the ionizing process. Plasma density and plasma temperature of carbon species with general air impurities can be expressed as follows:}\]

\[(5)\text{In the event of this thermal plasma, not all particles are fully ionized so that the density and temperature of the plasma depend on the source of the electric voltage, the effect of the electric field between the electrodes, the high particle velocity and the mean free path of the short particles distance facilitates recombination and particle association, although this is highly desirable in the formation of CNTs on the cathode surface. Therefore the voltage drop varies greatly with the gas pressure of the Alkane by the impurity of the air mixture.}\]

4. Results and Discussion
Observation of ionization on air is done by providing pressure variations. At 12 cmHg (570 V) pressure it produces the breakdown voltage of 0.53-0.57 kV and a current of 0.27-0.45 mA. The pressure of 16 cmHg (580 V) produces the breakdown voltage of 0.49-0.56 kV and a current of 0.31-0.48 mA. The pressure of 26 cmHg (920 V) produces the breakdown voltage of 0.86-0.88 kV and a current of 0.54-0.6 mA. Pressure 36 cmHg (1160 V) produces the breakdown voltage of 0.9-1.1 kV and 0.46-0.6 mA. This data shows an almost linear relationship between the pressure with the current and the resulting drop voltage. The DC voltage given is high because the gas ionization is at a relatively high pressure and the
density of the particles inside the tube is at $> 10^{24}$ particles/m$^3$. Electric current from electron particles and positive ions moves successively to the anode and cathode.

Movement of particles to the anode is assumed to be faster than that to the cathode because the electrons are lighter with much density, while the Carbon positive ions move slowly toward the cathode as the CNT builder. This movement is due to the influence of the potential difference of each electrode. When the pressure inside the tube is reduced then there is also a reduction in the density. The particle density also affects the resulting fall stress as shown in Figure 3.

High densities result in collisions occurring predominantly at the excitation level of atoms and electrons so that ionization is difficult to reach at high pressure because some of the energy is absorbed for even superelastic collisions. Some of thermodynamic data of plasma is shown in Figure 4.

Figure 3. Air ionization with variation of air pressure

Figure 4. Air ionization with some pressure

Figure 4 shows a nearly linear kinetic relation, although not all of all particles are ionized, this kinetic quantity is in thermodynamic equilibrium. Increased plasma density is followed by increased pressure so that plasma temperature will also increase. This temperature is the movement of electrons and ions in which both particles remain at the same temperature. At 13cmHg pressure, the density of electrons and ions is relatively low, the pressure is small so that the collisions are small and the temperature decreases.

The ionization of the butane gas is subjected to the variation of pressure to illustrate the resulting ionization difference. At a pressure of 20 cmHg (1199V) it has a particle density of $5.78 \times 10^{24}$ particles/m$^3$, the breakdown voltage of 536-775V and the current of 0.03-0.45mA. At pressure of 20 cmHg (866V) having a particle density of $2.77 \times 10^{25}$ particles/m$^3$ produces the breakdown voltage of 587-871V and the current of 0.05-1.10mA. Pressure of 26 cmHg 1007V has a particle density of $2.79 \times 10^{25}$ particles/m$^3$, resulting in breakdown voltage of 703-1007V and a current of 0.04-0.55mA. The pressure of 27 cmHg 1044V has a particle density of $2.80 \times 10^{25}$ particles/m$^3$, resulting in breakdown voltage of 675-1055V) and a current of 0.03-0.69mA.

The applied voltage for ionization of butane gas with air mixture tends to be greater than the total air gas due to increased butane density, relatively slow particle velocity, and the area of the gas particle cross section which tends to be large. These results indicate to ionize butane gas having a high voltage because butane has high density and large cross-sectional area.
Figure 5, 6, and 7 describe the breakdown voltage to the change in the density of the gas by the ionization occurring between the mixture of and air + butane.

Figure 5. Ionization of butane + air and propane + air ionization

Figure 5. shows the ratio of breakdown voltage generated by the butane propane gas. Butane drop voltage is not only contributed to the high electric field, but also the greater carbonized ionization opportunities. Butane has an ionization energy of 10.6 eV. The ionization of butane gas requires a high voltage even though the ionisation energy is large. From Equation 1, ionization Alkanes lies in the kinetic energy regime, the speed and the heat of butane.

Figure 6. Discharge of propane and butane gas with air mixture. Figure 6 shows the electrical discharge process between the two electrodes. Electrons move at speeds that are affected by electric potential, electric fields, drifting collisions, and collision frequencies that occur during the ionization process. The energy that is given to ionization is made up of mechanical energy and electromagnetic energy. The electric current is maintained from the effects of the system in order to maintain the balance of the arc discharge so that the plasma conditions remain in a few seconds.

Figure 7. Density of alkane particles in thermal plasma
The greater the plasma density occurs in the tube, the higher the plasma temperature is reached as shown in Figure 7. This is also followed by the addition of the gas pressure. This result is smaller than the ionization in air due to the relative butane mass greater than the air particles. The carbon chains of butane gas are also large so that ionization gets easier. Ionization of butane has a low temperature, due to the effect of un-ionized hot gas making it easy to recombine the load, greater butane cross-sectional effect.

5. Conclusions
The ionization of the carbon produced by the butane gas has a linear tendency. The design and operation of carbon plasma has been successfully carried out. The ionization of butane gas. At a pressure of 20 cmHg (1199V) has a particle density of 5.78x10^24 particles/m^3, the breakdown voltage of 536-775V, a current of 0.03-0.45mA, density plasma 1.01x10^23 particle/m^3 and plasma temperature is 2.66x10^4 K. At a pressure of 20 cmHg (866V) having a particle density of 2.77x10^25 particles/m^3 produces the breakdown voltage of 587-871V, a current of 0.05-1.10mA, density plasma 1.13x10^23 particle/m^3 and plasma temperature is 2.39x10^4K. Pressure of 26 cmHg, 1007V has a particle density of 2.79x10^23 particles/m^3, resulting in the breakdown voltage of 703-1007V, the current of 0.04-0.55mA, density plasma 1.32x10^23 particle/m^3 and plasma temperature is 2.65x10^4 K. The pressure of 27 cmHg, 1044V has a particle density of 2.80x10^25 particles/m^3, resulting in the breakdown voltage of 675-1055V, the current of 0.03-0.69mA, density plasma 1.34x10^23 particle/m^3 and plasma temperature is 2.72x10^4 K. The plasma density and temperature of butane have been calculated. The ionization has an additional voltage when the gas density increases. The butane + air mixture requires high pressure for ionization because of the cross-sectional, ionisation energy, and relative mass of the gas. The plasma ionisation in this research is the reactive Alkane gas with impurities of air mixture so that the resulting CNT product is not pure to the carbon composition.

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